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FUMIGATION OF ORNAMENTAL GREENHOUSE PLANTS WITH HYDROCYANIC-ACID GAS.

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CONTENTS.

INTRODUCTION.

Hydrocyanic-acid gas, if intelligently employed, is one of the cheapest and most efficient methods of controlling thrips, aphids, white flies, and various scale insects on plants grown under glass. That this method of control has not been generally adopted is no doubt owing to the deadly poisonous nature of the gas if inhaled, its disastrous effect on tender plants if improperly used, and the pre-

NOTE.—Hydrocyanic-acid gas was first used against greenhouse pests in 1895 by Messrs. A. F. Woods and P. H. Dorsett (see Circular No. 37, Bureau of Entomology, U. S. Department of Agriculture) in an effort to destroy insects on diseased plants under observation. Subsequently others have employed the gas in greenhouse fumigation, but with varying success, largely because of inexperience and improper methods of procedure. In the earlier experiments in greenhouses conducted by the Bureau of Entomology the senior author was assisted by Mr. H. L. Sanford, of the Federal Horticultural Board, and by Messrs. Eugene May, W. R. Lucas, and Charles Keller, of the Bureau of Plant Industry. The spelling of the botanical names used in this publication has been verified by Messrs. P. L. Ricker and H. C. Skeels.

CAUTION.—*Hydrocyanic-acid gas is colorless and is one of the most deadly poisonous gases known. It has an odor much like that of peach pits. In case of accidental inhalation of the gas, the person affected should be kept in the open air and required to walk to increase respiration.*

vailing impression that fumigation is a cumbersome procedure requiring considerable skill on the part of the operator. While it is true that much damage to the plants and injury to the operator may result from the *careless* use of hydrocyanic-acid gas, it is an established fact that this fumigant in competent hands is a safe, practical, and economical means of controlling virtually all insect pests found in greenhouses.

EQUIPMENT NECESSARY FOR FUMIGATION.

GENERATORS.

One-half gallon or one-gallon glazed earthenware jars serve as satisfactory generators, although it is preferable that the bottoms of the jars be rounded inside, so that the cyanid will be covered with the acid and water, even with small doses, thus insuring the maximum generation of the gas. The number of generators required is largely influenced by the size of the house or houses to be fumigated, and to avoid unnecessary delay in case of breakage several extra crocks should be available.

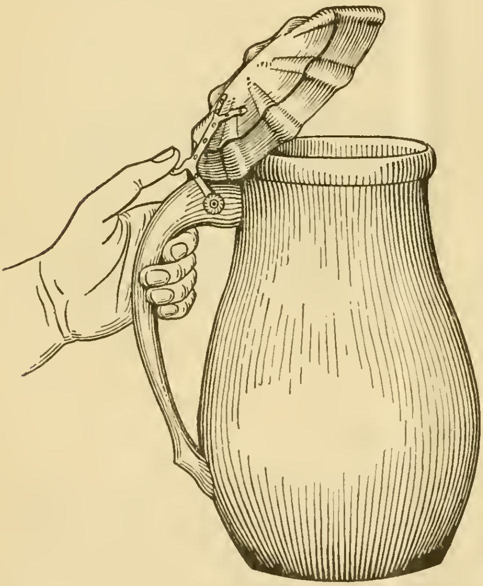

FIG. 1.—A cover device attached to a fumigation generator. Corrugations in cover allow gas to escape. (Woglum.)

To insure uniform distribution of the gas it is advisable to employ generators with covers, such as that illustrated in figure 1. This cover, which was designed by Mr. R. S. Woglum,[1] is made of copper stamped in a concave form with corrugations to permit the escape of the gas. It is attached to the generator by hinges and held in place by a bolt which extends through the handle and can be raised by a slight pressure of the thumb as shown in the figure. If it is not possible to secure crocks of this description, those with straight sides which are not constricted inside at the bottom can be used with good results, although to insure complete generation such a crock should be tilted slightly in order that the cyanid may be covered. Crocks

[1] Bul. 79, Bur. Ent., U. S. Dept. Agr., p. 58, fig. 21, 1909. Bul. 90, Part I, Bur. Ent., U. S. Dept. Agr., p. 75, fig. 12, 1911.

with straight sides are frequently sold with glazed earthenware tops. These tops or covers increase the cost of the generators and, furthermore, are useless for fumigation purposes. Therefore, when generators are ordered it should be indicated that tops are not desired. With this type of generator a cover may be improvised by using a piece of corrugated galvanized iron roofing or a board with cleats on the underside, to allow the free exit of gas.

MISCELLANEOUS REQUIREMENTS.

Correct scales or balances, reading in tenths of an ounce, are convenient for accurate work. An 8-ounce graduate is desirable for measuring the acid and water. To avoid splashing of the acid it should not be poured from a carboy or bottle into the graduate but should be transferred to a porcelain pitcher, from which it may be poured with safety. It is well to have on hand a supply of small bags or tissue paper in which to place the cyanid.

PREPARATION OF HOUSE FOR FUMIGATION.

As a preliminary to fumigating the house it is essential that the exposed glass surface be examined carefully and all broken glass replaced. All cracks should be thoroughly closed. The ventilators,

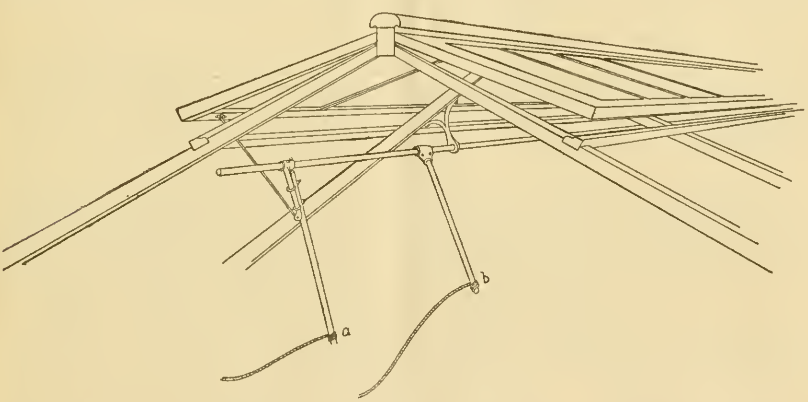

FIG. 2.—Methods of attaching rod and cord (*a*, *b*) to ventilator shaft of greenhouse so that the ventilators can be opened from the outside after fumigation. (Original.)

both side and top, where possible, should be so arranged that they can be opened on the outside of the house upon the completion of the exposure. This can be accomplished by disconnecting the "machine," or gear, of the top ventilators and attaching to the central ventilator shaft (see fig. 2) an arm (*a* or *b*) which can be controlled by a cord or wire which extends through the side of the house. The gears on the side ventilators may be disconnected so that the sash may be opened from the outside. If only one ventilator can be opened it is preferable that it be the one on the roof of the house.

METHOD OF COMPUTING THE CUBICAL CONTENTS OF EVEN AND THREE-QUARTER SPAN GREENHOUSES.

It is essential in every instance that the cubical contents of the house to be fumigated be determined accurately, and the following is a simple method of arriving at these figures: To facilitate matters a diagram indicating the necessary dimensions of the house should be made. (See figs. 3 and 4.)

To secure the cubical contents of the even-span house (fig. 4), compute the number of square feet in the rectangle *a* and in the right-angle triangles *b* and *c* and multiply the sum of the three by the length of the house. For example, A=5×20=100 square feet; B=5×10÷2=25 square feet[1]; and C=5×10÷2=25 square feet. A+B+C=150 square feet. 150 square feet × 100 feet (length of house)=15,000 cubic feet, cubic contents of the house.

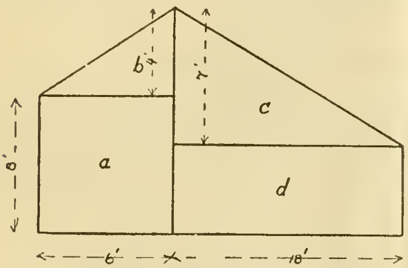

FIG. 3.—Diagram showing method of computing cubical contents of three-quarter-span greenhouse. (Original.)

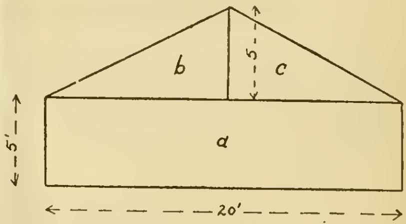

FIG. 4.—Diagram showing method of computing cubical contents of even-span greenhouse. (Original.)

To secure the cubical contents of the three-quarter span house (fig. 3) multiply the sum of the rectangles *a* and *d* and right-angle triangles *b* and *c* by the length. For example *a*=6×8=48 square feet; *d*=18×5=90 square feet; *b*=6×4÷2=12 square feet; and *c*=18×7÷2=63 square feet. *a*+*d*+*b*+*c*=213 square feet. 213 square feet × 100 feet (length of house)=21,300 cubic feet, cubic contents of house.

In estimating the cubic contents of a greenhouse it is not necessary to make allowances for the space occupied by the benches, pots, etc.

TIME FOR FUMIGATION.

Fumigation should be conducted not earlier than one hour after sunset and should not be attempted when the wind is high. It is undesirable to fumigate during extremely cold nights, when the thermometer is registering near zero, owing to the necessity of ven-

[1] To calculate the area of a right-angle triangle, multiply the base by the perpendicular and divide the product by two.

tilating the houses upon the completion of an exposure. It is inadvisable to fumigate on hot, humid nights, when the temperature in the house can not be lowered readily to the desired limit. The best temperature for fumigation is between 55° and 68° F.

The interval between fumigations naturally should be governed by the reappearance of the insect under control. With small dosages, which are imperative when fumigating a house containing an assortment of plants, it is possible to kill only the larvæ of scale insects, the adults and first larval stages of the greenhouse white fly, the adults of the Florida fern caterpillar, greenhouse leaf-tyer, and loopers, and a certain percentage of aphids. The eggs and pupæ of most greenhouse insects offer considerable resistance to hydrocyanic-acid gas, and furthermore the overlapping of broods necessitates several fumigations at short intervals. It has been proved repeatedly that three or four fumigations at short intervals will give practical control.

CHEMICALS REQUIRED FOR FUMIGATION.

The chemicals required in fumigating with hydrocyanic-acid gas are sodium cyanid (NaCN) or potassium cyanid (KCN), sulphuric acid (H_2SO_4), and water (H_2O). Potassium cyanid has been superseded recently by sodium cyanid in the generation of this gas, and the former is rarely used nowadays in fumigation. Sodium cyanid should be practically free from chlorin and contain not less than 51 per cent of cyanogen. It may be purchased either in lumps or in the shape of an egg, each "egg" weighing approximately 1 ounce. The latter is easily handled and the necessity of weighing each charge is obviated, providing, of course, the dosage is in ounces. For example, if the house requires 10 ounces of cyanid, 10 "eggs" are used. However, in small dosages, where the cyanid is measured in grams, it is necessary to use small lumps or break up the "eggs."

Cyanid is one of the most poisonous substances known and should be stored in air-tight cans, plainly labeled, and kept out of reach of those unacquainted with its poisonous nature.

Commercial sulphuric acid (about 1.84 sp. gr. or 66° Baumé) which is approximately 93 per cent pure is commonly used and gives very satisfactory results. The acid should be kept in a glass receptacle, properly labeled, and tightly corked with a glass stopper.

DETERMINING THE AMOUNT OF CYANID TO BE USED.

Satisfactory results are obtained only where it is possible to overcome the resisting power of the insects without overcoming the resisting power of the plant. Tender succulent plants, such as roses, geraniums, coleus, sweet peas, Wandering Jew, etc., are more susceptible to injury by hydrocyanic-acid gas than are certain hardy ornamentals, and this fact should be considered where an assortment of plants is to be fumigated. In case there is any doubt as to the amount of gas a plant will stand without injury, it is preferable that the initial dosage be not over one-fourth ounce of sodium cyanid per 1,000 cubic feet and increased with subsequent fumigations until the fatal point of the pest to be controlled is reached, it being borne in mind that in some instances it is not possible to effect an absolute control of all stages of some insects with one fumigation without injury to foliage or growing parts of certain plants. For example, the greenhouse white fly has been eradicated with three successive fumigations at intervals of 7 to 9 days, using one-half ounce of sodium cyanid (NaCN) per 1,000 cubic feet, in houses containing such susceptible plants as coleus, ageratum, heliotrope, fuchsia, etc., with no injury to the foliage. Moreover, such resistant pests as scale insects can be eliminated entirely by killing the immature stages with a small dosage repeated at frequent intervals.

Under favorable conditions houses which do not contain roses, rose geraniums, asparagus ferns, lemon verbena, snapdragon, Wandering Jew, or sweet peas can be fumigated with safety with an initial dosage of one-half ounce of sodium cyanid (NaCN) per 1,000 cubic feet.

To determine the total amount of cyanid to be used, ascertain from the tables on pages 12–18 the plants in your greenhouse which are most easily injured by the gas fumes and note the amount of cyanid which was used per 1,000 cubic feet with little or no injury to the plants. Then multiply the number of thousand cubic feet contained in the house by the amount of cyanid to be used per 1,000 cubic feet. For example, if one-half ounce of cyanid is to be used per 1,000 cubic feet, and the house contains 15,000 cubic feet, the total amount of cyanid necessary would be 7½ ounces.

In case there is any doubt as to the amount of gas the plant can stand without injury, the initial dosage, as previously stated, should not exceed one-fourth ounce per 1,000 cubic feet.

CHEMICAL FORMULA TO BE EMPLOYED.

The chemicals[1] should be mixed in the following proportions: For each ounce of sodium cyanid use 1½ fluid ounces of sulphuric acid and 2 fluid ounces of water.

[1] If potassium cyanid is used in place of sodium cyanid, the formula should be as follows: For each ounce of 98 to 99 per cent potassium cyanid containing 38.4 per cent cyanogen use 1 ounce of sulphuric acid and 3 ounces of water. The yield from 1 ounce of high-grade sodium cyanid is equivalent to the yield from 1⅓ ounces of high-grade potassium cyanid.

MIXING THE CHEMICALS.

After the generators have been distributed throughout the greenhouse, and before the chemicals have been mixed, the cyanid should be weighed accurately and the proper amount for each generator placed in a paper bag near the generator. The chemicals should be mixed invariably in the following manner: First, measure and place in each generator the amount of water required; second, measure and place in each generator the amount of sulphuric acid required; third, drop the cyanid into the diluted warm acid in each generator, close the covers, immediately leave the house, and post a danger sign on the closed door. The cyanid should be dropped gently, not thrown, into the generators, and the operator should begin at the generator farthest from the door and work toward the door. In case there are two rows of generators the cyanid should be dropped simultaneously by two operators. As little time as possible should elapse between the addition of the acid and the addition of the cyanid, as the heat which is liberated by the mixing of the acid and water assists in the generation of the gas.

The residue left in the generators after fumigation should be buried or poured into a sink and the generator washed before being stored for future operations.

NUMBER OF GENERATORS TO BE EMPLOYED.

The number of generators will depend largely upon the size of the house, and they should be so arranged that the gas will be uniformly distributed throughout the inclosure. To secure this advantage, it is advisable that a number of generators be used rather than one large generator. Generators should be spaced from 20 to 25 feet apart, and in case of a light wind a few extra generators should be placed on the windward side of the house. An ounce to each jar is as small a dose as is practicable, unless the generators are well rounded inside at the base or well tilted.

EXPOSURES.

Short exposures with a greater strength of gas have been found more satisfactory than a weaker strength of gas overnight. In fact, better results will be gained if the exposures do not exceed one to two hours. An exposure of one hour is satisfactory in most instances. Short exposures also have the additional advantage of permitting the house to become thoroughly aerated previous to the rising of the sun.

VENTILATION AFTER FUMIGATION.

If there is a light wind, a ventilation of 10 to 15 minutes, using side and top ventilation, will be sufficient and will not lower the house temperature to a dangerous point unless it is close to zero weather outside. If it is a still evening and the outside temperature is not below 32° F., a 20 to 30 minute ventilation is satisfactory.

In case it is necessary to enter the house shortly after ventilation to determine the temperature, the person entering should not remain any longer than is necessary.

EFFECTS OF WEATHER CONDITIONS ON FUMIGATION.

TEMPERATURE.

Much experimentation has proved that excessive heat and cold will affect the results of fumigation. In most instances it is not advisable to fumigate if the temperature in the frame exceeds 70° F., or if the temperature is less than 55° F. It is possible that a variation of five degrees from the latter temperature will not result in serious injury to the plants, providing, of course, that the plants are not affected by such a low temperature.

LIGHT.

Light unquestionably affects fumigation. It has been known for a long time that it is very undesirable to fumigate when the sun is high. Furthermore, recent experiments have demonstrated that some injury may result to plants which have been subjected to fumes if, on the following day, the sun is very bright.

MOISTURE.

The question of moisture has received considerable attention from various fumigators, and it appears to be the consensus of opinion that excessive moisture in the presence of the gas does not increase the injury to plants and plant products under fumigation. A large number of plants have been fumigated in boxes immediately after syringing, when the leaves were covered with a film of water, with apparently no injury to the plants, and the insects on the plants were successfully controlled, which corroborates the experience of Morrill,[1] Quaintance,[2] and Woglum.[3]

Hydrocyanic-acid gas is readily soluble in water, and as a result the presence of excessive moisture in greenhouses decreases the effectiveness of the gas and consequently lessens the possibility of injury to the plants by burning. Fumigation experiments have been

[1] Bul. 76, Bur. Ent., U. S. Dept. Agr., p. 12, 1908.
[2] Bul. 84, Bur. Ent., U. S. Dept. Agr., p. 24, 31, 1909.
[3] Bul. 90, Bur. Ent., U. S. Dept. Agr., p. 68, 1912.

conducted where the plants, beds, and walks were thoroughly soaked with water, and the injury which would be expected under normal conditions to such plants as cosmos, rose geraniums, roses, heliotropes, and *Asparagus plumosus* did not appear, nor were such insects as aphids and thrips appreciably affected. It is obvious, therefore, that in order to increase the effectiveness of the fumigation the plants should be syringed not less than four or five hours prior to the liberation of the gas, to avoid undue absorption of the gas by the water on the benches and walks.

The difference in the results noted above may be accounted for by the fact that in the case of box fumigation only the foliage was covered with a film of water, whereas in the case of the greenhouse experiments not only the foliage of the plants was covered with a film of water but the entire soil surface of the house was soaked, and the water undoubtedly absorbed much of the available gas, reducing the toxic effect of the gas on the plants and insects.

HUMIDITY.

Recent tests have demonstrated that a relatively high humidity (98 to 100), with temperature varying from 70° to 75° F., greatly increases the amount of injury to the foliage of the plants, whereas plants in the presence of a relatively high humidity (98 to 100), with a temperature of 60° to 65° F., do not exhibit injury in excess of that which would appear if the plants were fumigated with an excessive dosage under normal atmospheric conditions. It is apparent, therefore, that a relatively high humidity alone is not responsible for injury unless accompanied by temperatures exceeding 70° F.

ADVISABILITY OF A FUMIGATION BOX.

A fumigation box is desirable for two reasons, namely, for testing the amount of gas plants can stand without injury, and for ridding a limited number of potted plants of insects, and thus avoiding costly and laborious hand scrubbing of such plants. The size of the box will depend on the use to which it is to be put. A box with a capacity of 200 cubic feet can be used advantageously for nursery stock, palms, etc.

Plants to be fumigated in a box in the daytime should remain in the box with the door closed at least one hour before the gas is generated and should be shaded from the bright sunlight for at least two hours after the completion of the exposure.

HOW INSECTS ARE DISSEMINATED FROM HOUSE TO HOUSE.

Doubtless many houses become infested with insects through the agency of plants commonly referred to as "boarders." The practice of turning over home-grown plants to a florist to care for during the absence of the owner on a vacation is prevalent over the entire country, and often results in establishing pests not hitherto known to occur on the florist's premises. If the trade requires such a practice, plants of this character should be cleaned thoroughly of insect pests before being placed with the regular stock of the greenhouse.

Insect infestations in greenhouses have been traced to the following sources: Infested plants brought in from cold frames or propagation beds which have not received proper attention; cuttings, plants, and buds received from other establishments; and imported foreign or domestic stock. Adults of the greenhouse white fly, grasshoppers, beetles, aphids, etc., may enter through open ventilators from other houses or gardens; cutworms, wireworms, white grubs, etc., may be brought into the house with the soil; and roaches, ants, sowbugs, millipeds, etc., are sometimes brought in with packages, or they may crawl into the house through small openings.

COST OF HYDROCYANIC-ACID GAS FUMIGATION.

The economy in the use of hydrocyanic-acid gas as a means of controlling aphids, white flies, thrips, and the common greenhouse scale insects is apparent from the following figures, which are based on current prices:

Aphids can be controlled with a single fumigation at the rate of one-fourth ounce per 1,000 cubic feet at a cost of approximately $\frac{1}{2}$ cent per 1,000 cubic feet. Tobacco fumigation with standard tobacco paper costs from $1\frac{1}{2}$ to 3 cents per 1,000 cubic feet, and to secure a satisfactory control the operation must be repeated several times. Standard nicotine soap solution costs from 1 to 3 cents per gallon, and 4 gallons are required to cover plants which would occupy 1,000 cubic feet of space.

The greenhouse white fly can be controlled in three successive fumigations at the rate of one-half ounce of sodium cyanid per 1,000 cubic feet, with a total cost of 3 cents per 1,000 cubic feet for a complete control. Standard insecticides cost about 6 cents per 1,000 cubic feet for a single application, and fully four applications are required for a satisfactory control.

Thrips can be controlled on such plants as azaleas, lilies, and ferns with a single fumigation at the rate of one-half ounce of sodium cyanid per 1,000 cubic feet at a cost of 1 cent per 1,000 cubic feet. A single application of nicotine soap solution costs fully five times as much as the gas treatment and still gives only a partial control.

The common scale insects of greenhouses (excepting mealy bugs) can be controlled by fumigating the infested plants at the rate of three-fourths ounce of sodium cyanid per 1,000 cubic feet at a cost of $1\frac{1}{2}$ cents per 1,000 cubic feet. The standard proprietary insecticides commonly recommended for scale insects cost approximately 4 cents per gallon with an average cost of 16 cents per 1,000 cubic feet for each treatment. A 5 per cent homemade kerosene emulsion costs approximately one-half cent more per 1,000 cubic feet than does the gassing method, and gives very indifferent results.

The foregoing figures do not take into consideration the cost of labor. However, the time required for fumigation will not exceed the time required for the mixing and application of the sprays.

PRECAUTIONS.

Do not *guess* the amount of chemicals to be employed or the cubic contents of the house.

Do not fumigate plants in a greenhouse in daylight. (For box fumigation in daytime, see page 9.)

Do not fumigate when the temperature in the house is below 50° or above 70° F.

Do not leave the chemicals within reach of those unacquainted with their poisonous nature. Always have them properly labeled.

Do not handle the chemicals any more than is absolutely necessary, and always wash the hands thoroughly after doing so. It is well to have a pair of old gloves for this, and to use them for no other purpose.

Do not allow the acid to splash or drop on the clothing or skin.

Do not stay in the house any longer than is necessary to place the cyanid in the jars, and *never* enter a house charged with gas until it has been thoroughly aired.

Do not fail to post danger signs at all entrances before setting off the charge, and to see that the house is tightly closed.

Do not attempt to fumigate without adjusting the ventilators so that they may be operated from the outside.

Do not attempt to fumigate a large house alone.

Do not fumigate a frame adjoining a dwelling without notifying the occupants before fumigation and allowing them time to leave. Houses contiguous to fumigated frames should be aired thoroughly before the occupants are allowed to reenter.

Do not pour the water on the acid; pour the acid on the water.

Do not become negligent in any of the precautions; to do so may cause serious results.

PLANTS AND INSECTS FUMIGATED IN GREENHOUSES.

Table I is offered as a guide to those desiring to employ hydrocyanic-acid gas for controlling greenhouse pests. Space will not permit the inclusion of all plants which have been fumigated by the writers, but the table includes many ornamentals and a few tropical and subtropical plants commonly grown in greenhouses.

TABLE I.—*Plants and insects fumigated with hydrocyanic-acid gas in greenhouses.*

Name of plant.	Rate in ounces per 1,000 cubic feet.		Exposure in hours.	House temperature.	Infestation.	Results of treatment.	
	Sodium cyanid.	Potassium cyanid.				On plants.	On insects.
				°F.			
Abutilon sp	½	......	1	70	Greenhouse white fly.	No burning	All stages except egg and late pupæ killed.
Do	½	......	1	58	do	do	Do.
Do	¾	......	1	68	do	do	Do.
Do	¾	......	1	56	do	do	Do.
Abutilon vitifolia	½	......	1	64	do	do	Do.
Do	½	......	1	77	do	do	Do.
Acalypha sp	½	......	1	60		do	
Do	½	......	1	64		do	
Do	¾	......	1	60		do	
Achania sp	......	½	¾	52		do	
Do	......	¾	1	....		do	
Achyranthes sp	½	......	1	58		do	
Do	½	......	1	64		do	
Do	¾	......	1	55		do	
Do	¾	......	1	60		do	
Actinidia polygama	......	1 3/7	1	73		Slight burning	
Adenocalymma cosmosum	......	5	¾	66		No burning	
Agave americana	¾	......	1	68		do	
Agave sp	......	5/7	½	....		do	
Ageratum sp	½	......	1	64		do	
Do	½	......	1	58	Greenhouse white fly.	do	All stages except eggs and late pupæ killed.
Do	½	......	1	64	do	do	
Do	¾	......	1	56	do	do	
Air plant	½	......	1	70	Aphids	do	100 per cent killed.
Do	¾	......	1	68	do	do	Do.
Albizzia sp	......	1 3/7	1	73		Slight burning	
Aleurites sp	......	1 3/7	1	73		do	
Alpinia nutans	½	......	1	62		No burning	
Do	½	......	1	74		do	
Althaea sp	......	1 4/5	½	....	Aphids	do	Do.
Amaranthus sp	¾	......	1	55		do	
Amaryllis sp	½	......	1	60		do	
Do	½	......	1	70		do	
Do	¾	......	1	68		do	
Annona cherimola	......	8/7	½	....		do	
Annona sp	......	1 3/7	1	73		Slight burning	
Antidesma bunius	......	1 3/7	1	73		do	
Anthericum sp	½	......	1	60	Long scale	No burning	80 per cent killed.
Do	½	......	1	64		do	
Do	¾	......	1	60	Long scale	do	100 per cent killed.
Anthurium sp	......	8/7	½	....		do	
Aralia guilfoylei	½	......	1	66		do	
Ardissia sp	½	......	1	62		do	
Do	½	......	1	74		do	
Araucaria excelsa	½	......	1	66		do	
Do	½	......	1	77		do	
Aristolochia sp	......	5	¾	66		do	
Artemisia sp	1 3/7	......	1	73		Slight burning	
Artillery plant	½	......	1	70		No burning	
Asparagus plumosus	½	......	1	66		Tips burned	
Do	½	......	1	70		do	
Do	½	......	1	60		do	
Do	¾	......	1	68		Severe burning.	
Asparagus sprengeri	½	......	1	60		Tender tips burned.	
Do	½	......	1	70		No burning	
Do	¾	......	1	68		Tender tips burned.	
Do	¾	......	1	55		do	
Aspidistra sp	½	......	1	62		No burning	
Do	½	......	1	74		do	
Aster	½	......	1	62		do	
"Atamasco"	½	......	1	64		do	
Do	½	......	1	76		do	
Atropa sp	½	......	1	64		do	
Do	½	......	1	76		do	

TABLE I.—*Plants and insects fumigated with hydrocyanic-acid gas in greenhouses*—Continued.

Name of plant.	Rate in ounces per 1,000 cubic feet.		Exposure in hours.	House temperature.	Infestation.	Results of treatment.	
	Sodium cyanid.	Potassium cyanid.				On plants.	On insects.
				°F.			
Aucuba japonica	½	......	1	66	....	No burning	
Do	½	......	1	77	....	....do	
Do	¾	......	1	68	....	....do	
Avocado, see *Persea*.							
Azalea indica	......	5	¾	66	....	....do	
Azalea sp	½	......	1	60	Thrips	....do	95 per cent killed.
Do	......	......	....	....	Azalea lace-wing.	....do	100 per cent killed.
Do	¾	......	1	60	Azalea Eriococcus.	....do	50 per cent killed.
Do	¾	......	1	55	....	....do	
Do	......	5	¾	52	....	....do	
Do	......	7½	1	....	....	Slight burning	
Bamboo	......	1 3/7	1	73	....	Slight burning.	
Banana	½	......	1	60	....	No burning	
Do	¾	......	1	55	....	....do	
Basanacantha sp	......	1 3/7	1	73	....	Severe burning.	
Begonia argenteoguttata	½	......	1	60	Orthezia	No burning	70 per cent killed.
Do	½	......	1	64	....	....do	
Do	¾	......	1	60	....	....do	
Begonia diadema	½	......	1	60	....	....do	
Do	½	......	1	58	....	....do	
Do	¾	......	1	56	....	....do	
Begonia erfordii	......	5	¾	66	....	....do	
Begonia manicata	½	......	1	60	....	....do	
Do	½	......	1	58	....	....do	
Do	¾	......	1	56	....	....do	
Begonia metallica	½	......	1	66	....	....do	
Do	½	......	1	77	....	....do	
Begonia ricinifolia	½	......	1	60	....	....do	
Do	½	......	1	58	....	....do	
Do	¾	......	1	56	....	....do	
Begonia saundersoni	½	......	1	58	....	....do	
Do	½	......	1	64	....	....do	
Do	¾	......	1	56	....	....do	
Do	¾	......	1	60	....	....do	
Begonia (Leopard)	½	......	1	66	....	....do	
Do	½	......	1	77	....	....do	
Begonia (Lorraine)	½	......	1	62	....	....do	
Do	½	......	1	74	....	....do	
Begonia (Rex)	½	......	1	66	....	....do	
Do	½	......	1	77	....	....do	
Berberis rehderiana	½	......	1	62	....	....do	
Do	½	......	1	74	....	....do	
Berberis thunbergii	......	1 4/5	½	....	Aphids	Slight burning.	100 per cent killed.
Berberis vulgaris	......	1 4/5	½	....	....do	....do	Do.
Berberis sp	......	1 3/7	1	73	....	....do	
Belladonna	½	......	1	62	....	No burning	
Do	½	......	1	74	....	....do	
Bougainvillea	½	......	1	58	....	....do	
Do	½	......	1	60	....	....do	
Do	¾	......	1	56	....	....do	
Bradburya	......	1 3/7	1	73	....	Slight burning.	
Bromelia sp	......	1 3/7	1	73	....	Severe burning.	
Bunchosia sp	......	1 3/7	1	73	....	Slight burning.	
Buxus sp. (boxwood)	......	5	¾	52	....	No burning	
Do	......	7½	1	....	....	....do	
Cactus	½	......	1	70	....	....do	
Do	¾	......	1	68	....	....do	
Calla lily	½	......	1	64	....	....do	
Do	½	......	1	76	....	....do	
Do	......	5	¾	66	....	....do	
Caladium sp	¾	......	1	55	....	....do	
Do	......	5/7	....	....	....	....do	
Camellia japonica	......	5	¾	52	....	....do	
Camellia sp	¾	......	1	55	....	....do	
Do	......	7½	1	....	....	....do	

TABLE I.—*Plants and insects fumigated with hydrocyanic-acid gas in greenhouses*—Continued.

Name of plant.	Rate in ounces per 1,000 cubic feet.		Exposure in hours.	House temperature.	Infestation.	Results of treatment.	
	Sodium cyanid.	Potassium cyanid.				On plants.	On insects.
				°F.			
Camoensia sp		1 3/7	1	73		Slight burning.	
Canaga odorata	½		1	66		No burning	
Do	½		1	77		do	
Canna	½		1	64		do	
Do	½		1	77		do	
Carica papaya		1 3/7	1	73		Slight burning	
Carissa carandas		5/7	½			No burning	
Do		1 3/7	1	73		Slight burning.	
Carnation	½			62		No burning	
Do	½		1	76		do	
Do	¾		1	55		do	
Cassia beareana		1 3/7	1	73		Slight burning.	
Cassia fistula		1 3/7	1	73		do	
Catha edulis	½		1	66		do	
Do	½		1	77		do	
Ceiba pentandra		1 3/7	1	73		do	
Centaurea	½		1	60	Onion thrips	do	95 per cent killed.
Cereus (night-blooming)	½		1	64		No burning	
Do		5/7	½			do	
Ceropegia thorncroftii		1 3/7	1	73		Severe burning.	
Chrysanthemum	½		1	62		do	
Do	½		1	76	Aphids	do	100 per cent killed.
Do	¾		1	68		do	
Do		5	¾	66		do	
Cigar plant	½		1	70	Aphids	do	Do.
Do	¾		1	68		do	
Cineraria	¾		1	60		Old foliage burned.	
Cinnamomum camphora	½		1	66		No burning	
Do	½		1	77		do	
Do	¾		1	68		do	
Citrus aurantium	½		1	60	Long scale	do	80 per cent killed.
Do	¾		1	55		do	
Citrus plumbago		5	¾	52		do	
Citrus sp	½		1	64		do	
Do		1 3/7	½		Florida red scale.	do	90 per cent killed.
Do		7½	1			do	
Do		10	1⅓			Tender foliage burned.	
Clianthus dampieri	½		1	62		No burning	
Do	½		1	74		do	
Clerodendron		5	¾	66		do	
Cockscomb	½		1	64		do	
Coleus (Black Prince)	½		1	60	Orthezia	do	75 per cent killed.
Do	¾		1	66	do	Old foliage burned.	80 per cent killed.
Coleus (Firebrand)	½		1	60	do	No burning	75 per cent killed.
Do	¾		1	60	do	do	80 per cent killed.
Coleus (Golden bedder)	½		1	60	do	do	75 per cent killed.
Do	¾		1	60	do	Old foliage burned.	80 per cent killed.
Coleus (Golden Queen)	½		1	60	do	No burning	75 per cent killed.
Do	¾		1	60	do	do	80 per cent killed.
Coleus (Mrs. Hayes)	½		1	60	do	do	70 per cent killed.
Do	¾		1	60	do	do	80 per cent killed.
Coleus (Pfeister Red)	½		1	60	do	do	70 per cent killed.
Do	¾		1	60	do	do	80 per cent killed.
Coleus (Pfeister Yellow)	½		1	60	do	do	70 per cent killed.
Do	¾		1	60	do	do	80 per cent killed.
Coleus (Rose Bank)	½		1	60	do	do	70 per cent killed.
Do	¾		1	60	do	do	80 per cent killed.
Coleus (Shirrock Jr.)	½		1	60	do	do	70 per cent killed.
Do	¾		1	60	do	Old foliage burned.	80 per cent killed.
Coleus (Queen Victoria)	½		1	60	do	No burning	70 per cent killed.
Do	¾		1	60	do	do	80 per cent killed.

TABLE I.—*Plants and insects fumigated with hydrocyanic-acid gas in greenhouses*—Continued.

Name of plant.	Rate in ounces per 1,000 cubic feet.		Exposure in hours.	House temperature.	Infestation.	Results of treatment.	
	Sodium cyanid.	Potassium cyanid.				On plants.	On insects.
				°F.			
Coleus (Verschaffelti)	1/2	......	1	60	Orthezia	No burning	70 per cent killed.
Do	3/4	......	1	60	do	do	80 per cent killed.
Coleus (mixed)	1/2	......	1	64	do	do	100 per cent killed.
Coreopsis	1/2	......	1	62		do	
Cosmos	1/2	......	1	60		Tips burned	
Do	......	1 3/7	1	73		Slight burning	
Cotton	1/2	......	1	66		No burning	
Do	1/2	......	1	77		do	
Do	......	5/7	1/2	....	Greenhouse white fly.	do	All stages except eggs and late pupæ killed.
Croton (mixed varieties)	1/2	......	1	58		do	
Do	1/2	......	1	77		do	
Do	3/4	......	1	56	Long scale	do	100 per cent killed.
Do	......	1 4/5	1/2	....		do	
Cudrania javanensis	......	1 4/5	1	73		Slight burning	
Cudrania tricuspidata	......	1 4/5	1	73		do	
Cyclamen	1/2	......	1	58		No burning	
Do	1/2	......	1	74		do	
Do	3/4	......	1	68		do	
Cyphomandra sp	......	1 4/5	1	73		Slight burning	
Daffodil	3/4	......	1	55		No burning	
Do	......	1 4/5	1	73		Severe burning of new foliage.	
Deutzia gracilis	......	1 4/5	1/2	....	Aphids	No burning	100 per cent killed.
Deutzia scabra	......	1 4/5	1/2	....		do	
Digitalis	1/2	......	1	62		do	
Do	1/2	......	1	74		do	
Dioscorea pentaphylla	1/2	......	1	64		do	
Do	1/2	......	1	76		do	
Dracaena godseffiana	......	5	3/4	66		do	
Dracaena indivisa	......	5	3/4	52		do	
Do	......	7 1/2	1	....		do	
Entelea palmata	......	1 3/7	1	73		Slight burning	
Erica sp	1/2	......	1	64		No burning	
Do	1/2	......	....	76		do	
Epiphyllum sp	1/2	......	1	64		do	
Do	1/2	......	1	76		do	
Eupatorium sp	1/2	......	1	58		do	
Do	3/4	......	1	60		do	
Do	......	1 3/7	1	73		Severe burning of young foliage.	
Ferns:[1]							
Adiantum cuneatum	3/4	......	1	60		No burning	
Adiantum croweanum	3/4	......	1	60		do	
Birds nest	1/2	......	1	70		do	
Do	3/4	......	1	68		do	
Boston	1/2	......	1	60		do	
Do	3/4	......	1	68		do	
Holly	......	5	3/4	52		do	
Do	1/2	......	1	62		do	
Do	3/4	......	1	60		do	
Lastrea sp	1/2	......	1	70		do	
Do	3/4	......	1	68		do	
Nephrolepis scottii	3/4	......	1	55		do	
Nephrolepis scholzelii	3/4	......	1	55		do	
Nephrolepis whitmanii	1/2	......	1	62		do	
Do	3/4	......	1	68		do	
Polystichum sp	1/2	......	1	70		do	
Do	3/4	......	1	60		do	
Pteris sp	1/2	......	1	60		do	
Ficus utilis	......	1 3/7	1	73		Slight burning of new growth.	
Ficus sp	......	2 1/2	3/4	....	Cottony scale.	No burning	All stages except eggs killed.

[1] *Asparagus plumosus* and *A. sprengeri* belong to the Lily family and are to be found under *Asparagus*.

TABLE I.—*Plants and insects fumigated with hydrocyanic-acid gas in greenhouses*—Continued.

Name of plant.	Rate in ounces per 1,000 cubic feet.		Exposure in hours.	House temperature.	Infestation.	Results of treatment.	
	Sodium cyanid.	Potassium cyanid.				On plants.	On insects.
				°F.			
Ficus sp.	......	7½	1	....	Thread scale.	Severe burning; all leaves knocked. Injury largely due to close proximity of generator to plant.	All stages killed.
Forgetmenot	......	7½	1	....	....	Severe burning of tender foliage.	
Forsythia viridissima	......	1⅘	½	....	Aphids	No burning	100 per cent killed.
Freesia	½	......	1	60	....	...do	
Do	¾	......	1	60	....	...do	
Fuchsia	½	......	1	60	Greenhouse white fly.	...do	All stages except eggs and late pupæ killed.
Do	¾	......	1	68	...do	...do	Do.
Do	......	5	¾	66	....	Slight burning	
Gaillardia sp.	½	......	1	62	....	No burning	
Gardenia	½	......	1	60	....	...do	
Do	¾	......	1	68	....	...do	
Do	......	5	¾	66	....	...do	
Do	......	7½	1	....	....	Slight burning	
Genista	¾	......	1	55	....	No burning	
Do	......	5	¾	66	....	Flowers burned.	
Geraniums:							
Martha Washington	½	......	1	70	Aphids	New growth burned.	60 per cent killed.[1]
Do	½	......	1	70	...do	....	100 per cent killed.[1]
Peppermint	½	......	1	70	....	No burning	
Do	¾	......	1	68	....	...do	
Bedding	½	......	1	60	Greenhouse white fly.	...do	All stages except eggs and late pupæ killed.
Do	¾	......	1	68	...do	...do	Do.
Rose	½	......	1	64	....	New growth burned.	
Gladiolus	½	......	1	62	....	No burning	
Do	¾	......	1	55	....	...do	
Heather (Scotch)	½	......	1	70	....	...do	
Do	¾	......	1	68	....	...do	
Do	......	5	¾	52	....	Slight burning	
Do	......	7½	⅔	....	....	...do	
Heliotrope	½	......	1	64	....	No burning	
Do	¾	......	1	60	....	...do	
Hibiscus sp.	½	......	1	60	....	...do	
Do	¾	......	1	55	....	...do	
Hyacinth (water)	½	......	1	64	....	...do	
Do	¾	......	1	55	....	...do	
Hydrangea (French variety).	½	......	1	64	....	...do	
Do	¾	......	1	60	....	...do	
Ilex sp. (English)	......	5	¾	52	....	...do	
Do	......	7½	1	....	....	...do	
Impatiens sultani	½	......	1	66	Aphids	...do	100 per cent killed.
Do	¾	......	1	68	....	...do	
Ipomoea sp. (morning glory).	½	......	1	64	....	...do	
Do	¾	......	1	60	....	...do	
Iris (Spanish)	½	......	1	64	....	...do	
Do	......	5	¾	66	....	Tips burned	
Lantana sp.	½	......	1	60	*Orthezia*	No burning	70 per cent killed.
Do	¾	......	1	56	....	...do	
Laurus nobilis	......	5	¾	52	Soft brown scale.	...do	Immature stages killed.
Do	......	7½	1	....	...do	...do	90 per cent killed.

[1] The difference in results noted was due to the difference in the tightness of the two houses.

TABLE I.—*Plants and insects fumigated with hydrocyanic-acid gas in greenhouses*—Continued.

Name of plant.	Rate in ounces per 1,000 cubic feet.		Exposure in hours.	House temperature.	Infestation.	Results of treatment.	
	Sodium cyanid.	Potassium cyanid.				On plants.	On insects.
Lilies:				°F.			
Lilium formosum	½		1	60	Aphids	No burning	100 per cent killed.
Do	¾		1	60		do	
Lilium multiflorum	½		1	60	Aphids	do	Do.
Do	¾		1	60		do	
Chinese	¾		1	55		do	
Water		5	¾	66		do	
Loquat		1 3/7	1	73		Slight burning	
Mango	½		1	60		No burning	
Do	¾		1	55		do	
Do	5		½		Aphids	Slight burning	Do.
Marguerite	½		1	70	do	No burning	Do.
Do	½		1	60	Hemispherical scale.	do	95 per cent of immature scales killed.
Do	¾		1	68		do	
Marigold (French)	½		1	60		do	
Do	¾		1	64		do	
Mignonette	½		1	60		do	
Mimulus moschatus	½		1	70		do	
Do	¾		1	56		do	
Moon vine	½		1	60		Open flowers burned.	
Do	¾		1	60		Flowers and buds burned.	
Narcissus poeticus	¾		1	55		No burning	
Narcissus barri	¾		1	55		do	
Nasturtium	¾		1	55		do	
Nigella	½		1	62	Aphids	do	100 per cent killed.
Do		1 4/7	½			do	
Oleander	½		1	66		do	
Do		5	½	76		do	
Olive		5/7	½			do	
Orchid:							
Cattleya trianae	½		1	64		do	
Oxalis (flowering)	½		1	58		do	
Do	¾		1	56		do	
Palms:							
Areca lutescens	¾		1	60		do	
Chamaerops pumila	½		1	66		do	
Do	½		1	77		do	
Cocos sp		5/7	½			do	
Kentia belmoriana	½		1	60		do	
Do	¾		1	60		do	
Latania sp	¾		1	60		do	
Phoenix canariensis		5	¾	66		do	
Pandanus graminifolius	½		1	70		do	
Do	¾		1	68		do	
Pandanus veitchi	½		1	70		do	
Do	¾		1	68		do	
Pansy	½		1	62	Aphids	do	Do.
Do	¾		1	55	do	do	Do.
Pelargonium odoratissimum		1 3/7	1	73		Slight burning	
Pelargonium sp	½		1	62		No burning	
Do	¾		1	68	Aphids	do	75 per cent killed.
Pentstemon		5	¾	52		do	
Do		7½	1			Slight burning.	
Persea americana		¾	1	55	Hemispherical scale.	No burning	100 per cent immature scales killed.
Do		1 3/7	1	73		Slight burning.	
Do		¾	1	66	Avocado white fly.	No burning	All stages except eggs and late pupæ killed.
Petunia	½		1	60		do	
Poinsettia	½		1	62		do	
Pomegranate		4/7				do	
Poppy (Shirley)	½		1	60		do	

TABLE I.—*Plants and insects fumigated with hydrocyanic-acid gas in greenhouses*—Continued.

Name of plant.	Rate in ounces per 1,000 cubic feet.		Exposure in hours.	House temperature.	Infestation.	Results of treatment.	
	Sodium cyanid.	Potassium cyanid.				On plants.	On insects.
				°F.			
Primula chinensis	½	......	1	58	......	No burning	
Do	¾	......	1	56	......	do	
Do	......	5	¾	66	......	do	
Primula malacoides	¾	......	1	55	......	do	
Primula obconica	½	......	1	58	Greenhouse white fly.	do	All stages except eggs and late pupæ killed.
Do	¾	......	1	55	......	do	
Psidium guajava	......	5/7	½	....	......	do	
Do	......	1 3/7	½	....	Long scale	do	Immature stages killed.
Rhododendron	......	5	¾	66	......	do	
Rhyncospermum sp	......	7½	1	....	......	do	
Rosemary	½	......	1	64	......	do	
Do	½	......	1	76	......	do	
Rose	½	......	1	64	......	Tender growth burned.	
Do	½	......	1	62	Rose leafhopper.	do	100 per cent killed.
Do	......	1 3/7	1	73	......	do	
Sage, scarlet	½	......	1	74	......	No burning	
Do	½	......	1	60	......	do	
Do	¾	......	1	60	......	do	
Schizanthus sp	½	......	1	60	......	do	
Do	¾	......	1	56	......	do	
Scilla nutans	¾	......	1	55	......	do	
Smilax	......	5	¾	52	......	do	
Do	......	7½	1	....	......	Severe burning.	
Snapdragon	½	......	1	60	......	Tender tips burned.	
Do	¾	......	1	60	......	do	
Spiraea cantoniensis	......	1⅘	½	....	Aphids	No burning	Do.
Spiraea latifolia	......	1⅘	½	....	do	do	Do.
Spiraea thunbergii	......	1⅘	½	....	do	do	Do.
Spiraea vanhouttei	......	1⅘	½	....	do	do	Do.
Spiraea sp	¾	......	1	60	......	do	
Stephanandra flexuosa	......	1⅘	½	....	Aphids	do	Do.
Stenhanotis floribunda	......	5	¾	66	......	do	
Stevia sp	½	......	1	60	......	do	
Stocks	½	......	1	62	......	do	
Sweet peas	½	......	1	62	Aphids	Tips and blossoms burned.	Do.
Thunbergia erecta	½	......	1	64	......	No burning	
Do	½	......	1	76	......	do	
Tulip	¾	......	1	55	......	do	
Verbena	½	......	1	64	......	do	
Do	¾	......	1	60	......	do	
Verbena (lemon)	½	......	1	64	......	Tender growth burned.	
Vinca major variegata	½	......	1	58	......	No burning	
Do	¾	......	1	56	......	do	
Do	......	5	¾	66	......	do	
Vinca rosea	½	......	1	60	......	do	
Do	¾	......	1	60	......	do	
Wandering Jew	½	......	1	64	......	Severe burning.	
Yucca	......	5⅘	⅔	....	......	No burning	

PLANTS AND INSECTS FUMIGATED IN FUMIGATION BOX.

To determine the susceptibility of the plants listed in Table II, these plants were fumigated in an air-tight box under favorable conditions. Not only were they fumigated in an inclosure much tighter than a greenhouse, but they also received dosages much in excess of those commonly used in greenhouse work.

TABLE II.—*Plants and insects fumigated with hydrocyanic-acid gas in fumigation box.*

Name of plant.	Rate in ounces per 1,000 cubic feet.		Exposure in hours.	House temperature.	Infestation.	Results of treatment.	
	Sodium cyanid.	Potassium cyanid.				On plants.	On insects.
				°F.			
Alternanthera sp		5	½	76		No burning	
Do		10	1	73		do	
Amaranthus sp		3¾	½			do	
Arenga mindorensis		5	1	65	Long scale	do	100 per cent killed.
Atalantia glauca		5	½	76		do	
Do		10	1	73		do	
Banana		10	¾		Citrus mealy bug.	Tender foliage burned.	Do.
Do		5	1		do	No burning	95 per cent killed.
Belou glutinosa		10	1	73		do	
Carnation		5	½	76		Tender foliage burned.	
Catha edgmuthi		2½	¾		Long scale	No burning	60 per cent killed.
Croton	2½		¾	60	do	do	Do.
Do	5		¾	66	do	do	100 per cent killed.
Do	10		¾	68	do	do	Do.
Ferns:							
Boston	2½		1	60	Larvæ Florida fern caterpillar.	do	40 per cent killed.
Do	5		¾	62	do	do	100 per cent killed.
Do	7½		¾	68	do	do	Do.
Do	10		1	68	do	Tender growth burned.	Do.
Do		5	½	76	Aspidistra scale.	No burning	All stages except egg killed.
Adiantum cuneatum	2½		1	60	Larvæ Florida fern caterpillar.	do	40 per cent killed.
Do	5		¾	62	do	do	100 per cent killed.
Do	7½		¾	68	do	do	Do.
Do	10		¾	68	do	Tender growth burned.	Do.
Nephrolepis whitmanii	5		¾	66	do	No burning	Do.
Opuntia		5	½			do	
Do		10	½			do	
Orchids (in growing condition):							
Angraecum eburneum	5		1	62	*Diaspis* sp	Slight burning.	Do.
Cypripedium sp	5		1	62		No burning	
Coelogyne flaccida	5		1	62	Chaff scale	do	Do.
Coelia baueriana	5		1	62		do	
Dendrobium fimbricatum.	5		1	62	*Lepidosaphes* sp.	do	Do.
Schomburgkia undulata.	5		1	62		do	
Orchids (dormant):[1]							
Cattleya trianae	20		¾	70		do	
Cattleya sp		20	½			do	
Do		21	1			do	
Do		42	½			Slight burning; plant recovered.	
Osbeckia stellata		5	1	58	Long scale	No burning	Do.
Palms:							
Kentia belmoreana		5	½		Palm mealy bug and palm aphids.	do	Do.
Areca lutescens		10	1	65	Tessellated scale.	Old foliage burned.	Do.
Corypha elata		5	1	58	Long scale	No burning	Do.
Phoenix sp		10	1	73		do	
Pandanus veitchii		10	1	73	Florida red scale.	do	Do.

[1] Imported orchids without new growths.

In order that there may be no confusion on the part of the reader as to the insects referred to in the tables by their common names, both their common and scientific names are listed herewith:

Greenhouse white fly	*Trialeurodes vaporariorum* (Westw.).
Citrus mealy bug	*Pseudococcus citri* (Risso).
Long-tailed mealy bug	*Pseudococcus adonidum* (L.).
Palm or avocado mealy bug	*Pseudococcus nipae* (Mask.).
Greenhouse Orthezia	*Orthezia insignis* (Dougl.).
Florida red scale	*Chrysomphalus ficus* (Ashm.)
Long scale	*Coccus elongatus* (Sign.).
Soft brown scale	*Coccus hesperidum* (L.).
Palm aphis	*Cerataphis latanae* (Boisd.).
Hemispherical scale	*Coccus hemispherica* (Targ.).
Florida fern caterpillar	*Eriopus floridensis* (Guen.).
Aspidistra scale	*Hemichionaspis aspidistrae* (Sign.).
Tessellated scale	*Eucalymnatus tessellatus* (Sign.).
Azalea Eriococcus	*Eriococcus azaleae* (Horv.).
Azalea lacewing	*Stephanitis azaleae.* (Horv.).
Greenhouse thrips	*Heliothrips haemorrhoidalis* (Bouché).
Onion thrips	*Thrips tabaci* (Lind.).
Cottony scale	*Pulvinaria* sp.
Thread scale	*Ischnaspis longirostris* (Sign.).
Avocado white fly	*Trialeurodes floridensis* (Quaint.).
Rose leafhopper	*Typhlocyba rosae* (L.).
Chaff scale	*Parlatoria proteus* (Curt.).

CONCLUSION.

The results indicated in the foregoing pages are for the most part based on the fumigation of commercial houses under commercial conditions. The slight variations in the percentage of insects killed and injury to plants may be accounted for by the tightness or lack of tightness of different houses. It is obvious, therefore, that it is not practicable to give specific directions as to the amount of cyanid to be employed under all conditions. A knowledge of the pests to be controlled and of the condition of the plants and tightness of the house under consideration will render it possible to determine the dosage to be used.

In fumigating a house containing a large variety of plants, using the correct dosage and under proper conditions, it happens occasionally that some plants appear to have been injured. However, this injury is not permanent, as the plants will show new vigorous growth in a short time. Repeated tests have demonstrated thoroughly that the growth of many plants is stimulated by hydrocyanic-acid gas.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 535

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. ▼ June 28, 1917

THE HORSE-RADISH FLEA-BEETLE: ITS LIFE HISTORY AND DISTRIBUTION.

By F. H. Chittenden, *Entomologist in Charge of Truck Crop and Stored Product Insect Investigations*, and Neale F. Howard, *Specialist*.

CONTENTS.

INTRODUCTORY.

Nearly every year there is brought to this country some insect immigrant, and frequently, in the course of time, these immigrants prove to be pests. As a rule, they are introduced through the large seaports, particularly Boston, New York, New Orleans, and San Francisco, from which points they spread westward, northward, or southward, and less frequently eastward. Occasionally such an insect is carried by commerce beyond the coasts and makes its first appearance inland. This happened in the case of the insect to which the senior author has given the name of the horse-radish flea-beetle (fig. 1) and which is known zoologically as *Phyllotreta armoraciae*

Note.—Horse-radish is widely cultivated in the United States and especially where the horse-radish flea-beetle is now most injurious. The farm value of horse-radish is not far from $400,000 per annum, considering its growth for home use. Two other insects than the horse-radish flea-beetle are especially attracted to it, the horse-radish webworm (*Plutella armoracia* Busck) and the horse-radish caterpillar (*Evergestis straminalis* Hübn.). Neither of these is of any importance, but in the southern range of growth of horse-radish the harlequin cabbage bug is a most destructive pest, seeming to prefer this plant to other crucifers. The horse-radish flea-beetle will continue to spread and soon become a dangerous pest unless growers practice methods of control.

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Koch.[1] It was obtained for the first time in 1893 on the withered leaves of horse-radish in a vacant lot within a fourth of a mile of the grounds of the Columbian Exposition at Chicago, Ill. It is possible that the species was actually introduced at about that time, but probably the time was one, two, or more years earlier, and it was not reported as a pest until 1908.

The larvæ as well as beetles live on the leaves and petioles of the common horse-radish ([*Nasturtium*] *Radicula armoracia*) and when numerous injure the plant to such an extent as to reduce materially the root crop. The larvæ mine the petioles or midribs (fig. 2), while the adults feed on the leaves, causing the characteristic flea-beetle injury—withering and dying—or gouge deep pits in the petioles or midribs.

This beetle belongs to the same genus as the well-known injurious striped cabbage flea-beetle (*Phyllotreta vittata* Fab.) but may be distinguished readily from all other species occurring in this country by its elytra or wing-covers, which are mostly of a pale cream color with a comparatively narrow sutural black stripe, as shown in figure 1.

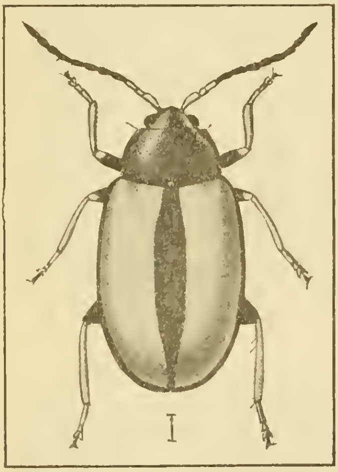

FIG. 1.—The horse-radish flea-beetle (*Phyllotreta armoraciae*): Adult. Greatly enlarged. (Original.)

The horse-radish flea-beetle, having recently become an economic factor in the growing of horse-radish[2] on a commercial scale in Brown County, near Green Bay, Wis., the junior author has been able to trace its life economy and history. It first appeared in sufficient numbers to be seriously injurious in the summer of 1914, when it was reported and observed by Prof. J. G. Sanders. In the two years following, the beetles reappeared in large numbers in the same locality.

While as yet not very generally distributed and confined to attacks on the relatively unimportant crop of horse-radish, the possibility that this insect in its new domain may adapt itself to the other and more important members of the cultivated cruciferous plants renders it worthy of such notice as can be supplied.

[1] Order Coleoptera, family Chrysomelidae, subfamily Halticini.

[2] The authors desire to acknowledge the cooperation of the Department of Economic Entomology, University of Wisconsin, and the many favors received from Mr. George B. Smith, Green Bay, Wis., on whose farm the junior author was stationed when many of the data in this paper were obtained.

DESCRIPTIVE.

THE ADULT.

In appearance *Phyllotreta armoraciae* is distinct from any species of flea-beetle belonging to or introduced into this country. It is somewhat larger and wider than any of the native species of the genus. It is of oval form, strongly convex, and black in color. The first three antennal joints, the apices or tips of the four anterior femora, the tibiæ, and the tarsi are reddish yellow. The elytra are very light yellowish, or cream color, nearly white, with a very thin black lateral margin and a broadened sutural stripe, widest at the middle and constricted at each end and extending from the base of the thorax to the apex of the elytra, where it joins the lateral line. The frons or front is very finely, and the prothorax and elytra densely, punctate. A sensitive pore from which proceeds a seta is located on the lateral margin, which is behind the anterior angle. In the male the fourth antennal joint is slightly thickened and longer than the fifth. In the female the fourth and fifth joints are equal.

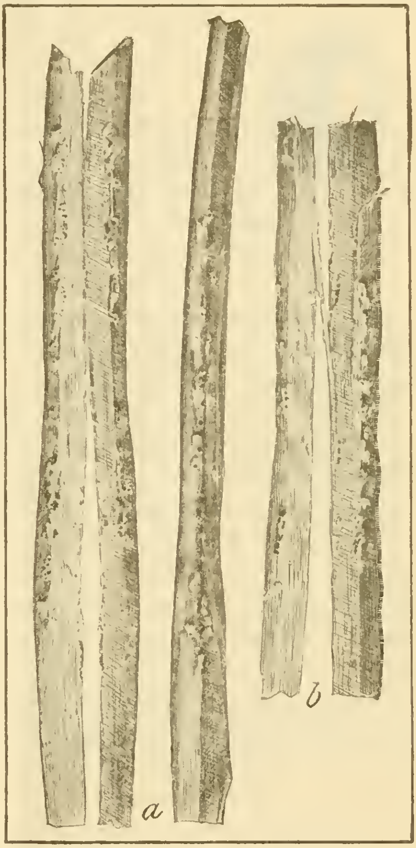

FIG. 2.—Work of the horse-radish flea-beetle in leaf petioles of horse-radish. (Original.)

The average length is from 3 to 3.3 mm., but individuals have been observed where there is a variation of from 2.6 mm. to 3.4 mm. and a variation in width of 1.3 mm. to 1.9 mm.

The following synonymy is recognized:

Phyllotreta armoraciae (Koch).

Haltica armoraciae Koch, Entom. Hefte, v. 2, p. 75, 1803.

Haltica vittata Steph., Mandibulata, p. 292, 1831.

The species is also treated systematically by Illiger, Duftschmidt, Gyllhenhal, Schilling, Redtenbacher, Seidlitz, Foudras, Allard, Leesberg, and others.

THE EGG.

The egg (fig. 3) is oval, capsule-like, deep orange in color, with no special characteristic marking or reticulations visible under a 4-millimeter objective. The following are the measurements taken from 22 eggs: Maximum, 0.47 mm. by 0.84 mm.; minimum, 0.26 mm. by 0.43 mm.; average, 0.33 mm. by 0.57 mm.

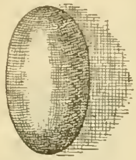

FIG. 3.—The horse-radish flea-beetle: Egg. Highly magnified. (Original.)

THE LARVA.

The immature larva.—The larva, just after hatching from the egg, is about 1.3 mm. long by 0.2 mm. wide; the color of the entire body is whitish, the head, thoracic plates, and anal plate varying from whitish to pale brown. Within a few hours the head, thoracic plate, and anal plate become darker, and a day or more later turn deep brown. In other major respects, excepting the numerous transverse wrinkles and the relative proximity of the setæ, the young larva is very similar to the older larva.

The mature larva.—The larva (fig. 4), when full grown, is slender subcylindrical, pale yellowish white, with dark brown head, thoracic plate, and anal plate; mandibles distinctly quadridentate; head with the usual V-shaped epicranial suture and dark median line caused by attachment of tentorium; five setæ on epicranium each side of median line, several setæ distributed irregularly about lateral margins of head as shown in figure 4; thoracic plates divided by distinct suture; row of three setæ along anterior lateral margin of each plate; one on lateral posterior angle; four minute setæ on posterior inner margin of each plate; one seta on inner anterior angle; mesothorax with pale chitinous plates bearing setæ, two in anterior row, four in posterior row, four on slightly elevated pleural area; metathorax similar. The thoracic legs each bear one claw.

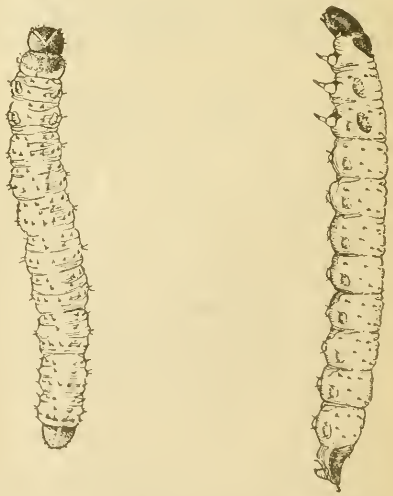

FIG. 4.—The horse-radish flea-beetle: Larva; at left, dorsal view; at right, lateral view. Tubercles and tuberculiferous hairs more prominent than in nature to show arrangement. (Enlarged.) (Original.)

The abdominal segments bear dorsally three rows of slightly elevated chitinous plates, each of which gives rise (when not continuous) to a seta; the first row comprises six, the middle row two, the third row four: at the ends of the third row, a little anterior, are the slightly elevated chitinous pleural plates, bearing three setæ each.

The anal plate approximates a rectangle in outline with the sides converging toward the posterior end and corners rounded. The whole surface except the chitinous plates is covered with minute granulations.

The length just prior to pupation is 4.8 mm., the width 0.8 mm.

THE PUPA.

The pupa (fig. 5) is white and about the same size as the mature beetle. The antennæ are placed along the dorsal margin of the wings and extend around on the ventral side about one-half way to the middle of the body. Between the wings, which extend down to the fourth abdominal segment, is a narrow space in which the tarsi of the three pairs of legs are placed. The femora and tibiæ of the anterior pairs of legs are parallel and extend transversely across the body over the wings, while these parts of the posterior pair of legs extend obliquely and are under the wings, the tips being just visible. Two forceps-like chitinous processes occur at the apex or tip of the last abdominal segment; a stout seta on the tip of each femur, and a number of setæ at various points on the head and body.

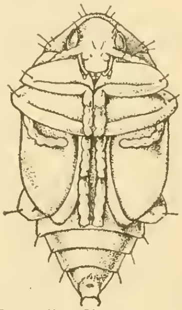

FIG. 5.—The horse-radish flea-beetle: Pupa, ventral view. Enlarged. (Original.)

DISTRIBUTION IN NORTH AMERICA.

The following is a list of localities in which the horse-radish flea-beetle is known to occur in North America. (Fig. 6.) This list is given in approximate order of the first noted appearance of the insect, with the name of the collector in each case:

Chicago, Ill., 1893 (Chittenden).
Guttenberg, Iowa, 1894 (Hugo Soltau).
Okauchee, Wis., 1896 (Dr. E. G. Love).
Dane County, Wis., 1900 (Dr. Wm. S. Marshall).
Bloomington, McLean County, Ill., 1900 (Wolcott).
Glencoe, Ill., 1908 (J. E. Fehd).
Milwaukee County, Wis., 1908 (Dr. S. Graenicher).
Whitewater, Wis., 1909 (Univ. Wis. Coll.).
Westmount, Quebec, 1910 (A. F. Winn).
Lake County, Ind., 1910 (Wolcott), (Blatchley).
Shermerville, Ill., 1912 (Retzinger).
Chester, N. J., 1913 (H. O. Marsh).
Green Bay, Wis., 1914 (J. G. Sanders), 1915 (N. F. Howard).
Highland Park, Mich., 1915 (L .Miller).
Omaha, Nebr., 1915 (Ehlers).
Potsdam, N. Y., 1915 (Chas. Dury).
Ashtabula County, Ohio, 1915 (Robt. Sim).
Madison, Wis., 1916 (N. F. Howard).

ORIGIN AND DISSEMINATION.

The horse-radish flea-beetle is of European origin, and was first described by Koch in 1803[1] from Germany. It is a well-known species in the Old World, and its specific name is derived from its favorite food plant (*Nasturtium*) *Radicula armoracia.* Like all of the striped flea-beetles of the true genus Phyllotreta, the present species breeds on cruciferous plants.

As to the means of introduction of this species in the heart of this country, it was probably brought in with horse-radish and less probably in marsh cress (*Radicula palustris*), or possibly with some potted plant. It is not impossible that these plants were brought to America expressly on account of, if not actually for, exhibition at

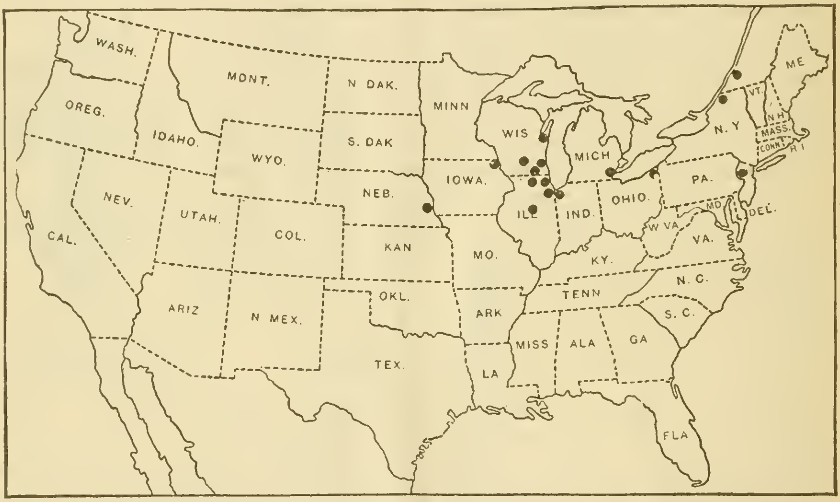

FIG. 6.—Map showing present known distribution of the horse-radish flea-beetle. (Original.)

the Columbian Exposition. It is remarkable, however, in being introduced, not near a seaport, but so far inland.

In the place of its nativity this species ranges throughout middle Europe. Among early records of its establishment in the United States are Guttenberg, Iowa; Chicago and Bloomington, Ill.; and Okauchee, Wis., about 30 miles due west of Milwaukee, and in 1896 there was a strong probability that it would soon spread to Missouri and perhaps to southern Minnesota and Michigan—in other words, that it would establish itself in the course of time in the upper Austral and, perhaps, a portion of the Transition region in the vicinity of its known range at that time. This would include Nebraska in the West and Ohio in the East. The natural progress of most insects introduced from Europe is westward, but there are several

[1] Numbers in parentheses refer to "Bibliography," p. 15.

examples, notably the Colorado potato beetle, of an insect pest which has first traveled eastward.

The predictions made in 1896 that the horse-radish flea-beetle probably would spread soon to southern Minnesota and Michigan were practically correct, as the species is known to be near the State line of Minnesota in Iowa. It had reached Michigan by 1915 and had spread to Ohio and Nebraska the same year. That it would take an eastward sweep as far as Potsdam, N. Y., Quebec, Canada, and northern New Jersey was scarcely expected for years to come. It is now near the border line of Pennsylvania and will undoubtedly spread to that State and to southern New York. The tendency is northward rather than southward, Bloomington, Ill., being the most southerly locality from which it has been reported.

Until otherwise known (and there is little likelihood of learning anything more definite with regard to the first appearance of the horse-radish flea-beetle), it must be concluded that this species was introduced first into Illinois in or around Chicago. From this center it has spread westward and northward, and has evidently taken large commercial jumps eastward, or has been introduced into New Jersey independently, but has made little progress to the south. From present knowledge it apparently prefers the regions about the Great Lakes, but in time doubtless it will be quite as numerous in other waterways and tributaries, even in moist places generally, which are the natural habitat of its principal food plants—horse-radish and marsh cress. In the course of time the somewhat scant records doubtless will be greatly enlarged, showing thereby a more general distribution than is known at present. It has been remarked that in Wisconsin, in the Green Bay region, conditions for the development of this species are highly favorable. This is in the northern portion of the Transition Life Zone, while Quebec is in the Canadian portion of the Boreal Zone.

REVIEW OF LITERATURE.

An account of the horse-radish flea-beetle was given by the senior author in 1895, which is now out of print (3).[1] In this article mention was made of the first occurrence of the species in this country and of the European literature, and the insect was compared with other species of its genus. The original technical description was published in 1803 (1). In 1893 Julius Weise (2) gave a systematic and detailed description of the species with biologic notes and bibliography. In 1897 (4) the senior author noted the occurrence of this insect in Wisconsin in 1896 and suggested the probable range

[1] Figures in parentheses refer to Bibliography, p. 15.

of the species. In 1900 A. B. Wolcott (5) made mention of the capture of the beetle at Bloomington, Ill. Injury by this species was briefly mentioned by J. J. Davis in Illinois in 1910 (6). In 1910, also, Blatchley (7) recorded its occurrence in Lake County, Ind., and in 1911 A. F. Winn (8) observed it at Westmount, Quebec, Canada, on horse-radish received from Montreal. It is not stated, however, whether the insect was believed to come from Montreal or from Westmount. In Europe brief notes were published by Heikertinger in 1911 and 1912 (9, 10).

FOOD PLANTS.

This beetle is partial to horse-radish and marsh cress. It was taken once on young cabbage in hotbeds in early spring by the junior author but was not observed to be eating. The future no doubt will reveal the possibility at least of other host plants.

SEASONAL HISTORY.

THE EGG.

The eggs are deposited from the latter part of April or early May through spring and summer until early August. The manner of placing and the position are variable, but the preferred location is on the tender petioles of young leaves, in the crevices where they leave the root. A few eggs have been found on the ground and on different places on the leaves, above and below the ground, and also carefully placed in the pits made in the stems and petioles by the larvæ or adults. They usually occur in small masses, either carefully arranged side by side in single rows, or two rows high, or carelessly piled without order. Occasionally an egg is found standing on end. The attachment to the plant is not very secure and often an egg-mass falls on the slightest disturbance. In the cages from 2 to 26 eggs were laid at intervals by a single female. While the most frequent number of eggs deposited was 22, at times 44 were deposited, indicating that about 22 eggs are developed in the ovarian tubes at one time. Copulation often takes place between deposition of batches of eggs, but it has not been determined whether or not this is necessary before the deposition of each batch. Judging from analogy, however, it may not be necessary. Hundreds of eggs were obtained in the insectary, but the egg record of one gravid female (Table 1) will suffice to show the egg-laying capabilities of the species. This female was placed in a vial with a portion of horse-radish leaf May 1, 1915, and the total number of eggs laid was 418.

TABLE 1.—*Egg record of a single female horse-radish flea-beetle.*[1]

Date.	Number of eggs deposited.	Remarks.
May 17	22	....
27	22	....
28	17	....
June 3	23	Within 48 hours.
7	26	....
8	2	....
14	4	....
17	....	Male added.
21	25	....
22	....	Copulating.
25	44	Within 48 hours.
27	24	....
29	44	Within 48 hours.
30	....	Copulating.
July 1	28	Hatched July 12.
2	21	....
3	22	....
12	39	Within 72 hours.
14	....	Mass; not counted; estimated at 22.
17	....	Copulating; eggs laid about July 11 hatched.
18	....	Copulating.
22	7	Copulating; within 36 hours.
30	26	Within 5 days.
Aug. 3	22	Within 72 hours.
7	....	Female dead; male still alive.

[1] Within 24 hours in each case, unless otherwise mentioned, eggs were always removed.

Incubation.—The incubation period of the egg varied from 7 to 14 days, as the following data show:

TABLE 2.—*Incubation period of eggs of horse-radish flea-beetle.*

Number deposited.	When deposited.	Date of hatching.	Incubation period.	Larvæ working.
			Days.	
20..........	May 1...........	Before May 17....	14 (approximate).....	May 17.
(.)..........	......do...........	May 11...........	10..................	....
39..........	May 11...........	May 25...........	14..................	....
28..........	July 1...........	July 12...........	11..................	....
	July 10, 11, 12....	July 17...........	7 (approximate)......	....
13..........	June 27..........	July 4 or 5........	8 (approximate)......	....

The months of May, June, July, and August were from 3.6° to 5° F. below normal.

THE LARVA.

On hatching the young larva crawls about the leaf for some time. Several individuals, observed over an hour, showed no particular course. Some went up toward the tip, others toward the crown, where they were lost from sight, but none started feeding. A small, tender petiole, recently invested by numerous larvæ, showed that they had entered at different places along the inner side.

As the larvæ grow and feed in the tissues of the petioles and midribs of the leaves, their presence is indicated by darkened or dead areas, where they have approached the surface. When the larvæ are very numerous, the petiole is tunneled to the extent that it shrinks considerably and causes the leaf to wither and die at the tip and about the margins. When the larva is ready for pupation, it leaves the petiole and enters the ground. The exit holes, which soon collapse and appear as brown spots, are also characteristic of larval injury.

When both larvæ and adults occur together, the former are the more injurious. The injury which the adults cause to the young shoots early in spring as they are breaking through the soil is possibly more serious than subsequent injuries.

That the larva may live in the roots of the plant has been clearly demonstrated since it was first reported to the senior author. A potted plant died and was left intact for about a month. When the pot was wanted for another experiment the soil was found to contain several larvæ and pupæ. Only the shell of a root remained, the contents having been completely devoured by the larvæ. The pupæ transformed to normal adults shortly afterward. This habit of descending to the roots is not very general, however, for it has never been observed while roots peeled for the shredder were being examined.

After leaving the plant the larva enters the soil to a depth of from one-eighth to one-fourth of an inch or even 3 inches. Here it remains for 4 or 5 days, when it becomes white and short and thick. In this form it is inactive. From 2 to 6 days, usually 3 or 4, intervene before pupation.

The total larval period of an individual which was deposited as an egg on May 1, and which was hatched about May 15, was 48 days (about May 15 to about July 6). Another required 52 days; two others required about 57 days, two others 64 days, and two others 66 days.

The two larvæ which developed in 48 and 52 days, respectively, each remained 10 days in the pupal stage. Three other individuals also passed the pupal stage in 10 days, but one required 12 days, while three required from 12 to 13 days.

On September 11, 1915, a few pupæ in the cages had not yet transformed. April 17, 1915, the adults were already numerous about the ground where the shoots of horse-radish were just appearing, or about to appear.

This flea-beetle, like others of its kind, and like most leaf-beetles, hibernates in the adult stage. Careful search for pupæ from time to time practically proves this.

In Wisconsin only one generation appears annually.

The total period of time from egg laying to adult ranges from 77 days to about 90 days in the cases where complete records were obtained. Repeated attempts to obtain eggs from the adults of the current season failed.

The length of the egg-laying period, as shown by the record of an individual given above, is about 75 days, from the middle of May to the first of August. It is certain that this beetle emerged in 1914, probably in August or the first of September, and it is fair to assume that the species would have lived longer in nature had it not been killed by predators, parasites, disease, or the like. This shows the species to be exceptionally long-lived, living about a year in the adult stage.

The fact that the males are as long lived as the females may possibly be due to the fact that copulation is necessary at intervals during the egg-laying period.

RECORD OF EXPERIMENTS IN 1916 AT GREEN BAY AND MADISON, WIS.

April 24, a pair of beetles confined with horse-radish plants.
April 30 to May 5, copulation observed.
May 11, 15 eggs deposited within 24 hours or less.
May 12, 12 eggs in fold of leaf; might have been overlooked the day before.
May 17, 31 eggs found deposited since May 12.
May 22, 24 eggs found over Sunday, about 48 hours.
May 24, 20 eggs and copulation observed.
May 25, 25 eggs observed.
May 29, 48 eggs obtained over Sunday in about 48 hours.
May 31, moved to Madison, Wis.
June 4, 66 eggs obtained since May 30; copulation observed.
June 9, 44 eggs, approximately, observed since June 4.
June 14, 60 eggs found in 24 hours.
June 15, 49 eggs seen in about 24 hours.
June 21, 27 eggs obtained since June 15.
June 24, 44 eggs seen in 24 hours.
June 27, 48 eggs deposited within 24 hours or less. At this point the observations were discontinued.

HATCHING RECORD.

The same difficulty which was experienced in 1915 in the hatching of the eggs was observed this year. Of the entire number of eggs obtained from the female whose record is given above, a total of 513, the following hatched:

June 4, 1 egg deposited May 17 hatched, 17 days.
June 9, 1 egg deposited May 17 hatched, 22 days.
June 14, 7 eggs deposited June 9 hatched, 7 days.

As noted in the table of the 1916 records (Table 3), some of the larvæ died and only a few of these cases are mentioned; the remainder, being unimportant to the records, are not recorded. All dates on which observations were made are given.

TABLE 3.—*Life-history record of the horse-radish flea-beetle during 1916.*

Date eggs laid.	Date larva leaves plant.	Egg and larval stages.	Date of pupation.	Prepupal period.	Date of emergence.	Total pupal period.	Egg to adult.
		Days.		*Days.*		*Days.*	*Days.*
	July 20	52	July 20	....	Died....	....	....
	21	53	27	6	....	....	....
	21	53	27	6	July 31	10	63
	24	56	27	3	31	7	63
	24	56	28	4	....	....	....
	....	....	24	....	Died....	....	....
	July 27	59	31	4	Aug. 5	9	68
	27	59	31	4	7	11	70
	27	59	31	4	7	11	70
	27	59	31	4	2	7	66
	27	59	31	4	Died....	....	....
	27	59	31	4	Died....	....	....
	....	....	27	....	July 31[1]	....	63
	....	....	27	....	31[1]	....	63
	....	....	31	....	Aug. 5	....	68
	Aug. 28	60	Aug. 2	5	5	8	68
	28	60	2	5	Died....	....	....
	28	60	3?	6	Died....	....	....
	31	63	....	....	Aug. 5	6	68
	31	63	5	5	13	13	75
	31	63	5	5	13	13	75
	31	63	5	5	13	13	75
	31	63	5	5	13	13	75
	Aug. 2	65	7	5	Died....	....	....
May 29[1]	2	65	9	7	Died....	....	....
	2	65	Died....	....	....	....	....
	2	65	Died....	....	....	....	....
	5	68	Aug. 7	2	Died....	....	....
	5	68	9	4	Died....	....	....
	5	68	Died....	....	....	....	....
	5	68	Died....	....	....	....	....
	5	68	Died....	....	....	....	....
	5	68	Died....	....	....	....	....
	....	....	Aug. 5	....	Died....	....	....
	Aug. 7	70	13	6	Died....	....	....
	7	70	Died....	....	....	....	....
	9	72	Died....	....	....	....	....
	9	72	Died....	....	....	....	....
	9	72	Died....	....	....	....	....
	9	72	Died....	....	....	....	....
	....	....	....	....	Aug. 7	....	70
	Aug. 13	75	Aug. 20	7	Died....	....	....
	13	75	20	7	Died....	....	....
	13	75	20	7	Died....	....	....
	....	....	13	....	Aug. 20	....	83
	....	....	13	....	Died....	....	....
	....	....	....	....	Aug. 20	....	83
	....	....	....	....	20	....	83
	....	....	20	....	25?	....	88[1]

[1] Approximate.

SUMMARY OF TABLE.

Average combined egg and larval stages .... days.. 61.4
Average prepupal period, 30 individuals .... do.... 4.9
Average total pupal period, 12 individuals .... do.... 10
Average egg to adult, 20 individuals .... do.... 71.8

OTHER RECORDS.

Appearance record: First observed on leaves of horse-radish just breaking through the ground at Green Bay, Wis., April 20, 1916.
Copulation first observed May 2.

RECENT INJURY.

An account of recent injury by the horse-radish flea-beetle was received from a correspondent at Shermerville, Ill., who wrote January 3, 1917, substantially as follows, and who, later, furnished specimens:

I should like your advice on an insect which destroys my horse-radish. It is causing thousands of dollars loss every year in this community, and there seems to be no way to destroy it. It is very small, yellow with black stripes, and it hops; inside of the leaves there are about 25 or 50, according to the size of the leaf. They do their damage when the horse-radish first sprouts after planting, eating off the sprouts as they come up. We have for years hauled out all old dead leaves, after marketing the horse-radish, and burned them. Paris green kills the leaves; kerosene solution does not kill the bug. Every year I plant about 35,000 plants, and the last two years only about 8,000 developed; besides the loss, I have less and less plants each year. There are several planters who have lost their entire crop on account of this insect.

NATURAL ENEMIES.

No parasite or disease of any sort has been observed in the field or in confinement. This is undoubtedly an oversight, since other flea-beetles have natural enemies, such as parasites of the adults, and in time these will probably come under observation. From Glencoe, Ill., a larva apparently predacious on the larva of this species was received.

ASSOCIATED INSECTS.

Associated with this species at Madison, Wis., were three species of minute maggots, (*Elachiptera*) *Crassiseta nigriceps* Loew, *Oscinis pallipes* Loew, and *Agromyza scutellata* var. *variegata* Meig. The first was found in horse-radish stems with the flea-beetle, and adults were reared from larvæ boring in the same stems, often in the same tunnels, as the flea-beetle larva. The third species was reared in horse-radish flea-beetle rearing cages with the preceding. This and probably one or more related species have often been reared from horse-radish stems both at Green Bay, Wis., and Madison, Wis., but just what part they play in the economy of this beetle is unknown. The adults frequently annoy the beetles by flying around and apparently attempting to alight on them.

METHODS OF CONTROL.

SPRAYING.

The injurious flea-beetles of the group to which this species belongs have never been satisfactorily treated by means of insecticides, to the knowledge of the authors. The same applies to other groups of small flea-beetles which attack solanaceous plants, like potato and egg-plant. The powerful hind legs which enable these insects to jump like fleas assist them in escaping from plants during spraying operations, and it is a matter of general knowledge among practical entomologists that it can not be very well determined how much poison, if any, they obtain by feeding on the poisoned surface of leaves. Many experiments have been made, and in practically every case the results have been negative. On the other hand, where Bordeaux mixture has been applied, the flea-beetles of different groups are nearly always repelled. It is evident that arsenicals repel, but in the case of flea-beetles Bordeaux mixture is more effective, a fact which has been known for many years.

During the season of 1914, when injuries by the horse-radish flea-beetle in Wisconsin were very serious and the root crop was much reduced, it was found necessary to bring roots from farther south to supply the usual trade. At this time arsenate-of-lead paste, 6½ pounds to 50 gallons of water, was used four times with considerable success. In the spring of 1915 the field was plowed, the roots collected, stripped of every vestige of leaves, and planted about a quarter of a mile from the old bed. This reduced the beetles to such an extent that very little injury was apparent until the middle of June, 1915.

On June 23 the plants were sprayed with arsenate of lead, and the numbers were reduced considerably. About three weeks later the poison was applied again. In the latitudes of Wisconsin, Michigan, Ohio, Pennsylvania, Delaware, New York, Indiana, and Iowa the spray should be administered at intervals from about the last week in April until late in July.

VALUE OF CULTURAL PRACTICES.

The importance of the employment of methods for the control of these insects as pests is exemplified by the experience of a firm at Green Bay, Wis. Before the advent of flea-beetles, truckers were able to raise horse-radish on a large scale from the same beds for several years at a time, but now the abundance and destructiveness of this flea-beetle makes it necessary to change these cultural practices completely in order to produce a crop, and it is necessary to replant a new bed from old roots every season.

SUMMARY.

The growing of horse-radish in the North is menaced by the introduction from Europe of a small insect known as the horse-radish flea-beetle. The beetle is oval in outline, about one-eighth of an inch long, with yellow elytra or wing-covers bordered with black, and with a longitudinal black band through the middle. The larvæ or young bore into the petioles or midribs of horse-radish, and the adults feed on the leaves and gouge deeply into the midribs, causing drying and death.

The beetle was first recognized in this country at Chicago, Ill., in 1893, since which time its area of distribution has increased until it now occurs from New York and New Jersey to Quebec, Canada, and westward to Nebraska.

The species passes the winter in hibernation as a beetle, coming forth in its northern range in April and May.

While as yet destructive only to horse-radish, its capabilities of becoming a pernicious pest, should it adapt itself to the economically more important cruciferous crops, must be acknowledged, and measures should be taken for its suppression wherever possible.

No systematic control program has been adopted as yet. Bordeaux mixture, a powerful repellent against flea-beetles, applied on the first appearance of the insect will prevent much injury, and if arsenate of lead is used later it should hold the insect in check.

When a new bed is to be planted a location should be chosen as far removed as possible from any infested bed. It is advisable also to destroy all volunteer plants, not only to keep the insect in check but in some cases to suppress it as a weed.

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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 536

Contribution from Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER January 26, 1918

THE MEDITERRANEAN FRUIT FLY IN HAWAII

By

E. A. BACK, Entomologist, and C. E. PEMBERTON,
Assistant Entomologist, Mediterranean and
other Fruit-Fly Investigations

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By E. A. BACK, *Entomologist*, and C. E. PEMBERTON, *Assistant Entomologist*, *Mediterranean and Other Fruit-fly Investigations.*

CONTENTS.[1]

INTRODUCTION.

The Mediterranean fruit fly (*Ceratitis capitata* Wied.) (fig. 1; Pl. 1, fig. 1) since its discovery in the Hawaiian Islands in 1910 has caused a serious and permanent check upon horticultural pursuits in these islands. The history of this pest shows that it has been gradually spreading to all tropical and subtropical countries. The frequency with which infested fruits from Hawaii are being discovered and condemned at California ports by representatives of the Federal Horticultural Board indicates that this fruit fly might have become established in parts of California and in our more Southern States and might now be doing untold injury to fruit interests but for the efficient quarantine maintained on the Pacific coast by State and Federal authorities. It is feared, however, that the Mediterranean fruit fly ultimately will be able to find some unavoidable weakness in the quarantine work and eventually become established on the mainland of North America.

The investigations reported in this publication have been carried on by the Bureau of Entomology, United States Department of Agri-

[1] It has been found necessary to omit a bibliography consisting of about 350 references accompanied by brief résumé material. Reference should be made to Silvestri, Bulletin No. 3, Hawaiian Bd. Agr. and Forestry, for the most complete printed bibliography.

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culture, under the immediate supervision of Mr. Charles L. Marlatt, assistant chief of the bureau and chief of the Division of Tropical and Subtropical Fruit-Insect Investigations. This work was undertaken during September, 1912, primarily to make available for mainland fruit-growing interests information that will prove of inestimable value in determining the extent of the possible distribution of this pest and the factors of control which will be most important in eradicating newly discovered outbreaks.

The senior writer wishes to acknowledge his obligations to Mr. Marlatt, who has greatly aided these investigations by his direction, and to express his appreciation of the assistance rendered by his associates, Messrs. C. E. Pemberton and H. F. Willard.

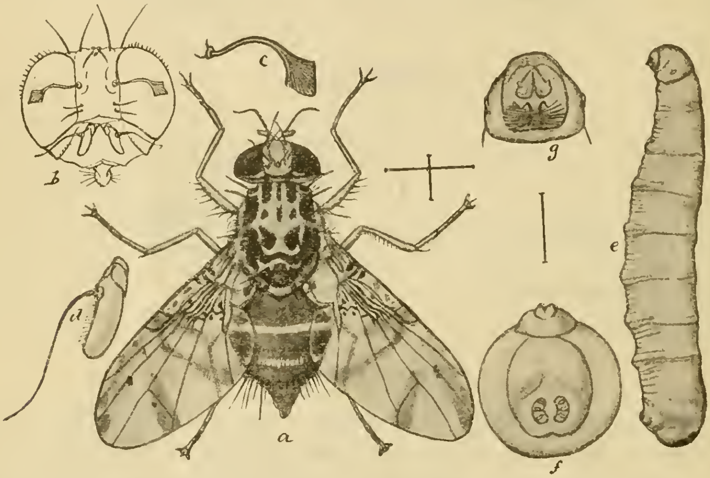


FIG. 1.—The Mediterranean fruit fly (*Ceratitis capitata*): *a*, Adult female; *b*, head of same from front; *c*, spatula-like hair from face of male; *d*, antenna; *e*, larva; *f*, anal segment of same; *g*, head of same. *a* and *e*, Enlarged; *b*, *g*, *f*, greatly enlarged; *c*, *d*, still more greatly enlarged. (Howard.)

COMMON NAMES.

The common name "Mediterranean fruit fly" was first used by Frogatt in 1899 to distinguish *Ceratitis capitata* from other fruit flies found in Australia. At the present time this name is the most widely used and most satisfactory of the common names by which this pest has been known and will be used by the writers. Other common names found in literature are "the fruit fly," "the maggot," "peach fly," "peach maggot," "fruit grub," "apricot worm," "trypeta fly," "West Australian fruit fly," "orange fly," and "orange fly trypeta."

ORIGIN.

Although Wiedemann first described *Ceratitis capitata* from specimens collected by Daldorf, supposedly in the East Indies, the failure of subsequent entomological exploration in the Indo-Malayan region to locate this species, except where it is known beyond question to have been introduced, has led entomologists to seek its original home elsewhere. Known facts concerning the artificial spread of this pest narrow its probable origin to the African continental area. According to Bezzi, the genus Ceratitis is of African origin. Information gained by various writers indicates that southern Europe is not its native home, although it has been recorded from this region for many years. Leonardi states that the Mediterranean fruit fly was not recorded as a pest in southern Italy until 1863, nor in Sicily until 1878. Had it been a native of Italy its ravages, as were those of the olive fruit fly (*Dacus oleae* Rossi), would have attracted the attention of writers prior to this time. While De Brême first records specimens reared in southern Spain in 1842, it is easier, in the light of more recent investigation, to believe Spain to be an adopted rather than the original home. Compere states that in 1903 there was living at Carcagente, Valencia County, Spain, an aged priest who could well remember the time in his childhood that peaches in that part of Spain were free from fruit-fly attack. Compere is also authority for the statement that commission merchants at Seville found that the pest was spreading farther inland to the north every season, even as late as 1903. The work of Graham (1910) and Silvestri (1912) has proved that *C. capitata* is present in the little-developed West African countries of Nigeria, Dahomey, and the Kongo, and Gowdy found the species already established in Uganda as early in the development of that country as 1909. These records, coupled with the information by the South African entomologists regarding its spread into the southern part of the African Continent, lend color to the statement of Silvestri that the natural habitat of *Ceratitis capitata* is "certainly tropical Africa south of 8° N. latitude." Silvestri, however, is of the opinion that one can not state whether the whole of this region should be considered as the natural habitat, or only the western portion, until careful studies have been made in French Equatorial Africa and British East Africa. Further exploration of the west coast of Africa north of 8° north latitude is very likely to establish new records of distribution and extend somewhat these limits of origin to include more semitropical territory.

DISTRIBUTION.

The Mediterranean fruit fly is at present established on every continent except that of North America. It has been recorded from the following regions:

Europe: Spain, France, southern Italy, Sicily, Greece, and Malta.
Asia: Asiatic Turkey (Beirut, Jerusalem, Jaffa.)
Africa: Egypt (Cairo and Kafir el Zayet), Tunis, Algeria, the Azores, Madeira Islands, Canary Islands, Cape Verde Islands, Dahomey, southern Nigeria, the Kongo, Cape Colony, Natal, Delagoa Bay, southern Rhodesia, British East Africa, Uganda Protectorate, Mauritius, and Madagascar.

Australasia: Western Australia, New South Wales, Victoria, and Queensland, northern New Zealand, and Tasmania.
South America: Brazil and Argentina (Buenos Aires).
North America: Bermuda Islands.
Hawaiian Islands.

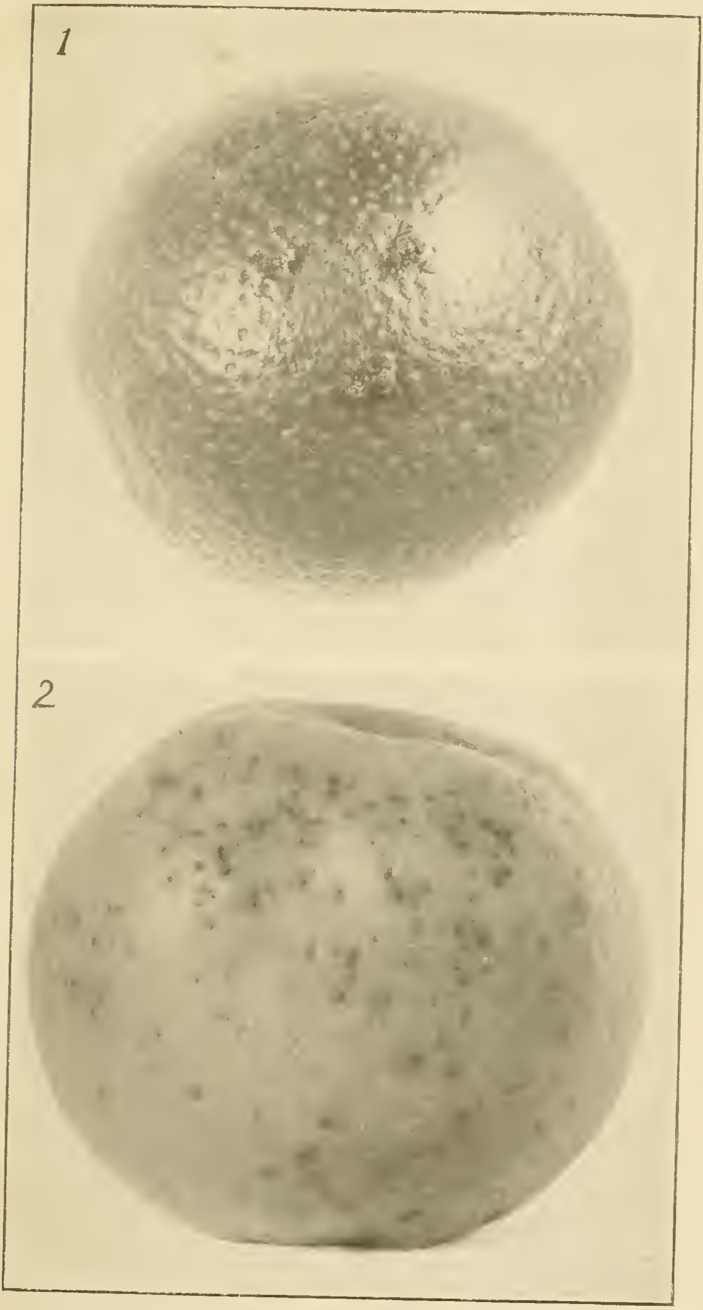
MEDITERRANEAN REGIONS.

The dates of the first discovery of the Mediterranean fruit fly in the countries bordering on the Mediterranean can not be used with precision in establishing a chronology of dispersion, since the pest may have been present many years prior to the first entomological observations recorded unless statements to the contrary are made in literature. Aside from our first record of establishment in Mauritius by Latreille in 1817, the earlier records refer to damage in the Mediterranean region. According to MacLeay this pest was well established in the Azores, Cape Verde, and Madeira Islands as early as 1829, and was the source of much injury to oranges arriving at London from these islands. It was first recorded from Spain in 1842, from Algeria in 1859, and from Tunis in 1885. Compere gives us our first records of its presence in Egypt at Port Said and in Asiatic Turkey at Beirut, Jaffa, and Jerusalem in 1904. During the same year, Cartwright records the infestation of oranges at Kafir el Zayet (Egypt) and four years later Froggatt found many infested oranges in the Cairo (Egypt) markets. Literature does not record the presence of this pest in Malta until 1890, although it was known to have become established there about 1875. In France the Mediterranean fruit fly was reared from apricots at Courbevoie, in the environs of Paris, in 1900, and by 1904 the fruit industry around Maritimes was ruined, according to Hooper. In 1916 the citrus crops in Attica (Greece) and Epirus (Southern Albania) were reported infested.

AFRICA.

Very little is known regarding the general distribution of the Mediterranean fruit fly throughout the great central portion of the African continent. While it is known to be a serious pest along the Mediterranean shores and to have spread into the southern portion, too few entomological observations have been made to warrant statements concerning spread throughout the more tropical regions. Graham in 1910 and Silvestri in 1913 state that it occurs in Dahomey, southern Nigeria, and the Kongo. Gowdey's records from Uganda in 1909 are the first from tropical East Africa, although Anderson states in 1914 that he had found *C. capitata* infesting coffee cherries in British East Africa. In 1912 Jack lists *C. capitata* as abundant throughout southern Rhodesia, but Morstatt states definitely that the pest did not occur in coffee cherries in German East Africa during 1913 and 1914.

The first record of injury caused by the Mediterranean fruit fly in South Africa was made by Miss Ormerod in 1889; but, as Mally states



THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—Three adults of the Mediterranean fruit fly (*Ceratitis capitata*) about natural size, attempting to oviposit in an orange; note the relative size of flies and fruit. FIG. 2.—Ripe apple showing many punctures in the skin made by *C. capitata* in confinement. (Original.)

in 1904, it was introduced many years before. In 1893 Bairstow writes that he was familiar with *C. capitata* in South Africa in 1880, and that the Rt. Rev. Bishop Richards remembered damage done as far in the past as 40 years. In 1903–4 Fuller records *C. capitata* as one of the newly observed pests among the Natal orchards. It is not known whether the introduction in South Africa was by infested fruit from the Madeiras or by the gradual spread overland along the coastal regions, although the Madeiras seem the more probable source.

C. capitata was first recorded from Madagascar during 1914, when it was found seriously injuring the peach crop.

AUSTRALASIA.

Western Australia.—The Mediterranean fruit fly was first recorded in literature as a pest in Australia in 1897 by Fuller, who states that it had been known to have been established in western Australia for about two years in Claremont and Perth and along the Swan River, especially at Guildford. According to Despeissis, the first report of injury in Australia was made to the Bureau of Western Australia in 1894, which was, in his opinion, about one or two years after the date of its actual introduction. The pest has since been recorded from as far north as Geraldton and Northampton and as far south as Bunbury.

New South Wales.—In New South Wales the Mediterranean fruit fly was first reared in 1898. French found that peaches imported into Victoria from Sydney were infested and notified Froggatt. Within a few days Froggatt was able to verify this record by rearings of his own from fruit supposed to have been infested by the Queensland fruit fly (*Bactrocera tryoni* Froggatt). As Froggatt had been on the watch for *C. capitata*, it is probable that it became established about Sydney during 1898, although Rose, in 1897, states that in the northern part of New South Wales, at Warialda, peaches and nectarines had been nearly all destroyed in 1897 by a fruit fly first appearing about 1895 and identified by Froggatt as probably *C. capitata*. According to Froggatt, the pest has spread throughout all the citrus orchards of New South Wales to a greater or less extent.

Victoria.—Editorial comment in 1907 states that serious infestation of *C. capitata* had been recently discovered in the orchards in Goulburn Valley and farther west at Bendigo and at Horsham, and Froggatt is authority for its establishment at Albury and for the statement that it is present throughout the northern half of Victoria.

Queensland.—There are very few references to the presence of *C. capitata* in Queensland. Froggatt states, in 1909, that for a long time it was believed that it was not to be found in this part of Australia, but that, while it might not be abundant, he had specimens from Brisbane. Voller, in 1903, mentions Brisbane, Toowoomba, and Warwick as places especially subject to *C. capitata* attack.

Tasmania.—The Mediterranean fruit fly became established in Tasmania about Launceston during the early part of 1899 and, according to Lea, attacked apples, pears, and peaches. As the result of a meeting of the Tasmania Council of Agriculture, held on June 1, to discuss correspondence regarding establishment and methods of eradication, a vigorous clean-culture campaign was authorized, which apparently was responsible for the eradication of the pest. No cases of infestation have since been observed in Tasmania fruit.

New Zealand.—Kirk states in 1901 that the Mediterranean fruit fly had not, up to that time, appeared in any New Zealand fruit-growing district. Two outbreaks were later recorded, at Blenheim and at Napier, respectively, but were reported to have been quickly stamped out by the destruction of the fruit and treatment of the soil. A third instance of temporary establishment in New Zealand was recorded in 1908 at Davenport. At present the Mediterranean fruit fly is not known to exist in New Zealand.

Islands about Australia.—In 1904 Kirk states that he had never reared *C. capitata* from fruits received in New Zealand from the islands of Suva, Nukualofa, Vavau, Rarotonga, Mangaia, Heratine, and Samoa.

BERMUDA ISLANDS.

The Mediterranean fruit fly was not recorded from the Bermuda Islands until 1890, when specimens of infested peaches were sent Dr. C. V. Riley. It was known as a pest in Bermuda during the 25 years previous, and is supposed to have become established about 1865, when a vessel carrying a cargo of fruit from the Mediterranean region, bound for New York, was forced by severe storms to discharge her cargo in Bermuda.

WEST INDIES.

There are no known records of the presence of *Ceratitis capitata* in the West Indies. The fact that the Jamaica Botanical Department in 1900 published a bulletin on orange culture and diseases, by Borg, in which reference is made to *C. capitata* as a pest of the orange, has led some to believe that the Mediterranean fruit fly has become established in Jamaica. The subject-matter of this bulletin was originally presented before the Malta Archeological and Scientific Society and contains nothing to warrant the conclusion that the author was dealing with the subject except in a most general way, particularly as he speaks of the fly occurring only about the Mediterranean.

Ballou, in an article published in 1913 on the prevalence of some pests and diseases in the West Indies during 1912, states that "fruit-fly" attacks were not so general in Dominica as in former years. The editor of the Review of Applied Entomology erroneously identified the "fruit fly" as "*C. capitata.*" Ballou has since denied in correspondence that *C. capitata* was the insect in question.

SOUTH AMERICA.

Dr. L. O. Howard first identified the Mediterranean fruit fly from South America from specimens reared from peaches sent him by Dr. H. von Ihering in 1901. Compere, in 1904, and Lounsbury, in 1905, found the pest in the States of Sao Paulo and Rio de Janeiro. In 1906 Hempel states that *C. capitata* was the most common of the fruit flies attacking peaches in Sao Paulo.

In writing of fruit culture in Argentina in 1905, Lounsbury states that peaches near Buenos Aires were badly affected by an undetermined species of fruit fly which he thought likely to be *Ceratitis capitata.* Silvestri definitely records *C. capitata* from Buenos Aires, presumably as a result of this statement of Lounsbury.

HAWAIIAN ISLANDS.

The Mediterranean fruit fly was first observed in the Hawaiian Islands by Mr. D. T. Fullaway, who captured a living adult in the insectary at the U. S. Department of Agriculture Experiment Station on June 21, 1910. During the following September another adult was captured by Terry and Perkins on the laboratory windows of the Hawaiian Sugar Planters' Association. Observations made in the field during September by Terry showed that the pest was already established in the Punchbowl district of Honolulu on oranges and limes, and from that time new records of infestation were rapidly brought to light. By October, 1911, the pest had already become established on the island of Kauai, and was known to exist on Molokai at least by January, 1912, when it was first recorded from the Kohala district of the island of Hawaii. During March, 1912, specimens of infested coffee cherries were reported from the Kona district of Hawaii. The first records of establishment in the Puna district of Hawaii were made during March, 1913, when infested oranges and peaches were found at Naalehu and Hilea. Peaches were not reported infested in the Hilo district of Hawaii until the spring of 1914, but soon after infestations were found throughout the Hilo and Hamakua districts. The fruit fly was found established on the Island of Maui by May, 1912. By July, 1914, the Mediterranean fruit fly had spread to every important island of the Hawaiian group, and at present is well established in every village and wild guava scrub examined by the writers. Judging from the rapidity with which this pest has spread throughout new districts in Hawaii, the writers agree with Ehrhorn that the pest secured its first foothold in Hawaii at Honolulu about 1907, although there are several well-informed horticulturists in Honolulu who believe establishment occurred even one or two years earlier.

SOURCE OF HAWAIIAN INFESTATION.

There is little doubt that the Mediterranean fruit fly was carried to the Hawaiian Islands from Australia on one or more of the ships

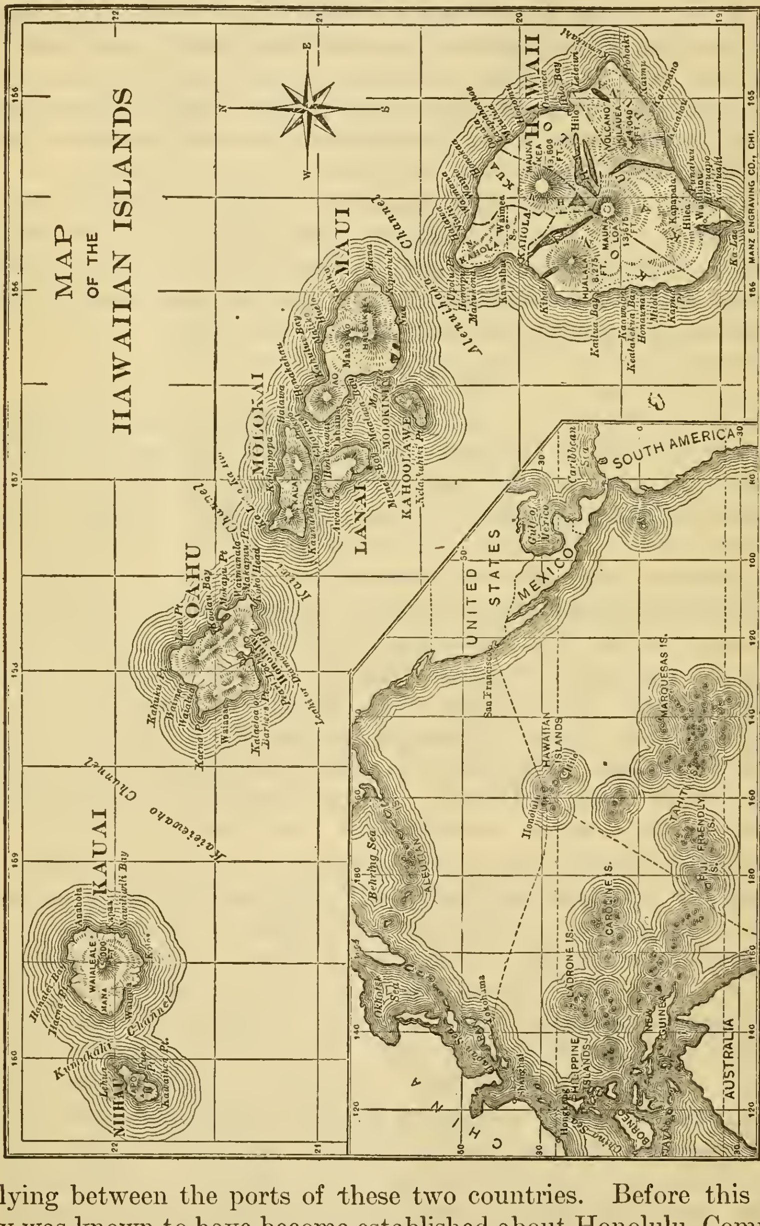


FIG. 2.—Map of the Hawaiian Islands, showing their relative position and their relation to one another in the distribution of the Mediterranean fruit fly.

plying between the ports of these two countries. Before this fruit fly was known to have become established about Honolulu, Compere, as a traveler between Australia and Honolulu, observed *C. capitata* larvæ emerging from host fruits stored on the deck of his vessel and pupating in the corners of the fruit containers and in secluded spots about the deck. It would have been quite possible for larvæ thus emerging to have completed their development during the days required for the voyage between Sydney and Honolulu and emerged as adults while the ship lay at anchor at Honolulu within several hundred yards of host fruit trees. As the Mediterranean fruit fly did not become established about Sydney and the eastern portion of Australia until 1898–1907, its establishment about Honolulu between 1907 and 1908 came as a natural sequence. This is most forcibly brought to the attention of those interested in horticultural development when they appreciate the frequency with which this pest has attempted to bridge the Pacific between Honolulu and San Francisco since its establishment at Honolulu, as indicated by the interception of infested fruit at San Francisco by officers of the Federal Horticultural Board.

CONDITIONS FAVORABLE TO ESTABLISHMENT IN THE HAWAIIAN ISLANDS.

CLIMATIC CONDITIONS IN HONOLULU.

The climate of the littoral regions of Hawaii, and up to an elevation of 1,500 feet, is most favorable to the establishment and rapid increase of *C. capitata*. At Honolulu the temperature very rarely drops as low as 58° F., and then only for a few hours during one or two nights in the year. The data in Table I, taken from the monthly meteorological summaries of the U. S. Weather Bureau at Honolulu for 1914, are given as a fairly reliable guide to the ranges in temperature throughout littoral Hawaii.

TABLE I.—*Temperature and relative humidity at Honolulu during 1914.*

Month.	Temperature.									Relative humidity.		
	Maximum.	Minimum.	Daily range.			Mean at [1]			Mean of maximum and minimum.	Maximum.	Minimum.	Mean.
			Maximum.	Minimum.	Average.	6 a. m.	2 p. m.	9 p. m.				
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	P. ct.	P. ct.	P. ct.
January	78	60	18	6	10	67.4	74.0	68.9	[2] 69.1	83	50	66.4
February	81	61	14	8	11.4	66.2	72.4	68.3	71.4	82	52	70.9
March	80	57	15	7	10.5	67.5	74.8	89.6	70.9	86	53	68.6
April	82	60	15	7	10.7	68.6	75.8	70.9	72.5	81	52	68.7
May	83	66	14	6	9.4	72.6	79.9	74.6	74.3	82	56	70.1
June	83	69	12	6	9.1	74.0	80.4	76.0	76.6	80	58	68.8
July	85	70	15	6	9.2	75.2	81.5	76.3	78.4	81	62	69.6
August	86	71	12	5	9.1	76.0	81.4	76.8	79.0	80	58	69.2
September	87	70	12	6	8.1	75.9	80.6	77.0	78.7	85	62	71.4
October	83	67	14	7	9.4	73.6	79.7	75.1	77.0	74	60	68.0
November	83	65	13	5	10.2	71.4	77.2	72.9	74.6	85	52	70.5
December	80	61	14	7	10.7	67.6	74.3	69.7	71.1	89	60	72.7

[1] Compiled from 1914 and 1915 data, taken from the 1916 Hawaiian Annual.
[2] The normal mean for January is 71.1° F.

It will be observed that the daily range is very small, averaging between 8 and 11 degrees, and that the normal monthly mean temperatures range between 70.9° and 79° F. In Table II are given the monthly and yearly means, together with the yearly maximum and minimum temperatures, recorded at different places on the islands of Hawaii, Maui, and Oahu, which, at their respective elevations, represent the variations in range of temperature from that in Honolulu, to be found at points in Hawaii where host fruits are grown.

TABLE II.—*Monthly and annual mean and maximum and minimum temperatures of representative localities in Hawaii where host fruits of the Mediterranean fruit fly may be grown.*

Locality.	Elevation.	Monthly mean temperatures.												Annual.		
		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Mean.	Highest temperature recorded.	Lowest temperature recorded.
Island of Oahu:	*Feet.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
Honolulu	111	70.0	69.7	71.4	73.3	74.3	75.3	76.4	78.1	76.8	75.2	74.7	72.4	74.0	85	58
Waialua Mill	30	70.4	68.7	71.0	72.7	73.4	74.4	75.8	77.0	75.9	73.9	72.8	70.5	73.0	91	55
Waianae	6	71.3	70.4	71.9	73.8	74.8	77.3	79.2	80.0	79.3	75.5	74.8	73.2	75.1	91	52
Schofield Barracks	990	66.6	65.8	67.4	68.9	69.8	71.0	73.0	74.0	73.2	71.2	66.4	68.1	69.6	89	51
Tantalus Heights	1,300	63.6	64.1	66.3	67.2	68.0	67.7	69.3	70.4	69.1	68.5	67.4	65.6	67.3	84	54
Island of Maui:																
Kaanapali	12	70.2	70.4	71.4	74.0	76.0	77.3	79.3	80.0	79.4	76.5	75.2	73.0	75.2	92	57
Wailuku	250	68.8	69.2	69.8	72.2	73.0	74.1	75.5	77.4	75.8	74.0	72.8	70.9	72.8	89	56
Haiku	700	67.2	67.2	68.6	69.6	70.7	70.7	72.8	74.2	72.4	71.8	70.4	68.7	70.4	83	57
Island of Hawaii:																
Hilo	100	68.4	68.7	69.4	70.8	71.3	72.4	74.0	74.6	73.8	73.0	71.4	69.6	71.4	88	55
Honokaa	470	67.6	67.8	70.1	71.0	72.3	72.6	73.4	74.6	72.8	72.4	71.2	69.0	71.2	90	53
Holualoa	1,350	67.0	66.6	66.7	68.8	68.3	69.4	70.8	71.2	70.8	69.4	68.2	66.2	68.6	84	51
Huehue	2,000	65.2	65.4	66.4	68.3	68.6	70.1	72.6	73.3	71.7	69.8	68.8	66.8	68.9	87	50
Pahala	850	68.6	68.4	68.7	71.2	71.2	72.1	74.0	75.2	74.9	73.0	72.4	72.0	71.8	91	53
Kohala Mill	270	68.4	67.9	69.7	70.9	72.2	72.6	74.2	75.2	74.2	73.1	71.7	70.2	71.7	86	54
Waimea	2,720	58.6	60.4	62.0	61.9	61.9	61.8	63.6	65.1	63.7	64.2	61.7	60.4	62.1	80	44
Volcano House	4,000	57.8	58.6	59.0	59.6	59.2	60.1	60.0	59.2	59.3	61.0	60.8	60.4	59.6	72	42

Biological work has shown that even the lowest monthly means of localities up to 1,500 feet elevation have little effect upon *C. capitata* other than to retard development somewhat. It is never cold enough throughout littoral Hawaii to render either the adults or the larvæ inactive. As a result there are no periods of the year at any Hawaiian port when the climatic conditions are unfavorable for the establishment or increase of this pest. Data presented later in the text indicate that a continuous temperature ranging between 58° and 62° F., or the lowest range of temperature usually experienced in littoral Hawaii, does not increase the normal mortality among the immature stages of the fruit fly, and that these stages withstand for short periods, without injury, temperatures lower than any recorded in Table II. The two stations, Holualoa and Huehue, at about 1,350 and 2,000 feet elevation, respectively, may be taken as fair examples of altitudes above which host fruits are only scatteringly grown, but at which the fruit fly has demonstrated its capacity to injure fruits seriously.

HOST CONDITIONS.

Favorable as are the climatic conditions for the establishment and increase of the Mediterranean fruit fly in Hawaii, the host conditions are even more so. Mr. H. J. Quayle, who has studied fruit-fly conditions throughout southern Europe, and Mr. J. C. Bridwell, who has had similar opportunities in western and southern Africa and in Australia, have stated to the writers that nowhere have they found host conditions so favorable for establishment and rapid increase as in littoral Hawaii, especially about Honolulu and Hilo. Under the subject of host fruits, on page 24, the writers record 72 species of fruits growing in Honolulu that are subject to attack by *C. capitata*. The discussion of their susceptibility to attack, however, throws little light upon their numerical abundance or upon the seasons of the year during which their fruit is available for fruit-fly infestation. During the clean-culture campaign waged against this pest in Honolulu during 1913, data were secured which forcibly demonstrate the ideal host conditions found in Honolulu, making possible extraordinary increase and excessive infestations. The residents of Honolulu are justly proud of their magnificent vegetation and have taken great pleasure in growing an unusually large assortment of trees and shrubs upon their town properties. An inventory of such trees and shrubs, that bear fruits subject to infestation, growing upon 60 blocks in that portion of Honolulu bounded by Liliha, Punchbowl, Beretania, and School streets, is given in Table III.

TABLE III.—*Number of host trees and shrubs of the Mediterranean fruit fly growing during 1913 in that portion of Honolulu bounded by Liliha, Punchbowl, Beretania, and School streets.*

Block.	Lots in block.	Trees in block.	Block.	Lots in block.	Trees in block.	Block.	Lots in block.	Trees in block.	Block.	Lots in block.	Trees in block.
1	19	81	16	18	90	31	7	19	46	9	160
2	10	64	17	6	13	32	10	62	47	4	51
3	10	105	18	5	20	33	5	10	48	15	217
4	3	0	19	23	101	34	5	22	49	23	167
5	16	137	20	12	48	35	5	9	50	6	111
6	9	28	21	18	118	36	8	51	51	16	112
7	9	64	22	7	59	37	14	134	52	9	41
8	4	59	23	3	0	38	13	108	53	5	65
9	6	18	24	14	75	39	41	115	54	14	83
10	9	124	25	3	8	40	12	74	55	23	112
11	28	132	26	7	25	41	36	135	56	26	158
12	6	163	27	4	7	42	17	76	57	12	37
13	9	66	28	4	15	43	18	208	58	4	0
14	9	66	29	9	42	44	24	144	59	3	124
15	25	86	30	2	39	45	9	54	60	12	98

Total number of lots in 60 blocks, 712; total number of trees, 4,610; average number of trees per lot, 6.5; average number of trees per block, 76.8.

From this it will be seen that there was a total of 4,610 trees and shrubs on the 712 lots under consideration, or an average of 6.5 trees per dooryard capable of supporting the fruit fly. In Table IV are given data indicating the relative abundance of different hosts.

TABLE IV.—*Number and species of host trees of the Mediterranean fruit fly growing in that portion of Honolulu covered by Table III.*

Apricot	1	Fig	201	Mandarin	28	Rose apple	25
Avocado	653	Guava, common	94	Mango	1,154	Sapodilla	5
Breadfruit	58	Guava, strawberry	73	Mangosteen	7	Sapota	30
Carambala	48	Java plum	80	Mountain apple	41	Soursop	57
Chinese inkberry	6	Kamani, ball	4	Mock orange	33	Spanish cherry	1
Chinese orange	148	Kamani, winged	13	Orange, sweet	372	Star apple	4
Coffee	298	Kumquat	4	Papaya	687	Surinam cherry	63
Coffee, Liberian	8	Lemon	22	Peach	69	Wi	19
Cotton	11	Lichee	40	Pear, Bartlett	2	Waiawai	60
Custard apple	1	Lime	10	Pomegranate	128		
Damson plum	4	Loquat	33	Pomelo	15	Total	4,610

In Hilo, island of Hawaii, host conditions are quite as favorable for fruit-fly development as in Honolulu. Thus the following numbers of host trees and shrubs were found in certain yards of Hilo during March, 1914:

YARD 1.	YARD 2.	YARD 3.	YARD 4.
1 Rose apple.[1]	2 Surinam cherry.	11 Rose apple.	4 Peach.
4 Surinam cherry.	2 Papaya.	2 Mango.	6 Mango.
2 Japanese plum	1 Thevetia.	3 Thevetia.	1 Loquat.
6 Mountain apple.	2 Orange.	1 Avocado.	3 Winged kamani.
1 Star apple.	2 Strawberry guava.		2 Surinam cherry.
34 Coffee trees.	14 Coffee.		1 Strawberry guava.
20 Common guava.	Bananas.		
15 Brazilian banana.	2 Avocado.		
4 Avocado.	1 Peach.		
3 Mango	3 Fig.		
2 Papaya.	2 Mountain apple.		
5 Orange	2 Lichee nut.		
1 Peach.	3 Common guava.		
1 Grape.			
1 Winged kamani.			
1 Mangosteen.			
1 Fig.			
1 Mimusops.			

There is no time in Hawaii when fruits are entirely out of season. The fact that several hosts, such as the Chinese orange (*Citrus japonica*), Surinam cherry (*Eugenia michelii*), and mock orange (*Murraya exotica*), bear several crops a year, while others, such as certain specimens of ball kamani (*Calophyllum inophyllum*) (Pl. VI) and winged kamani (*Terminalia catappa*) (Pl. XIX), appear to be seldom entirely free from ripening fruits, assures food for the fruit fly the year round.

The succession of fruits is also increased by the individuality of trees of the same species, or even of certain branches of a single tree, which results in a very uneven ripening of the fruit. While the data in Table V do not indicate the seasonal abundance of host fruits, they have been summarized from the collections of clean-culture inspectors made during 1913 to show the remarkable succession of host fruits found ripening in greater or less quantities throughout

[1] For scientific names of fruits see section on host fruits, p. 24.

RELATION OF FLORA OF HAWAIIAN ISLANDS TO THE MEDITERRANEAN FRUIT FLY.

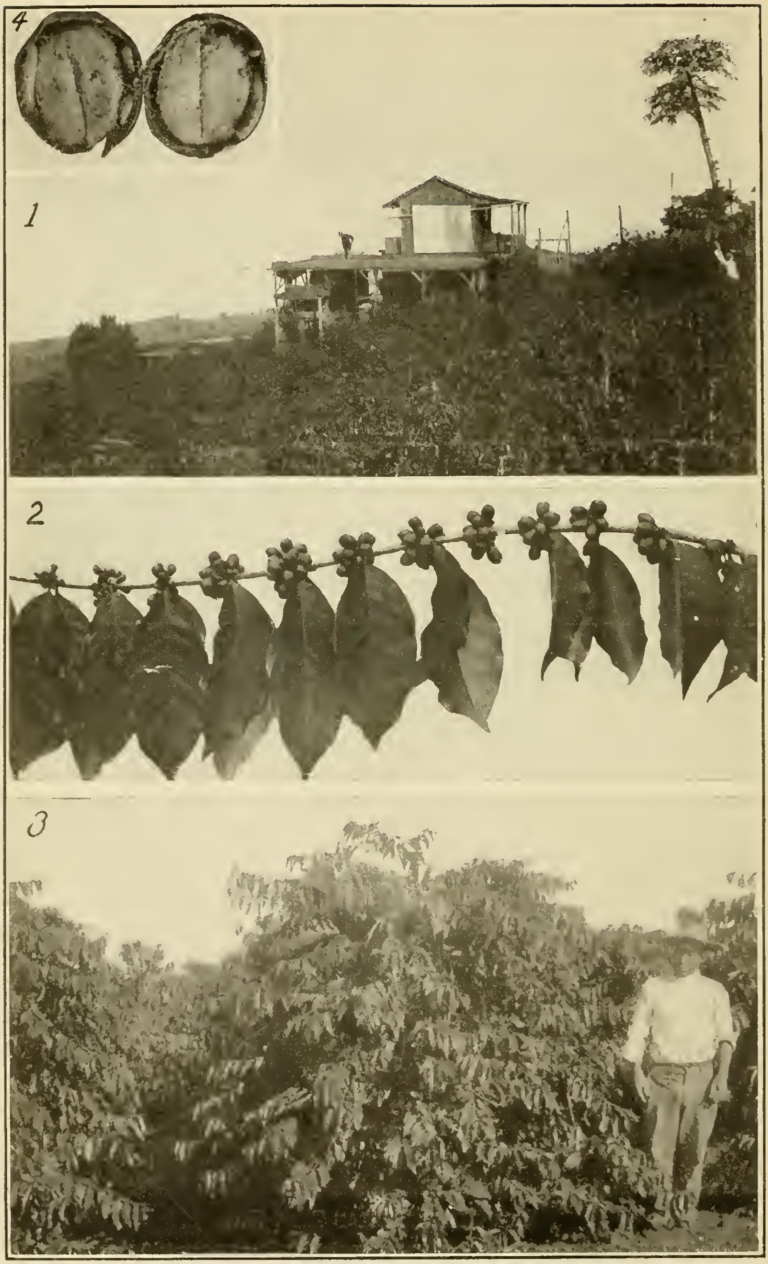
FIG. 1.—Men grubbing out a guava scrub which has taken possession of pasture land. Many thousands of acres are thus overrun in Hawaii and furnish excellent breeding grounds for the fruit fly. The ripening fruits fall into the dense grass and the larvæ within them develop unmolested by the heat of the sun. FIG. 2.—Thickets of guava bushes often crowd upon the country roads and ripen tons of fruit. This fruit is gathered by pedestrians and autoists and carried to all parts of the islands, thus becoming a medium for the wide dissemination of the pest. (Original.)

RELATION OF THE FLORA OF THE HAWAIIAN ISLANDS TO THE MEDITERRANEAN FRUIT FLY.

It is difficult to find in Hawaii cultivated fields of any crop that are not closely surrounded by wild hosts of the fruit fly. In the above illustration, between the pineapple field in the foreground and the ocean, are growing, at the right and left, dense thickets of guava, while in the center are many large Terminalia trees. In such places the fruit fly finds, in the ripening fruits of these hosts, food for its support throughout the entire year. Throughout the precipitous and gullied mountains in the background the fruit fly is thoroughly entrenched in wild host fruits. (Original.)

THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—A dense forest growth of the mountain apple (*Jambosa malaccensis*) near Hilo, which illustrates one of the many strongholds in Hawaii that the fruit fly found favorable to its thorough entrenchment. FIG. 2.—Rose apple trees (*Eugenia jambos*). While the fruit of this tree ripens chiefly during the months of March to May, a few may be found beneath trees at any time. Fruits of both the mountain apple and the rose apple are among a class of host fruits that are carelessly taken on board ships by tourists, in whose possession they have been intercepted by the officers of the Federal Horticultural Board at San Francisco. (Original.)



THE MEDITERRANEAN FRUIT FLY AND THE COFFEE INDUSTRY.

FIG. 1.—Coffee plantation on the Kona slopes of Hawaii. FIG. 2.—A fruiting branch. FIG. 3.—Low type of coffee tree. FIG. 4.—Coffee cherry cut to show the two large beans which are of commercial value, and the very thin outer pulp. This pulp is the only portion of the cherry eaten by the fruit-fly larvæ. Note that the well-grown larvæ illustrated feed so close to the papery epidermis that parasites have no difficulty in ovipositing in them. Thousands of acres are densely planted to coffee on the island of Hawaii and offer food for the fruit fly the year round. (Original.)

the year in Honolulu. The presence of so much ripening fruit, coupled with the favorable climatic conditions and the hardiness of the fruit fly itself, has made the establishment of *C. capitata* and its multiplication a most easy problem within the city limits.

While the fruit fly finds host conditions most favorable within the city limits, because of the large number of host trees and shrubs, some of which are bearing at all seasons of the year, it has been able to establish itself and multiply in the country, often miles from towns, in some one or more of its hosts which have escaped cultivation, and to have spread over uncultivated and uncultivable areas. Of such hosts, the common guava (*Psidium guayava*) is the most abundant. It has taken possession of the roadsides, pastures (Pl. II), vacant town lots, mountain gulches and hillsides, and even crevices in precipices, from sea level up to 1,500 feet elevation.[1] So easily does this plant grow from seed, and so thoroughly distributed are its seeds by cattle, birds, and man, that it is seldom that a bush can not be found within a stone's throw. In the lowland pastures and mountain gulches up to an elevation of at least 1,300 feet, particularly when sheltered from strong winds and well watered, the guava may become very treelike and form dense thickets (Pl. III). At higher altitudes, and in wind-swept or arid areas, it may remain a low, scrubby bush. While the guava fruits most heavily during the spring and fall months, the bushes are continually blooming and ripening a sufficient number of fruits to support the fruit fly every month in the year. The writers are depending upon the illustrations to acquaint the reader, as words can not, with the well-nigh universal distribution of this host and the wonderful opportunities it offers *C. capitata* for easy establishment and thorough intrenchment.

Second to the guava as a host occurring in wild, uncultivated areas is the prickly-pear cactus (*Opuntia vulgaris*) (Pl. XVII). While the fruits of this plant are not preferred by the Mediterranean fruit fly, they are sufficiently infested in the absence of more favored hosts to serve as food, and, as in the case of the guava, there is almost no time during the year when a few ripe fruits may not be found in any cactus scrub.

Other host fruits, wild or escaped, are not so universally distributed. As a few of the many examples, there may be mentioned a grove of ball kamani trees in an isolated valley on the island of Molokai, gulches overgrown with the passion vine (*Passiflora* sp.) and the damson plum (*Chrysophyllum oliviforme*) on the island of Maui, the thickets of winged kamani growing along the windward shores of the island of Oahu, and the wild coffee and mountain apple (Pl. IV, fig. 1) in the forests of Oahu and Hawaii.

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[1] Stunted bushes have been observed at 4,000 feet elevation.

TABLE V.—*Data indicating the seasons of the year when inspectors of the clean-culture campaign in Honolulu collected various fruits infested by the Mediterranean fruit fly.*[1]

Host.	Jan. 1-11.	Jan. 13-18.	Jan. 20-25.	Jan. 27-Feb. 1.	Feb. 3-8.	Feb. 10-15.	Feb. 17-22.	Feb. 24 Mar. 1.	Mar. 3-8.	Mar. 10-15.	Mar. 17-22.	Mar. 24-29.	Mar. 31-Apr. 5.
Avocado	...	...	...	x	...	...	...	x	...	...	...	...	x
Carambola	x	x	x	x	x	x	x	x	x	x	x	x	...
Chinese orange	x	x	x	x	x	x	x	x	x	x	x	x	x
Chrysophyllum spp.	...	...	...	...	...	...	...	...	...	...	...	...	...
Coffee	x	x	x	x	x	x	x	x	x	x	x	x	x
Damson plum	x	x	x	x	x	x	x	x	x	x	...	...	...
Surinam cherry	x	x	x	x	x	x	x	x	x	x	x	x	x
Fig	x	x	x	x	...	x	x	x	x	x	x	x	x
Grapefruit	x	x	x	x	x	x	...	x	x	x	x	x	...
Guava	x	x	x	x	x	x	x	x	x	x	x	x	x
Kamani, ball	x	x	x	x	x	x	x	x	x	x	x	x	x
Kumquat	...	x	x	x	...	x	x	...	...	...	x	...	...
Lime	x	x	x	x	x	x	x	x	x	x	...	x	x
Loquat	x	x	x	x	x	x	x	x	x	x	x	...	x
Mango	x	x	x	x	x	x	x	x	x	x	x	x	x
Mock orange	x	x	x	x	x	x	x	x	x	x	x	x	x
Mountain apple	...	...	x	x	x	...	x	x	...	x	...	...	...
Orange	x	x	x	x	x	x	x	x	x	x	x	x	x
Papaya	x	x	x	x	x	x	x	x	x	x	x	x	x
Peach	...	x	x	x	x	x	x	x	x	x	x	x	x
Pepper	x	x	x	...	x	x	x	x	x	x	x	x	x
Prickly pear	...	...	x	...	...	x	...	...	...	...	...	...	x
Rose apple	...	x	...	x	x	x	x	x	x	x	x	x	...
Star apple	...	...	...	...	...	...	...	...	x	x	x	x	x
Bestill	x	x	x	x	x	x	x	x	x	x	x	x	x
Soursop	...	...	...	x	x	x	x	x	...	x	x	x	x
Mandarin	x	x	x	x	x	x	x	x	x	x	x	...	x
Lemon	x	x	...	x	...	x	...	x	x	x	x	x	...
Kamani, winged	x	x	x	x	x	x	x	x	x	x	x	x	x
Spanish cherry	...	x	x	...	...	...	...	...	...	...	...	...	...
Bartlett pear	...	...	...	...	...	...	...	...	...	...	...	x	x

Host.	Apr. 7-12.	Apr. 14-19.	Apr. 21-26.	Apr. 28-May 3.	May 5-10.	May 12-17.	May 19-24.	May 26-31.	June 2-7.	June 9-14.	June 16-21.	June 23-28.	June 30-July 5.
Avocado	...	...	...	...	...	...	x	...	...	...	...	...	x
Carambola	x	x	...	x	...	...	...	...	...	...	...	...	...
Chinese orange	x	x	x	x	x	x	x	x	x	x	x	x	x
Chrysophyllum spp.	...	...	...	...	...	...	...	...	...	...	...	...	...
Coffee	x	x	x	x	x	x	x	x	x	x	x	x	x
Damson plum	...	x	x	x	x	x	x	x	...	...	...	...	...
Surinam cherry	x	x	x	x	x	x	x	x	x	x	x	x	x
Fig	x	x	x	x	x	x	...	x	x	...	...	...	...
Grapefruit	x	...	...	...	x	x	...	...	x	...	...	...	...
Guava	x	x	x	x	x	x	x	x	x	x	x	x	x
Kamani, ball	x	x	x	x	x	x	x	x	x	x	x	x	x
Kumquat	x	...	...	x	x	x	...	...	x	...	...	...	...
Lime	...	x	x	...	...	...	x	...	x	x	x	...	x
Loquat	x	...	x	x	...	...	x	x	...	...	...	...	...
Mango	x	x	x	x	x	x	x	x	x	x	x	x	x
Mock orange	x	x	x	x	x	...	x	x	x	x	...	x	...
Mountain apple	...	x	x	x	x	x	x	x	x	...	...	x	...
Orange	x	x	x	x	x	x	x	x	x	x	x	x	x
Papaya	x	x	x	x	x	x	x	x	x	x	[illegible]	x	[illegible]
Peach	x	x	x	x	x	x	x	x	x	x	[illegible]	x	[illegible]
Pepper	x	...	...	...	...	...	...	...	...	...	[illegible]	...	[illegible]
Prickly pear	...	x	x	...	...	x	x	...	...	x	[illegible]	x	x
Rose apple	x	x	x	x	x	x	x	x	x	x	x	x	x
Star apple	...	x	...	x	x	x	...	x	x	...	...	...	...
Bestill	x	x	x	x	x	x	x	x	x	x	x	x	x
Soursop	x	x	x	x	x	x	x	...	x	x	x	x	x
Mandarin	x	x	x	x	x	x	x	...	...	...	...	x	...
Lemon	x	x	x	x	x	x	x	x	x	x	x	x	x
Kamani, winged	x	x	x	x	x	x	x	x	x	x	x	x	x
Spanish cherry	...	...	...	...	...	...	...	...	x	x	x	x	x
Bartlett pear	x	...	...	...	...	...	...	...	...	...	...	x	...

Host.	July 7-12.	July 14-19.	July 21-26.	July 28-Aug. 2.	Aug. 4-9.	Aug. 11-16.	Aug. 18-23.	Aug. 25-30.	Sept. 1-6.	Sept. 8-13.	Sept. 15-20.	Sept. 22-27.	Sept. 29-Oct. 4.
Avocado	x	x	x	x	x	x	x	x	x	x	x	x	x
Carambola	...	x	x	x	x	x	x	x	x	x	x	x	x
Chinese orange	x	x	x	x	x	x	x	x	x	x	x	x	x
Chrysophyllum spp.	...	...	...	...	...	x	x	...	...	x	x	...	x
Coffee	x	x	x	x	x	x	x	x	x	x	x	x	x
Damson plum	...	...	...	...	...	...	...	...	...	...	...	...	...
Surinam cherry	x	x	x	x	x	x	x	x	x	x	x	x	x
Fig	x	x	...	x	...	x	x	...	x	x	...	x	...
Grapefruit	...	...	...	x	...	...	x	...	...	...	...	...	x
Guava	x	x	x	x	x	x	x	x	x	x	x	x	x
Kamani, ball	x	x	x	x	x	x	x	x	x	x	x	x	x
Kumquat	...	...	...	...	x	...	x	x	...	x	x	x	x
Lime	x	...	x	x	x	x	x	x	...	x	x	x	x
Loquat	...	...	...	...	...	...	...	...	...	...	...	...	...
Mango	x	x	x	x	x	x	...	...	x	...	...	...	...
Mock orange	x	x	...	x	...	x	x	x	x	x	...	x	x
Mountain apple	...	...	...	...	...	...	...	...	...	...	...	...	...
Orange	x	x	x	x	x	x	x	x	x	x	x	x	x
Papaya	[illegible]	[illegible]	[illegible]	[illegible]	x	x	x	x	x	x	x	x	x
Peach	[illegible]	[illegible]	[illegible]	[illegible]	...	x	...	...	x	...	...	...	x
Pepper	[illegible]	[illegible]	[illegible]	[illegible]	x	...	...	...	x	x	...	x	...
Prickly pear	x	x	x	x	x	x	x	x	x	x	x	x	x
Rose apple	x	x	x	x	...	x	x	...	...	...	...	x	x
Star apple	...	...	...	...	...	...	...	...	...	...	...	...	...
Bestill	x	x	x	x	x	x	x	x	x	x	x	x	x
Soursop	x	x	...	x	x	x	x	x	x	x	x	x	x
Mandarin	x	...	x	x	...	x	x	x	x	x	x	x	x
Lemon	x	x	x	x	x	x	x	x	x	x	x	x	x
Kamani, winged	x	x	x	x	x	x	x	x	x	x	x	x	x
Spanish cherry	x	x	x	x	x	x	x	x	x	x	x	x	x
Bartlett pear	...	...	...	x	...	...	...	...	...	...	...	...	...

Host.	Oct. 6-11.	Oct. 13-18.	Oct. 20-25.	Oct. 27-Nov. 1.	Nov. 1-9.	Nov. 11-16.	Nov. 18-23.	Nov. 25-30.	Dec. 2-7.	Dec. 9-14.	Dec. 16-21.	Dec. 23-31.
Avocado	...	...	x	...	...	...	...	...	x	x	x	x
Carambola	x	x	x	x	x	x	x	x	x	x	x	x
Chinese orange	x	x	x	x	x	x	x	x	x	x	x	x
Chrysophyllum spp.	...	...	x	...	...	...	...	...	...	...	...	...
Coffee	x	x	x	x	x	x	x	x	x	x	x	x
Damson plum	...	...	...	...	...	...	...	...	...	...	...	...
Surinam cherry	x	x	x	x	x	x	x	x	x	x	x	x
Fig	x	...	...	...	x	...	x	x	x	x	...	x
Grapefruit	x	...	x	x	x	x	...	x	x	x	x	x
Guava	x	x	x	x	x	x	x	x	x	x	x	x
Kamani, ball	x	x	x	x	x	x	x	x	x	x	x	x
Kumquat	x	x	x	x	...	...	...	x	x	...	...	x
Lime	x	x	x	x	x	x	x	x	x	x	x	x
Loquat	...	...	...	...	x	x	x	x	x	x	x	x
Mango	...	...	...	x	x	x	x	...	x	x	x	x
Mock orange	x	x	x	x	x	x	x	...	x	x	x	x
Mountain apple	...	...	...	...	x	...	x	...	x	...	...	x
Orange	x	x	x	x	x	x	x	x	x	x	x	x
Papaya	x	x	x	x	x	x	x	x	x	x	x	x
Peach	...	...	...	...	x	...	...	...	...	...	...	x
Pepper	...	...	x	x	x	x	x	x	x	x	x	x
Prickly pear	x	x	x	...	...	...	...	...	x	x	x	x
Rose apple	...	x	x	...	...	...	...	...	...	...	x	x
Star apple	...	...	...	...	...	...	...	...	...	x	...	...
Bestill	x	x	x	x	x	x	x	x	x	x	x	x
Soursop	x	x	x	x	...	...	...	x	...	x	...	x
Mandarin	x	x	x	x	x	x	x	x	x	x	x	x
Lemon	x	x	x	x	x	x	x	x	x	x	x	x
Kamani, winged	x	x	x	x	x	x	x	x	x	x	x	x
Spanish cherry	x	x	x	x	x	x	...	...	...	x	x	x
Bartlett pear	...	...	...	...	...	...	...	...	...	...	...	...

[1] This table is not intended to indicate the seasonal abundance of host fruits.

In addition to the wild fruits in country places, the fruit fly finds strongholds in the many, and often very isolated, native-home sites scattered throughout the littoral regions. About these may be growing the mango (Pl. XII), rose apple (Pl. IV, fig. 2), orange, peach, avocado, ball and winged kamanis, etc. In the Kona district of the island of Hawaii there are large areas containing thousands of acres of coffee under cultivation (Pl. V) in which the fruit fly finds food in the pulp of the ripening cherries at all seasons of the year because of the irregularity in blooming and the long harvesting season due to the varying altitudes at which coffee is grown.

ECONOMIC IMPORTANCE.

The economic importance of the Mediterranean fruit fly as a pest of fruits varies with the climate of its habitat. Thus in France, near Paris, where it has been known to attack apricots, pears, and peaches, it has not become a serious pest because of climatic checks, and such checks to the severity of its attack have been noted in portions of Australia and South Africa and would be operative in continental United States, except in parts of California and of the Southern States. On the other hand, in tropical and semitropical climates this fruit fly is capable of becoming a pest of prime importance and, as in the Hawaiian Islands, may be classed as the most important insect check to horticultural development. A study of the fruits infested by this world-wide pest shows that practically every fruit crop of value to man is subject to attack. Not only is the Mediterranean fruit fly of importance as a destroyer of fruit, but it is the cause of numerous stringent quarantines which cost the State and Federal governments much money to make effective, and rob countries of good or prospective markets for their fruit. Fortunately it has been found that the Chinese banana (*Musa cavendishii*) and the pineapple (*Ananas sativus*), the two most valuable species of fresh fruits formerly exported from Hawaii, offer so little danger as carriers of the Mediterranean fruit fly when they are packed for shipment that this part of Hawaii's export trade with the coast may still be carried on, provided the inspections of the Federal Horticultural Board now in force are continued. The necessary quarantine against all other host fruits, however, particularly against such fruits as the avocado and mango, two fruits which can be grown very well in Hawaii, has had, and will continue to have, a serious effect upon horticultural pursuits and the development of the small farmer.

At the present time the infestation of edible fruits in littoral Hawaii is general and about as severe as could be expected. Aided by the melon fly (*Bactrocera cucurbitae* Coq.), the Mediterranean fruit fly has effected a most serious and permanent check upon the horticultural development of the Hawaiian Islands unless a successful method for combating it is developed. In the Bermuda Islands the peach industry has been a ruined one for many years. MacLeay and Westwood wrote, during the early part of the nineteenth century, of the increased cost to the inhabitants of London of citrus fruits imported from the Azores as a result of fruit-fly attack. Lounsbury and Mally, of South Africa, consider *C. capitata* one of the greatest drawbacks to the development of the fruit industry in Cape Colony, and have stated that during certain favorable seasons large areas of apricots, figs, pears, plums, apples, and quinces were almost all affected. Hooper, writing from Southern France, states in 1904 that, as a result of fruit-fly attack, what was once an important and lucrative industry was at that time little more than a haphazard traffic in fruit casually produced. In 1903 Compere found that peach growing about Barcelona, Spain, had been so demoralized by fruit-fly attack that few trees were being grown and that the market was supplied by fruit from the Balearic Islands, while at Cadiz the fruit merchants no longer cared to handle peaches owing to the fact that they were badly infested. At Malaga, according to Compere, the bitter Seville oranges are seriously affected. Wickens, writing in 1913 in Western Australia, states that the fruit industry there was suffering not only directly as a result of the actual loss of fruit infested, but indirectly through the restricted plantings in districts where the fruit fly was abundant. About Perth, where late peaches can be grown to perfection, very few are being cultivated; instead, many trees have been cut down. Other instances of damage caused to citrus crops in southern Europe, South America, Africa, and Australia might be added which would impress one, unfamiliar with the ravages of *C. capitata*, that it is a very serious pest. Its economic importance is so great that every effort should be taken to prevent its establishment in new territory.

INJURY.

NATURE OF INJURY.

The injury caused by the Mediterranean fruit fly is confined to the fruits of the hosts attacked. The foliage, stems, and roots are not attacked so far as investigators have been able to determine. No better idea of the nature of the injury caused by the fruit fly can be gained than from an examination of the illustrations. The larvæ hatching from the eggs deposited just beneath the epidermis burrow their way throughout the pulp and, as they develop, cause by their feeding, and through the development of fungi and bacteria, decayed areas which vary in extent according to the age and number of the larvæ and the ripeness of the host. Since the larvæ most frequently burrow at once to the pit or core of the fruit, they are able to feed for some time before their work is evident from the surface; thus peaches and oranges may be quite thoroughly devoured within and yet maintain a fairly normal appearance externally. In rapidly growing fruits, or those oviposited in while they are still too green to support larval growth, slight deformities are developed which injure the appearance of the fruit. In lemons, oranges, and grapefruit which have been provided so well by nature to withstand fruit-fly attack, the rind may become badly infested with eggs and young larvæ, while the pulp remains edible. The breaks in the skin made by the female fly in depositing eggs, however, affect the shipping qualities of such citrus fruits and, from this commercial aspect, may cause an injury the nature of which is quite as serious as is any to the pulp.

EXTERNAL EVIDENCES OF INJURY.

There are always external evidences of infestation, but these are often so inconspicuous that they are overlooked by the average person. The eggs are deposited by the adult through a break, no larger than a pin prick, made in the skin. While these punctures are readily discernible under the hand lens as soon as made, there is nothing about them to attract attention. Soon after oviposition, however, the tissues about the egg cavity begin to wither and there develops about the puncture a discolored or sunken area in the skin. In certain hosts the immediate area about the puncture may remain green long after the remainder of the fruit has turned yellow, as in the loquat (*Eriobotrya japonica*), or red, as in the strawberry guava (*Psidium cattleyanum*). In green oranges the fruit may turn yellow about the puncture while the rest of the fruit remains green. Such tender-fleshed fruits as the ripening Surinam cherry (*Eugenia michelii*) may develop sunken areas without discolorations. Often filaments of clear gummy excretions exude from punctures made in peaches, lemons, and grapefruit. Punctures made in green star apples (*Chrysophyllum cainito*) are usually marked by exuding white latex which dries about and over the puncture. Punctures made in quite green winged kamani nuts (*Terminalia catappa*), in which no development of larvæ occurs, are marked by depressions in the flesh due to permanently arrested development at the punctured point. Oviposition or attempted oviposition in bananas and partially ripe mangoes is followed by exudations which run down the sides of the fruit and dry as a dark stain. The evidences of early infestation such as have just been mentioned are too numerous to warrant description. No one host responds to infestation exactly the same each time; much depends on the degree of ripeness at the time of attack. There may be no gummy exudations from peaches or citrus fruits, and there may be no development of discolored areas in any of the host fruits. Avocados seldom give evidence of infestation by any external mark except the puncture in the skin. Fruits already ripened when infested show none of the usual signs of attack until the larvæ have begun to work. It is due to this failure of fruits to record their infestation by some external sign, other than the inconspicuous puncture, that so much fruit is purchased as sound in the markets, or shipped from orchards, or taken on board ships.

As the larvæ hatch and begin their work of destruction within the host, the signs of infestation increase rapidly. The sunken areas about the punctures of tender-fleshed fruits may increase until the entire fruit has a collapsed appearance.

In all fruits well infested within there is a "give" to the area beneath the puncture, indicating destroyed tissues beneath. In hard-fleshed fruits such as some varieties of apples (Pl. XI, fig. 2), pears, and quinces there may be no external evidence of larval work except a ring of dark decay about the puncture, and yet the outer portion of the pulp alone may be unaffected. Peaches are often thoroughly infested within and still maintain their normal shape and give evidence of infestation only by a dull and slightly darkened color of the skin. A hole in the rind, no larger than the lead of a pencil, from which juice exudes when the fruit is compressed, may be the only indication of infestation in oranges and grapefruit, although rings of decay usually develop in infested citrus fruits containing numerous larvæ. Fruits of the elengi tree (*Mimusops elengi*), which have an orange shell-like exterior (Pl. VIII, fig. 2), may appear normal, but on being broken open are found to be literally packed with well-grown larvæ. It is never possible for the average man to examine casually any host fruit and state conclusively that it is not infested.

METHODS OF SPREAD.

There are numerous records on file which demonstrate clearly the methods by which the Mediterranean fruit fly is spread, not only between widely separated countries, but about land areas. The development of rapid transit and cold storage and the increase in tourist travel have been the greatest factors in dissemination in more recent times. Geographical isolation is no longer a protection against introduction, as has been proved almost monthly by the interception of fruit flies at the ports of entry of the United States by the agents of the Federal Horticultural Board.

SHIPS.

The unrestricted consignments of fruit and ships' stores have been responsible for much of the spread of *C. capitata* between countries. MacLeay, as early as 1829, records the importation at London of cargoes of oranges from the Azores that contained larvæ, and Middleton, in 1914, states that in the same city hundreds of larvæ and pupæ are imported every year from Spain and destroyed in the manufacture of marmalade. The establishment of *C. capitata* in both the eastern and western parts of the Australian continent is traceable to the development of cold storage and rapid ocean transportation which made possible the large exports of citrus fruits from the Mediterranean region to Australia. Kirk records the receipt at Auckland, New Zealand, of a case of peaches from Cape Colony which contained living larvæ, although they had been en route in cool storage for four weeks. The same writer intercepted 47 cases of infested apples at Wellington, New Zealand, imported from New South Wales. Lea, in 1908, states that larvæ of *C. capitata* were seen in numbers every year in fruit imported into Tasmania from Sydney. The establishment of this pest in the Bermudas and South America is beyond doubt the result of the importation of infested fruit from Mediterranean regions. Increased knowledge of fruit flies and the quarantines in force in several countries now make the introduction of this pest in consignments of fruits less likely.

The vigilant work of the quarantine officials at the Pacific ports of the United States, however, demonstrates the grave danger that still exists of introducing the Mediterranean fruit fly in ships' stores. Instances of the discovery and destruction of the pest in fruits in ships' stores on vessels entering the port of San Francisco during the past four years are recorded in the reports of Frederick Maskew, chief quarantine officer of the California Horticultural Commission and collaborator of the Federal Horticultural Board.

TOURISTS.

The desire on the part of tourists to carry to their friends at home specimens of exotic fruits is at the present time the most likely avenue for the introduction of this fruit fly into California as well as the southern United States. This has been clearly proved not only by the large variety of host fruits offered for inspection at Honolulu, but by the interceptions at the California ports. To the quarantine officer the tourist is a difficult problem. Fruits carried in containers are easily observed, but smaller fruits are found with difficulty. Strong, in 1913, discovered in the overcoat pocket of a tourist landing at San Francisco infested nuts of the winged kamani (*Terminalia catappa*), which were intended for planting in southern California. In like manner infested coffee cherries were found at Honolulu in the pocket of a gentleman about to sail during February, 1916, from Honolulu direct to San Pedro, Cal.

DISSEMINATION ON LAND BY PUBLIC AND PRIVATE CONVEYANCES.

On land, railroads, automobiles, hawkers' carts, carriages, etc., are all responsible for much spread. The fact that host fruits only slightly infested appear normal to the average man leads to the purchase by the traveling public of much fruit which later, when found to be infested, is discarded, often many miles from the point of origin. Bairstow as long ago as 1893 records the selling of infested apricots by native girls to passengers on trains about to leave for interior points of South Africa. The spread of the pest in Australia has been most rapid along the railroads. French, in 1896, states that peaches imported by rail into Victoria from Sydney were infested and Newman states that in Western Australia many instances have come under his observation in which infested fruits thrown from the windows of coaches of both suburban and country trains were responsible for introductions into districts previously free from attack.

In the Hawaiian Islands the spread from village to village and from island to island unquestionably has been hastened by the habit of the poorer population of carrying small lots of fruit in their travels, either for food while en route or as presents for their friends. Much of this fruit is more or less infested, and when an attempt to eat it proves the interior to be infested and unpalatable, it is discarded either along the road or at the point of destination. The inspection service of the Hawaiian Board of Agriculture has shown that even the most stringent regulations have not prevented the movement of infested fruits from point to point by man in automobiles, in carriages, or on foot.

POSTAL AND EXPRESS PACKAGES.

The interception at Washington, D. C., by officers of the Federal Horticultural Board of a package from Mexico containing a living pupa of the papaya fruit fly (*Toxotrypana curvicauda* Gerst.) attached to an unknown vine, and of a living adult of the olive fruit fly (*Dacus oleae* Rossi) and a dead adult of another species of fruit fly, apparently *Dacus semispharens* Becker, in a package of olive seed, 28 days after it had been mailed in South Africa, indicates the possibilities for spread by means of parcel post. The persistency with which uninformed persons insist upon including among bananas and pineapples intended for shipment by express from Hawaii to the mainland United States small contraband host fruits has demonstrated fully the danger of express packages as carriers of *C. capitata*.

NURSERY STOCK.

A fruit-fly pupa (species unknown) was found at Auckland, New Zealand, in the soil about the roots of a plant imported from Australia. Newman has called attention to the danger of spreading the fruit fly in the pupa stage, in the soil about the roots of nursery stock grown beneath host fruit trees.

PACKING MATERIALS.

Larvæ developing in fruits packed in wooden crates or in bags often pupate against the sides of such containers. Second-hand packing crates and old burlap, etc., recently used as containers are apt to carry the pest and should be guarded against until experience for the locality and temperature concerned has proved that the adults have emerged. Certain instances of spread in western Australia are believed to have occurred through carelessness in the use of second-hand packing cases. In Hawaii, Hilo grass (*Paspalum conjugatum*), gathered from beneath guava bushes (Pl. XIV, fig. 1, insert), was discontinued as a packing material for bananas for fear pupæ of the fruit fly attached to it might reach California.

COLD STORAGE.

While cold-storage temperatures may be used to render fruits free from danger as transporters of the fruit fly (see p. 108), the use of temperatures fluctuating above 38° F. may be one of the greatest aids in prolonging the duration of fruit-fly life within host fruits.

WIND.

That adult males of the Mediterranean fruit fly can be carried by the wind distances varying from one-fourth to 1½ miles from points of liberation has been demonstrated by Severin, who states further that in all probability some of the flies which he had set free at the head of Manoa Valley "were caught up and carried far into the city of Honolulu, or even away beyond into the sea, miles away from the points of liberation." The writers agree with Severin as to the ability of winds to carry adults considerable distances. The discovery by Mr. H. T. Osborn of an adult upon the summit of Konahuanui (elevation 3,105 feet), the highest peak of the range separating the windward and leeward sides of the island of Oahu, and at a considerable distance above the highest range of host plants, makes it easier for the writers to believe that the few adults which they captured in traps in the scant vegetation on the leeward shore line, and at considerable distances from known sources of infestation, during very windy weather, were specimens caught on the windward side in strong ascending air currents and carried entirely across Oahu. There is no doubt that the adult on Konahuanui observed by Osborn was transported thus from the lower windward levels.

HOST FRUITS.

The writers know of no edible fruit commonly grown in the Hawaiian Islands, except the pineapple, that is not subject to attack by the Mediterranean fruit fly. From a practical trade standpoint the banana should not be considered a host when grown and shipped in accordance with the regulations of the Federal Horticultural Board.

FRUITS ERRONEOUSLY LISTED AS HOSTS.

No infestation has been found in pineapples (*Ananas sativus*), banyan (*Ficus indica*), pride of India or chinaberry (*Melia azedarach*), noni (*Morinda citrifolia*), jujube (*Zizyphus jujuba*), mulberry (*Morus nigra*), tamarind pods (*Tamarindus indica*), wine palm (*Caryota ureus*), *Ixora coccinea*, *Canarium commune*, *Sideroxylon sandwichensis*, mammee apple (*Mammea americana*), durion (*Durio zibethinus*), Cape gooseberry or poha (*Physalis peruviana*), ohelo berry (*Vaccinium reticulatum*), kukui nut or candlenut tree (*Aleurites moluccana*), night-blooming cereus (*Cereus triangularis*), and jack fruit (*Artocarpus integrifolia*).

PINEAPPLE.

The pineapple (*Ananas sativus*) is not a host fruit of the Mediterranean fruit fly in Hawaii. Negative data are given here because of the persistent reports that this fruit is subject to fruit-fly attack. Illingsworth reared the pineapple fruit fly (*Dacus xanthodes* Broun) from pineapples in Fiji in 1913. In 1904 Kirk states that he had reared only the Queensland fruit fly (*Dacus tryoni* Frogg.) from pineapples exported from Queensland into New Zealand. In 1908 Kirk again states that *Dacus xanthodes* was commonly found in pineapples and oranges from Fiji and Rarotonga entering New Zealand. Gowdey, in 1913, reports rearing *C. capitata* from pineapples in Uganda, British East Africa. So far as the writers are aware no data have ever been published from careful experiments to determine the true status of the pineapple as a host fruit, and the writers know of no positive evidence that *C. capitata* has ever been reared from this fruit.

It is certain that during a period of over three years not one of seven entomologists in Honolulu has succeeded in rearing adults from this fruit. Fullaway, of the United States Experiment Station, obtained negative results from fruits placed in a large cage. The market and plantation inspectors of the Federal Horticultural Board have brought to the office during the past three years many partially decayed fruits, but no fruit flies were reared from them, although many decay flies were. Although pineapples are grown profitably only under the best horticultural conditions (Pl. III), none of the developing fruits are sufficiently isolated from other varieties of host fruits affected to warrant the belief that adult fruit flies are not present in large enough numbers to infest each fruit were the pineapple susceptible to infestation.

In an attempt to force an infestation within the laboratory, 50 ripe pineapples were placed either singly or by twos in large glass jars containing from 300 to 500 adult flies in a mature egg-laying condition, and allowed to remain with the flies from 2 to 4 days. The pineapples were then removed and placed over sand in covered jars. No flies were reared from the fruits. The flies readily deposited eggs in apples placed with them both before and after exposure of the pineapples. A record of the time each of the 50 fruits was exposed is as follows:

TABLE VI.—*Nonsusceptibility of pineapples to the attack of the Mediterranean fruit fly.*

Number of fruits exposed.	Dates of exposure to infestation.	Number of fruit flies reared.
	1913.	
2	Oct. 14–15	None.
1	Oct. 17–18	
1	Oct. 19–22	
2	Oct. 23–24	
6	Oct. 27–29	
10	Oct. 30–Nov. 2	
12	Nov. 5–7	
16	Nov. 9–11	

During July 18–20, 1913, a very ripe pineapple was hung in a jar containing flies. An examination of the fruit after this two-day exposure revealed 2 punctures in the pulp containing respectively 16 and 11 eggs. One puncture had been made in a slight abrasion; the other in normal tissue between the eyes. Seven other batches of eggs, containing 9, 5, 8, 7, 4, 5, and 4 eggs, respectively, had been deposited on the surface of the fruit, but in the creases between the eyes.

In experimental work the writers have had no difficulty in transferring larvæ from one favored host fruit to another. Experiments in transferring first, second, and third stage larvæ to pineapple invariably resulted in the death of the larva. A total of 925 larvæ were transferred, as follows:

TABLE VII.—*Failure of larvæ of the Mediterranean fruit fly to develop in the pulp of ripe pineapples.*

Date of transfer.	Number larvæ transferred.	Instar when transferred.	Results.
Apr. 22	150	Second	All died by Apr. 26.
Apr. 23	200	....do	Do.
Apr. 22	100	First	All died by Apr. 24.
Do	25	Second	19 dead by Apr. 25; 6 dead by Apr. 26.
Do	150	Young third	All dead by Apr. 25.
Apr. 23	150	....do	Do.
Apr. 22	150	Well grown third	Do.

While the experiments above reported indicate that under forced laboratory conditions a few eggs may be deposited within the pulp of very ripe pineapples, the failure of all stages of the larvæ to survive in a medium of fresh ripe pineapple pulp is conclusive evidence that the pineapple should be dropped from lists of host fruits of the Mediterranean fruit fly.

PROVEN HOSTS IN HAWAII.

Adults of the Mediterranean fruit fly have been reared from the fruits of the trees, shrubs, and vegetables in the following list. The hosts are arranged alphabetically according to scientific name, and not according to the preferences shown by the fruit fly. The numbers in parentheses refer to the degree of preference for each fruit as a host. Fruits that are heavily or generally infested are marked (1), those that serve occasionally as hosts or of which many escape infestation are marked (2), while those rarely infested are marked (3). The writers appreciate that differences of opinion may arise over any classification of hosts according to degree of infestation, and realize that in colder climates than Hawaii some of the fruits classed as (2) would fall into class 3, or even might not be recorded as hosts at all. The list following represents conditions in littoral Hawaii, particularly about Honolulu:

Hosts of Mediterranean fruit fly in Hawaii.

Scientific name.	Common name.
1. *Achras sapota* (3)	Sapodilla.
2. *Acordia* sp. (3)	Acordia.
3. *Anona muricata* (2)	Sour sop.
4. *Arenga saccharifera* (3)	Sugar palm.
5. *Artocarpus incisa* (3)	Breadfruit.
6. *Averrhoa carambola* (2)	Carambola.
7. *Calophyllum inophyllum* (1)	Ball kamani.
8. *Capsicum annuum* var. *grossum* (2).	Bell pepper.
9. *Carica papaya* (2)	Papaya.
10. *Carica quercifolia* (2)	Dwarf papaya.
11. *Carissa arduina* (2)	Carissa.
12. *Casimiroa edulis* (1)	Sapota.
13. *Cestrum* sp. (3)	Chinese inkberry.
14. *Chrysophyllum cainito* (1)	Star apple.
15. *Chrysophyllum oliviforme* (1).	Damson plum.
16. *Chrysophyllum polynecium* (1).	
17. *Citrus japonica* (1)	Chinese orange.
18. *Citrus japonica* (1)	Kumquat.
19. *Citrus nobilis* (1)	Tangerine.
20. *Citrus nobilis* (1)	Mandarin.
21. *Citrus medica limetta* (1)	Lime.
22. *Citrus medica limonum* (1)	Lemon.
23. *Citrus decumana* (1)	Grapefruit.
24. *Citrus decumana* (1)	Shaddock.
25. *Citrus aurantium* (1)	Orange.
26. *Citrus aurantium* var. *amara* (1).	Sour orange.
27. *Clausena wampi* (3)	Wampi.
28. *Coffea arabica* (1)	Coffee.
29. *Coffea liberica* (1)	Liberian coffee.
30. *Cydonia vulgaris* (1)	Quince.
31. *Diospyros decandra* (1)	Persimmon.
32. *Eriobotrya japonica* (1)	Loquat.
33. *Eugenia brasiliensis* (1)	Brazilian plum or Spanish cherry.
34. *Eugenia jambos* (1)	Rose apple.
35. *Eugenia michelii* (1)	Surinam cherry.
36. *Eugenia uniflora* (1)	French cherry.
37. *Ficus carica* (1)	Fig.
38. *Garcinia mangostana* (2)	Mangosteen.
39. *Garcinia xanthochymus* (2)	Mangosteen.
40. *Gossypium* spp. (2)	Cultivated cotton.
41. *Jambosa malaccensis* (2)	Mountain apple.
42. *Latania löddigesii* (3)	Blue palm.
43. *Lycopersicum esculentum* (2).	Tomato.
44. *Litchi chinensis* (3)	Lichee nut.
45. *Mangifera indica* (1)	Mango.
46. *Mimusops elengi* (1)	Elengi tree.
47. *Murraya exotica* (1)	Mock orange.
48. *Musa* spp. (3)	Banana.
49. *Noronhia emarginata* (3)	Noronhia.
50. *Ochrosia elliptica* (2)	Ochrosia.
51. *Opuntia vulgaris* (2)	Prickly pear.
52. *Passiflora coerulea* (3)	Passion vine.
53. *Persea gratissima* (2)	Avocado.
54. *Phoenix dactylifera* (3)	Date palm.
55. *Psidium cattleyanum* (1)	Strawberry guava.
56. *Psidium guayava* (1)	Sweet red and white lemon guavas.
57. *Psidium guayava pomiferum* (1).	Common guava.
58. *Psidium guayava pyriferum* (3).	Waiawi.
59. *Prunus persica* (1)	Peach.
60. *Prunus persica* var. *nectarina* (1).	Nectarine.
61. *Prunus armeniaca* (1)	Apricot.
62. *Prunus* spp. (1)	Plum.
63. *Punica granatum* (3)	Pomegranate.
64. *Pyrus* spp. (1)	Apple.
65. *Pyrus* spp. (1)	Pear.
66. *Santalum freycinetianum* (3).	Sandalwood.
67. *Solanum melongena* (3)	Eggplant.
68. *Spondias dulcis* (3)	Wi.
69. *Terminalia chebula* (1)	Natal plum.
70. *Terminalia catappa* (1)	Tropical almond or winged kamani.
71. *Thevetia neriifolia* (1)	Bestill.
72. *Vitis labrusca* (3)	Grape.

1. Sapodilla (*Achras sapota*).

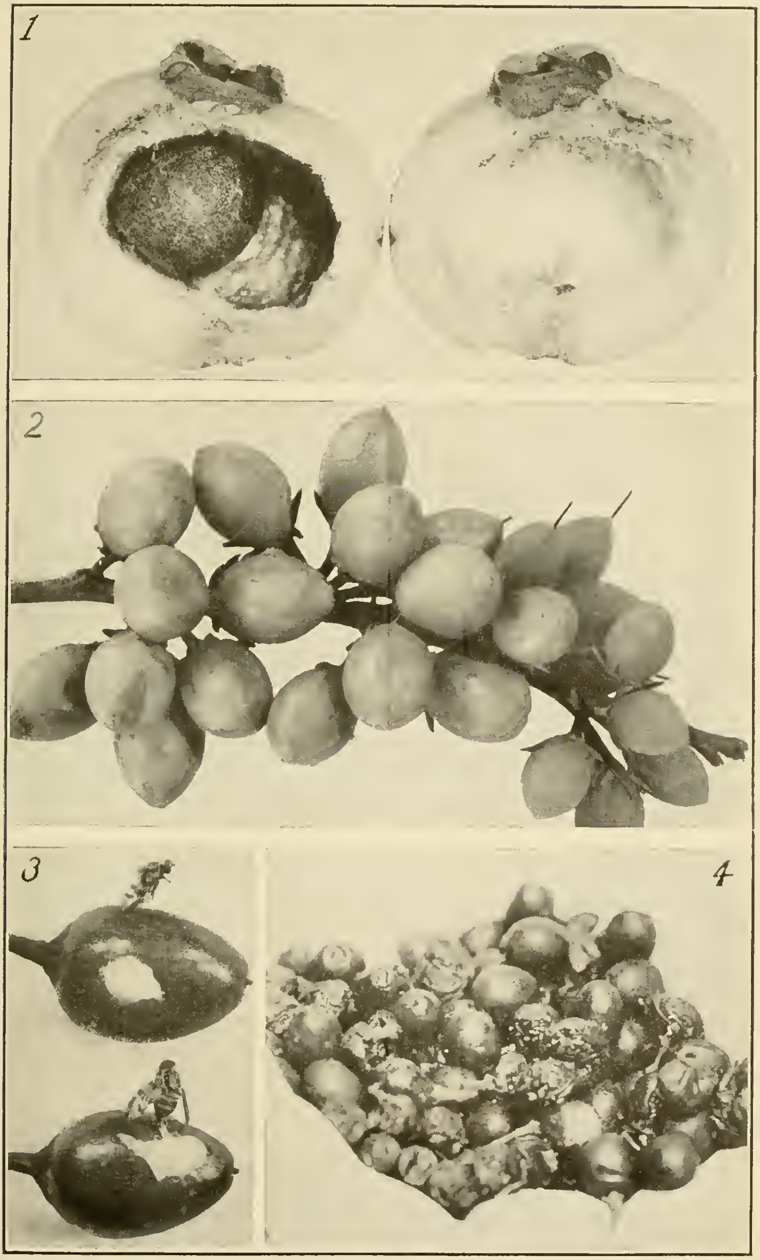
The sapodilla or naseberry (*Achras sapota*) is not a preferred host of *C. capitata* in Honolulu. A large percentage of the fruits ripen without becoming infested. Infestations are slight. Only 3 adults were reared from 1 fruit.

HOST FRUITS OF THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—A grove of large ball kamani trees (*Calophyllum inophyllum*) producing shade for a country home on windward Oahu. Fruits from these trees are badly infested and are falling throughout the year. FIG. 2.—The inedible fruit consists of a round seed, covered by a thin fibrous pulp in which the larvæ of the fruit fly work. (Original.)

HOST FRUITS OF THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—*Carissa arduina*. Typical of a class of fruits which are protected from infestation until they are practically ripe by a copious flow of white sticky sap from punctures in the skin made by the adult fly. Note this dried white sap covering punctures on fruits. FIG. 2.—Bartlett pear (*Pyrus* sp.). Fruit-fly larvæ may eat out the entire center of a pear and yet the fruit may remain attached to the tree and shrivel up after the larvæ have fallen to the ground. (Original.)



FOUR FAVORITE HOST FRUITS OF THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—Rose apple (*Eugenia jambos*) sectioned to show the large hollow interior on the surface of which larvæ prefer to feed. FIG. 2.—*Mimusops elengi;* fruit of an ornamental tree which sheds its infested fruit throughout a 3 to 4 month period. FIG. 3.—Adult *C. capitata* captured in sticky exudations of solidified sap about punctures in *Chrysophyllum oliviforme*. FIG. 4.—A handful of mock-orange (*Murraya exotica*) berries. The mock orange fruits several times each year and the berries falling become hidden in the grass. (Original.)

2. Acordia sp.

The fruit of an Acordia with white fleshy pulp was found infested in Bermuda during December, 1913, by the senior writer. The fruit of the Acordia in Honolulu, which is a different species and more woody, is not infested.

3. Sour Sop (*Anona muricata*).

The sour sop (*Anona muricata*) is a fruit which is not ordinarily infested until well grown and is found in the markets in season in perfect condition. Under certain conditions it may become heavily infested. Of 6 overripe fruits, 5 yielded 95, 67, 132, 87, and 2 adults.

4. Sugar Palm (*Arenga saccharifera*).

A single adult fly was reared from the fruit of the sugar palm (*Arenga saccharifera*) during May, 1912, by the Hawaiian Board of Agriculture and Forestry. From a lot of 14 fruits gathered March 17, 1914, only 3 yielded adults. From these 3 fruits, 1, 4, and 2 flies were reared.

5. Breadfruit (*Artocarpus incisa*).

There are no definite records of infestations of the breadfruit (*Artocarpus incisa*). No adults were reared from 100 very much overripe fruits taken from the ground during August, 1914, and placed over sand in jars. Three larvæ were found in one partially decayed fruit, but they were the only ones ever seen by the writers in breadfruit during a three-year period.

6. Carambola (*Averrhoa carambola*).

The carambola (*Averrhoa carambola*) becomes infested usually only as it ripens, in spite of the fact that it is fragrant and thin skinned. Many fruits escape infestation even in badly infested districts. Of 40 very ripe fruits collected during September, 10 yielded no adults. The other 30 yielded 172 adults, 5 fruits yielding 2, 6, 11, 15, and 20 adults. Only 22 of 62 ripe fruits gathered during August produced adults; from these a total of 289 adults were reared.

7. Ball Kamani (*Calophyllum inophyllum*).

The ball kamani (*Calophyllum inophyllum*) is badly infested at times (Pl. VI). The adults oviposit very abundantly in the thin, stringy pulp covering the huge seed, as the fruit ripens, but successful larval development often depends largely upon whether the fruit in falling lodges in a place where it remains moist. The fruits on separate trees differ in regard to infestation. On certain trees the pulp may be largely consumed and the larvæ well grown when the fruit falls. Generally speaking, the larvæ in ball kamani are apt to be underfed, their pupæ unusually small, and the adults so depauperized that they may be undeveloped sexually. In a few instances where fruits have fallen in grass on the windward island areas the larvæ have developed to normal size. As many as 120 larvæ have been reared in one fruit. In April, 1913, 7 fruits taken from the ground in Honolulu contained 39, 86, 0, 27, 6, 82, and 115 larvæ. From 104 fruits picked from a tree at Waikiki during April, 1913, 927 larvæ emerged. Of 20 fruits taken from a second tree 11 yielded no adults; the remaining 9 yielded 77 adults, 19 being the largest number from any one fruit. Of 20 fruits of a thick-skinned variety picked from the tree, only 1 yielded adults; a single adult was reared from this fruit. From 1,555 fruits collected during December, 1915, 4,213 larvæ were reared.

8. Peppers (*Capsicum annuum* var. *grossum*).

Peppers (*Capsicum annuum* var. *grossum*) grown in market gardens and generally known as "bell" or "green sweet" peppers, and used uncooked in salads, are frequently, although not generally, infested. Five pounds of peppers gathered August 1 at Waikiki, containing very green as well as overripe fruit, yielded no adults when placed over sand in jars. Of 221 ripe peppers gathered at the same place during November, 1915, 213 were not infested; the 8 infested fruits contained from 1 to 5 larvæ each, or a total of 19 larvæ. Thirty-five adults were reared during December, 1913, from 100 ripe peppers, while from 13 peppers collected on March 25, 1913, 14 adults were reared. The fruit fly was first reared from peppers in Honolulu by E. M. Ehrhorn, who reared 6 adults from peppers collected at Kaimuki. While there are reports that all peppers are infested, the writers have never known infestation to exceed 5 per cent of the fruits examined.

Chile peppers (*Capsicum* spp.) have never been found infested by the writers, although many fruits have been under observation.

9, 10. Papaya (*Carica papaya* and *C. quercifolia*).

The papaya (*Carica papaya*) is one of the commonest plants about Honolulu and its fruit is the universal breakfast fruit, yet the writers have never seen a fruit sufficiently ripe and fit for eating purposes infested with larvæ. Only fruits too ripe for the table or those having decayed spots are found infested. Sound fruits cut from the tree several days before they soften, a practice which is customary among fruit dealers, are always free from infestation. The milky juice which exudes copiously from cuts in the skin of the fruit contains a digestive principle said to be similar to pepsin. The hands of horticulturists working with the papaya soon become sore if exposed to this juice. It has been shown by Knab and Yothers that the larvæ of the papaya fruit fly (*Toxotrypana curvicauda*) can not live in the pulp of papayas still green, because of this juice. This is true also in the case of *C. capitata* until the fruits are ripe, although several of about 500 eggs introduced artificially into well-grown but still green-colored papayas attached to the tree were able to hatch; the larvæ died. It has been stated in Honolulu that fruits were infested while still green, but the writers have never been able to verify this and all evidence would appear to disprove it.

During January, 1914, an adult female was observed ovipositing in a perfectly sound fruit that was just beginning to turn color. Much juice had exuded around the ovipositor and had formed a gummy semisolid globule. After about 3 minutes the fly withdrew her ovipositor with comparative ease, but the mass of solidified juice remained fast to the tip of the abdomen. The fly freed herself from this mass with considerable difficulty. Seven eggs were found within the puncture, but they failed to develop.

During the winter months very ripe fruits are more heavily infested, as a rule, because of the relative scarcity of other hosts. From 2 fruits picked from the tree on January 18, 1914, 205 and 67 adults, respectively, were reared. Thirty-eight adults were reared from a decayed area in a fruit picked July, 1913. From 6 fruits gathered during May and June, 1913, 27, 13, 49, 2, 30, and 61 adults, respectively, were reared. From one lot of 7 overripe fruits gathered during May only 1 was infested.

The dwarf papaya (*Carica quercifolia*) serves also as a host fruit of *C. capitata*.

11. *Carissa arduina*.

The fruits of *Carissa arduina* are often found generally infested. Even at as late a period in development as that when the fruit has turned deep red, slight abrasions in the thin skin are followed by exudations of white sap which dries about the punctures, as illustrated in Plate VII, figure 1. Every fruit becoming fully ripe on one hedge was found, during February, to be well infested and as many as 30 adults were reared from single fruits.

12. Sapota (*Casimiroa edulis*).

The white sapota (*Casimiroa edulis*) is quite generally infested about the time it ripens. Practically every ripe fruit falling to the ground is variously infested. As many as 40 adults have been reared from a fruit 2 inches in diameter. While green the fruits are protected by white sap which exudes copiously from skin abrasions.

13. Chinese Inkberry (*Cestrum* sp.).

The Chinese inkberry (*Cestrum* sp.) is seldom infested, although the trees produce an abundance of fruit. Samples of several hundred fruits, each taken from the ground among badly infested coffee trees, have yielded no adults. In one instance 3 adults were reared from fruits collected by the Hawaiian Board of Agriculture in Manoa Valley in November, 1911.

14. Star Apple (*Chrysophyllum cainito*).

The star apple (*Chrysophyllum cainito*) is a preferred host and is always grossly infested. The writers have not observed a single mature fruit during the past three years that was uninfested. The milky, sticky juice exudes from abrasions in the skin until the fruit is overripe. Often, as is the case with other species of Chrysophyllum, this juice solidifies so rapidly that the female fruit fly is caught by the ovipositor and held captive until death. From four very ripe fruits collected at Haleiwa, May 30, 1913, 188, 110, 105, and 5 adults, respectively, were reared. Five fruits from the same tree, picked May 27, 1914, yielded 18, 96, 54, 105, and 44 adults, respectively.

15. Damson Plum (*Chrysophyllum oliviforme*).

The small plum *Chrysophyllum oliviforme* is one of the preferred hosts of *C. capitata*. Like its relative, the star apple (*Chrysophyllum cainito*), it is well protected by the white sticky juice which exudes rapidly from breaks made in its skin until quite well grown. (Pl. VIII, fig. 3.) Although larvæ develop to a very large size in this fruit and scarcely a fruit ripens uninfested, the average number of larvæ per fruit is small. Of a sample of 48 fruits collected during February, 18 produced no adult flies. From the remaining 30 fruits an average of 2.4 adults resulted, 14 being the largest number of adults reared from a single fruit.

16. *Chrysophyllum polynecium*.

This fruit, which is round and about half an inch in diameter, is congeneric with the star apple (*Chrysophyllum cainito*) and the Damson plum (*Chrysophyllum oliviforme*). Like them it is a preferred host and always grossly infested. From two lots of 500 fruits each gathered from the ground during May, 1914, 1,584 and 1,140 adult flies were reared.

17–26. Citrus Fruits.

In a previously published paper [1] on the susceptibility of citrus fruits, the writers present data secured under Hawaiian conditions which show why such thin-skinned fruits as the tangerine, mandarin, Chinese orange, and kumquats are readily infested, and why oranges, lemons, and grapefruit resist infestation of the pulp with such remarkable success. All varieties of citrus have been found in Hawaii containing well-grown larvæ of *C. capitata* in their pulp and first-instar larvæ transferred to the sourest, and even half-grown lemons have been reared to the adult stage, so there is no question as to the correctness of classifying all citrus fruits among the hosts of *C. capitata*. While it seems evident that the acidity of partially ripe lemons has a detrimental effect upon larval growth, it has been proved experimentally and by field observation, both by Quayle and the writers, that no fruit is too acid for larval development. Savastano, in 1914, giving the results of experimental work carried on in Italy, exaggerates the part played by the acidity of citrus fruits in protecting them from *C. capitata* attack. In Hawaii his conclusions have not been borne out by the results of investigations by the writers. The data in Table VIII are presented in detail because of the difference of opinion existing between investigators as to the cause of egg and larval mortality in the citrus groups. The conclusions of the writers, based upon extensive examinations,

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[1] Back, E. A., and Pemberton, C. E., Susceptibility of citrus fruits to the attack of the Mediterranean fruit fly. Jour. Agr. Research, v. 3, no. 4, Jan. 15, 1915.

are that, in Hawaii at least, citrus fruits resist fruit-fly infestation of their pulp in proportion to the thickness and texture of the rag underlying the rind, the quantity of oil liberated from the oil cells during the process of oviposition, and their ability to develop quickly about the egg cavity the gall-like tissues which so often make of the cavity a prison for the larvæ that hatch. The data in Table VIII emphasize the large numbers of eggs deposited in the skin of *Citrus* spp., and the relatively small number of these that produce larvæ able to reach and enter the pulp except in the Chinese oranges, limes, and tangerines. Larvæ that succeed in entering the rag from the egg cavity in the rind are unable to reach the pulp except in astonishingly small numbers because of the imperviousness of the rag. It is the persistent attack of successive lots of larvæ hatching from different batches of eggs, laid very often in the same puncture, that finally breaks down the barrier between the young larvæ and the pulp. If the types of mortality among eggs and larvæ in the rind of oranges, grapefruit, and lemons protect those fruits so well under Hawaiian conditions, where the weather is so warm that the adult flies can deposit their eggs every day in the year, they should constitute a valuable factor in control when supplemented by climatic cultural conditions more adverse to the development of *C. capitata* in other countries.

TABLE VIII.—*Infestation of citrus by the Mediterranean fruit fly.*

Fruit.	Punctures.		Eggs, appearance.		Larvæ.					
					Alive.			Dead.		
	Empty.	Not empty.	Normal.	Abnormal.	In puncture.	In rag.	In pulp.	In puncture.	In rag.	In pulp.
Chinese orange:										
1	0	2	15	....	....	....	6	....	....	....
2	0	1	....	....	....	....	4	....	....	....
3	0	1	....	....	....	....	8	....	....	....
4	0	2	9	....	....	....	5	4	....	4
5	0	1	....	....	....	....	9	....	....	....
6	0	1	....	26	....	....	....	....	....	....
7	0	1	....	....	....	....	7	....	....	....
8	1	1	....	....	....	....	19	....	....	....
9	0	1	....	....	....	....	3	....	....	....
10	0	1	....	....	....	....	....	1	....	6
11	0	1	....	....	....	....	....	....	6	....
12	0	4	15	....	....	....	12	....	....	....
13	0	3	....	12	....	....	7	....	....	....
14	0	1	....	....	....	....	11	....	....	....
15	0	1	....	....	....	....	5	....	....	....
Lime:										
1	10	0	....	....	....	....	....	....	13	....
2	6	5	15	....	....	....	....	....	....	....
3	7	4	34	....	....	....	....	4	4	....
4	4	6	....	....	....	....	....	10	30	....
5	1	5	53	1	....	....	1	21	1	....
6	6	9	....	1	....	....	....	20	15	....
7	0	7	33	....	....	....	9	33	....	....
8	3	5	80	2	....	....	....	9	11	....
9	3	0	....	....	....	....	....	....	....	....
10	8	9	....	15	....	....	....	56	4	....
11	0	9	....	....	....	....	....	....	49	....
12	6	5	61	27	....	....	....	6	3	....
13	4	2	....	....	....	....	....	7	....	....
14	9	2	....	15	....	....	....	2	....	....
15	7	7	....	44	....	....	....	9	17	....
16	5	0	....	....	....	....	....	....	....	....
17	11	0	....	....	....	....	....	....	....	....
18	5	13	....	14	....	....	....	14	37	....
19	7	9	....	....	....	....	....	30	12	....
20	5	0	....	....	....	....	....	....	....	....
Grapefruit:										
1	7	25	83	514	....	....	....	19	28	....
2	1	12	369	111	....	1	....	26	4	....
3	0	3	17	16	1	....	....	10	....	....
4	2	3	4	....	....	....	....	....	5	....
5	5	6	42	9	....	....	....	4	....	....
6	7	14	43	203	....	....	....	13	45	....

TABLE VIII.—*Infestation of citrus by the Mediterranean fruit fly*—Continued.

Fruit.	Punctures.		Eggs, appearance.		Larvæ.					
					Alive.			Dead.		
	Empty.	Not empty.	Normal.	Abnormal.	In puncture.	In rag.	In pulp.	In puncture.	In rag.	In pulp.
Grapefruit—Contd.										
7	8	14		484				17	7	
8	4	19	9	666				10	7	
9	2	4		69				59	61	
10	5	24		404					89	
11	1	11		232				5		
12	14	8	32	75	8			25		
13	0	27	5	385				3		
14	0	18	88	208				4	9	
15	0	5		86	3					
16	0	11	8	195				19	15	
17	0	6		42	8			6		
18	0	4		74						
19	0	10		307						
20	0	13		329				29		
Lemon:										
1	3	4	23		[1] 29			4		
2	0	2	30					13		
3	5	0								
4	4	1		7						
5	14	4	15					18		
6	2	2	3					9		
7	3	2	5					4		
8	4	0								
9	28	12	47	60				14		
10	8	3	15	12						
11	6	10	129	32				2		
12	11	5	39	15				1		
13	9	5	38	2						
14	15	1	10					1		
15	4	0								
16	16		64						5	
17	8	2	10							
18	1	0								
19	7	0								
20	12	15	19	53				82		
21	30	3	11							
22	53	10	23	21				9		
23	12	3		18				20		
24	11	5		45				12		
25	5	2		3				3		
26	5	0								
27	2	4	14	1				4	10	
28	6	22	0	71				32		
29	2	1	44							
30	4	8	62	20				12		
31	4	1	0	7						
32	11									
33	6	12	67	122				16		
34	4	2						7		
35	4	2	16					5		
Sweet orange: [2]										
1	2	7						41	10	
2	13	11						42	29	
3	0	2							25	
4	2	5						15	5	
5	2	3						14	3	
6	0	1							6	
7	0	12						17	45	
8	5	16						83	6	
9	1	1		4						
10	2	8						37	27	
11	0	2						11		
12	2	5						19	26	
13	1	4						36	12	
14	1	5					[3] 5	13	19	
15	1	9	21					6	94	
16	7	17						75	58	

[1] These 29 newly hatched larvæ were feeble and appeared to be about ready to die.

[2] Fruits of sweet oranges 1 to 13 picked Mar. 7, examined Mar. 10, 1914; 14 to 20 picked Feb. 24, examined Mar. 6 and 7, 1914; 21 to 26 picked Sept. 10, examined Sept. 16, 1913; 27 to 29 picked Sept. 10, examined Sept. 18, 1913; 30 picked Sept. 4, examined Sept. 15, 1913.

[3] Third-instar larvæ in pulp; orange not decayed.

TABLE VIII.—*Infestation of citrus by the Mediterranean fruit fly*—Continued.

Fruit.	Punctures.		Eggs, appearance.		Larvæ.					
					Alive.			Dead.		
	Empty.	Not empty.	Normal.	Abnormal.	In puncture.	In rag.	In pulp.	In puncture.	In rag.	In pulp.
Sweet orange—Con.										
17	0	8	......	......	......	......	......	0	45	......
18	2	11	......	......	......	......	......	......	79	......
19	6	4	......	......	......	......	......	3	25	......
20	5	5	......	9	......	......	[1] 12	19	10	......
21	7	20	3	25	......	......	......	107	63	......
22	15	18	7	24	......	......	......	66	51	......
23	8	9	......	33	......	......	......	7	29	......
24	29	16	12	68	......	......	......	18	37	......
25	4	13	14	21	......	......	......	48	65	......
26	3	10	......	21	......	......	......	35	13	......
27	4	9	40	30	......	......	......	27	6	......
28	10	12	25	52	......	......	......	......	37	......
29	......	......	13	17	......	......	......	52	40	......
30	12	11	150	36	......	......	......	......	......	......
Sour orange.[2]										
1	5	5	11	15	......	9	......	......	1	......
2	2	6	0	94	......	......	......	31	......	......
3	3	8	19	15	......	......	......	6	......	......
4	2	8	30	32	......	......	11	......	......	......
5	0	8	12	10	......	......	......	37	......	......
6	3	10	75	250	......	......	......	32	14	......
7	2	8	4	45	......	......	......	24	7	......
8	1	7	7	57	......	......	59	16	......	......
9	1	7	0	4	18	......	7	23	10	......
10	4	9	10	48	......	......	......	43	......	......
11	1	27	12	48	......	......	28	51	......	......
12	1	12	36	116	......	......	......	36	......	......
13	1	5	0	25	......	......	......	16	7	......
14	2	2	10	14	......	......	25	......	......	1
15	0	2	0	9	......	......	36	......	......	......
16 [3]	......	......	......	......	......	......	49	......	......	......
17	7	0	......	......	......	......	......	......	......	......
18	2	1	5	......	......	......	......	......	......	......
19	4	4	57	12	......	......	......	......	......	......
20	1	2	0	44	2	......	......	......	......	......

[1] Third-instar larvæ in pulp beneath soft but undecayed spot in rind.
[2] Fruit of sour oranges, 1 to 16 picked Mar. 3, examined Mar. 10 and 11, 1914; 17 to 20 picked Sept. 4, examined Sept. 5, 1913.
[3] Very badly decayed.

17–21. CITRUS FRUITS EASILY INFESTED IN HAWAII.

The varieties of *Citrus japonica* in Hawaii known as the Chinese orange and the kumquats ("testa di turco" of the Italians), of *Citrus nobilis*, known as the mandarin and tangerine, and of *Citrus medica limetta*, or lime, are easily infested by *C. capitata*. The data of Table VIII on the infestation of Chinese oranges and Hawaiian limes are introduced as examples of infestation for the varieties of *C. japonica* and *C. nobilis*. The rind of the Chinese orange and of many limes, mandarins and tangerines is so thin that the adult fly is able to deposit eggs either directly within the pulp or between the rind and the skin covering the pulp, but parallel with the rind and at a slight distance away from the ruptured oil cells where they more often escape the fatal action of the oil or hindrances in the form of a dense rag. Of 609 eggs deposited between the rind and the pulp in Chinese oranges, 98.5 per cent hatched and the larvæ, unhindered by the presence of an impervious rag, entered the pulp. The infestation of the pulp of limes, tangerines and mandarins is in inverse proportion to the thickness of the rind. It is interesting to note that eggs in the Kusaie limes, the rind of which is sufficiently thick so that the eggs are usually deposited directly beneath the puncture, die with great regularity, while the eggs in Hawaiian limes, the rind of which may be sufficiently thin to permit the eggs being deposited as in Chinese oranges, or so thick (according to the individual tree) that the eggs are laid either in the cavity in the rind, or between the rind and pulp but directly beneath the puncture, suffer a degree of mortality between that of eggs deposited in Chinese oranges and Kusaie limes. Mandarins and tangerines in Hawaii usually are infested if allowed to ripen thoroughly upon the tree. The Satsuma orange is a fruit that easily becomes infested because of the looseness of the rind and lack of well-developed rag.

22. Lemon.

Because of the danger of introducing the Mediterranean fruit fly from the Mediterranean regions in lemons, the importance of this fruit as a host has been thoroughly investigated at the request of Mr. C. L. Marlatt, chairman of the Federal Horticultural Board. The observations of Martelli and Savastano in Italy have led them to definite statements as to the immunity of commercial lemons to *C. capitata* in Italy. H. J. Quayle, who conducted an investigation during 1913 in the Mediterranean citrus regions under the direction of the Federal Horticultural Board, found less than 15 lemons with infested pulp during a search of eight weeks throughout commercial lemon orchards in Italy and Sicily. It is interesting to record that of the 15 fruits containing larvæ within the pulp, all had the appearance of having been injured, either mechanically or by fungi, and in all but two instances they were found in an overripe and overdeveloped condition on the ground beneath the trees. The two fruits found infested while still attached to the tree were partly decayed on one side. These instances of infestation recorded by Quayle, who is thoroughly competent to judge from long experience with citrus in California, refute the argument that lemons are too acid to support *C. capitata* larvæ, although the small number of lemons found infested, of the thousands examined during the eight-week period, strengthens the argument set forth by the Italian entomologists, as well as by the writers, that lemons, commercially grown and cured, will not support the fruit fly if they are not first subjected to some mechanical or other injury while still attached to the tree.

In Hawaii, where climatic and host conditions are so favorable to *C. capitata* activity and where every host is subjected to the severest tests, the writers have never found a lemon of either the commercial or the rough-skinned type showing infestation of the pulp unless it had first received mechanical injuries. Although there are comparatively few lemon trees in Hawaii, those known to the writers have seldom been found infested. By "infested" is meant, in this instance, an infestation by *C. capitata* larvæ in the pulp. Out of 235 well-grown and for the most part ripe lemons of the commercial type, picked from the tree, only one eventually developed adults, three in number, and this fruit when picked was partially decayed as the result of a thorn prick. Out of 161 lemons of the same variety taken from the ground in a very much overripe condition, only two developed larvæ, 1 and 5, respectively. No larvæ developed in 434 ripe, rough-skinned, but badly punctured lemons picked from the tree. One partially decayed rough-skinned lemon picked from the ground produced 12 larvæ. These instances of infestation of the pulp, taking place in the field, are the only ones which have come to the attention of the writers during the past four years in Hawaii.

The recording of so small a number of lemons with larvæ developing in their pulp should not be interpreted as meaning that lemons are particularly free from attack in Hawaii. The data of Table VIII prove that, in reality, lemons of the commercial type grown in Hawaii are very attractive to adult *C. capitata* as host fruit. The many fruits listed above from Hawaii from which no adults were reared were as heavily infested in the peel as those recorded in Table VIII. Particular attention is drawn to this point since it is the contention of the writers that the immunity of lemons, otherwise uninjured, is due not so much to the acidity of the pulp as it is to the imperviousness of the rag. It seems incredible that lemons heavily oviposited in should be able to resist successfully infestation of their pulp, yet this is true. Examination of 5 lemons showed that 73 of 79 egg cavities or punctures had been made between the oil-cells, hence the immunity of lemons is due chiefly to the imperviousness of the rag and the gall-like developments about the egg cavity which make it difficult for the hatching larvæ to leave the cavity.

In the laboratory a comparison was made between the infestation of the rind of cured California lemons and well-grown fruits picked fresh, both green and yellow in color, from the trees. About the egg cavities in freshly picked fruits infested by adults in the laboratory, a hard, more or less gall-like condition of the walls and adjoining tissues develops rapidly. In the well-cured fruits no such gall-like hardenings were detected following infestation, and after hatching the larvæ had little difficulty in working their way out of the puncture into the rag. Thus six California-grown lemons such as are found on the markets were exposed between April 3 and 5, 1915, in large glass jars containing each about 200 flies. After removal they were held until April 12, when an examination showed them to have been oviposited in 16, 26, 31, 29, 39, and 20 places, respectively. Of the 161 punctures, only 8 had been made in, or through, an oil-cell and in these the *C. capitata* (numbering, respectively, 2, 1, 1, 3, 0, 2, 5, and 8) were dead. From the remaining 153 punctures, made between the oil-cells, 441 larvæ had escaped into the rag beneath, where, without exception, they were found dead. Other well-grown but greenish colored lemons were gathered from the trees and immediately exposed to adults within similar glass jars between April 14 and 16, 1915. These fruits were examined April 19–20. Before being exposed in the jars all punctures in the rind, made previously in the field, were covered with gummed paper. The results of the examination of two of these fruits are given here as typical:

Fruit No. 1.

Puncture 1. One dead larva in puncture located between oil-cells.
2. One unhatched egg in puncture in oil-cell.
33. Three unhatched eggs in puncture between oil-cells.
4. Six unhatched eggs in puncture between oil-cells.
5. Two larvæ barely alive in rag beneath puncture made between oil-cells.
6. Five unhatched eggs in puncture between oil-cells.
7. Seven unhatched eggs in puncture between oil-cells.
8. Four unhatched eggs in puncture between oil-cells.
9. Six dead larvæ in puncture between two oil-cells.
10. One dead larva in puncture between two oil-cells and one dead in rag close by.
11–19. These nine punctures were shallow and contained nothing.

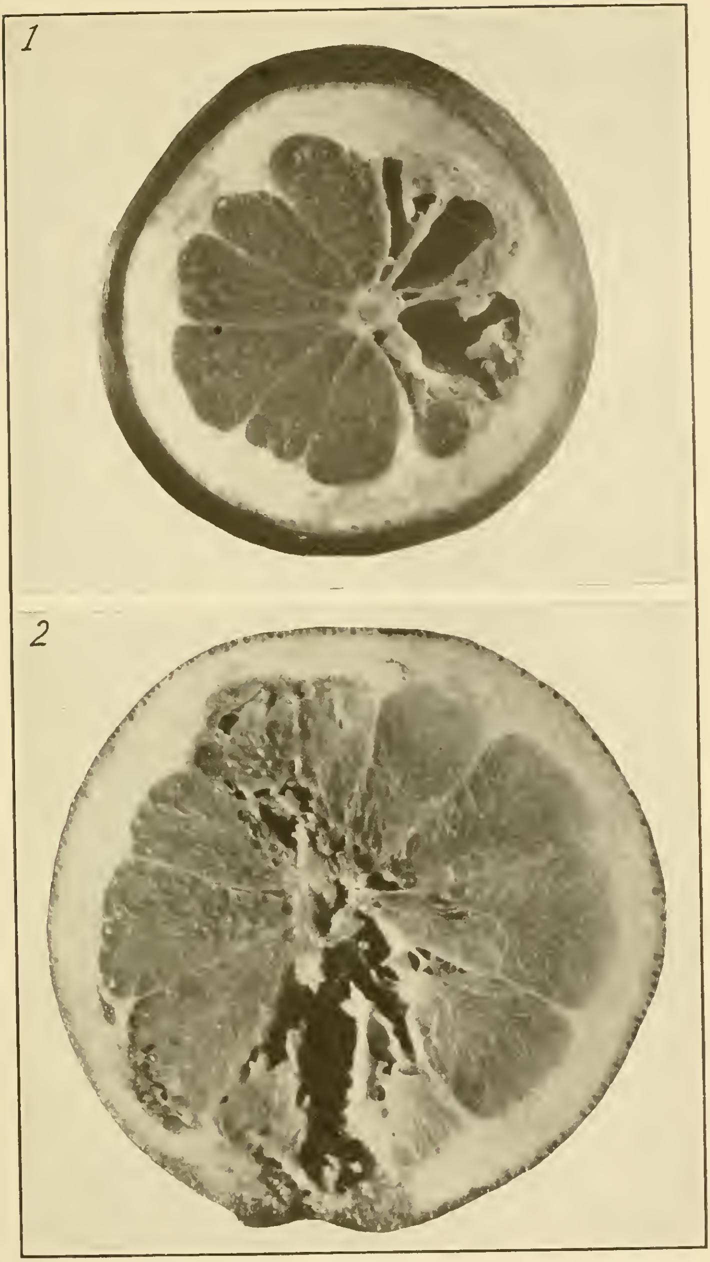
Fruit No. 2.

Puncture 1. Nine dead larvæ in rag beneath puncture between oil-cells.
2. One dead larva in puncture made between oil-cells.
3. Four dead larvæ in puncture made between oil-cells.
4. Three unhatched eggs in puncture made between oil-cells.
5. One dead first-instar larva in rag beneath puncture made between oil-cells.

These data indicate the way citrus fruits are protected from infestation of the pulp, and they supplement previously published data on the development of larvæ within lemons.

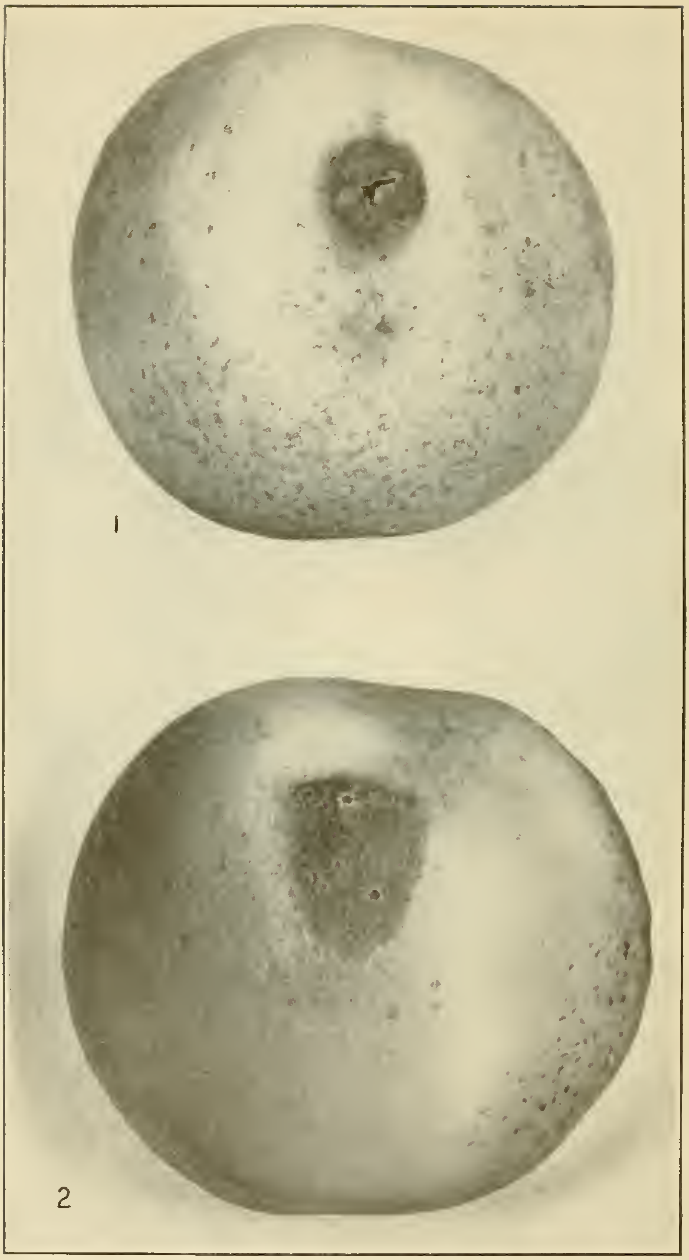
23. Grapefruit.

The ordinary types of grapefruit which have come under the observation of the writers have been particularly resistant to attack up to the time when they are fit for table use as indicated by the data of Table VIII. These data were secured during September. Many fruits from these trees in Manoa Valley, Honolulu, which were sufficiently ripe to fall to the ground, have been held over sand in the laboratory but yielded no adult flies. The writers have found other trees bearing fruits with rinds of a looser texture from which they have reared adults, and in certain instances have found fruits still attached to the trees, which, though much overripe, were badly infested. It seems very probable, therefore, that should the fly reach the citrus regions of the mainland, certain thin-skinned varieties of grapefruit might



GRAPEFRUIT AS A HOST OF THE MEDITERRANEAN FRUIT FLY.

Two types of infestation. FIG. 1.—Larvæ have eaten out a portion of the fruit while the rest remains unaffected. FIG. 2.—Infestation extending throughout the pulp. Note that the rind shows evidence of infestation of the pulp only at the decayed spot on the lower side. (Original.)



THE ORANGE AS A HOST FRUIT OF THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—Orange infested with larvæ of the Mediterranean fruit fly. Note that the fruit looks sound, except about the irregular hole, through which a few well-grown larvæ have already left the fruit. FIG. 2.—Orange infested with larvæ of the Mediterranean fruit fly showing two breathing holes of the larvæ in the decayed area. (Author's illustration.)

become seriously infested unless gathered and sold early. Three grapefruit out of five dropping from the tree in an overripe condition, two months after they had been marked as sufficiently ripe for eating, produced four, two, and four adults. It is interesting to record that when these five fruits were marked they already had been oviposited in. E. M. Ehrhorn reared 16 adults from an overripe grapefruit grown in the Punahou district of Honolulu during November, 1911. The grapefruit grown at ex-Gov. Frear's city and mountain residences have been found infested when much overripe. The fruits used as illustrations (Plate IX) were taken from Tantalus during a particularly wet season when it appeared to the writers that the action of numerous showers had aided the larvæ in breaking down the protective rag of the rind.

The exudation of gum from punctures does not always occur, although at times it may be very excessive in Hawaii.

24. Shaddock.

The large, very thick-rinded shaddocks are not infested successfully until they are very much overripe. During March, 1914, fruits were gathered from a tree in Hilo, Hawaii, from which fruits had been taken for the table during the months of January and February. During those months no infestation of the pulp had been noted by the owner. Examinations made of the fag end of the crop showed that larvæ had successfully penetrated the pulp and had been able to burrow about through the loose-textured rag. Instances were found in which the larvæ had completed their entire development within the rag. As many as 22, 17, 9, 17, 16, 25, 19, 8, 1, and 18 living larvæ were found in the rag of 10 fruits. Of these 10 fruits only four possessed 27, 13, 3, and 12 living larvæ in the pulp. On examination, made at the same time, of equally ripe fruits of another shaddock tree that possessed a firmer rag, there were found 6 normal and 39 abnormal appearing eggs; 5, 2, and 3 living larvæ in the punctures, rag, and pulp, respectively; and 405, 696, and 1 dead larvæ in the punctures, rag, and pulp, respectively.

25. Sweet Oranges.

Oranges are subject to severe attack from the time they are nearly grown until they fall to the ground or are picked. (See Pl. X.) Ten oranges just beginning to turn color, collected in Honolulu in November, 1915, had 14, 33, 74, 4, 22, 13, 99, 11, 20, and 14 punctures, respectively, in their rind; 10 others of another crop gathered during June, 1913, had 29, 17, 34, 14, 11, 17, 33, 17, 18, and 17 punctures, respectively. Ten ripe fruits picked in the same general locality as these 20 fruits during October, 1915, had 21, 2, 17, 10, 10, 3, 2, 46, 9, and 3 punctures, respectively. In spite of the fact that 39 oranges picked in September when they were just becoming well yellowed had an average of 32 punctures per fruit, none of them developed larvæ within the pulp. But of 784 oranges gathered during March, 1914, when very much overripe, 254 produced 2,272 larvæ, or an average of 9 larvæ to the fruit. Such data as these, coupled with the more detailed data of Table VIII, throw much light on the wonderfully resistant power of oranges to fruit-fly attack. Were oranges not so well equipped by nature to withstand attack they would be ruined long before any of them could ripen. Considering the number of eggs deposited, very few adults emerge even from fruits that become infested in the pulp. Thus, only 5, 13, 4, 1, 6, 12, 6, 30, 8, 4, 1, 1, 14, 26, 1, 12, 31, and 2 adults were reared from 18 fruits picked because they appeared to be badly infested.

26. Sour Oranges.

The ordinary sour orange commonly found in Florida groves is as severely attacked as is the sweet orange, but on account of the looseness of the rind and rag it becomes infested in the pulp more easily. A larger percentage of fruits become infested in the pulp when well ripened than of sweet oranges. (See Table VIII for data on infestation.)

27. Wampi (*Clausena wampi*).

The wampi (*Clausena wampi*) is a native of China. While a large percentage of the fruit produced by a tree growing at Beretania and Punahou Streets, Honolulu, was found free from attack during June, 1914, certain overripe fruits contained larvæ of *C. capitata*. From 200 fruits gathered during July, 1913, only four adults were reared.

28, 29. Coffee.

Coffee cherries (*Coffea arabica* and *C. liberica*) are favorite hosts of the Mediterranean fruit fly. *Coffea arabica* is grown in various portions of the Hawaiian Islands, but commercially, at the present time, only on the island of Hawaii. (Pl. V.) During the fiscal year ended June 30, 1915, there were exported from the islands 4,363,606 pounds of raw coffee beans valued at $651,907, besides the coffee locally consumed. Fortunately for the coffee growers in Brazil and Africa, as well as in Hawaii, the larvæ of the fruit fly attack only the pulp of the cherry surrounding the beans or seeds and in no way affect the value of the latter. The chemical analyses of Miss A. R. Thompson, formerly of the United States experiment station at Honolulu, have proved that beans from infested cherries do not differ chemically from those from uninfested cherries, and tasting tests of coffee made from roasted beans by Messrs. L. Macfarlane and Robert Wallace, coffee growers of Hawaii, Mr. H. L. Lang, of the office of Home Economics of the United States Department of Agriculture, Dr. E. V. Wilcox, formerly director of the Hawaii Federal Experiment Station, and the writers have failed to discover differences in either the flavor or the aroma.

The unrestricted development of larvæ within coffee cherries does, however, bring about certain losses to the growers and mill owners that are apt to be overlooked except by those best informed. Before the introduction of parasites into the coffee districts cherries were infested, often as soon as they began to turn white from green, in the final ripening process. The larvæ, numbering from 2 to 8, were able to become nearly full grown by the time the cherries had turned red. An examination of the coffee cherries as illustrated (Pl. V, fig. 4) shows that the beans occupy the larger portion of the fruit. The pulp itself, with its thin, easily punctured epidermis, varies in thickness from 0.04 to 0.14 inch, or is scarcely thicker than a well-grown larva of the fruit fly. Therefore, by the time the cherry would ordinarily be ready for harvesting the larvæ have devoured practically all the pulp, leaving the seeds hanging more or less loosely within a sack composed of the thin epidermis. If the weather happens to be dry, the epidermis shrivels and hardens about the beans and the cherry remains on the branch indefinitely, resembling closely those killed by disease. However, should the harvesting season be rainy, the epidermis decays rapidly and under the weight of the beans the cherry falls to the ground. The writers have been in certain coffee fields where a slight jar to the tree would cause many cherries to fall to the ground, where they are lost. This type of loss necessitates extra pickings and greater cost of labor. Since the successful introduction of parasites the fruit fly has been so reduced, as discussed on page 99, that while cherries are infested in about the same proportion as formerly, the infestation occurs so late in the ripening process that extra pickings now are not necessary and the cherries on reaching the mills during the height of the harvesting season contain chiefly eggs or young larvæ which have not had an opportunity to reduce the pulp. Whether these improved conditions of 1914 and 1915 will continue remains to be seen.

For some time after the advent of the fruit fly into the coffee districts, prices for coffee in the cherry delivered at the pulping mills remained the same per pound. During 1912 and 1913 when the fly attack was severe it was difficult to find at the mills cherries which were normally bright red and sound. Practically every cherry that was red was badly infested and its pulp had been consumed, and the floors about the delivery platforms were well strewn with emerging larvæ. As the pulp only had been destroyed, a pound of coffee cherries badly infested contained in reality many more coffee beans, or of that portion of the cherry that had any commercial value. Counts made of samples of badly infested cherries, and of those in which the infestation had not progressed sufficiently far to affect the weight, were made and the loss both in numbers and percentage of cherries is given in Table IX.

TABLE IX.—*Loss of weight and pulping quality of coffee cherries due to infestation by Mediterranean fruit fly.*[1]

Weight of sample.	Number of cherries.		Loss due to infestation.		Cherries failing to pulp.		Cherries partly pulped.	
	Badly infested.	Firm bright red.	In number of cherries.	In percentage.	Badly infested.	Firm bright red.	Badly infested.	Firm bright red.
6 pounds	3,060	1,980	1,080	54.5	692	0	334	25
10 pounds	3,675	2,892	783	27.1	833	11	699	227
4 pounds	1,828	1,277	551	43.1	274	3	357	274
3 pounds	1,171	736	435	59.1				
10 pounds	3,562	2,561	1,001	39.8				

[1] Attention is called to the fact that differences in the size and succulency of coffee cherries is responsible for the differences in the number of cherries per pound in the different samples. While several ordinary weighing machines were used in securing data in Tables IX and X, the uninfested and infested cherries or beans of the same sample were weighed on the same machine.

It will be noted that loss in the number of coffee cherries due to heavy infestation, when the cherry is sold by the pound at prices paid before the advent of the fly, ranged in the particular examples taken from 27.1 to 59.1 per cent. In practice, however, this loss is considerably reduced by the addition of half-ripe fruits in the fields. This loss has been appreciated by the small Japanese coffee growers and has been responsible, in the opinion of the writers, for the erection of many small pulping mills throughout the Kona coffee district. It has also encouraged coffee renters who deliver their crop at the large mills to put in their sacks a high percentage of "too-green" cherries which will not pulp and are therefore lost.

Badly infested cherries do not pulp as easily as do sound fruits, as shown in the data of Table IX. Thus in 6, 10, and 4 pounds of badly infested cherries, run through a gasoline pulping mill, 692, 833, and 274 failed to pulp, whereas in three samples of the same weight of unaffected cherries, 0, 11, and 3 cherries failed to pulp. The number of badly infested cherries that only partly pulped is also much larger than that of unaffected cherries.

To determine whether the beans from infested and noninfested cherries differed in weight after they had been dried and sacked for several months the beans of 1,000 cherries were weighed separately with the results given in Table X.

TABLE X.—*Relative weights of thoroughly dried beans from badly infested and uninfested coffee cherries.*

Weight of sample of dried beans from 1,000 cherries.					
Lot.	Infested.	Not infested.	Lot.	Infested.	Not infested.
	Ounces.	*Ounces.*		*Ounces.*	*Ounces.*
1	11	11	3	10	10
	11	11.5		10.5	10.5
	10.5	11	4	12	12
2	9.5	10		11.5	11
	10	10		11	11.5
	9.5	10		12	12
	9.5	9.5		12	12
	9.5	9.5			

The data indicate that the weight of the bean is not affected by infestation.

In experimental work coffee cherries should be avoided, if possible, as a source of fruit-fly larvæ unless one is working close to coffee fields. While from 2 to 8 larvæ may mature in each fruit if the fruit remains attached to the tree, the fruit heats and decays so rapidly after being picked and placed in containers that only a relatively small number of adults can be reared. Only 427 adults were reared from 1,500 ripe infested cherries placed over sand in lots of 25. If these cherries had been allowed to remain on the tree they would have produced at least 6,000 adults.

30. Quince (*Cydonia vulgaris*).

The quince (*Cydonia vulgaris*) is not grown in Hawaii, but fruits obtained from the mainland were readily infested. The quince is frequently infested in Australia, South Africa, and Spain.

31. Persimmon (*Diospyros decandra*).

The brown persimmon (*Diospyros decandra*) is the only Diospyros grown in Hawaii. Mr. G. P. Wilder has grown fruits a few of which have become infested on reaching maturity. From one ripe fruit 57 adults were reared during December, 1911, by the Hawaiian Board of Agriculture. The persimmon has been reported infested from Algeria, South Africa, and Australia.

32. Loquat (*Eriobotrya japonica*).

The loquat (*Eriobotrya japonica*) is badly infested in Hawaii, and appears to be a favored host. Infested loquats often hang on the tree and shrivel up after the larvæ have become full grown and dropped to the ground. When punctured before the fruits are ripe, the areas about the punctures remain green after the rest of the fruit turns yellow, thus making these infestations very evident. As many as 11 punctures have been counted in a single fruit. From lots of 200 and 150 fruits each, 1,261 and 990 adults, respectively, were reared. From one cluster of 17 fruits 458 adults, or an average of about 27 flies per fruit, were reared.

In Bermuda the loquats are badly infested and serve as a host by means of which large numbers of flies pass the winter and spring months.

33. Brazilian Plum or Spanish Cherry (*Eugenia brasiliensis*).

The Brazilian plum or Spanish cherry (*Eugenia brasiliensis*) is easily and badly infested. It is doubtful if a single fruit comes to maturity in Honolulu without becoming at least partially infested. The larvæ develop well in this fruit and often as many as 20 adults may be reared from a single fruit slightly over one-half inch in diameter.

34. Rose Apple (*Eugenia jambos*).

The rose apple (*Eugenia jambos*) (Pl. IV, fig. 2, and Pl. VIII, fig. 1) is a preferred host and is everywhere generally and badly infested about Honolulu. From 36 fruits gathered during July, 1913, in Manoa Valley there emerged a total of 1,688 adults, or an average of about 47 per fruit. Each fruit yielded adults, 10 fruits yielding 53, 6, 91, 36, 44, 58, 1, 18, 56, and 92, respectively. A total of 1,395 adults, or an average of 19.6, were reared from 75 fruits collected in Nuuanu Valley during March, 1914. One fruit from Kalihi Valley in July, 1913, yielded 20 adults.

35, 36. Surinam Cherry (*Eugenia michelii*) and French Cherry (*Eugenia uniflora*).

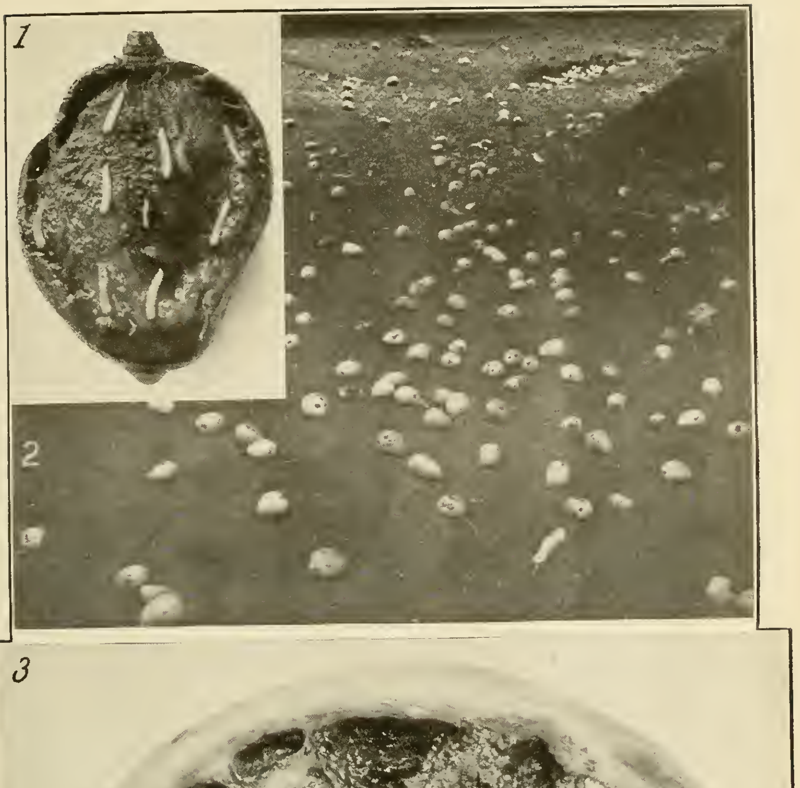
The Surinam cherry (*Eugenia michelii*) and the French cherry (*Eugenia uniflora*), known in Spanish countries by the general term "pitangas," are fruits very generally infested, and although they never yield many adult flies in proportion to their size, very few fruits escape attack. In Bermuda the former was found to be one of the principal hosts of *C. capitata*. From 437 supposedly badly infested fruits gathered

HOSTS OF THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—The Mediterranean fruit fly attacks cotton bolls about the time they are nearly full grown. This attack, however, appears to be of a secondary nature and follows that of the pink bollworm (*Pectinophora gossipiella*). As many as 10 well-grown larvæ have been removed from a single boll. FIG. 2.—Cross section of an apple (*Pyrus malus*) showing the destruction caused by feeding larvæ of the Mediterranean fruit fly. (Original.)

THE MANGO AS A HOST FRUIT OF THE MEDITERRANEAN FRUIT FLY.

Mango trees may become very large (fig. 1) and bear enormous crops of fruit (fig. 2), which, when ripening and falling, present impossible conditions for the fruit-fly inspector. (Original.)



THE MANGO AS A HOST FRUIT OF THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—Larvæ of the Mediterranean fruit fly, about natural size, in infested mango. FIG. 2.—No matter how diligently clean-culture inspectors gather fruit during the mango season, each day finds the ground beneath the trees well strewn with fallen infested fruits. FIG. 3.—Infested fruit about natural size. Note large cavity in upper right side containing several hundred white eggs. (Fig. 1, from Severin; figs. 2 and 3, original.)

during July, 1913, only 191 adults were reared. Of 45 fruits gathered during February, 1916, only 29 were infested. These 29 fruits yielded 55 adults, or an average of about 2 per fruit. Seven is the largest number of adults reared from any one of 16 infested fruits during April, 1913.

37. Fig (*Ficus carica*).

The fig (*Ficus carica*) is very generally infested. Because of the white, sticky sap which exudes copiously from abrasions made in its skin it does not become infested until the fruits are sufficiently ripe for the market. The larvæ are very small, as a rule, when the fruits are offered for sale and because of the interior structure of the fruit are easily overlooked. Only 6 out of 24 very ripe figs purchased in the market during July produced a total of 9 adult flies. Of ripe fruits purchased during March, 6 out of 22 produced 34 adults. From 12 apparently perfect figs, purchased during June, 36 adults were reared. Of 44 figs sufficiently ripe that little sap ran when they were gathered from trees in Manoa Valley, 10 proved to be uninfested. From the remaining 34 fruits 430 adults were reared, 12, 25, 28, 32, 44, and 48 adults being reared from 5 individual fruits. Kirk records rearing 241 adults from 7 figs imported into New Zealand from Australia.

38, 39. Mangosteens (*Garcinia mangostana* and *Garcinia xanthochymus*).

The mangosteens (*Garcinia mangostana* and *G. xanthochymus*) do not become infested until ripe. They are not preferred hosts under Hawaiian conditions. The writers have never reared more than an average of 2 adults from infested fruits. A large percentage of the fruits are uninfested.

40. Cotton (*Gossypium* spp.).

The Mediterranean fruit fly was first reared from cotton bolls (Pl. XI, fig. 1) on October 19, 1911, by E. M. Ehrhorn from bolls collected by D. B. Kuhns from trees growing on King Street, Honolulu. Numerous flies were reared during June, 1915, by August Busck from bolls collected on the U. S. Experiment Station grounds in Honolulu and at Kaneohe, Oahu. During the same month the writers found 10 out of 201 and 6 out of 174 bolls infested. In 10 bolls 32 larvæ were found, 10 larvæ being in one boll. In all cases infestation by *C. capitata* was secondary to attack by the pink bollworm, *Pectinophora gossypiella* (Saunders), and the larvæ of the fruit fly appeared to be feeding only upon the affected portions of the bolls rather than upon the cotton fiber itself.

41. Mountain Apple (*Jambosa malaccensis*).

The mountain apple, or "ohia ai" of the Hawaiians (*Jambosa malaccensis*), is a wild tree thriving well up to 1,800 feet elevation. The trees frequently are found growing in forests (Pl. IV, fig. 1). The fruits maturing in the forests do not appear to be more than slightly, and often not at all, infested. Fruits ripening on trees within the city of Honolulu are often badly infested. All the fruits ripening during August, 1914, on a tree growing in Pauoa Valley were infested. Ehrhorn reared adult flies from fruits from Kalihi Valley during August, 1911. As a rule, the fruits from the mountains, offered for sale in Honolulu, are free from infestation.

While none of three varieties of water apples (*Jambosa* spp.), of which there are a few trees in Honolulu, have been found infested, there is no reason why they should not be infested, as they are similar in texture to *Jambosa malaccensis*.

42. Blue Palm (*Latania löddigesii*).

One nut of 12 collected from a tree growing on Keeamaku Street, Honolulu, was found infested. Two adult flies were reared. Prof. O. H. Swezey has also reared adults from the overripe nuts of this palm.

43. Tomato (*Lycopersicum esculentum*).

The ordinary cultivated tomato (*Lycopersicum esculentum*) is not generally infested by *C. capitata*, although many adults of *Bactrocera cucurbitae* and certain decay flies (Drosophilidae) are reared. Thus 270 ripe fruits gathered promiscuously from the market gardens of Waikiki during June, 1916, yielded no adult flies when held over sand in jars. Sixteen ripe fruits gathered from the market gardens of Moiliili on March 25, 1913, yielded the melon fly (*B. curcubitae*). It is interesting to note that of seven lots of tomatoes collected during 1911 and early 1912 by the Hawaiian Board of Agriculture, none produced adults of *C. capitata*. That *C. capitata* may be reared in numbers from tomatoes under field conditions has been demonstrated by the ease with which adults oviposit in both ripe and green, although well-grown, fruits in the laboratory under forced conditions. Of 4 ripe tomatoes placed singly for 7 hours in jars containing about 200 adults, only one yielded 3 adults, although all 4 were oviposited in and contained on removal from the jars an average of 13 punctures. One fruit yielding no adults contained 42 punctures. From one green but well-grown fruit exposed in a jar for 7 hours with 200 adults, only 5 adults were reared. From six other ripe fruits similarly exposed in two lots of 3 each, there emerged only 16 adults; and only 5 adults developed in one lot of 3 fruits containing 29 punctures in the skin.

The currant tomato (*Solanum pimpinellifolium*), the grape tomato (*Solanum lycopersicum*), and the "popolo" tomato (*Solanum nodiflorum*) have never been found infested. Newman writes that *C. capitata* has often been reported infesting tomatoes and other Solanum species, but that he had never reared from them any fly in Western Australia but *Lonchaea splendida* Loew, the tomato fruit fly—a fly which does not occur in Hawaii.

44. Lichee Nut (*Litchi chinensis*).

The lichee nut (*Litchi chinensis*) is not infested so long as the fruits remain perfect. The shell-like covering of the fruits often splits as the fruit reaches maturity, and in the pulp thus exposed the adult can, and has been known to, deposit eggs. Several split fruits were found infested during September, 1913. One depauperized adult was reared by the Hawaiian Board of Agriculture from a split fruit during July, 1912. It is possible for infestation to occur in fruits infested by the tortricid *Cryptophlebia illepida* Btl. Seven ripe fruits, freshly picked and sound in every way, were hung in jars of adult flies for a two-day period during June, 1915. An examination of them after their removal proved that the flies had not been able to puncture the shell.

45. Mango (Plates XII, XIII).

The mango (*Mangifera indica*) is a favorite host of the fruit fly. In Hawaii the common seedling varieties are so badly attacked that many owners are willing to have the crops removed and destroyed before they ripen. Twelve fruits picked from the ground in upper Manoa Valley yielded 313 adults, 95 adults emerging from one fruit. Of a total of 47 fruits from the same locality taken from the ground on July 27, 25 yielded 423 adults. Sixteen of 33 fruits taken from the ground at the Hawaiian Church, Manoa Valley, yielded no adults, but 502 were reared from the remaining 17 fruits. Of fruits taken from the ground on the Cooper estate, Manoa Valley, 26 of 35 yielded 527 adults during August. These records are fair samples of the infestation of seedling sweet mangoes in the outlying districts of Honolulu, where there are many wild guavas bushes.

The mango is one of the fruits subject to attack which becomes infested only as it ripens. Up to that time it is quite well protected from attack by the copious exudations of distasteful sap which follow attempts at oviposition. Often where the combined attack of the mango weevil (*Cryptorhynchus mangiferae* Fab.) and fruit-fly adults is severe the fruits are well stained with the exuded sap. It has been the experience of the writers that very few adults can be reared from hard well-grown fruits picked from or beneath trees on which many fruits are ripening and falling to the ground, even where they show many indications of attempted oviposition. Thus from a total of 292 such fruits representing 12 lots collected from the ground in Pauoa Valley, Moanalua Gardens, and Nuuanuu Valley, during July and August, only 6 adults were reared. The thicker the skin of the fruit the more difficulty does the adult have in ovipositing successfully.

TABLE XI.—*Varietal susceptibility of mangoes to the attack of the Mediterranean fruit fly under forced conditions.*[1]

Combination of varieties.	Number of— Punctures.	Number of— Eggs.
Common mango	48	327
Cambodiana	8	61
Brinda Bani	0	0
Oahu	3	42
Piri	0	0
Brinda Bani	0	0
Common mango	8	73
Wood chutney[2]	60	584
Samoan chutney[2]	12	138
Common mango	5	52
Cambodiana	9	86
Wooten chutney	10	115
Common mango	40	293
Cambodiana (hard)	0	0
Cambodiana	18	182
Common mango	15	111
Strawberry	8	91
Brinda Bani	0	0
Strawberry	15	206
Seedling No. 1928	3	32
Brinda Bani	0	0
Divine	0	0
Wooten chutney[3]	44	314
Brinda Bani	0	0
Piri	1	68
Jamshedi	0	0
Divine	0	0
Wooten chutney[3]	6	27
No. 1928[3]	4	28
Cambodiana[3]	8	93

Combination of varieties.	Number of— Punctures.	Number of— Eggs.
Strawberry	16	139
Wood chutney	11	129
Brinda Bani	0	0
Common mango	14	129
Oahu	23	249
Totofori	0	0
No. 1928	3	18
Samoan chutney	29	291
Brinda Bani	0	0
Common mango	20	223
Wooten chutney	25	403
Totofori	7	43
No. 1928	0	0
Piri	0	0
Wood chutney	8	112
Piri (hard)	2	11
Piri (slightly soft)	21	196
Divine	0	0
Strawberry	1	5
Jamshedi	0	0
Strawberry[3]	14	132
No. 1928	4	42
Brinda Bani	0	0
Common mango[3]	4	35
Oahu[3]	5	38
Totofori[3]	7	40
Common mango	5	60
Wooten chutney	24	272
Totofori	0	0

Combination of varieties.	Number of— Punctures.	Number of— Eggs.
Common mango[4]	0	0
Jamshedi[4]	0	0
Divine[4]	0	0
No. 1928	1	9
Alphonse	0	0
Brinda Bani	0	0
Common mango	28	370
Oahu	5	59
Brinda Bani	0	0
Common mango	13	139
Strawberry[5]	25	178
Brinda Bani	0	0
Wooten chutney[4]	0	0
Wooten chutney[3]	5	38
Common mango	23	441
Cambodiana	0	0
Brinda Bani	0	0
Common mango[4]	6	53
Jamshedi[4]	0	0
Strawberry[3]	45	481
Common mango[3]	29	196
Piri[3]	2	14
Piri (hard)	0	0
Common mango[4]	1	11
Cambodiana[4]	0	0
Wooten chutney[3]	19	101
Wooten chutney	6	41
Divine	0	0
Brinda Bani	0	0

[1] Unless otherwise noted, the fruits used in each experiment were equally hard, though fully matured and from trees on which fruits had already begun to ripen.
[2] Less hard than the common mango.
[3] Soft.
[4] Very hard.
[5] Slightly softer than other two fruits.

While the common thin-skinned sweet mangoes are badly infested when they ripen, many chutney mangoes and certain highly developed horticultural varieties of eating mangoes are less susceptible to attack, owing, in the one instance, apparently to a greater amount of "turpentine" in the skin, and, in the other, to a much thicker skin. Under forced conditions adults will oviposit heavily in chutney mangoes which, ripening on the tree, escape infestation. Three fruits of a "Chinese" chutney variety[1]

[1] For purpose of future identification it may be stated that one tree of this variety is grown by Mr. G. P. Wilder, of Honolulu.

said to be free from attack were exposed to adults in the laboratory and 219, 285, and 222 eggs, respectively, were laid in them. To determine whether the confinement of different varieties of improved mangoes would throw any light upon their varietal susceptibility, the various combinations indicated in Table XI were placed in jars of ovipositing adults and allowed to remain 24 hours. This experiment was made possible by the gift by the Federal Experiment Station at Honolulu of fruits which had been protected from fruit-fly attack by paper bags. The extent of infestation under these forced conditions shows that the Piri, Brinda Bani, and Divine were least affected. The Divine and Brinda Bani are varieties so little attacked in the open that they are not protected by paper bags during development. It is interesting to note that the Piri, which is one of the very best eating varieties of mangoes grown in Honolulu, is the least susceptible to attack of the varieties used in the experiments with the exception of the Brinda Bani and Divine. The Black Alfonse and Cowasjee Patel grown at the Moanalua Gardens appear equally resistant with the Piri, and from these gardens Mr. S. M. Damon has sent out many superb fruits of these three varieties, which reach maturity uninfested and unprotected.

46. Elengi Tree (*Mimusops elengi*).

The fruits of *Mimusops elengi* grown in Hawaii appear to belong to two varieties. Both are infested as they become fully ripe, but the glabrous variety supports many more larvæ than the pubescent variety (Pl. VIII, fig. 2). The fruits of both have a tough, firm outer shell, a mealy pulp, a proportionally large central stone, and are about three-fourths of an inch long. Of 34 fruits of the glabrous variety gathered from the ground during February only 7 yielded no adults. From the remaining 27 fruits, 355 adults, or an average of about 13 adults per fruit, were reared. Of 15 fruits of the pubescent variety gathered from the ground at the same time, 8 yielded no adults, and 7 yielded 27 adults. From 10 fruits of the glabrous variety 17, 15, 13, 10, 7, 30, 21, 22, 19, and 2 adults were reared.

47. Mock Orange (*Murraya exotica*).

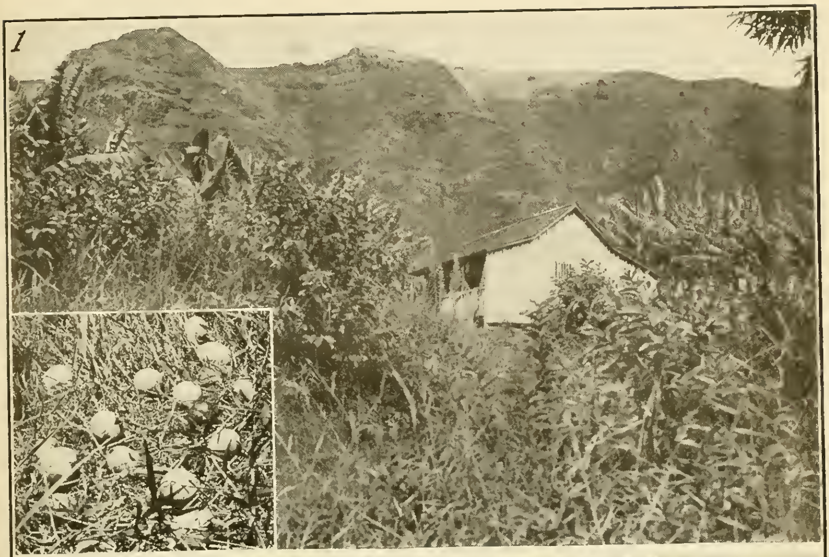
The small fruits of the mock orange or orange jessamine (*Murraya exotica*) are preferred hosts (Pl. VIII, fig. 4). From 1 to 3 larvæ only are able to mature in a single fruit. Of 111 fruits gathered during March, 1914, 26 were not infested. From the remaining 85 fruits 148 adults were reared; 10 fruits yielding, respectively, 1, 1, 2, 3, 2, 1, 1, 2, 1, and 3 adults.

48. Banana (Pl. XIV, XV, XVI).

The banana export trade of the Hawaiian Islands amounted to 256,319 bunches during the year ended June 30, 1915. For the most part, the shipments were composed of the chief commercial variety of Hawaii, the Chinese banana (*Musa cavendishii*), although a small number of Bluefields (*Musa sapientum*) entered into the shipments. With the appearance of *C. capitata* in Hawaii, it became imperative, therefore, to determine to what extent, if any, this established trade jeopardized the mainland fruit interests. Previous to the experimental work in Hawaii, the banana had been classed among the host fruits of *C. capitata* by officials of the Australian Commonwealth and by Gowdey [1] of British East Africa without modifying statements.

A critical review of the Australian literature seems to indicate that the positive references to the presence of *C. capitata* in bananas should be questioned, as it is more than probable that the similarity in the appearance of fruit-fly larvæ has led to a con-

[1] In a letter to the writers dated July, 1916, Gowdey writes that his previously reported rearing of *C. capitata* from bananas was made under abnormal or laboratory conditions. He succeeded in rearing adults from overripe bananas infested in the laboratory. He was not attempting to prove the immunity, or otherwise, of this fruit when green, although sufficiently ripe for the trade, and makes no claim that under field conditions the banana is a host fruit of this fly.

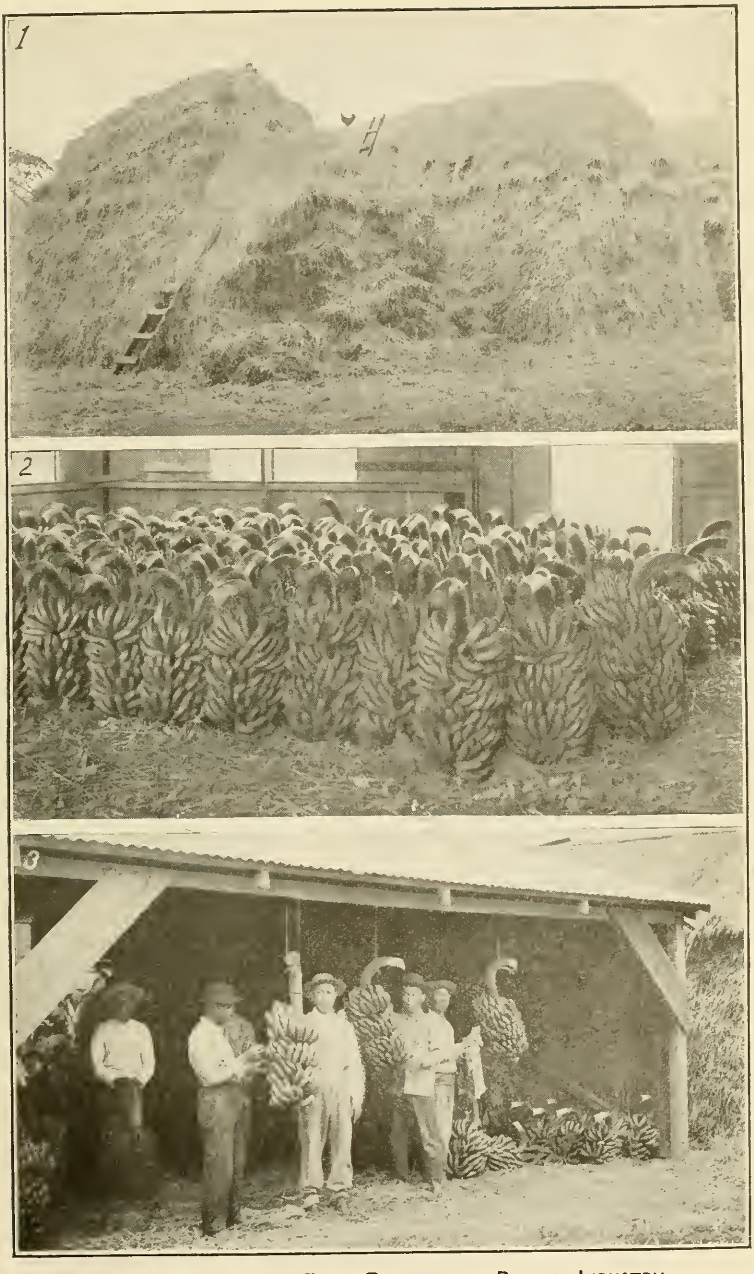


REGULATING MEDITERRANEAN FRUIT-FLY CONDITIONS.

As a result of the regulation of the Federal Horticultural Board the unsanitary fruit-fly conditions about banana plantations have been corrected. FIG. 1.—A small Chinese banana plantation. At present, such guava bushes as are shown, and all other host plants about or in plantation from which fruit is shipped, are cut sufficiently often to prevent fruiting, thus removing the opportunity for fruit-fly larvæ emerging from fallen fruit (see insert) to become attached as pupæ to wrapping material and be transported to California. FIG. 2.—General surroundings of small banana plantations in Kalihi Valley, Oahu, from which fruit is shipped to California. The fruit fly is thoroughly entrenched on all the mountain slopes. (Original.)

THE MEDITERRANEAN FRUIT FLY AND THE BANANA INDUSTRY.

FIG. 1.—Typical Chinese house and packing shed at small banana plantations. The rice straw and dried banana leaves used for wrapping all export fruit are stored in open sheds similar to one illustrated to left of view. FIG. 2.—In a bluefield banana plantation at Hilo. Note the dead dried leaves hanging to the trees; when these are thoroughly dry they are cut and stored for wrapping export fruits. (Original.)

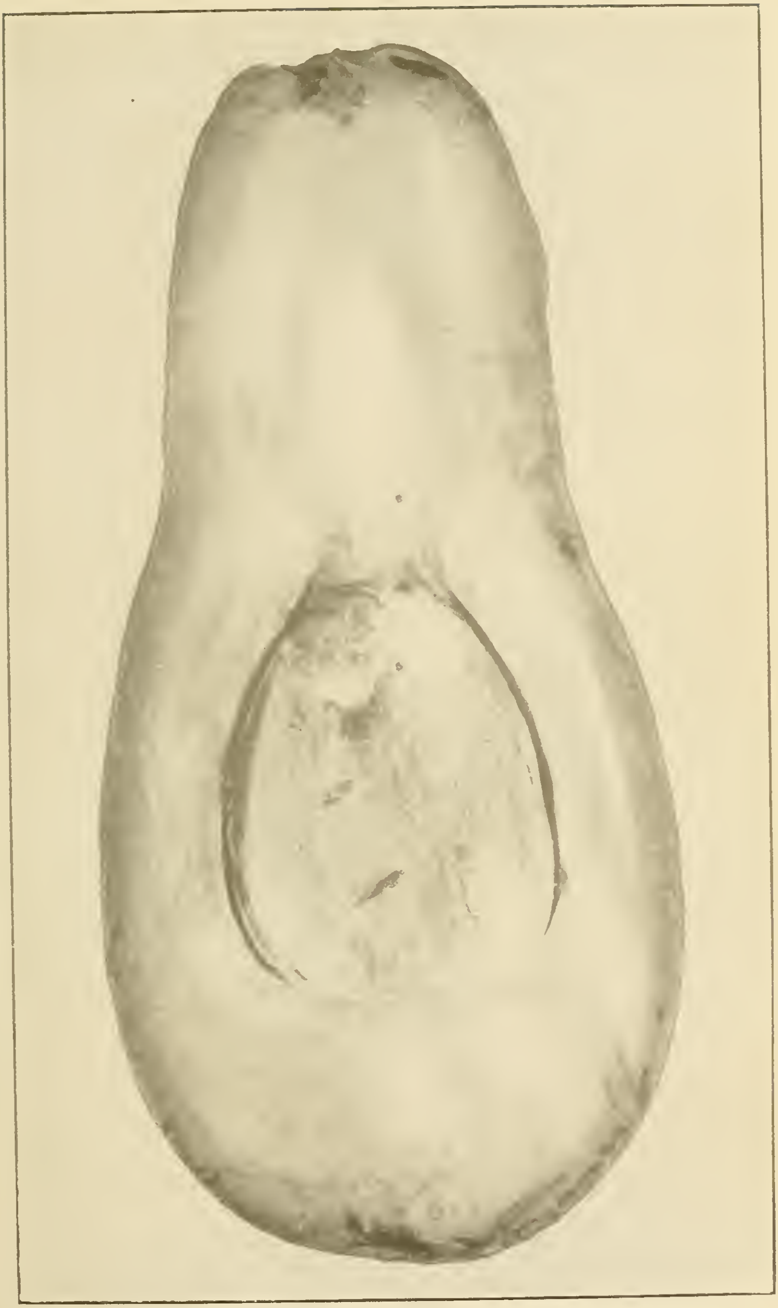


THE MEDITERRANEAN FRUIT FLY AND THE BANANA INDUSTRY.

FIG. 1.—Rice straw stacked in the open to be used as wrapping material for export bananas. FIG. 2.—Chinese bananas cut and cleaned, waiting inspection by officer of Federal Horticultural Board. FIG. 3.—Chinamen remove all split, overripe, and bruised fruits as the bananas are brought to the packing sheds from the field. Each bunch is thus cleaned previous to inspection as a safeguard to mainland interests. (Original.)

THE PRICKLY PEAR AS A HOST FRUIT OF THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—Heavily fruiting plant growing on dry arid and waste lands of the Island of Hawaii. In many places this wild host, with the spiny Acacia, forms dense thickets in which the fruit fly can breed. FIG. 2.—A sample of dense growth of prickly pear along the road near Kailua, Hawaii. The seed pods of the algaroba tree (*Prosopis juliflora*) are not infested. (Original.)



THE AVOCADO OR ALLIGATOR PEAR AS A HOST OF THE MEDITERRANEAN FRUIT FLY.

Cross section of improved fruit. Note slight infestation at stem and blossom ends. Infestation is not always general and usually does not interfere with local consumption. The slight infestations, however, have forced this fruit into the quarantine list, thereby ruining a profitable and growing export trade. (Original.)

fusion of other fruit-fly species, known definitely to attack bananas, with *C. capitata*. Illingworth, in 1913, reared the banana fruit fly (*Dacus curvipennis* Frogg.) from larvæ taken in Sydney from bananas imported from Suva. Lea, in Tasmania in 1908, thoroughly familiar with the Mediterranean fruit fly as a result of the campaign for its eradication about Launceston, states that the Queensland fruit fly (*Dacus tryoni* Frogg.) only was found in bananas imported into Tasmania, and does not list this fruit among the host fruits of *C. capitata*. Broun states that, in 1906, *Dacus tryoni* was the only fruit fly reared from bananas imported during February and March into New Zealand from Fiji and Rarotonga. In the report of the biologist of Western Australia in 1898 we read that a consignment of 50 cases of bananas supposed to have originated in Fiji, but more likely having been transhipped to Sydney from an original source in Queensland, had been destroyed at Freemantle because found infested by the Queensland fruit fly. Quinn, in 1907, writes "after seven years experience with bananas * * * we have not yet found the maggots in green bananas. If green when arriving here (South Australia), how very green indeed must they have been when cut from the trees about three weeks previous." French, of Victoria, appears to be the only person in Australia who definitely makes the statement that he has reared *C. capitata* from bananas exported from Queensland into Victoria. Yet Tryon, of Queensland, in a conversation with the senior writer in 1913, stated that *C. capitata* had never been taken in the banana fields of Queensland. The inclusion of the banana among the fruits infested by *C. capitata* and intercepted at the entry ports of New Zealand by Kirk seems to have been an editorial error, as already pointed out in the paper on the banana as a host referred to below. From the foregoing references, it is possible to assume that the results obtained by the writers in Hawaii, where fruit-fly attack is as severe as anywhere, will be verified when opportunity is presented for such careful experiments in other countries as the commercial value of this fruit warrants. Because of the controversial statements of French and Severin it is desirable that Australian entomologists publish data secured in field experiments.

Those particularly interested in the status of the banana as a host fruit are referred to a paper [1] already published by the writers, giving experimental data from which the following conclusions were drawn:

Since the Mediterranean fruit fly (*Ceratitis capitata* Wied.) has not been found infesting the Chinese banana (*Musa cavendishii*) or the Bluefield banana (*Musa* sp.) during the three years that the Federal Government has had charge of the inspection of export bananas in the Hawaiian Islands, it is evident that some reason exists for this practical immunity. This is the more apparent since adult flies of both sexes have been found present in all parts of banana plantations, and surrounding fruits known to be hosts have been heavily infested.

This immunity is shown to be due to the fact that neither the egg nor the nearly hatched larva of the fruit fly can survive in the tannin-laden peel of green, though mature, fruit. In fact, the copious and sudden flow of sap from egg punctures made by fruit flies in unripe bananas renders the successful deposition of eggs in such fruits difficult and rare.

The fact that not 1 of 1,044 fruits of the Chinese banana ripening singly and prematurely among bunches growing in the field, and upon which, as in the case of other host fruits, one might expect gravid females to concentrate their attention for the purpose of oviposition, has been found to be infested, leads to the conclusion that even ripe bananas are not desired as host fruits by adult fruit flies under Hawaiian conditions. On the other hand, the rearing of flies from the ripe and yellow fruits of the thin-skinned Popoulu variety, as well as from ripe fruits of other varieties under forced and unnatural conditions, leads to the equally acknowledged fact that ripe bananas in the field may serve as hosts and should therefore be properly guarded against in all quarantine work.

From the facts stated, the writers believe that bunches of any variety of bananas [2] now growing in the Hawaiian Islands, when properly inspected for the removal of

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[1] Back, E. A., and Pemberton, C. E. Banana as a host fruit of the Mediterranean fruit fly. Jour. Agr. Research, v. 5, p. 793–804. 1916.

[2] As an added precaution against the spread of *C. capitata* to the mainland, cooking bananas of all types are excluded from the trade.

prematurely ripe, cracked, or partially decayed fruits, offer no danger as carriers of the Mediterranean fruit fly, provided they are wrapped and shipped in accordance with the demands of the trade and the Federal regulations.

In addition to the data already presented by the writers, on the immunity of bananas during a 10-day period after the fruit is sufficiently mature for shipment during the summer months, other experimental work has been carried out by H. F. Willard under the writer's direction. This experimental work in detail emphasizes so well the immunity of well-grown bananas still attached to the tree but green in color, although many fruits on the same bunch have either cracked or ripened, that portions of the data are given herewith. The hands of fruit are numbered from the stem end of the bunch.

On November 30, 1915, 14 bunches of Chinese bananas marked in the field at Moiliili for shipment within two days to California were requisitioned and held uncut for experimental work to determine how long during the winter months the bunches could hang after they were sufficiently ripe for the export trade and still ward off attack. A wire-screen cage containing 300 adult flies was placed over one bunch December 13–15, and three days after its removal an examination of the 131 fruits on the bunch, all green in color, showed 108 fruits to be free from attack. Of those attacked 20, 1, and 1 had respectively, 3, 1, and 4 punctures, all of which contained no eggs and were more or less superficial; a single puncture in the remaining fruit contained two living first-stage larvæ which later died.

A second bunch from which there had been cut on December 22 1 sound yellow fruit, on December 27, 2 sound and 2 cracked yellow fruits, and on December 29, 3 cracked yellow fruits, was caged on the last date with 300 adults. On December 31, or one month after the fruit was sufficiently ripe for shipment, the cage was removed and on January 3 examined with the following results:

Hand 1: 13 fruits; 7 green and puncture free. Six yellow, 2 puncture free; 1, 1, and 2 had, respectively, 4, 2, and 1 empty punctures.
Hand 2: 15 fruits; 10 green and puncture free. Five yellow, 2, 1, 1, and 1 had 0, 2, 1, and 9 punctures. Punctures empty but ones which contained 2 first stage larvæ that soon died.
Hand 3: 15 green puncture-free fruits.
Hand 4: 14 green fruits; 12 puncture free, 2 had 1 empty puncture each.
Hand 5: 9 green fruits; 7 puncture free, 2 had 1 empty puncture each.
Hand 6: 12 green fruits; 11 puncture free, 1 had 1 empty puncture.
Hand 7: 14 green fruits; 13 puncture free. One fruit had been bruised, so that it was yellow and had begun to decay on one side; it had 7 punctures, of which 2, 2, 1, and 2 contained 6, 1, 4, and 0 eggs, respectively. From this fruit 4 adult flies were reared.
Hand 8: 7 green fruits; 5 puncture free, 1 with 3 empty punctures, and 1 with 1 empty and 3 dead and 1 living first-instar larvæ. Living larvæ died in puncture.

A third of the bunches marked November 10 was caged with 300 adults on January 5, after 43 yellow bananas had been cut from the bunch. On January 7 the cage was removed and the bunch cut. An examination made on January 11 gave the following results:

Hands 1 and 2: Fruits had ripened and been cut before caging.
Hand 3: 4 yellow fruits, 3 puncture free. Remaining fruit had 2 punctures with eggs and eggshells. No adults were reared though the fruit was held over sand.
Hand 4: 8 yellow fruits, 5 puncture free; 1, 1, and 1 fruits had 3, 1, and 1 empty punctures.
Hand 5: 12 yellow fruits, 9 puncture free; 1, 1, and 1 had 3, 2, and 1 empty punctures, respectively.
Hand 6: 13 fruits, 12 green and 1 yellow; no punctures.
Hand 7: 12 green fruits, 11 puncture free; 1 had 2 empty punctures.
Hand 8: 11 green fruits, 9 puncture free; 2 had 1 empty puncture each.

The results of the foregoing experiments, together with others on file, strengthen the conclusions quoted above that bananas cut, wrapped, and shipped according to trade and Federal regulations are not a source of danger as carriers of *C. capitata.* Particular attention is called to the very slight infestation secured under forced conditions, even among fruits actually turning yellow on the tree. Many hundred adults would have been reared from favored host fruits similarly caged with adults.

49. *Noronhia emarginata.*

Noronhia emarginata is a native fruit of Madagascar and Mauritius. The writers have never found it infested, but Mr. E. M. Ehrhorn reared 24 adults from a sample of fruit during July, 1912. Mr. Ehrhorn is also authority for the rearing of adults from fruits grown on Kauai.

50. *Ochrosia elliptica.*

The shrub *Ochrosia elliptica* is grown because of the ornamental value of its scarlet fruits. These are occasionally infested. Thirty adult flies were reared from one lot of 12 fruits maturing in the Punahou district of Honolulu, and 8 from one fruit grown at Waikiki.

51. Prickly Pear (*Opuntia vulgaris*).

Although the prickly pear (*Opuntia vulgaris*) grows wild (Pl. XVII) on waste arid lands in Hawaii, it is not a preferred host. From 23 overripe fruits taken from the ground during August, 1912, on Punchbowl, only 15 flies were reared, while no flies were reared from 28 similar fruits gathered at the same time. No flies were reared from 29 lots totaling 254 fruits collected in Pauoa, Palola, Makiki, Moanalua, and Kalauao during September–December, 1912. These fruits were all ripe, many too ripe to remain erect on the plant, and some had fallen to the ground. From 8 fruits ripe, but erect on the plant, cut from plants on Punchbowl close to the Federal Experiment Station, 8 flies were reared; 10 fruits taken from the ground near the top of Punchbowl at the same time (September, 1912) yielding only 1 fly. Of 8 lots of ripe fruits gathered from plants during December, 1914, from Ewa, Fort Shafter, Kalauao, Red Hill, Salt Lake Road, upper and lower Palolo and Manoa Valleys, totaling 118 fruits, only 1 lot of 5 fruits from Ewa yielded 2 adults.

Compere reports the prickly pear about Malaga, Spain, to be infested by *C. capitata.*

52. Passion Vine (*Passiflora coerulea*).

The fruits of only one species (*Passiflora coerulea*) of passion vines have been found infested by *C. capitata* in Hawaii. Infestation is by no means severe. At Haiku, island of Maui, a search among several hundred ripe fruits proved only two fruits to have been infested, and from these six adults were reared. While numerous fruits of different sizes have been found deformed by punctures on Oahu no adult flies have been reared. It is doubtful if this passion vine supports *C. capitata* except when growing luxuriantly in shaded localities.

Fruits of *Passiflora quadrangularis, edulis, laurifolia, alata* and *foetida* have not been found infested. The common water lemon (*P. laurifolia*) found upon the markets of Hawaii is impervious to attack when ripe, as proved by hanging fruits in jars of adult flies.

53. Avocado (*Persea gratissima*).

The avocado (*Persea gratissima*), palta, or alligator pear as it is sometimes called (Pl. XVIII), is one of the host fruits of *C. capitata* that become infested, if at all, late in their development. In fact, the nature of its infestation for most horticultural varieties is so obscure that the general belief prevails that avocados are free from attack. Previous to the introduction of *C. capitata* in Hawaii a small and growing export trade was being developed and, because of the excellence of the improved Hawaiian avocado, it promised to become a financial asset to the islands. Even since the quarantines of the Federal Horticultural Board stopped shipments of avocados to the mainland of the United States shipments have been made to the Philippine Islands in cold storage. The following data are the first ever published on the infestation of avocados and are given here to refute arguments for reestablishing the avocado trade on its former basis:

There are many horticultural varieties of the avocado growing in Hawaii, but there appears to be little difference in their degree of susceptibility to attack. The nutmeg or Guatemala variety is the only one free from attack when growing uninjured. Under forced laboratory conditions adults can not oviposit through its unusually thick rind. The skin of all other varieties of avocados, whether very thin or of usual toughness, can be punctured by the adult fly, as proved by the examination of many fruits. The avocado, like the ordinary pear, is best if picked when still hard and allowed to ripen in storage.

If left on the tree too long, the fruits drop and soften on the ground. With most varieties it is not until the fruits are mature enough for gathering or dropping that adults oviposit in them. As they are sufficiently soft for eating purposes within two to four days after being cut from the tree, the larvæ are still very young, if not just hatched, and are to be found feeding close to the tough leathery rind. Their presence, therefore, is seldom observed by those eating avocados served whole or cut in half to be eaten with a spoon. When served cut in small pieces, with mayonnaise, the paring process usually crushes the small larval burrows on the outer surface of the pulp and the larvæ go to the table unobserved. As thousands of larvæ are thus consumed yearly in Honolulu alone, it may be well to state that they do no harm.[1] Fruits in which the larvæ have become well grown are usually too soft for eating purposes.

Several thousand fruits have been examined carefully by the removal of the skin. Of 1,027 fruits thus examined, picked from the trees at Wahiawa and representing 10 separate lots of fruit, 173, or 16.8 per cent, were found to contain eggs or larvæ; of 384, representing six lots of fruit picked from the ground at Wahiawa, 57 fruits, or 14.8 per cent, were infested. Notes on certain uninfested fruits show that of the green varieties 354 were thick skinned and 75 were thin skinned; of the purple varieties, 254 were thick skinned and 101 were thin skinned. Of 120 infested fruits, 42 and 12 were green varieties with thick and thin skins, respectively, while of the purple varieties, 32 and 34 were thick skinned and thin skinned, respectively. The considerably larger proportion of thin-skinned purple fruits found infested agrees in the main with observations on similar fruits found on the markets. Eleven purple fruits of an early thin-skinned variety picked from the tree in the Makiki district of Honolulu had an average of over 41 punctures in the skin, no fruit having less than 12 or more than 119 punctures. A fruit of a second thin-skinned purple variety grown by Mr. G. P. Wilder, of Honolulu, known to be generally infested if the fruits are allowed to remain on the tree too long, was hung in a jar of adult flies for about 18 hours beside a fruit similar in appearance and degree of ripeness, taken from another tree. An examination after removal of the fruits showed 7 eggs to have been deposited in 1 puncture in 1 fruit while in the Wilder fruit 487 eggs had been deposited in 56 punctures. In a green fruit with a hard, tough skin exposed to adults for 5 hours, 32 eggs were deposited in 14 punctures. One lot of 863 fruits of all varieties gathered by a fruit dealer from trees in upper Manoa Valley and the Punahou district of Honolulu were not infested, but these were picked several days earlier than they might have been picked. Avocados shipped rather green from the islands of Hawaii and Kauai to Honolulu (Oahu) were not found infested, but their freedom from infestation was due to the earliness of their gathering. Ten thin-skinned purple fruits grown at Waikiki and purchased in the market had an average of over 9 punctures per fruit, 1 fruit having 33 punctures and

[1] The writers have personally conducted experiments in which it is estimated persons have eaten 2,000 eggs and young larvae in plums without injurious results.

only 1 being puncture free. Ten thick-skinned green fruits in the market from Kalauao had an average of 6.2 punctures, with no fruit puncture free; 4 of 6 thin-skinned purple fruits taken from the market were puncture free, the remaining 2 fruits having 1 and 3 punctures, respectively. One thick-skinned green fruit picked by the owner and brought to the laboratory as an example of a fine fly-proof variety was found when examined in his presence to contain 230 eggs in 18 punctures. The details of the examinations of many hundred individual fruits are on file and open to those desiring further information on the infestation of avocados at the time they are offered for sale.

In spite of the frequency of infestation as indicated above, the avocado does not appear to be a very satisfactory host for *C. capitata* when one considers its relatively large size and the number of adult flies that can be reared from it. The larval mortality is greater than in many preferred hosts. From thin-skinned purple fruits containing 119, 41, 29, 19, and 37 punctures, 4, 7, 39, 6, and 0 adults were reared. Only 36 adults were reared from a green-skinned variety known to have contained 230 eggs. From 1 fruit that had begun to wither on the tree, an unusual occurrence, 16 adults were reared. Forty-eight is the largest number of adults ever reared from a single fruit by the writers. Of 81 fruits of all varieties known to have been infested when placed separately in jars over sand, 39 produced no adults, while from the remaining 42 fruits 570 adults were reared. No adults were reared from 427 fruits gathered promiscuously and placed in jars without examination to prove them infested.

54. Date Palm (*Phoenix dactylifera*).

Although thousands of fruits of the unimproved date palm (*Phoenix dactylifera*) ripen each year in Hawaii, the writers have found only one instance of infestation. Thirty-five green, but well-grown, dates collected August 11, 1913, at Ainahau, Waikiki, which appeared to have been affected by some disease that rendered them abnormally moist, yielded 2 adults of *C. capitata*. This was probably a chance infestation.

55. Strawberry Guava (*Psidium cattleyanum*).

The strawberry guava (*Psidium cattleyanum*) is a preferred host, and the fruits are usually badly infested. From 96 out of 145 fruits picked March 16, 1913, 364 adults were reared, or an average of 3.8 per fruit. No fruit yielded more than 8 adults. From 500 fruits an average of 4.1 adults were reared during April, 1913. From 90 fruits collected during February, 1916, an average of 4.8 adults per fruit were reared; 15 fruits yielding 1, 3, 2, 11, 7, 7, 6, 5, 9, 7, 6, 2, 8, 6, and 18 adults, respectively.

56–58. Guavas.

The common guavas of Hawaii (*Psidium guayava, P. guayava pomiferum* and *P. guayava pyriferum*) are subject to general infestation. While the guava grows wild up to 4,000 feet elevation and forms dense thickets on the lower levels, even many miles from habitations (Pls. II, III), and is an ever-present source of adult flies, many statements previously published exaggerate the degree of infestation of individual fruits. The writers have never been able to collect samples of 25 miscellaneous fruits without finding some infestation; 14, 18, 15, 17, 10, 10, 10, 24, 7, 6, 6, and 6 fruits collected at 14 places on the windward and leeward sides of Oahu on September 9, 1914, yielded respectively 60, 46, 46, 107, 119, 11, 19, 4, 41, 1, and 2 adults. Each of 62 fruits, except 7, picked ripe from bushes at points along the Tantalus Road yielded adults; from 55 fruits 307 adults were reared. During January, 1916, 75 per cent of all fruits examined along the same road were found infested. From 18 fruits collected May 30, 1913, from bushes near the Libby, McNeil, and Libby Cannery, windward Oahu, at sea level, 423 adults, or an average of 23.5 flies per fruit, were reared. Nine fruits collected between Wahiawa and Haleiwa, Oahu, on January 21, 1912, yielded 96 adults. The writers have never reared more than 34 adults from a single fruit.

That it may be appreciated that, contrary to the belief of many, the wild guavas in the mountains back of Honolulu are a continual source of adult flies, particularly in midwinter, the following records were made:

21 fruits picked on and near the top of Round Top, Tantalus, 1,100 feet elevation, December 19, 1913, yielded 63 adults.
24 fruits from Pauoa Flats, 1,100 feet elevation, December 22, 1913, yielded 69 adults.
42 fruits from rim of Palolo Crater during December, 1913, yielded 362 adults.
22 fruits from top of east ridge, Manoa Valley, 1,000 feet elevation, yielded 100 adults.
50 fruits from head of Palolo Valley, 1,000 feet elevation, on January 2, 1914, yielded 84 adults.

59. Peach (*Prunus persica*).

The peach (*Prunus persica*) is the most preferred of all host fruits grown in Hawaii and in other countries (fig. 3). While excellent peaches have been grown in the islands, at the present time scarcely a peach matures on the lower levels, and usually the fruits are utterly destroyed before they are more than half to three-fourths grown. From 128 fruits, about three-fourths grown, picked from the ground during April, 1913, 2,929 adults, or an average of about 23 adults per fruit, were reared. From 10 of these fruits 34, 12, 25, 8, 49, 78, 64, 17, 6, and 54 adults, respectively, were reared. As many as 90 larvæ have been taken from a single fruit.

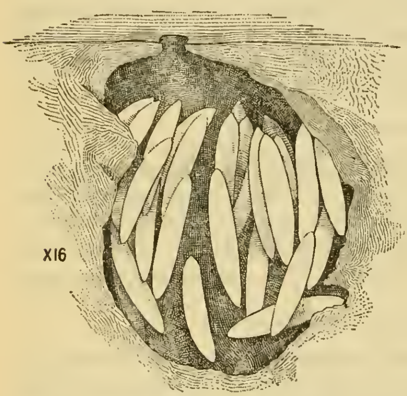


Fig. 3.—Cross section of peach, showing the general shriveling of the walls of the egg cavity and the separation of the eggs. Drawing made 1½ days after oviposition. (Authors' illustration.)

The writers have on file data secured during experimental work on the infestations of several thousand individual fruits, but they throw no additional light on the severity of peach infestation.

60–62. Nectarine (*Prunus persica* var. *nectarina*), Apricot (*Prunus armeniaca*), and Plum (*Prunus* spp.).

Varieties of *Prunus* spp. known as plums, apricots (fig. 4), and nectarines are reported well infested where grown in infested regions. These fruits are imported in season to Hawaii from California and have been easily infested under forced laboratory conditions. It seems probable that they will serve best as hosts when partially grown, as the excessive moisture content of the well-ripened fruits, particularly of such varieties as the Japanese plums, causes a high mortality among young larvæ.

63. Pomegranate (*Punica granatum*).

The writers have never reared *C. capitata* from pomegranate. Mr. O. H. Swezey, of Honolulu, reared an adult identified by the senior writer as *C. capitata* from a fruit partially decayed. The writers have examined many perfect and split fruits without detecting evidences of infestation. Compere records finding infested fruits in Asia Minor, and Trabut in 1901 reports infestation in Algeria.

64. Apple (*Pyrus* spp.).

Only a few apple trees (*Pyrus malus*) are found growing in those regions of Hawaii sufficiently warm for *C. capitata*, hence the writers can offer no observations on the infestation of this fruit occurring in the field. Apples have been found infested in

South Africa and Australia by other investigators. Gurney, of New South Wales, lists the apple among host fruits occasionally infested. Wickens, in 1914, in western Australia, writes that "the apple growers who have been hoping that they would not suffer so severely as growers of soft fruits are now becoming seriously alarmed at the presence of fruit-fly punctures and larvæ in their export varieties of apples. Fortunately the two apple-producing centers of the State (Bridgetown and Mount Baker) are free from the pest." Lounsbury, in South Africa, writes that "ordinarily only peaches, nectarines, and pears are severely infested, but last year apricots, figs, pears, plums, apples, and quinces were almost all attacked." Newman states that in western Australia eggs deposited in undeveloped apples and pears rarely hatch and that if they do the larvæ die. The senior writer found apples grown throughout eastern and southern Spain quite generally infested during 1916.

The writers have used apples extensively in their experimental work and have found them an excellent fruit for securing large numbers of larvæ and eggs for temperature studies. The firmer apples, if not overinfested, serve better than any fruit as a medium for carrying the pest along within the laboratory for considerable periods. Some fruits become too moist and these are not satisfactory. For one type of infestation see Plate I, figure 2, and Plate XI, figure 2.

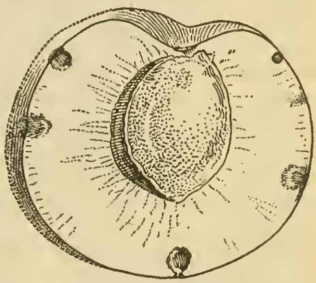


FIG. 4.—Small apricot, natural size, showing eggs of the Mediterranean fruit fly deposited in five places. (Original.)

65. PEAR (*Pyrus* spp.).

There are few pear trees grown in yards in Honolulu. The fruits are generally and badly infested, the interior often becoming badly eaten out by larvæ while the exterior appears unaffected. Often fruits, entirely destroyed, may dry up and remain attached to the tree. Such a fruit is illustrated in Plate VII, figure 2.

66. SANDALWOOD (*Santalum freycinetianum* var. *littorale*).

Adults of *C. capitata* were reared during the summer of 1916 from the fruits of the native sandalwood by Messrs. O. H. Swezy and J. C. Bridwell. The infested material was taken from a tree growing about 50 feet above sea level at Waianae, Island of Oahu.

67. EGGPLANT (*Solanum melongena*).

The eggplant (*Solanum melongena*) has been found infested only once during four years by the writers. One hundred and fifteen fruits of all ages gathered from the vines in the Moiliili market garden during April 26–30, 1914, showed no infestation when examined May 2 to 5 by the removal of the skin. One thousand fruits in all conditions of soundness were examined by the junior writer during November, 1915, by carefully removing the skin from each fruit. In only one fruit were larvæ found. These were well grown, several in number, and in tunnels immediately beneath the skin. Adults of *C. capitata* were reared from these larvæ. The senior writer has personally examined many fields superficially, but has never seen infestation due to either *C. capitata* or *Bactrocera cucurbitae*.

68. WI (*Spondias dulcis*).

The "wi" (*Spondias dulcis*), a native tree of the Society Islands but common to the tropics of both hemispheres, is common in Honolulu and bears heavily. Its fruits are only slightly infested by *C. capitata*. From 200 very ripe fruits gathered on

October 2, 1913, only 7 adults were reared. Four adults were reared from 33 ripe fruits in which many eggs were laid under forced laboratory conditions during December, 1915, and January, 1916. The fruits usually ripen uninfested.

69. Natal Plum (*Terminalia chebula*).

The Natal plum (*Terminalia chebula*) is well infested as the fruits ripen and has proved an excellent source of larvæ for experimental work. From two lots of fruit of 12 pounds each, 2,761 and 2,655 adults, respectively, were reared during October–November, 1915.

70. Tropical Almond or Winged Kamani (*Terminalia catappa*).

The tropical almond or winged kamani (*Terminalia catappa*) is a preferred host. It is one of the most reliable sources for fruit-fly material in the Hawaiian Islands. The pulp, upon which the larvæ feed as the fruit ripens, is scarcely three-eighths of an inch thick. (See Pl. XIX.) Severin obtained from 25 fruits 1,380 larvæ; 98 larvæ from one fruit. The writers have reared many thousands of larvæ for experimental work. From 16 lots of fruit from different Honolulu localities collected during October, 1915, totaling 1,531 fruits, 10,005 larvæ developed. From 3,902 fruits collected from 28 localities during November and December, 1915, only 11,481 larvæ developed. It remains to be seen whether the scarcity of larvæ in the fruits developing during late 1915 was due to the work of parasites or to other causes.

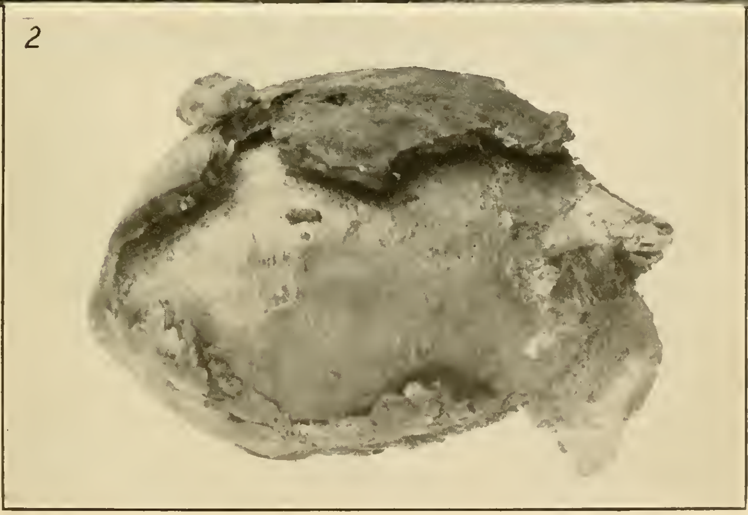
71. Bestill (*Thevetia neriifolia*).

The bestill or yellow oleander (*Thevetia neriifolia*) is never infested until it begins to turn black when ripening. Until then it is excellently protected by its white sticky sap which exudes rapidly from any slight abrasions in the epidermis. The pulp is quite dry and pithy and often escapes infestation, particularly during dry spells. When the fruits ripen very slowly during colder weather and fall to damp shaded spots, as many as 38 adults may be reared from a single fruit. In Bermuda, in the absence of an abundance of other hosts, the Thevetia was found very badly infested with unusually large larvæ during December. In Honolulu many fruits ripen uninfested.

72. Grape (*Vitis labrusca*).

The Isabella grape (*Vitis labrusca*) is the only grape grown in any quantity in Hawaii. The fruits mature and are sold on the markets and appear to be entirely free from fruit-fly attack. This variety of grape is, however, subject to slight attack. One fruit inspector detailed to collect suspicious-appearing fruits brought to the office 978 berries as the result of a 4-day search. A careful examination by H. F. Willard of these with a hand lens revealed five well-grown larvæ in two lots of fruit totaling 201 berries. Two of the larvæ died, but the other three developed into adults identified as *C. capitata*.

Newman, in western Australia, states, in 1912, that he found *C. capitata* frequently in grapes, yet in 1914 he writes that at Crawley little or no sound fruit had been picked for years except grapes. Lounsbury, in 1907, states that he found grapes only slightly infested in South Africa. Whatever the degree of infestation is elsewhere, in the Hawaiian Islands it is so slight that it is never noticed in the vineyards where fruit is grown for the production of wine or where fruits are ripening for table purposes on isolated vines growing in badly infested districts of Honolulu. Excellent bunches of grapes are picked within a few feet of badly infested peaches.



A HOST FRUIT OF THE MEDITERRANEAN FRUIT FLY.

FIG. 1.—A large winged kamani tree (*Terminalia catappa*) with a 6-foot man standing beneath for comparison. The fruits of this species are badly infested and, because they ripen and fall in large or small numbers during the entire year, greatly interfere with successful clean-culture work. FIG. 2.—The nuts are from 2 to 2.5 inches long; the fruit-fly larvæ feed only on the thin pulp covering the nut. (Original.)

LIFE HISTORY AND DESCRIPTION.

THE EGG.

DESCRIPTION.

The eggs (figs. 3–6) are glistening white, about 0.945 mm. long, elongate elliptical, and often more convex on the dorsal side.

DURATION OF EGG STAGE.

Martelli gives the duration of the egg stages at Portici, Italy, as 2 days in August and from 4 to 5 days in October. Newman states that in Western Australia eggs hatch in from 2 to 4 days during summer and in from 14 to 19 days during winter. Mally, in South Africa, found the egg stage to be from 2 to 4 days in midsummer. Other data have been published but give no additional information and, being unaccompanied by temperature records, may be omitted. Newman appears to be the only investigator who has made an effort to secure data for the winter period.

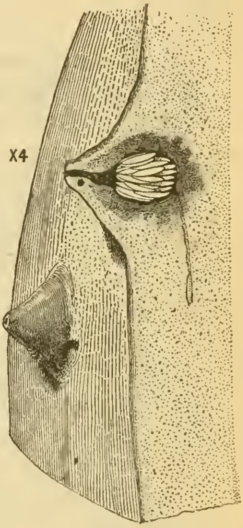


FIG. 5.—Section of grapefruit rind, showing two egg cavities, one in cross section. Drawing made one week after fruit was picked. Note conical elevation about the egg cavities left by the withering of the rind; also the thickened walls of the egg cavity and the single larval channel in the rag. (Authors' illustration.)

In Honolulu, or littoral Hawaii in general, the length of the egg stage is very short, and agrees with the minimum periods indicated by writers in other countries. In Table XII are recorded data on observations on 4,066 eggs secured at Honolulu, which indicate that the largest number of eggs hatch in from 2 to 3 days after deposition during the hottest weather. At a mean temperature of 79° F., 208 eggs hatched in from 49 to 51 hours after deposition, while 79 hatched in from 52 to 53 hours, and 3 in from 53 to 54 hours. At a mean temperature of 78.9° F., 134 eggs hatched between 49 and 54 hours after deposition, although 12 eggs deposited at the same time did not hatch until from 66 to 72 hours later. At a mean of 71° F., 695 eggs hatched within 72 hours, while 3 hatched in from 120 to 144 hours, or about 6 days after deposition. At a mean of 70.5° F., 437 eggs hatched in from 77 to 83 hours after deposition and 227 after a period of 83 to 91 hours had elapsed. At a mean of 69.8° F.,

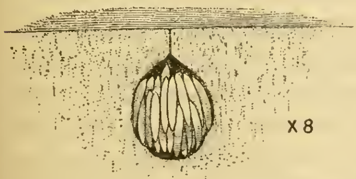


FIG. 6.—Cross section of peach, showing egg cavity of the Mediterranean fruit fly with eggs. Drawing made directly after oviposition. (Authors' illustration.)

356 eggs hatched after a period of from 84 to 91 hours, 216 after 91 to 92 hours, 127 after 92 to 93 hours, 33 after 93 to 94 hours, 8 after 94 to 95 hours, 5 after 95 to 96 hours, and 3 after 104 to 106 hours. Eighty-eight eggs hatched between 4 and 4.5 days after deposition at a mean temperature of 68.7° F.

TABLE XII.—*Duration of the egg stage of the Mediterranean fruit fly at Honolulu under normal conditions.*

Number of eggs under observation.	Eggs deposited.	Eggs hatched.	Average mean temperature.
			°*F.*
88	Jan. 21–22, 4 p. m. to 10 a. m	Jan. 26, 6 a. m. to 3 p. m	68.7
350	Mar. 9, 10 a. m. to 12 m	Mar. 12–13, 4.30 p. m. to 8 a. m	70.2
102	Mar. 27, a. m. to 1 p. m	Mar. 30, a. m	71
695	.....do	Mar. 30, a. m., to Mar. 31, a. m	71
28	.....do	Mar. 31–Apr. 1, 9 a. m. to 8 a. m	71
3	.....do	Apr. 1, 2 p. m. to 8 a. m	71
176	May 12–13, 3 p. m. to 12 m	May 15, a. m	75
243	.....do	May 15–16, 2 p. m. to 8 a. m	75
44	June 18, 1.30 to 3.30 p. m	June 20–21, 6 p. m. to 8 a. m	77
90	June 19, 10 a. m. to 1 p. m	June 21–22, 6 p. m. to 8 a. m	76.6
77	June 20, 9 a. m. to 4 p. m	June 22–23, 6 p. m. to 7.30 a. m	77
63	June 24, 1.30 to 4.30 p. m	June 26–27, 4.30 p. m. to 6 a. m	77
134	July 15, 3.30 to 4.30 p. m	July 17, 4.30 to 6 p. m	78.9
128	.....do	July 17, 6 to 8 p. m	78.9
20	.....do	July 17, 9 to 10 p. m	78.9
12	.....do	July 18, 10 a. m. to 4 p. m	78.3
208	Aug. 24, 10.30 to 11.30 a. m	Aug. 26, 11.30 a. m. to 1 p. m	79
79	.....do	Aug. 26, 1 to 2 p. m	79
3	.....do	Aug. 26, 2 to 3 p. m	79
47	Sept. 9, 3 to 4 p. m	Sept. 11, 3 to 9 p. m	79.7
101	Nov. 13–14, 4 p. m. to 9 a. m	Nov. 16, 2 to 6 a. m	75.5
10	.....do	Nov. 16, 6 to 11 a. m	75.5
356	Dec. 15, 11 a. m to 1 p. m	Dec. 18–19, 11 p. m. to 6 a. m	69.8
216	.....do	Dec. 19, 6 to 7 a. m	69.8
127	.....do	Dec. 19, 7 to 8 a. m	69.8
33	.....do	Dec. 19, 8 to 9 a. m	69.8
8	.....do	Dec. 19, 10 to 11 a. m	69.8
5	.....do	Dec. 19, 11 a. m to 12 m	69.8
3	.....do	Dec. 19, 8 to 10 p. m	69.8
437	Dec. 16, 11 a. m. to 1 p. m	Dec. 19, 4 to 10 p. m	76.5
227	.....do	Dec. 19–20, 10 p. m. to 6 a. m	70
4,066			

While eggs hatch in from 2 to 6 days after deposition in any fruit-growing section in the Hawaiian Islands, they may require a much longer period for development under colder weather conditions. In the course of experimental work, the writers have secured data showing that under varying conditions of temperature the duration of the egg stage may be extended to at least 25 days. In Table XIII data of special interest, as indicating how dependent embryonic development is upon temperature, are recorded.

All of 131 eggs one day old when placed at Puulehua, where the temperature ranged between 39° and 89° F., with a mean of about 52° F., were still unhatched after 16 days at Puulehua, after which they were taken to Kealakekua, where they hatched the following day, or when 18 days old.

Twenty-three eggs deposited in apples at Kealakekua, Kona, Hawaii, at about 1,100 feet elevation, on February 9–10, 1915, and taken on February 11 to the summit of Hualalai, 8,250 feet elevation, where the temperature ranged between 30° and 62° F., with a mean of 46° F. for the period of observation, were still unhatched after exposure for 14 days. After 14 days on Hualalai eggs were carried in their host to Kealakekua and there hatched on February 27, or 17 to 18 days after they were deposited.

Additional information on the duration of the egg stage has been secured under cold-storage conditions. Eggs hatch in refrigeration at temperatures ranging between 54° and 62° F. Five eggs deposited August 15–16 and placed in a refrigerator at 54° to 57° F. on August 16 hatched within the refrigerator on August 23, or in from 7 to 8 days after deposition; 19 eggs deposited at the same time were removed unhatched on August 23 but hatched on the 24th, outside the refrigerator, or 8 or 9 days after deposition. A single egg also deposited on August 15–16 and similarly placed at 54° to 57° F. had not hatched by August 30, when it was removed to normal temperature, where it hatched within 24 hours, or 14 or 15 days after deposition. Thirty-two eggs deposited on July 15–16 and placed on July 16 at 58° to 62° F. hatched in the refrigerator on July 20 or in from 4 to 5 days after being deposited, whereas 6 eggs of the same lot were unhatched in storage on July 24, after which they were removed to normal temperatures where they hatched on July 25, or 7 to 8 days after deposition. Eggs deposited on February 11–12, and placed at 48° to 52° F. on February 12, failed to hatch at this temperature, but 20 removed after 14 days hatched within 16 to 17 days after deposition; 11 removed after 19 days hatched within 21 to 22 days after deposition; while 1 removed after 22 days of refrigeration hatched on March 8, or 24 to 25 days after deposition. The examination of a second lot of fruit containing 1,853 eggs, deposited during a 24-hour period before they were placed at a temperature of 48° to 53° F., showed that one egg hatched in storage 18 days after the inward date and after 24 and 27 days of refrigeration 64 and 56 first-instar larvæ had hatched and died in the punctures. Of these 1,853 eggs, 1,014 removed after refrigeration for 18 to 27 days were dead; of 115 removed to normal temperatures after refrigeration for 16 days, 35, 25, and 9 hatched in 17, 18, and 19 days, respectively, after deposition. Eggs deposited during a 4-hour period were placed immediately at 49° to 56° F.; after refrigeration for 21 days, 1 living and 7 recently dead first-instar larvæ and 51 unhatched eggs were found. Of other eggs deposited at the same time but held at normal temperatures for from 44 to 47 hours before being placed in storage, 8, 12, and 48 had hatched after refrigeration for 16, 19, and 21 days. One egg, two days after deposition, was held in storage at a temperature of from 40° to 45° F. for 20 days (June 27 to July 17), when it was removed to normal temperatures where it hatched three days later, or 25 days after deposition. One egg placed in storage at 26° to 30° F. when one day old, and held at this temperature for 7 days, hatched three days after removal, or 11 days after deposition.

TABLE XIII.—*Duration of the egg stage of the Mediterranean fruit fly under low temperature conditions.*

Number of eggs under observation.	Eggs deposited.	Cold-storage dates.		Dates of hatching.	Number of days in storage.	Length of egg stage.	Temperatures.	
		Inward.	Outward.				Range in storage.	Mean outside storage.
							°F.	°F.
10	July 6, 1913	July 7	July 8	July 9	1	3	26–30	78
4	do	do	July 9	July 10	2	4	26–30	78
1	do	do	do	July 12	2	6	26–30	78
2	do	do	July 8	do	1	6	26–30	78
388	Nov. 3, 1914	Nov. 4	Nov. 8	Nov. 10	4	7	26–30	76.5
6	June 30, 1913	July 2	July 8	July 9	6	9	26–30	77
1	Nov. 3, 1914	Nov. 4	Nov. 11	Nov. 14	7	11	26–30	76.5
520	Sept. 25, 1914	Sept. 26	Sept. 28	Sept. 29	2	4	32	77.6
216	do	do	Sept. 30	Oct. 2	4	7	32	77.6
1	do	do	Oct. 5	Oct. 7	9	12	32	77.5
21	Sept. 7, 1914	Sept. 9	Sept. 17	Sept. 19	8	12	33–34	79.5
4	do	do	do	Sept. 21	8	14	33–34	78.9
242	Nov. 16, 1914	Nov. 17	Nov. 25	Nov. 28	8	12	36	69.5
5	do	do	Nov. 27	Dec. 1	10	15	36	70.4
5	July 4, 1913	July 5	July 8	July 9	3	5	33–38	77.2
11	do	do	July 9	July 12	4	8	33–38	77.4
13	do	do	July 16	July 18	11	14	33–38	78.2
1	July 17, 1913	July 18	Aug. 1	Aug. 4	14	18	33–38	78.9
1	June 25, 1913	June 27	June 30	June 30	3	5	38–45	77.8
3	do	do	do	July 2	3	7	38–45	77.6
7	do	do	July 5	July 6	8	11	38–45	77.3
1	do	do	July 8	July 10	11	15	38–45	77.4
6	do	do	July 14	July 15	17	20	38–45	77.7
1	do	do	July 17	July 18	20	23	38–45	77.9
1	do	do	do	July 20	20	25	38–45	77.8
20	Feb. 11–12, 1915	Feb. 12	Feb. 26	Feb. 28	14	16–17	48–53	69.8
11	do	do	Mar. 3	Mar. 15	19	21–22	48–53	70.5
1	do	do	Mar. 6	Mar. 8	22	24–25	48–53	70.6
19	Aug. 15–16, 1914	Aug. 16	Aug. 23	Aug. 24	7	8–9	54–57	79.1
5	do	do	(1)	Aug. 23	7	7–8	54–57	79.1
1	do	do	Aug. 30	Aug. 31	14	14–15	54–57	79.1
32	July 15–16, 1914	July 16	(1)	July 20	4	4–5	59–62	79.5
6	do	do	July 23	July 24	7	7–8	59–62	79.5
172	Sept. 9, 11 a. m. to 2 p. m.	Sept. 9, 3 p. m.	(1)	Sept. 16	7	7	60–64	79.2
23	Feb. 9–10, 1915	[2] Feb. 11	Feb. 25	Feb. 27		17–18	[4] 30–62	69.4
131	Feb. 20, 1915	[3] Feb. 21		Mar. 6		14	[5] 39–89	67.8
1,720								

[1] Fruit not removed. Eggs hatched in storage.
[2] Not placed in cold storage, but exposed to normal tmperatures at summit of Mount Hualalai, 8,200 feet elevation.
[3] Not placed in cold storage, but exposed to normal temperature at Puulehua, about 4,500 feet elevation.
[4] Mean temperature about 46° F.
[5] Mean temperature about 70° F.

These data, together with those recorded in Table XIII, demonstrate the great variation, from a fruit-fly standpoint, in the duration of the egg stage.

THE LARVA.

DESCRIPTION.

A clear idea of the general shape of the larva or maggot of the Mediterranean fruit fly can be gained by reference to text figures 7 and 8, and Plate XIII, figure 1. When first hatched from the egg, the larva is about 1 mm. long but increases in size to from 7–8 mm. long when full grown. Each larva passes through three well-defined instars. While normally white in color, it may appear creamy yellow, pink, or with colorations of red or black, according to the nature of its food, which shows through the semitransparent body walls.

First larval instar (fig. 8).—Length about 1 mm. The first-instar larva is so small that it is seldom observed. Aside from its size, it is most easily distinguished from the succeeding instars by the absence of anterior spiracles. The tracheal system in this instar opens to the exterior only at the posterior spiracles, and consists of two main

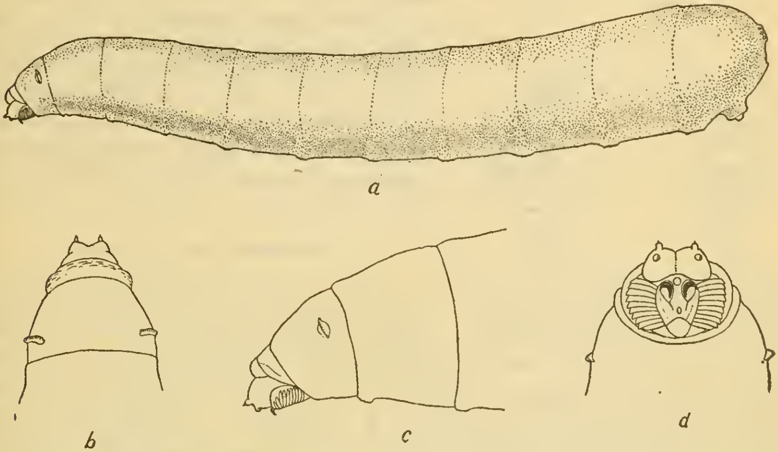


FIG. 7.—Third-instar larva of the Mediterranean fruit fly: *a*, Lateral view of entire larva; *b*, dorsal view of anterior portion; *c*, lateral view of same; *d*, ventral view. (Original.)

trunks extending the full length of the body. The posterior stigmatic plates, the outer edges of which are about 0.061 mm. apart, have two instead of three slits, as illustrated in figure 9, *a*. The mandibles or mouth hooks are not conspicuous and are of the shape indicated in figure 10, *a*.

Second larval instar.—In size the second larval instar is sufficiently large to be distinct from the first instar, but not from undersized third-instar larvæ. It may, however, be easily distinguished from the third instar by the shape of the anterior spiracles

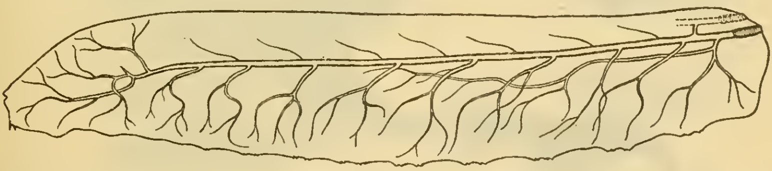


FIG. 8.—First-instar larva of the Mediterranean fruit fly, showing one of the two main tracheal systems opening at the posterior spiracles. (Original.)

(fig. 11, *a*), the mandibles (fig. 10, *b*), and posterior spiracles (fig. 9, *b*). The distance between the outer edges of the stigmal plates is about 0.13 mm.

Third larval instar.—The third-instar larva, which is about 7 to 8 mm. long, may be distinguished when well grown from the two preceding instars by its jumping habit when removed from its host, by the well-defined mandibles or mouth hooks (fig. 10, *c*), and by the prominence of the posterior spiracles. The anterior spiracles possess from 9 to 10 lobes (fig. 11, *b*) and are borne on the second segment as in the preceding stage. The posterior stigmal plates each bear three slits arranged as illustrated and are armed with four batches of delicate inconspicuous hairs (fig. 12).

The dotted lines of figure 12, indicate the general shape of the terminal chambers of the tracheal system. The body is composed of 12 distinct segments, the last of which bears the posterior stigmata upon the upper distal portion and the anus before the center of the venter in the middle of a rounded tubercle (fig. 7, *a*). The head when viewed from above or below is bilobed; each lobe bearing a distinct antennal protuberance; the dorsal and more distal one terminating in a short inconspicuous arista; the more ventral one less antennalike and without a terminal arista (fig. 7, *b*, *c*, *d*). Mouth hooks sheathed (fig. 7, *d*). Body armed only with inconspicuous spicules arranged in broken bands forming fusiform areas on the venter of the 4–12 segments; portions of the head and an irregular rind upon the anterior portion of segments 2 and 3 armed with similar spicules. There are no distinct fusiform lateral areas of spicules.

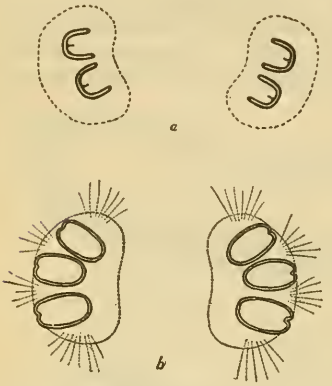


Fig. 9.—Posterior spiracles of larvæ of the Mediterranean fruit fly: *a*, First-instar larvæ; *b*, second-instar larvæ. (Original.)

DURATION OF LARVA STAGE.

The duration of the larval instars has been variously given by many writers. Martelli found that larval development at Portici, Italy, required from 9 to 10 days during summer, 11 to 12 days during early autumn, and 15 days during November and December. Severin found that larvæ matured in the winged kamani (*Terminalia catappa*) in from 8 to 17 days. Newman states that from 14 to 16 days during summer and 25 to 45 days during winter in Western Australia are the periods required for development. Other data might be given but they add nothing new to the foregoing information. No records previously published except by the writers have been accompanied by temperature data, hence they can not be satisfactorily interpreted.

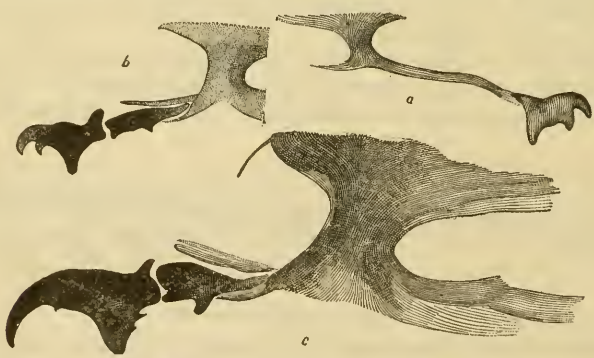


Fig. 10.—Mandibles of larva of the Mediterranean fruit fly: *a*, First-instar larva; *b*, second-instar larva; *c*, third-instar larva. (Original.)

In Honolulu larval life [1] is completed within 5.1 to 26 days. The data in Table XIV indicate the variation found in the developmental

[1] Back, E. A., and Pemberton, C. E. Life history of the Mediterranean fruit fly from the standpoint of parasite introduction. Jour. Agr. Research, v. 3, no. 5, 1915, p. 363–374.

period. During June when the mean temperature was 77.6° F. two larvæ completed their entire development in 5.1 and 5.5 days, respectively, but they were transferred daily to fresh pieces of ripe papaya and thus were surrounded by the best of conditions. However, other larvæ equally well cared for and similarly fed and transferred did not reach maturity and pupate until 6.7, 12, and 14 days. Ordinarily larvæ complete their development in from 6 to 10 days at an average mean temperature of 76° to 79° F.

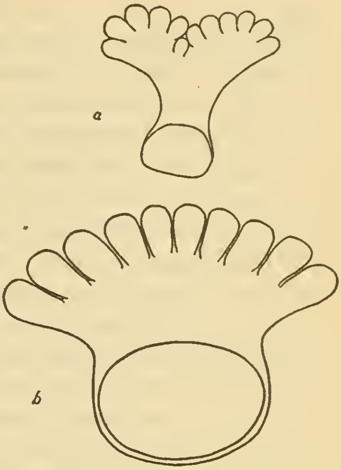


FIG. 11.—Anterior spiracles of larva of the Mediterranean fruit fly: *a*, Second-instar larva; *b*, third-instar larva. (Original.)

During the cooler part of the year, when the average mean temperature is about 69.6° F., larvæ transferred daily to fresh ripe papaya did not become fully grown until 9, 10, and 14 days old, while at about the same temperature 18, 12, and 1 larvæ required 10, 11, and 15 days for development in a green half-grown peach. At a mean temperature of about 70° to 71° F., 12, 14, 3, 1, and 1 larvæ pupated 14, 16, 19, 22, and 26 days, respectively, after hatching. Larvæ hatching during December 25 to

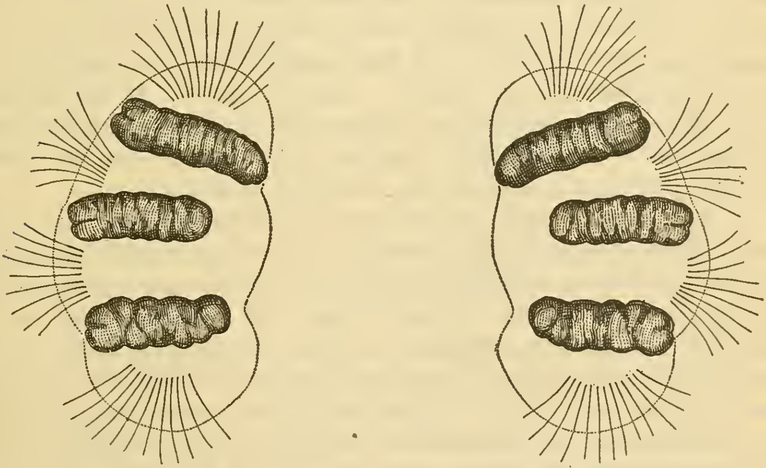


FIG. 12.—Posterior spiracles of third-instar larva of the Mediterranean fuit fly. (Original.)

26 in a very firm textured apple required 19, 25, and 35 days for development when the mean temperature averaged about 68° F. Four and 3 larvæ became full grown in 6 and 7 days, respectively, in a ripe soft peach at a mean temperature of from 77° to 78° F., whereas

under identical conditions 6 larvæ required 9.5 days in a ripe but still hard peach.

All data secured by the writers indicate that during the warmest portions of the year larval development progresses rapidly and fairly uniformly. With the approach of colder weather larval life is not only lengthened but subject to considerable and entirely unexplainable variation, even with larvæ hatching at the same time in the same fruit, especially if the host fruit happens not to be in the best condition to support larval life. The three larvæ requiring 19, 25, and 35 days for development in a very hard apple furnish a good example. In Table XV are recorded data showing the ability of cold weather greatly to increase larval life.

The data in Table XIV indicate that under favorable conditions as regards temperature and host the first larval instar is passed in from 26 to 48 hours, the second in 24 to 48 hours, and the third in 48 to 265 hours. It is profitable, therefore, to compare these and other data in Table XIV with the data of Table XV.

At an elevation of 8,250 feet, on the summit of Mauna Hualalai, Hawaii, where the temperature ranged between 27° and 73° F., but averaged for the period about 48° F., the first larval instar was found to range up to 57 days. Eighty-nine larvæ in apples were found still in the first instar after 30 days, 3 after 46 days, 7 after 54 days, and 1 after exposure for 57 days. Thirty-three larvæ in the second instar placed on Hualalai were still in this instar after 32 days, and 1 after 54 days. At Strawberry, Hawaii, a ranch station, where the temperature ranged from 39° to 79° F., 49 first-instar larvæ were found still in this instar after 27 days and 19 after 29 days. At Kealakekua, where the temperature ranged between 58° and 80° F., with a mean of about 68° F., three larvæ in apples required 28, 58, and 74 days to become fully grown and to leave the fruit to pupate.

In cold storage under what may be called artificial conditions, larval life may be variously prolonged. Thus one second-instar larva and one third-instar larva in peaches placed in storage at temperatures varying from 40° to 45° F. were found still in those instars at the end of 29 and 45 days, respectively, while check larvæ at the laboratory in the same species of host fruit completed their entire development in from 6 to 9 days. Three third-instar larvæ in apples placed in a refrigerator at temperatures varying from 48° to 52° F. were still active after 60 days and one was alive after 79 days. In a second refrigerator at temperatures ranging from 58° to 62° F., larvæ completed their development and pupated in 24, 36, 40, 44, and 50 days.

TABLE XIV.—*Duration of the larva stage of the Mediterranean fruit fly in Honolulu.*

Host fruit.	Number of specimens under observation.	Larva hatched.	Molted into second stage.	Molted into third stage.	Larva pupated.	Length of larva stage.	Temperature of developmental stage. Range.	Mean.
							°F.	°F.
Papaya....	3	Dec. 19, 9 to 10 a. m.	Dec. 21, 10 a. m. to 2 p. m.	Dec. 23, 4 p. m.	Dec. 28, 12 m.	9	61–78	69.6
Do.......	1	.....do........	.....do........	Dec. 23, 10 a. m. to 2 p. m.	Dec. 28, 4 a. m.	9	61–78	69.6
Do.......	2	.....do........	.....do........	Dec. 23, 4 to 10 p. m.	.....do........	9	61–78	69.6
Do.......	1	.....do........	.....do........	Dec. 23, 10 a. m. to 2 p. m.	Dec. 28, 12 m.	9	61–78	69.6
Do.......	1	.....do........	.....do........	Dec. 23, 4 to 10 p. m.	Dec. 28, 10 a. m.	9	61–78	69.6
Do.......	1	.....do........	.....do........	Dec. 23, 2.45 p. m.	Dec. 28, 11 a. m.	9	61–78	69.6
Do.......	1	.....do........	.....do........	Dec. 23, 4 to 10 p. m.	.....do........	9	61–78	69.6
Do.......	1	.....do........	.....do........	.....do........	Dec. 28, 12 m.	9	61–78	69.6
Do.......	1	.....do........	.....do........	.....do........	Dec. 29, 4 a. m.	10	61–78	69.6
Do.......	1	.....do........	Dec. 21, 2 to 4 p. m.	Dec. 23–24, 10 p. m. to 6 a. m.	Dec. 29, 3 p. m.	10	61–78	69.6
Do.......	1	.....do........	Dec. 21, 4 to 9 p. m.	.....do........	Dec. 29, 12 m.	10	61–78	69.6
Do.......	1	.....do........	Dec. 21, 10 a. m. to 2 p. m.	.....do........	Jan. 2, 1 p. m.	14	61–79	70
Do.......	2	June 12, a. m.	June 14, a. m.	June 16, a. m.	June 18, a. m.	5.1	71–83	77.6
Do.......	3	June 12, p. m.	.....do........	.....do........	.....do........	5.5	71–83	77.6
Do.......	1	June 19, a. m.	June 20–21, 4 p. m. to 8 a. m.	June 21–22, 4 p. m. to 8 a. m.	July 1, a. m..	12	72–83	77
Do.......	1	.....do........	.....do........	.....do........	July 3, a. m..	14	72–83	77.1
Do.......	1	.....do........	June 20, 1 to 4 p. m.	.....do........	June 25, p. m.	6	72–83	76.4
Do.......	17	.....do........	June 20–26, 4 p. m. to 8 a. m.	.....do........	.....do........	6	72–83	76.4
Do.......	2	.....do........	.....do........	.....do........	June 26, a. m.	7	72–83	76.6
Green peach	2	June 22........			July 2........	10	72–83	77.2
Do.......	7	.....do........			July 3........	11	72–83	77.2
Ripe hard peach.	6	June 26........			July 6........	9.5	72–83	77.4
Ripe soft peach.	4	.....do........			July 2........	6	72–83	77.8
Do.......	3	.....do........			July 3........	7	72–83	77.7
Green peach	18	Mar. 31........			Apr. 10........	10	61–77	69.6
Do.......	12	.....do........			Apr. 11........	11	61–77	69.8
Do.......	1	.....do........			Apr. 15........	15	61–82	71.0
Commercial lemon.	12	Mar. 13........			Mar. 27........	14	57–80	70.2
Do.......	14	.....do........			Mar. 29........	16	57–80	70.3
Do.......	3	.....do........			Apr. 1........	19	57–80	70.5
Do.......	1	.....do........			Apr. 4........	22	57–80	70.4
Do.......	1	.....do........			Apr. 8........	26	57–80	70.4
Apple......	1	Dec. 25, 1914..			Jan. 13, 1915..	19	67–81	71.6
Do.......	1	.....do........			Jan. 19, 1915..	25	67–81	71.1
Do.......	1	Dec. 26, 1914..			Jan. 30, 1915.	35	67–81	70

The data recorded in Table XV only indicate the possibilities in lengthening larval life. Except at temperatures from 58° to 62° F., none of the larvæ would have been able to mature had they been kept at the temperatures recorded. The data merely bring out the fact that upon the examination of the host fruits after so many days the larvæ recorded were found alive. A very large percentage of the larvæ within the same fruits were dead, but this mortality, due to exposure to cold for prolonged periods, is discussed elsewhere.

TABLE XV.—*Showing ability of low temperatures to lengthen larval life of the Mediterranean fruit fly.*[1]

Number of specimens under observation.	Instar.	Locality.	Temperature.		Length of instar or instars.
			Range.	Mean.	
			°F.	°F.	Days.
1	2	Cold storage	33-38	....	15
2	3		33-38	....	17
1	2		40-45	....	29
1	3		40-45	....	45
12	3	Refrigerator No. 1	48-54	50	24
1	3		48-54	50	36
3	3		48-54	50	60
1	3		48-54	50	79
1	1,2,3	Refrigerator No. 3	58-62	60	24
1	1,2,3		58-62	60	36
1	1,2,3		58-62	60	40
1	1,2,3		58-62	60	44
3	1,2,3		58-62	60	50
1	1,2,3	Kealakekua	58-80	69	28
1	1,2,3		58-80	69	58
1	1,2,3		58-80	69	74
41	1	Hualalai	27-73	48	12
1	1		27-73	48	26
89	1		27-73	48	30
1	1		27-73	48	45
3	1		27-73	48	46
7	1		27-73	48	54
1	1		27-73	48	57
33	2		27-73	48	32
1	2		27-73	48	54
133	1	Puulehua	....	....	54
1	1		....	....	17
14	1		....	....	36
49	1	Strawberry	39-79	....	27
19	1		39-79	....	29

[1] In securing these data apples were used as host fruits in all but the first four records for cold storage, for which peaches were used.

In spite of the ability of cold temperatures to prolong larval life greatly beyond the usual period required for development during warm Hawaiian weather, it is interesting to record that individual larvæ whose development has been slowed down, or even practically suspended, will continue their development normally when returned to warmer temperatures. Thus one second-instar larva which had been held for 54 days on Hualalai on being taken to Kealakekua on March 26, where the mean temperature was about 66.8° F., and then to Honolulu on March 29, molted into the third instar on March 30. A second larva placed on Hualalai just after hatching and kept there until March 17, or 45 days, on being taken to Kealakekua molted into the second instar on March 21, into the third instar on March 24, pupated March 28, was taken to Honolulu on March 29, and emerged as an adult on April 10.

PUPA.

DESCRIPTION OF PUPARIUM.

Puparium (Fig. 13, *a*, *b*, *c*).—Puparium elliptical in general shape; a little more convex on the dorsal side; length about 4 to 4.5 mm. The size and color of puparium vary and depend upon the amount and nature of larval food. Puparia formed by larvæ feeding on coffee cherries dull white; the usual color light or dark testaceous. There are only 11 distinct segments, the first being composed of the first and second larval segments, and therefore bearing indications of the mouth opening and anterior spiracles of latter; last segment likewise bearing the remains of anal and stigmatal openings of larva

DURATION OF PUPA STAGE.

Mally has found in South Africa, at Grahamstown, that the duration of the pupa stage may be as long as 35 days in a rearing box kept "at the ordinary seasonal temperature." Martelli states that in southern Italy the pupa stage varies with the progress of the season; that it may be from 10 to 11 days during summer (August), 18 to 20 days during autumn (October), or 30 or more days during the winter. Newman found in Western Australia the periods to be from 12 to 14 days during summer and 25 to 50 days during winter. Nearly all writers have offered data on the duration of this stage, but, unaccompanied by temperature or humidity records as they are, they add nothing new to the foregoing information.

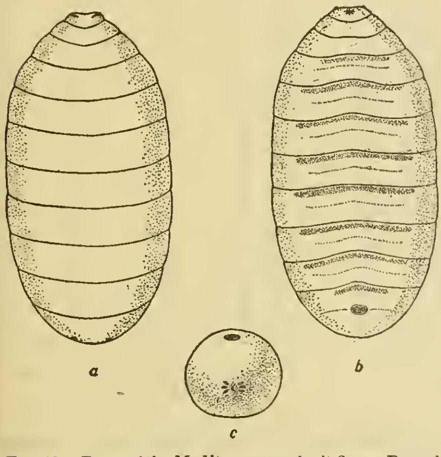


FIG. 13.—Pupa of the Mediterranean fruit fly: *a*, Dorsal view; *b*, ventral view; *c*, posterior end, showing anal scar and spiracles. (Original.)

In a previous paper the writers give data, accompanied by temperature records, on observations including about 2,000 pupæ developing under Honolulu conditions. From these it would appear that the minimum length of pupal life is about 6 days when the mean temperatures range between about 76° and 79° F. During the warmest Honolulu weather the largest proportion of any lot of pupæ require from 9 to 11 days before yielding adults. Thus at a mean of about 76° F. 5, 14, 101, 160, 7, and 3 pupæ yielded adults 6, 9, 10, 11, 12, and 13 days, respectively, after the formation of the puparium.

The pupa stage may be increased to at least 19 days when the daily means drop to about 69° to 71° F. The data in Table XVI covering observations on 7,000 pupæ are given in corroboration of this statement. At a mean temperature of about 66.8° F., pupæ required from 20 to 28 days to complete their development at Kealakekua, Kona, Hawaii. In Table XVI are given a large number of records covering the coldest portions of the year in the usual fruit-growing sections of the islands. These records, together with many others on file, given in Table XXV in connection with parasite work, indicate that there occurs no dormancy among pupæ at these temperatures. In other words, while development is considerably retarded, there is no yielding of adults by a few pupæ while others yield adults after a period of dormancy for several months as has been found to be true of the parasites *Diachasma tryoni* and *Diachasma fullawayi.*

TABLE XVI.—*Duration of the pupa stage of the Mediterranean fruit fly in Hawaii (7,000 pupæ).*

Date of pupation.	Date of emergence.	Number adults emerging.	Length pupa stage.	Mean temperature.	Date of pupation.	Date of emergence.	Number adults emerging.	Length pupa stage.	Mean temperature.
			Days.	° F.				Days.	° F.
Feb. 3 [1]	Feb. 23	9	20	66.8	Dec. 18–20	Jan. 1	167	12–14	72.9
Do	Feb. 24	3	21	66.8	Do	Jan. 2	466	13–15	72.8
Do	Feb. 25	82	22	66.8	Do	Jan. 3	152	14–16	72.7
Do	Feb. 26	69	23	66.8	Do	Jan. 4	3	15–17	72.5
Do	Feb. 27	1	24	66.8	Do	Jan. 5	2	16–18	72.4
Do	Mar. 3	1	28	66.8	Do	Jan. 6	1	17–19	72.3
Feb. 27 [2]	Mar. 13	7	14	70.4	Dec. 22–29	Jan. 4	27	11–13	72.4
Do	Mar. 14	40	15	70.3	Do	Jan. 5	528	12–14	72.3
Do	Mar. 15	15	16	70.4	Do	Jan. 6	541	13–15	72.1
Do	Mar. 17	17	18	70.9	Do	Jan. 7	804	14–15	71.9
Do	Mar. 18	3	19	70.9	Do	Jan. 8	57	15–17	71.5
Dec. 1	Dec. 12	8	11	73.2	Do	Jan. 10	1	17–19	71.3
Do	Dec. 13	279	12	73.1	June 10	June 16	5	6	76.4
Do	Dec. 14	269	13	73.1	Do	June 19	14	9	76.3
Do	Dec. 15	116	14	73.2	Do	June 20	101	10	76.3
Do	Dec. 16	29	15	73.4	Do	June 21	160	11	76.2
Dec. 8–10	Dec. 19	2	9–11	73	Do	June 22	7	12	76.1
Do	Dec. 20	1	10–12	73	Do	June 23	3	13	76.3
Do	Dec. 21	98	11–13	73.1	July 13	July 20	1	7	79.2
Do	Dec. 22	478	12–14	73.2	Do	July 21	3	8	79.2
Do	Dec. 23	189	13–15	73.2	Do	July 22	39	9	79.2
Do	Dec. 24	2	14–16	73.2	Do	July 23	43	10	79.1
Dec. 16–18	Dec. 27	24	9–11	73.3	Do	July 24	3	11	79
Do	Dec. 28	96	10–12	73.1	June 8	July 16	2	8	76.2
Do	Dec. 29	654	11–13	73.2	Do	July 17	15	9	76.2
Do	Dec. 30	712	12–14	73.2	Do	July 18	28	10	76.1
Do	Dec. 31	72	13–15	73.2	Do	July 19	53	11	76.1
Dec. 18–20	Dec. 29	4	9–11	73.2	Do	July 20	53	12	76.1
Do	Dec. 30	41	10–12	73.1	Do	July 21	5	13	76.1
Do	Dec. 31	415	11–13	73					

[1] At Kealakekua, Kona, Hawaii. [2] At Honolulu.

While it is probable that the duration of the pupa stage in any fruit-growing section in Hawaii is never more than 20 to 28 days (average mean temperature 66.8° F.) the writers have shown that it may be much longer under cooler conditions. As a contribution toward what the maximum duration may be, the following data are presented.

In a glass refrigerator of the usual type for displaying fruits and vegetables, which was kept at a temperature of from 58 to 62° F., the duration of pupal life was found to range between 23 and 38 days when the pupæ were placed within storage within half a day after the formation of the puparium. Thus 4, 12, 9, 16, 44, 367, 1,217, 159, 25, 11, 5, 1, and 1 adults emerged in the refrigerator after 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, and 38 days, respectively, of refrigeration. One pupa 8 days old was held in storage at from 40 to 45° F. for 27 days and yielded an adult 2 days after removal to normal temperature, or 37 days after pupation. One hundred pupæ placed in a refrigerator when one-half day old and held continuously at a temperature of from 54 to 57° F. for 24 days, on removal to normal temperatures produced 2, 27, and 5 adults in 4, 5, and 6 days, respectively, after removal, or 28, 29, and 30 days after pupation. A second lot of 100 pupæ, placed at 54 to 57° F. when 1 day old, produced 3, 16, 9, 3, 2, 4, and 2 adults in refrigeration in 31, 32, 33, 34, 35, 36, 37, and 38 days, respectively, after pupation.

Pupæ formed by larvæ pupating within a refrigerator held at 52 to 56° F. yielded 2 and 1 adults within storage after refrigeration for 38 and 52 days, respectively. Out of 39,500 pupæ held in like manner at from 49 to 51° F. only 1, 2, 2, 3, and 1 pupæ yielded adults in storage after 20, 23, 44, 46, and 47 days, respectively, of refrigeration. These 9 pupæ yielding adults were 5 days old when placed in cool storage; hence they were 25, 28, 49, 51, and 52 days old when they yielded adults. One 3-day-old pupa held at an even temperature of 32° F. for 9 days, on removal to normal temperature produced an adult on November 14, 10 days later, or when 23 days old. Two 1-day-old pupæ refrigerated for 19 days and then removed to normal temperatures yielded adults in 29 and 30 days, respectively, after pupation. Investigators working in countries where the temperature falls for short periods to or slightly below freezing are referred for other data to a previous paper by the writers [1] in which are given data on the effects of 32°, 33° to 34°, 33° to 36°, 28° to 40°, 38° to 40°, 40° to 45°, 49° to 51°, 52° to 56°, and 54° to 57° F. upon 173,318 pupæ.

During January–March, 1915, the writers secured data on the effect upon the duration of pupal life of out-of-door temperatures at elevations of about 3,700 feet at Strawberry, at 5,000 feet at Puulehua, and on Mauna Hualalai at 8,250 feet. Pupæ formed at Honolulu on January 31, shipped to Kealakekua on February 9–10, and placed at Strawberry on February 11, were found to have produced 1, 72, 392, 4, and 6 adults on February 24, 25, 27, and March 3. The temperature at Strawberry for these periods ranged from 42 to 69° F. with a mean of about 56° F. Other pupæ formed at Honolulu on February 8, shipped to Kealakekua February 9–10, and placed at Strawberry February 11, were found to have yielded 3, 307, 503, and 13 adults on March 11, 17, 20, and 25, respectively. Pupæ formed at Honolulu on February 6, shipped to Kealakekua February 9–10, placed at Puulekua February 11, where the temperature between February 11 and March 26 ranged from 38° F. to 72° F., with a mean of 53° to 54° F., were found to have yielded 2, 10, 108, 126, and 13 adults on March 9, 17, 20, 25, and 26, respectively. The pupæ yielding adults on March 26 were 48 days old. Other pupæ formed at Kealakekua on January 26 and taken the same day to Puulehua yielded no adults before March 25, when they were removed to Kealakekua, where the temperature ranged during March 24–27 between 60 and 84° F. At Kealakekua 2 and 16 pupæ yielded adults on March 26 and 27, respectively, *or when 59 and 60 days old.* Pupæ formed at Honolulu February 12, shipped to Kealakekua February 17, and placed at Puulehua February 24, were found to have yielded 4, 96, and 1 adults on March 9, 17, and 20, respectively. Pupæ formed at Kealakekua January 27, taken to Hualalai January 31, and removed to Kealakekua March 26, produced no adults, and on examination appeared not to have been able actually to pupate. The temperature on Hualalai for the period ranged between 31° and 70° F. Pupæ formed at Honolulu February 9, placed on Hualalai February 12, and removed to Kealakekua March 2, yielded 10 adults between March 17 and 20, or when 36 to 39 days of age. Pupæ formed at Honolulu February 5 and taken to Hualalai February 11 were found to have yielded 51 adults between March 23 and 26. On March 26 they were removed to Kealakekua, where 17 and 2 yielded adults on March 27 and 28, respectively, or 50 and 51 days after pupation. Of this lot of pupæ, 1,820 did not survive the Hualalai temperature. Pupæ formed at Honolulu February 7, placed on Hualalai February 12, and removed to Kealakekua March 26, yielded 52 adults on March 31, or 52 days after pupation, but 1,506 failed to survive.

The data presented are of particular interest in bringing out the ability of pupæ to survive various climatic conditions apt to be experienced in countries harboring fruit flies. It will be noted that 60 days is the longest period obtained by the writers for pupal development.

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[1] Back, E. A., and Pemberton, C. E. Effect of cold-storage temperatures upon the pupae of the Mediterranean fruit fly. Jour. Agr. Research, v. 6, no. 7, 1916, p. 251–260.

THE ADULT.

DESCRIPTION.

A general idea of the relative size and coloration of the adult of the Mediterranean fruit fly may be gained by an examination of text figures 1 and 14, and Plate I figure 1, and Plate VIII figure 3. The adults vary from 3.5 to 5 mm. in length. The description by Froggatt is as follows:

Size 4 to 5 mm. about the size of an average house-fly, but looking somewhat smaller when dead, because the body shrinks up beneath the thorax. General color, ocherous yellow, lighter on the sides of thorax and basal joints of the antennae. The eyes of the usual reddish purple tint, with a blackish blotch in the center of the forehead, from which spring two stout black bristles, a fine fringe of similar bristles round the

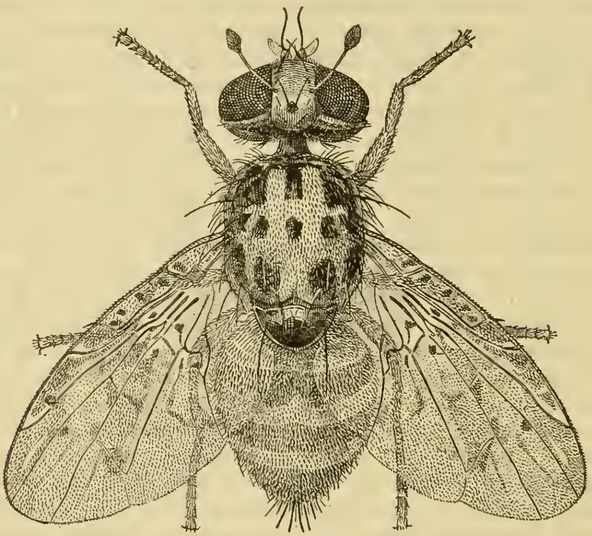

FIG. 14.—The Mediterranean fruit fly (*Ceratitis capitata*): Adult male. Greatly enlarged. (Original.)

hind margin of the head, with some coarser ones curving round in front of the head between the eyes. The thickened basal joints of the antennae pale yellow, the terminal segments black to the tips. The dorsal surface of the thorax convex, raised, and broadly rounded with the scutellum, the ground color creamy white to yellow, marbled with shiny black blotches forming an irregular mosaic pattern, the lighter portions clothed with very fine white bristles. These light-colored bristles more lightly scattered over the dark areas, and the whole bearing large stout black bristles thickest on the black surface. In many of the pictures of this insect the black areas are drawn as if they were projecting bosses or knobs, but this is incorrect; the whole forms a regular rounded surface.

The wings are broad, semiopaque, with the extreme base blotched with ocherous or brownish yellow, with the rest of the basal area curiously marked with black, forming dark lines of the radiating nervures, with dark lines and spots between; beyond this is a broad irregular transverse ocherous band, slightly lined with black, blotched at the extremity; another similar shaped and colored blotch runs along inside but not in contact with the costal nervure, also blotched towards the extremity in the angular space. Between these bands is another shorter black band running parallel with the first transverse band.

The oval abdomen is clothed on the upper surface with fine, scattered black bristles, and has two rather broad transverse silvery white bands on the basal half of the body. The male differs from the female in being furnished with a pair of stalked appendages standing out in front of the head in a line with the front margin of the eyes, the extremities of which filaments are produced in spatulate appendages, black, finely striated, and diamond shaped.

The living fly is an active little creature, running about over the foliage or fruit on the trees, with its wings drooping down on the sides of the body. When disturbed it has a short flight, seldom flying more than a few yards at the most, and it often returns to the same spot.

EMERGENCE.

The adults of the Mediterranean fruit fly emerge in largest numbers early in the morning during the warmer portions of the Hawaiian year, but more scatteringly during the cooler portions. During the summer the larger proportion of adults emerge between 5 and 8 a. m. On December 31, 1914, when the temperature ranged from 66° to 78° F. and the mean relative humidity was 72 per cent, 55, 58, 125, and 16 adults emerged between the hours 6 to 8 a. m., 8 to 10 a. m., 10 a. m. to 1 p. m., and 1 to 4 p. m., respectively. On January 2, 1915, when the temperature ranged from 68° to 76° F. and the relative humidity was 58 per cent, 141, 159, 28, and 12 adults emerged between the hours 6 and 8 a. m., 8 and 10 a. m., 10 a. m. and 12 m., and 12 m. and 2 p. m., respectively.

The adult when issuing from the puparium seems invariably to cause a fairly regular split from the cephalic tip of the puparium straight back along each side to near the middle of the fourth segment and then upward over the dorsum, following a line fairly well in the center of the fourth segment, and often splitting entirely around the center of this segment. Thus the upper half of the first three segments and the upper anterior half of the fourth segment of the puparium are usually broken away by the pressure of the ptilinum, and often the entire anterior portion of the puparium is broken off back to the middle of the fourth segment during the emergence of the adult.

Once out of the puparium, the adult forces its way to the surface of the soil or out of other confinement, with the aid of the ptilinum. Before the natural coloration appears and while the chitin of the body is still pliable, the adults are able to force their way through incredibly small openings or cracks, through loose cotton stoppers, and sometimes beneath rubber bands. Often the united efforts of a few adults will force an exit in places from which single adults unaided could not escape.

DURATION OF ADULT LIFE.

WITHOUT FOOD.

If adults have no opportunity to feed after emergence they die within 4 days. Ninety adults issuing on March 15 and kept under starvation conditions were all dead by the end of the third day. On the second and third days, 68 and 22 adults, respectively, died, and at 9 a. m. on the third day only 4 were barely alive, and these were dead by 5 p. m. Of 50 adults emerging on March 14, 1, 48, and 1 died on 1, 3, and 4 days later. French states that he found that adults died in Australia within 4 days if kept without food. The writers have handled many thousands of adults during the past 3 years and have never had flies live longer.

If given only water, life is slightly prolonged. Of 300 adults emerging on October 17, 250 had died by the end of the second day, while the remaining 50 were dead by the end of the third day. Of 42 adults emerging May 20, 12, 25, 4, and 1 died after 2, 3, 4, and 5 days.

WITH FOOD.

In 1899, Lounsbury in South Africa confined adult flies in a wire cage out of doors to determine the length of adult life. By the use of apples as food, 1 female out of an original number of 60 was kept alive from March 30 to July 19, or about 16 weeks. French states that adults live to be 25 days old during March in Victoria, Australia. Gurney found that in confinement adults live from a few days to three weeks. Newman states that he has found that flies live usually 6 weeks, but when no suitable food is available for oviposition, they may live from 8 to 10 weeks. Later the same writer gives the length of adult life in western Australia as ranging from 28 to 40 days in summer and from 28 to 65 days in winter.

The writers have found that even when given the best of care many adults die very young. In every lot confined in jars about 50 per cent may be expected to die during the first 2 months. The early death of many flies does not seem to be caused always by overcrowding, for frequently single adults given the best of care in separate jars die at all ages from 1 to 2 days on. The greatest interest in connection with the longevity of adults must center in the minority that live for long periods.

In a preliminary paper the writers record 1 adult that lived from December 31, 1913, to May 11, 1914, or 131 days, and others emerging on February 28, 1914, that were still alive on August 1, or 5 months after emergence. Additional data have since been secured. One female emerging on the same date died on September 4, or at the age of 5 months; another female emerging on the same date died on September 30. About 500 adults emerging on June 28 were placed in large glass jars; on August 14 only 40 were still living. The last two of these 40 adults died on October 2, at the age of 97 days. The rate of mortality for the 40 is as follows: On August 14, 28; September 4, 9, 12, 15, 17, 19, 21, 23, 24, and October 2 and 3, there were alive 40, 30, 17, 12, 11, 10, 10, 7, 5, 4, 2, 2, 0 adults. Two hundred and twenty-five adults which emerged on December 31, 1913, were placed in a large glass jar and fed daily. The last fly which died lived to be 131 days old. A general idea of the mortality of these flies may be had from the fact that when examinations were made on March 9, 13, 18, 22, 26, 31, April 1, 6, 13, 15, 17, 18, 19, 26, 27, 28, 30, May 1, 3, 5, 7, 9, 10, and 11, there were living 225, 214, 202, 171, 139, 94, 59, 47, 36, 32, 28, 25, 18, 16, 13, 12, 11, 9, 7, 5, 4, 3, 2, and 1, respectively.

One female emerging on February 28, 1914, died on August 3; two males emerging on the same date died on October 5 (7 months, 5 days), and on October 15 (7 months, 15 days), respectively. One female emerging on March 3, 1914, died on September 8 (6 months, 3 days). The death rate among 95 males and 58 females, the only survivors on July 3 of a lot of 800 adults emerging on February 28, 1914, is given in Table XVII. The oldest fly lived 230 days, or 7 months and 10 days.

Table XVII.—*Data on longevity of adults of the Mediterranean fruit fly emerging on Feb. 28, 1914, which had survived until July 3.*

Date.	Adults still alive.		Date.	Adults still alive.		Date.	Adults still alive.	
	Male.	Female.		Male.	Female.		Male.	Female.
July 3	95	58	Aug. 15	19	2	Sept. 11	5	0
July 9	80	38	Aug. 18	14	2	Sept. 12	3	0
July 13	58	25	Aug. 22	11	2	Sept. 18	2	0
July 18	48	20	Aug. 25	10	2	Oct. 5	1	0
July 25	41	12	Aug. 29	9	2	Oct. 16	1	0
Aug. 1	35	6	Sept. 1	8	2	Oct. 17	0	0
Aug. 8	26	3	Sept. 8	6	0			

One female, emerging May 22, 1914, and kept continuously in a well-lighted glass refrigerator at 58°–62° F., lived until April 1, 1915, 315 days, or 10 months and 10 days. The rate of mortality of the flies still living of this lot on December 4 is recorded in Table XVIII.

Table XVIII.—*Data on longevity of adults of the Mediterranean fruit fly emerging on May 22, 1914, and kept in a glass refrigerator at 58°–62° F.*

Date.	Adults still alive.		Date.	Adults still alive.		Date.	Adults still alive.	
	Male.	Female.		Male.	Female.		Male.	Female.
Dec. 4	43	62	Jan. 5	17	32	Feb. 4	4	10
Dec. 15	31	55	Jan. 8	16	30	Feb. 10	1	6
Dec. 19	26	51	Jan. 13	14	28	Feb. 13	1	4
Dec. 23	24	48	Jan. 18	14	24	Feb. 17	1	3
Dec. 26	24	43	Jan. 26	9	20	Mar. 6	0	2
Dec. 29	24	37	Jan. 29	7	16	Apr. 1	0	1
Jan. 2	21	36	Feb. 1	4	12	Apr. 2	0	0

Of the adults kept at 58–62° F. the majority died after the sixth month of life, being caught by the wings in moisture gathering on the sides of the containing jars. Under more favorable conditions the writers believe that adult life may be extended to cover a full year.

MATING.

Martelli first described the mating process. He says that when the male desires to copulate he "seeks to attract the female by curving up and raising the last abdominal segment, then bending the extremity, swelling it to the form of a pinhead, while the venter is drawn back half its length and the abdomen is puffed out laterally, etc." These evidences of sexual stimulation have been verified by the writers. In addition to the dorso-ventral contraction and lateral expansion of the abdomen, the male may vibrate his wings rapidly for periods of 10 to 15 seconds, at the same time that he extrudes the rectum (?) to form the white bulbous structure which is held almost perpendicularly over the tip of the abdomen.

Often the female will move toward the head of the male from the opposite direction to be greeted when within an inch of the male by a violent fanning of the wings of the latter. When the female is within half an inch of the male, the male moves forward in a halting fashion until the heads of each almost touch, when the male springs forward and endeavors to clasp the female, but is often repulsed. One pair were observed to go through this process five times in 30 minutes before copulation occurred. Having once placed himself, the male makes vigorous efforts to bring the tip of his abdomen in contact with the tip of the ovipositor, trying at the same time to grasp the very tip of the ovipositor with the strong chitinized claspers situated on the seventh sternite. The female need only extend the tip of the ovipositor to but a very slight degree from within the last abdominal segment and the male will quickly clasp it and draw it out to a considerable length. The operation of clasping the ovipositor and drawing it out usually takes from 10 to 20 seconds. At the end of 15 to 20 seconds, or even sooner, the long narrow ribbonlike chitinized copulatory organ begins slowly to uncoil from its position. It extends up over either the left or right side of the sixth and seventh abdominal segments and makes one, or sometimes two, loops about the distal fourth with the tip resting under the posterior edge of the fifth tergite. From this position the penis uncoils until the tip comes to a position almost between the claspers, where it enters the vaginal opening.

Both males and females mate frequently throughout life. One male was observed mating between 3 and 4 p. m., February 3, 1915, and between 11 a. m. and 12 m. and 1 and 3 p. m., February 4. Males observed mating on February 4, 1914, mated again on February 5, 6, 7, and 8. Individual females kept for oviposition records have been observed to mate frequently with the males accompanying them. Such data indicate that mating is frequent. Such frequent mating is, however, unnecessary for egg fertility, inasmuch as one female emerging August 12 and observed mating September 8 (probably not for the first time) was isolated on that date and placed with fruit. She deposited 139 eggs between September 16 and November 25, and all hatched normally. Records on file show that the eggs deposited by 12 other females isolated after mating on September 8 hatched normally.

SEXUAL SMELL.

The writers have found that the males of the Mediterranean fruit fly emit a peculiar odor by which they may be recognized. A segregation of the sexes proved that the females do not emit this odor, or at least that no odor can be detected. That given off by the males is very evident and, while difficult of description, resembles somewhat that of stale mucus. No odor can be detected until the males begin courting the females, but from that time on it is sufficiently strong so that during calm weather a person sitting as far as 4 feet from jars containing adults is able to state whether the flies within are *Ceratitis capitata* or *Bactrocera cucurbitae*. The latter species emits no odor. The writers have attempted to make use of the odor emitted by the males to trap the females in the laboratory and field, but in no instance were females attracted to jars containing males, although the odor eminating from the latter was pronounced. Males kept at 58° to 62° F. neither courted the females nor gave off their characteristic odor.

AGE AT WHICH MATING AND OVIPOSITION BEGIN.

Adults, upon emerging from the pupa, must feed for several days before they show evidences of sexual activities or begin oviposition. Berlese, in Italy in 1905, published the first data bearing on this subject. He states that the female does not oviposit until 10 to 12 days after emergence. Severin states that in Honolulu no fully developed eggs were present in the ovaries of 3 females 8 days after emergence. Although from the eighth day on he made daily dissections of 3 females, he found no mature eggs until the fourteenth day, with the exception of a few in the ovaries of a single female 11 days after emergence. The most careful observations appear to have been made by Martelli, who states that females do not oviposit until from 4 to 7 days after emergence during summer, or 10 to 12 days during the autumn. Aside from Martelli's general reference to the season, no writer has published along with his statements data on temperatures, which the writers have found to be an important factor.

The age at which the first eggs are deposited varies with the temperature. During late July and early August, 1913, when the daily temperatures at Honolulu ranged between 74° and 86° F., with a mean for the period of 79° to 80° F., males began to show sexual activity within 3 days, while mating and egg laying took place within 4 to 5 days. In securing infestation of fruits it was found that while few eggs were deposited within 4 to 5 days after emergence, it was not until 7 to 10 days after emergence that any lot of females seemed to reach their full egg-laying capacity. These observations are based on work with over 20,000 adults. During the period May 21 to 28, 1913, when the daily temperatures ranged between 69° and 82° F., with a mean temperature for the period of 76° F., and with a mean relative humidity about 66 per cent, many females were not observed mating until 7 to 9 days.

During the period December 14 to 24, 1914, when the weather was unusually cool for Honolulu, with the daily temperatures ranging between 61° and 78° F. (a mean for the period about 69.8° F.), and the mean relative humidity about 72 per cent, 1 male was observed giving the usual evidences of sexual maturity 8 days after emergence, and several others after 9 days. The first eggs, 3 in number, from about 150 females were obtained 8 days after emergence, while 10 and 38 eggs, respectively, were secured after 9 and 10 days. Adults emerging on January 3, 1916, did not contain well-developed eggs until 10 days later, as shown by daily dissections. The temperature during this period ranged between 60° and 75° F., with a mean of 68.7° F. The general process of egg formation as it takes place in the egg tubes is shown in figures 15 and 16, representing the development of the eggs 1, 3, 8, and 10 days after emergence.

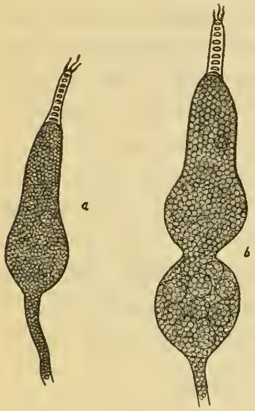

FIG. 15.—Egg tubes of female Mediterranean fruit fly: *a*, At time of emergence; *b*, 3-5 days after emergence; during January, 1916. (Original.)

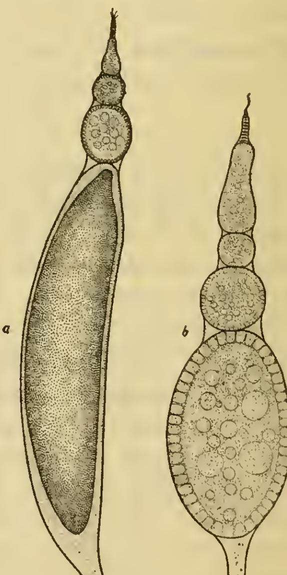

FIG. 16.—Egg tubes of female Mediterranean fruit fly: *a*, Development after 10 days; *b*, after 8 days; during January, 1916, at Honolulu. (Original.)

PORTIONS OF PLANT SELECTED.

Adults of the Mediterranean fruit fly oviposit only in the fruit of the host. The female appears to have no preference for any particular area in the epidermis of very soft fruits, such as the strawberry guava, mock orange, coffee, peach, sapota, or eugenia, as egg punctures are to be found on all portions of the fruit. But even in these fruits adults oviposit most freely in prematurely ripened areas. In the case of other fruits, the epidermis of which the fly has greater difficulty in puncturing, females are apt to take advantage of previously made abrasions caused by thorn pricks, fungus attack, old egg punctures, etc. Thus the females often deposit eggs in large numbers only in a single break made by the mango weevil or fungus attack on the skin of a large choice Indian mango. In cotton bolls eggs appear to be deposited only in breaks made by the larvæ of the pink bollworm (*Pectinophora gossypiella* Saund.). In some varieties of avocados eggs are most often deposited, in certain localities, in the cracks made by fungi, although other varieties with thinner skins are freely oviposited in at all points.

DAILY RATE OF OVIPOSITION.

No data on the daily rate of oviposition have ever been published except by the writers. In a preliminary paper they record the daily rate of oviposition during the first 18 weeks after emergence. In Table XIX these data have been continued to include the oviposition records of the same females throughout life. For the daily rate of oviposition for old females see Table XX. It will be noted that there is considerable variation in the frequency of oviposition among those specimens seemingly less hardy, but that those living longest, and apparently the most normal, oviposited with great regularity a few eggs nearly every day. The 9 females, the oviposition records of which appear in Table XIX, emerged on April 4, 1914, and were placed with fruit April 14.

The best record in Table XIX is that of fly No. 5, which oviposited with great regularity from April 16 to September 2. During life this fly oviposited on 106 days of 153. Of the 47 days on which she laid no eggs, 20 were the first 20 days of her life and 13 of these 20 were evidently consumed in reaching sexual maturity. Hence, after she began ovipositing with regularity she failed to oviposit on only 27 of 133 days. Fly No. 8, which lived 147 days, oviposited on 80 days. Fly No. 9, which lived 65 days, deposited only 3 eggs on May 4 and 5. Had it been possible to secure oviposition data on many individuals it is probable that the record of fly No. 5 would have been exceeded and that many gradations would have been secured between the records of flies Nos. 5 and 9. This is probable, inasmuch as other females recorded under the subject of longevity lived to be over 10 months old, and there is no evidence that oviposition necessarily ceases before death. It is not likely, however, that the actual number of eggs deposited on individual days would have been found greater than those recorded in Table XIX. This actual number of eggs deposited on individual days was found to vary from 1 to 22. The average numbers of eggs deposited by the 9 females, taking into consideration only the days on which oviposition occurred, are 6.6, 3.1, 5.7, 7.5, 5.9, 6.1, 5.9, 5.2, and 1.5. Flies Nos. 5 and 8, which lived the longest, deposited, respectively, an average of 5.9 and 5.2 eggs.

TABLE XIX.—*Daily rate of oviposition of the Mediterranean fruit fly in 1914.*

[Females emerged on Apr. 4, 1914, and were placed with fruit on Apr. 14, 1914.]

Date of oviposition.[1]	Number of eggs deposited.								
	Fly No. 1.	Fly No. 2.	Fly No. 3.	Fly No. 4.	Fly No. 5.	Fly No. 6.	Fly No. 7.	Fly No. 8.	Fly No. 9.
Apr. 16	3	0	0	0	0	0	0	0	0
17 to 20	14	7	11	24	19	14	0	0	0
20 to 22	0	0	0	0	0	0	5	0	0
22 to 24	0	0	7	0	0	0	0	2	0
25 to 26	0	7	13	0	13	0	14	0	0
27 to 28	11	8	6	0	16	15	0	20	0
29 to 30	0	0	0	0	17	16	23	0	0
May 1 to 3	0	0	0	3	25	19	19	13	0
4 to 5	25	0	0	0	12	0	0	0	3
6	2	0	0	0	0	0	9	0	0
7	8	0	0	0	19	12	2	8	0
8	9	0	0	0	9	3	1	0	0
9	9	0	0	0	7	7	4	3	0
10	0	0	0	2	0	6	2	0	0
11	17	0	0	0	7	3	0	0	0
12	4	4	0	0	10	4	8	0	0
13	14	0	0	0	7	8	11	0	0
14	8	4	0	0	10	2	9	0	0
15	8	0	0	5	5	6	6	1	0
16	5	0	0	0	11	6	8	14	0
17	8	0	0	0	0	4	3	0	0
18	2	0	0	13	3	3	3	8	0
19	3	4	0	0	5	0	3	9	0
20	2	(2)	0	0	6	9	3	11	0
21	0	....	0	0	2	2	9	8	0
22	5	....	0	0	5	0	1	9	0
23	10	....	20	4	6	10	4	4	0
24	4	....	2	18	3	1	4	7	0
25	5	....	19	4	2	3	3	3	0
26	0	....	2	9	6	2	0	3	0
27	0	....	6	15	9	0	5	8	0
28	0	....	(3)	3	3	5	3	4	0
29	9	....	....	9	3	14	7	7	0
30	1	....	....	12	0	8	10	4	0
31	0	....	....	9	6	13	21	8	0
June 1	0	....	....	8	3	10	5	5	0
2	0	....	....	13	5	6	14	6	0
3	0	....	....	9	12	4	7	2	0
4	5	....	....	3	3	4	3	9	0
5	0	....	....	7	8	0	6	5	0
6	0	....	....	4	6	0	4	3	0
7	0	....	....	18	11	15	15	12	0
8	0	....	....	0	0	1	0	1	0
9	0	....	....	15	7	8	12	9	0
10	0	....	....	6	5	11	1	2	(4)
11	0	....	....	12	7	11	9	6	....
12	(4)	....	....	0	6	3	3	6	....
13	....	....	....	7	2	4	7	0	....
14	....	....	....	4	2	7	1	8	....
15	....	....	....	0	7	2	7	2	....
16	....	....	....	0	9	4	5	3	....
17	....	....	....	0	6	5	0	2	....
18	....	....	....	0	0	0	0	3	....
19	....	....	....	0	6	3	3	8	....
20	....	....	....	4	4	12	0	4	....
21	....	....	....	10	10	7	0	9	....
22	....	....	....	4	0	0	0	5	....
23	....	....	....	10	2	(5)	9	0	....
24	....	....	....	0	9	....	12	12	....
25	....	....	....	0	7	....	3	3	....
26	....	....	....	0	9	....	0	2	....
27	....	....	....	5	6	....	7	4	....
28	....	....	....	16	14	....	12	4	....
29	....	....	....	6	5	....	0	2	....
30	....	....	....	0	2	....	6	2	....
July 1	....	....	....	3	7	....	2	8	....
2	....	....	....	10	0	....	7	1	....
3	....	....	....	3	0	....	3	1	....
4	....	....	....	7	4	....	8	6	....
5	....	....	....	0	6	....	2	3	....
6	....	....	....	0	3	....	4	0	....

[1] Dates on which none of the flies oviposited are omitted from the table.
[2] Died on this date; 30 eggs present in abdomen.
[3] Escaped on this date.
[4] Died on this date.
[5] Died on this date; 15 eggs present in abdomen.

TABLE XIX.—*Daily rate of oviposition of the Mediterranean fruit fly in 1914*—Contd.

Date of oviposition.	Number of eggs deposited.								
	Fly No. 1.	Fly No. 2.	Fly No. 3.	Fly No. 4.	Fly No. 5.	Fly No. 6.	Fly No. 7.	Fly No. 8.	Fly No. 9.
July 7				0	2		0	0	
8				(1)	3		9	2	
9					6		3	4	
10					2		3	4	
11					0		8	2	
12					9		4	0	
13					2		0	0	
14					5		3	5	
15					2		0	3	
17					4		0	0	
19					0		0	4	
20					0		2	0	
22					14		0	0	
23					0		3	0	
24					11		4	0	
25					7		7	0	
26					11		0	3	
27					5		0	0	
28					2		3	0	
29					3		0	0	
30					2		0	2	
31					6		0	6	
Aug. 1					3		0	4	
2					7		(2)	4	
3					4			2	
5					5			5	
6					2			5	
7					3			0	
8					0			2	
9					4			0	
10					6			0	
13					14			14	
14					3			3	
15					0			13	
16					4			0	
17					3			6	
18					5			0	
19					2			0	
21					4			0	
25					3			0	
27					3			0	
28					6			0	
29					3			0	
30					0			(3)	
Sept. 2					3				
4					(4)				
Total	191	34	86	314	622	312	426	405	3

1 Died on this date; 16 eggs present in abdomen.
2 Died on this date; no eggs in abdomen.
3 Died on this date; 2 eggs in abdomen.
4 Died on this date; 3 eggs in abdomen.

ABILITY OF FEMALES TO BEGIN OVIPOSITING REGULARLY AFTER A PERIOD OF SEVERAL MONTHS DURING WHICH HOST FRUITS WERE NOT AVAILABLE.

Females which have been kept in confinement without an opportunity to oviposit in host fruits will begin actively ovipositing when such fruits are made available. Thus, females emerging on February 28, 1914, were kept in glass jars until about 4 months old, when, on June 28, they were placed with fruits and a record kept of the eggs deposited. These data secured from 6 females show that for the days on which they oviposited they laid an average of 8.1, 4.6, 0, 6.3, 4, and 7.2 eggs. These averages compare favorably with the averages for females given an opportunity to oviposit from the time they were sexually mature until death. Fly No. 1, with its average of 8.1 eggs, deposited 22 eggs on July 26, or when it was

148 days old, and this is the largest number of eggs ever obtained by the writers during one day from any female. The flies of Table XX oviposited on the sides of their containing jars during the period up to the time they were given fruits in which to deposit eggs, but not in a normal manner.

TABLE XX.—*Daily rate of oviposition of the Mediterranean fruit fly.*

[Females emerged on February 28, 1914; hence were 4 months old on June 28, 1914. Given an opportunity to oviposit on fruit for first time on July 1.]

Date.[1]	Number of eggs deposited.						Date.[1]	Number of eggs deposited.					
	Fly No. 1.	Fly No. 2.	Fly No. 3.	Fly No. 4.	Fly No. 5.	Fly No. 6.		Fly No. 1.	Fly No. 2.	Fly No. 3.	Fly No. 4.	Fly No. 5.	Fly No. 6.
1914.							1914.						
July 1....	0	0	0	0	6	0	July 19....	6	2	......	0	0	......
2....	9	0	0	0	2	0	20....	0	5	......	4	0	......
3....	0	0	0	0	4	0	21....	5	2	......	6	0	......
4....	10	4	0	0	0	6	22....	0	8	......	7	0	......
5....	4	0	0	0	0	0	23....	0	2	......	0	0	......
6....	5	6	0	4	0	0	24....	2	6	......	13	([4])	......
7....	0	0	0	0	0	12	25....	6	2	......	0	......	......
8....	10	6	0	0	0	6	26....	22	1	......	0	......	......
9....	0	4	0	9	0	13	27....	9	2	......	0	......	......
10....	15	6	0	3	0	2	28....	9	0	......	5	......	......
11....	5	2	0	0	0	4	29....	6	7	......	0	......	......
13....	12	7	([2])	5	0	0	30....	0	5	......	0	......	......
14....	2	0	......	5	0	([3])	Aug. 1....	0	([5])	......	0	......	......
15....	7	9	......	0	0	......	2....	0	......	......	0	......	......
16....	0	8	......	0	0	......	3....	([6])	......	......	([2])	......	......
17....	13	3	......	11	0	......							
18....	5	0	......	4	0	......	Total..	162	97	0	76	12	43

[1] Dates on which none of the flies oviposited are omitted from the table.
[2] Died on this date; no eggs in abdomen.
[3] Died on this date; 11 eggs in abdomen.
[4] Died on this date; 5 eggs in abdomen.
[5] Died on this date.
[6] Died on this date; 4 eggs in abdomen.

One female emerging March 3, 1914, was isolated from fruits until August 29, or for 5 months and 26 days. When placed with fruit on August 29 she deposited 4, 5, 11, 14, 9, and 9 eggs on August 31, September 3, 4, 5, 6, and 7, or an average of 8.7 eggs for each day on which she oviposited. She deposited 11, 14, 9, and 9 eggs, respectively, on the first 4 days of the seventh month of her life, but died on the fifth day.

NUMBER OF EGGS DEPOSITED BY SINGLE FEMALES.

No attempts have been made by previous writers to determine the egg-laying capacity of the female. In 1906 Fuller assumed as a basis for data on multiplication that each female deposited 50 eggs at one time. Silvestri, after becoming familiar with the work of the writers while in Honolulu, stated that the total number of eggs deposited is not less than 300. In general, entomologists invariably have used the number of eggs found in the body as a basis for computing the egg-laying capacity.

In Table XIX the only data obtained by the writers on this subject show that the total number of eggs deposited by a single female may be as high as 625. Fly No. 5 deposited 622 eggs and held 3 well-formed eggs in her oviducts at death. Fly No. 9, on the other hand, deposited only 3 eggs during her life. The writers believe that hardy females may deposit as many as 800 eggs, or even more, under favorable conditions. Fly No. 5, which deposited 622 eggs, lived only 153 days, while other females have oviposited for periods covering more than 10 months and might be expected to deposit more eggs. As noted above, one female deposited 11, 14, 9, and 9 eggs during the first 4 days of the seventh month of her life.

NUMBER OF EGGS DEPOSITED AT ONE TIME.

During the period from January 23 to 27, 1914, when the temperatures during the heat of the day ranged between 74° and 76° F., 15 females were observed to oviposit in apples. The time required from the instant the females started ovipositing until the ovipositor was withdrawn varied from 2 to 5 minutes, with an average of 3.8 minutes. Each puncture was found to contain from 1 to 4 eggs, and averaged 2.4 eggs.

During the warmer period of the year, on April 13, 1914, when the temperature averaged about 82° F., 8 females consumed from 2.5 to 4.5 minutes in completing the process of oviposition in apples, and deposited from 3 to 9 eggs, or an average of 5.4 eggs in each puncture.

NUMBER OF EGGS DEPOSITED IN A SINGLE EGG CAVITY.

Females oviposit repeatedly in egg cavities or punctures in table fruits, especially in those fruits in which they have difficulty in making egg chambers. Thus while females, as already noted, deposit normally only from 3 to 9 eggs in a puncture in apples at one time, cavities in apples left with females from 3 p. m. until the following morning contained from 42 to 106 eggs. As many as 300 eggs have been taken from one egg cavity in the rind of grapefruit, 129 from a cavity in a lemon, and 926 from a cavity in a mango. (Pl. XIII, fig. 3.) Observations indicate that after depositing a few eggs the females feed and move about only to return in many instances to the same spot to continue ovipositing. Frequently newly laid eggs can be found in punctures in citrus fruits in which several batches of eggs already have been hatched. Bearing in mind that only from 1 to 9 eggs are usually deposited in an egg cavity at one time, the data in Table XI will prove interesting.

OVIPOSITION BY VIRGIN FEMALES.

Females confined in jars immediately after emergence and given no opportunity to mate will deposit eggs, but none of the eggs will hatch. On September 10, 1913, 500 newly emerged virgin females were placed in a jar and began ovipositing in a normal manner on September 16, or after 6 days. One hundred and twenty-eight eggs deposited September 16 did not hatch. The temperature during this period varied between 71 and 84° F., with a mean for the period of 78.5° F., and the relative mean humidity averaged about 66 per cent. Two hundred females emerging November 13, 1914, were confined without males and began ovipositing November 23, or after 10 days. During this period the temperature ranged between 65 and 80° F., with a mean of 74.6° F.; the relative humidity, averaging 69.2 per cent, ranged between 52 and 85 per cent. Although no daily oviposition records of these females were kept, 450 eggs deposited by them in apples on 17 different occasions when they were given an opportunity to oviposit between November 13 and March 4-5 failed to hatch. In three other experiments not one of 2,264 eggs deposited by virgin females hatched.

Virgin females which have been depositing eggs that failed to hatch may mate later and deposit fertile eggs. Thus 200 virgins emerging on March 13, 1915, oviposited quite regularly until May 14, when males were placed in the jar with them. Previous to May 14 all eggs deposited had failed to hatch. On May 16, 11 eggs were deposited; of these all hatched but 2.

INFLUENCE OF WEATHER CONDITIONS ON ADULT ACTIVITIES.

No satisfactory data on this subject can be secured out of doors in the Hawaiian Islands, as the colder temperatures which seriously affect adult activities are not to be had except at higher altitudes, where the fly is not to be found. At the Volcano House, Hawaii, at about 4,000 feet elevation, where the November mean is about 60° F. and the daily range is between 45° and 72° F., adults in jars were inactive during the early mornings and late afternoons. During the warmer period of the day adults became active and oviposited in apples hung in their jars after the temperature reached 61° F. At Honolulu, at a temperature of 65° to 67° F., 27 eggs were deposited in peaches by about 40 females, and 40 eggs by a lot of 60 females. At higher temperatures many more eggs would have been deposited under otherwise similar conditions. Adults in jars were noted to mate as usual on March 17, when the temperature was 69° F. On March 18, 9 a. m., at 67° F., adults endeavored to oviposit in apples, but did not seem to succeed in puncturing the skin. A female emerging on August 12, 1914, was placed in a large glass refrigerator, the temperature of which averaged 61° F., but varied for the period between 58° and 62° F. She was accompanied by males and deposited 3 and 6 eggs on September 12 and 20, respectively, but died on September 25. This fly was replaced by another of like age, which deposited 9, 5, 8, 4, and 6 eggs, respectively, on September 26, 27, 28, 29, and October 2.

At a mean temperature of about 78° F., adults may deposit eggs during the night, but deposition during this portion of the day has been found most unusual. In the laboratory and out of doors adults feed and oviposit at all times of the day during the warmer months. Lounsbury has stated that in South Africa adults seek shelter beneath dried leaves, etc., in rearing cages during the colder weather, and Compere has observed adults active on orange trees in Spain during the warm hours of a day following freezing night temperatures.

LENGTH OF LIFE CYCLE.

During the warmest Hawaiian weather, when the mean temperatures average about 79.5° F., the egg, larva, and pupa stages may be completed in as few as 13 or as many as 33 days, according to the individual and its host. At this season large numbers pass through the immature stages in from 18 to 20 days. As the length of the adult life has been found to vary from a few days to 230 and 315 days, it is evident that the life cycle may be as long as 11 months when the fly passes its immature stages during the warmest portions of the year. At an average mean temperature of about 68° F., which is the coolest mean found by the writers where host fruits were readily available for study, the immature stages required from 40 to 69 days. Data already discussed indicate the difficulty in stating just what variations there may be in the length of the life cycle in still cooler climates. Thus the egg stage has been increased from 2 to 24 or 25 days by the application for 22 days of a temperature of from 48° to 53° F. A third-stage larva survived a temperature of 48° to 54° F. for 79 days, while another larva remained in the first instar 57 days at an out-of-door temperature ranging from 27° to 73° F., with a mean of about 48° F. The fruit fly has been held in the pupa stage at an out-of-door temperature ranging between 38° and 72° F., with a mean of about 53° to 54° F. for about 2 months. At Kealakekua, where the temperature ranged between 58° and 80° F., with a mean of about 68° F., 3 larvæ in very firm apples required 28, 58, and 74 days to become fully mature and leave the fruit to pupate. Add to the 74 days required for larval maturity 4 days for the egg stage and 20 days for the pupa stage, and one has a cycle for these stages of 98 days, or over 3 months. A very conservative estimate for the possible length of the immature stages, or a period sufficiently long to outlast the coldest seasons of semitropical regions, is 3 to 4 months.

SEASONAL HISTORY.

In littoral Hawaii there may be as many as 15 or 16 generations of the Mediterranean fruit fly each year, provided one considers the length of a generation as extending from the time the eggs are deposited until the female of the next generation begins to oviposit. With such an understanding a generation at Honolulu may require under the most favorable conditions as few as 17 days during the warmest weather, or as few as 31 days during the coolest winter weather. As the females are capable of living long periods and of depositing small batches of eggs almost daily, the generations become hopelessly confused. In those portions of the islands where the winter monthly means drop to about 68° F., as in the Kona district of Hawaii at about 1,300 feet elevation, there may be not more than 10 to 12 generations. The number of generations is naturally less in colder habitats. At Strawberry, a ranch station on Hawaii at about 4,500 feet elevation, there appears to be only a single generation a year, which is evident in the last fruit to ripen on a few peach trees.

As may be expected, adults are abundant at all seasons in the littoral regions of Hawaii where host plants are grown. With the hopeless confusion of generations that exists, there can be no seasonal broods. Instead, adults may be found actively ovipositing every day of the year. That the cooler weather of the winter months does lengthen the life cycle has already been proved. This slowing down of development naturally results in the emergence of fewer adults. This is indicated by the data of Table XXI.

TABLE XXI.—*Seasonal abundance of adult Ceratitis capitata at Honolulu.*

[Average daily catch of 147 kerosene traps for the weeks indicated below, from Apr. 21, 1913, to Aug. 4, 1914. Traps exposed in Punahou district of Honolulu, east of Punahou Street and south of Wilder Avenue.]

Date.	Number.	Date.	Number.	Date.	Number.	Date.	Number.	Date.	Number.
Apr. 26..	279	Aug. 2....	905	Nov. 8....	353	Feb. 13....	58	May 23....	291
May 3...	347	Aug. 9....	937	Nov. 15...	237	Feb. 20....	117	May 30....	259
May 10..	677	Aug. 16...	763	Nov. 22...	137	Feb. 28....	64	June 6.....	389
May 17..	901	Aug. 23...	562	Nov. 29...	132	Mar. 7.....	71	June 13....	729
May 24..	1,738	Aug. 30...	439	Dec. 6.....	219	Mar. 14....	49	June 20....	1,074
May 31..	1,498	Sept. 6....	316	Dec. 13....	324	Mar. 21....	74	June 27....	935
June 7...	1,413	Sept. 13...	219	Dec. 19....	355	Mar. 28....	64	July 4.....	1,676
June 14..	1,047	Sept. 20...	152	Dec. 27....	240	Apr. 4.....	92	July 11....	2,503
June 21..	855	Sept. 27...	141	Jan. 2.....	176	Apr. 11....	123	July 18....	2,002
June 28..	1,084	Oct. 4.....	167	Jan. 9.....	48	Apr. 18....	150	July 25....	1,677
July 5...	769	Oct. 11....	200	Jan. 16....	84	Apr. 25....	124	Aug. 1.....	964
July 12..	723	Oct. 18....	200	Jan. 24....	46	May 2.....	188	Aug. 4.....	523
July 19..	769	Oct. 25....	205	Jan. 31....	51	May 9.....	343		
July 26..	727	Nov. 1....	270	Feb. 7.....	72	May 16....	455		

These data on the number of males captured in 147 traps in an area equal to about four city blocks are taken as indicating the relative abundance of adults in a single year, in a section of Honolulu where many host trees occur. The adults are most numerous during late May, June, and July, and less numerous during January, February, and March. The numerical abundance of adults in Honolulu, where the climate never seriously retards development, is affected more by the numerical abundance of ripening host fruits, which is greatest during the early summer and least during the winter. The fact that there are relatively fewer adults during the winter months is of no practical value to growers of fruit in Hawaii, since the smaller amount of fruit ripening at that season is nearly as badly affected as are the fruits ripening during the summer.

NATURAL CONTROL.

No striking examples of control by natural agencies were evident in Hawaii previous to the introduction of parasites. As indicated below, there are several minor factors of natural control, aside from parasites, but they are of no practical value under Hawaiian conditions. A certain amount of natural mortality occurs among larvæ and pupæ, but it is small under ordinary conditions. It has been suggested that there occurs an unusually high mortality among pupæ formed by larvæ developing in such juicy fruits as the mango, but this has been disproved by experimental work. The high rate of mortality among pupæ derived from mangoes in laboratories is produced by the severe sifting process necessary to separate the pupæ from the wet sand in which they form, or from insanitary conditions.

EXCESSIVE HEAT.

The larvæ within fruits which lie in the direct sunlight after they have fallen are killed in large numbers. Often all the larvæ in the portion of a fruit exposed to the sun will be found dead. During August, 1914, mangoes were exposed to the sun for two days over sand in shallow trays. Examinations later proved the 17 fruits to contain 17 living and 84 dead third-instar larvæ, with 14 larvæ dead on the surface of the fruits. One larva died when partly out of a fruit and 103 succeeded in pupating normally. In 23 other fruits held in the shade as a check there were found 168 living and 9 dead third-instar larvæ, and beneath them 167 pupæ. While every larva in certain of the fruits exposed to the sun was killed, it is evident the many larvæ in the protected portion of the fruit may escape and pupate normally.

PREDACIOUS ENEMIES.

Although Compere reported certain staphylinid beetles in Brazil and forficulids in India attacking larvæ of fruit flies, they seem to be of little value as practical checks. The writers have observed earwigs within decayed areas of fruits infested by *C. capitata* and drosophilid larvæ in Hawaii under conditions which indicated that they were feeding upon fruit-fly larvæ. Earwigs confined in jars within the laboratory were observed to attack and devour well-grown *C. capitata* larvæ. Their numbers, however, are far too small to have any effect upon fruit-fly increase..

The small brown ant (*Pheidole megacephala* Fab.), known also as the Madeira house ant and the harvester ant, unquestionably is an important factor in natural control. This ant, which inhabits most abundantly the littoral regions, is frequently found swarming over and throughout fallen fruits, killing many larvæ as they leave the fruit to pupate. Ants were observed to remove from a fallen ball kamani nut 86 medium sized *C. capitata* larvæ between 11.18 and 11.58 a. m., April 5, 1913. An examination at the end of this period showed that 34 larvæ in a firm portion of the flesh had escaped attack. Within the laboratory this ant has demonstrated its ability to destroy pupæ.

CLIMATIC CONTROL.

There is little opportunity in Hawaii to study the effect of adverse climatic conditions upon the Mediterranean fruit fly. Development appears to progress most rapidly after the Hawaiian temperature means reach 75° or 76° F. At a mean of 68° F. the developmental period is about doubled. A temperature ranging between 58° and 62° F. has no detrimental effect upon the development as shown by the emergence of adults from pupæ held in a well-lighted refrigerator. These emergence data, recorded in Table XXII, and supplemented by four other experiments, indicate that the pupa stage may be increased from 38 to 41 days, or that, at this temperature, the length of development may be increased to three or four times the normal during the warmest weather. Only 9 out of 39,500 pupæ held at a temperature of from 49° to 51° F. yielded adults within refrigeration, while the remainder died. All cold-storage data obtained by the writers indicate that approximately 50° F. is the temperature at which little or no development can take place and below which complete mortality occurs if exposures are continued sufficiently long.

TABLE XXII.—*The effect upon pupal development of the Mediterranean fruit fly of 58° to 62° F.*

Days in storage.	Age of pupæ when placed in storage and number yielding adults.									
	½ day.	1 day.	2 days.	3 days.	4 days.	5 days.	7 days.	8 days.	9 days.	10 days.
1										27
2								11	334	1,290
3								3	949	657
4								20	1,469	28
5							10	135	96	14
6							8	2,066	38	
7						4	36	918	37	
8						2	687	55	2	1
9						10	2,118	13	2	1
10						23	479	4	1	1
11					1	18	43	4		1
12				2	2	604	95		6	
13			6	1	5	930	5		1	
14			4		6	640				
15		1	3		1	773				
16		2	3	4	14	169				
17			5		33	9				
18			15	2	566	53				
19		2	1		1,324	21				
20		4	29	25	381	19				
21			131	319	38	5				
22	1	4	203	1,316	4	3				
23	4	6	399	335	2					
24	12	4	1,477	21	1	1				
25	9	36	1,013	6	1					
26	16	392	158							
27	44	1,515	15	1						
28	367	708	4							
29	1,217	49								
30	159	3								
31	25									
32	11									
33	5									
34	1									
38	1									

This conclusion drawn from cold-storage experiments[1] will be found, the writers believe, to hold true for out-of-door conditions. During January to March, 1914, the writers exposed infested apples on the slopes and summit of the extinct volcano Hualalai, at elevations of about 5,000 and 8,250 feet. At about 5,000 feet elevation, where the temperature ranged from 31° to 64° F., during January, with a mean of about 51° F., the larval development was apparently held at a standstill, although as the minimum temperatures increased with the approach of spring, larvæ were able to more than hold their own. During March, when the daily temperatures ranged from 40° to 70° F., with a mean of about 55° F., development of all stages occurred attended by no unusual mortality. At 8,250 feet elevation, where the minimum temperatures ranged from 27° to 43° F., with the maximums between 42° and 70° F., and a mean for the maximums and minimums of about 48° F., no development took place. Instead, the mortality was very great. As spring approached, the temperatures increased until, during March 20 to 25, they ranged between 38° and 67° F. The result of examinations made of infested apples after indicated periods of exposure are given in Table XXIII.

TABLE XXIII.—*Mortality among eggs and larvæ of the Mediterranean fruit fly in apples exposed on the summit of Hualalai from Jan. 31 until date of removal.*

Fruit removed from mountain.	Date of examination.	Eggs unhatched.	Larvæ.					
			First instar.		Second instar.		Third instar.	
			Alive.	Dead.	Alive.	Dead.	Alive.	Dead.
Feb. 4	Feb. 5	....	221	1	....	....	....	....
Feb. 12	Feb. 15	....	334	20	522	82	33	....
Feb. 17	Feb. 19	5	3	115	97	16	2	....
Feb. 25	Feb. 26	28	27	350	37	434	3	154
Mar. 4	Mar. 6	10	55	481	33	216	....	....
Mar. 17	Mar. 19	2	3	315	....	278	6	500
Mar. 26	Mar. 27	24	1	872	2	56	2	965

These data prove that at the Hualalai temperatures a very few larvæ may survive, although by far the largest percentage are killed. The data given elsewhere (p. 108–111) on the effect of cold storage and freezing temperatures upon the various stages of the fruit fly prove how easily this pest can withstand for short intervals colder temperatures than are likely to occur for long periods in fruit-fly countries. Thus the egg itself has been known to withstand a freezing temperature of from 24° to 30° F. for 7 days and still hatch. These low temperatures, however, produce a very great mortality that has been emphasized by data already published.

That adverse climatic conditions have been a valuable aid in curbing fruit-fly attack is appreciated by entomologists dealing with this

[1] See Journal of Agricultural Research, v. 5, 1916, p. 657–666; v. 6, 1916, p. 251–260.

pest. Newman, in Western Australia, has found that a very large percentage of the pupæ are killed by a cold, wet winter when the ground is frequently flooded. Such conditions so lessen the abundance of the fruit-fly that there are relatively few flies, numerically speaking, to infest the early fruits of the succeeding season. On the other hand, unusually severe outbreaks of the pest in both South Africa and Australia have been attributed to exceptionally dry, mild winters which made it possible for many adults to be present the following spring to start large early summer generations. The successes attributed to clean cultural methods for the eradication of the fruit fly in the apple orchards at Harvey, Western Australia, and possibly in New Zealand and Tasmania, may be due quite as much to the work of adverse climatic conditions. The effect of climate upon fruit-fly development can not be intelligently interpreted, inasmuch as previous writers have not included climatological data with their statements.

PARASITES.

Ceratitis and Dacus Parasites.

Literature contains numerous references to parasites reared from various species of fruit flies. The only parasites discussed at length here are those which have been successfully introduced and give promise of being useful as factors in controlling *Ceratitis capitata.* Of the parasites at present being reared from *Ceratitis capitata* under natural conditions, *Opius humilis* is the only one reared originally from this fruit fly.[1] All other parasites now known to attack *Ceratitis capitata* in the field in Hawaii have adapted themselves to this host. There appears to be no reason why certain others of the parasites already reared from other fruit flies may not be used ultimately in controlling the Mediterranean fruit fly. Silvestri records and discusses the following parasites studied by him:

BRACONIDÆ.

Subfamily Opiinae: *Opius concolor* Szepligeti (ex *Dacus oleae*, Susa, Tunisia), *O. dacicida* Silvestri (ex *Dacus oleae*, Eritrea), *O. lounsburyi* Silvestri (ex *Dacus oleae*, Transvaal), *O. dexter* Silvestri (ex *Dacus longistylus*, Dakar, Senegal), *O. perproximus* Silvestri (ex *Dacus brevistylus* and *Ceratitis giffardi*, Kotonou and Segboroue, Dahomey), *O. perproximus modestior* Silvestri (ex *Ceratitis nigerrima* Aburi, Gold Coast, and Olokemeji, Nigeria), *O. humilis* Silvestri (ex *Ceratitis capitata*, Constantia, Cape Colony), *O. inconsuetus* Silvestri (ex *Ceratitis tritea*, Olokemeji, Nigeria), *O. inquirendus* Silvestri (identity of host unknown, Victoria, Kamerun), *O. africanus* Szepligeti (ex *Dacus oleae*, South Africa and Transvaal), *O. africanus orientalis* Silvestri (ex *Dacus oleae*, Eritrea), *Hedylus giffardii* Silvestri (ex *Ceratitis punctata*, Conakry, French Guinea), *Diachasma fullawayi* Silvestri (ex *Ceratitis giffardi* and *tritea*, Dakar, Senegal, Olokemeji, Nigeria, and Kakoulima, French Guinea), *D. fullawayi robustum* Silvestri (ex *Dacus bipartitus*,

[1] The writers reared a single specimen of a parasite from a *C. capitata* pupa which was identified by D. T. Fullaway as *Spalangia* sp. It seems probable that this was primarily a parasite of some other dipteron, as no other specimens were reared.

Conakry, French Guinea), *D. tryoni* Cameron (ex *Bactrocera tryoni*, New South Wales and Queensland, Australia), *Biosteres caudatus* Szepligeti (ex *Ceratitis giffardi, tritea, nigerrima, anonae, antistictica*, and *Dacus bipartitus* and *brevistylus*, West Africa).

Subfamily Sigalphinae: *Sigalphus daci* Szepligeti (ex *Dacus oleae*, Transvaal).

Subfamily Braconinae: *Bracon celer* Szepligeti (ex *Dacus oleae*, Stellenbosch and Wellington, South Africa).

PROCTOTRUPIDAE.

Subfamily Diapriinae: *Galesus silvestrii* Kieffer (ex *Ceratitis anonae*, Olokemeji, Nigeria; ex *C. nigerrima*, Aburi, Gold Coast; ex *C. giffardi*, Kotonou, Dahomey), *G. silvestri robustior* Silvestri (ex *Ceratitis punctata*, Conakry, French Guinea), *Trichopria capensis* Kieffer (ex *C. capitata*, Constantia, Cape Colony).

CHALCIDIDAE.

Subfamily Chalcidinae: *Dirhinus giffardii* Silvestri (ex *Ceratitis anonae*, Olokemeji, Nigeria), *D. ehrhorni* Silvestri (ex *Ceratitis giffardi*, Olokemeji, Nigeria).

Subfamily Pteromalinae: *Spalangia afra* Silvestri (ex *Ceratitis anonae*, Olokemeji, Nigeria).

Subfamily Eulophinae: *Tetrastichus giffardii* Silvestri (ex *Ceratitis antistictica, giffardi, colae*, and *Dacus bipartitus*, West Africa), *T. oxyurus* Silvestri (ex *Ceratitis tritea*, Olokemeji, Nigeria), *T. giffardianus* Silvestri (ex *Ceratitis giffardi*, Nigeria and Dahomey), *T. dacicida* Silvestri (ex Dacus *bipartitus*, West Africa), *Syntomosphyrum indicum* Silvestri (ex Dacus, India).

In addition to these, Ihering records the following parasites from Brazilian fruit flies: *Eucola* (*Hexamerocera*) *brasiliensis* Ashmead, *Biosteres brasiliensis* Szepligeti, *B. areolatus* Szepligeti, *B.* sp., and *Opiellus trimaculatus.* Gowdey states that he reared a single chalcidid parasite from *C. capitata* pupæ in one out of many attempts to secure parasites.

To the foregoing list of fruit-fly parasites should be added *Pachycrepoideus dubius*, introduced by D. T. Fullaway at Honolulu from the Philippines during the early part of 1914. Although a parasite of a dung fly (species not recorded) and introduced to aid in the control of the horn fly, it has since been reared from *C. capitata* pupæ by the writers.

GENERAL HISTORY OF PARASITE INTRODUCTIONS.

Attempts have been made to introduce fruit-fly parasites to control *Ceratitis capitata* from India into Western Australia by Compere, from India into South Africa via Western Australia by Lounsbury, from India into Italy by Silvestri, from Brazil into South Africa by Lounsbury and Fuller, and from Africa and Australia into the Hawaiian Islands by the Hawaiian Board of Agriculture and Forestry. So far as is at present known, these attempts have failed in all countries except in the Hawaiian Islands. Compere arrived at Perth, Australia, on December 7, 1907, with fruit-fly pupæ secured at Bangalore, India. Although he reared from these pupæ an estimated 2,000,000 specimens of *Syntomosphyrum indicum* and 300 specimens representing two braconid species and was able to make numerous liberations in badly affected areas, the West Australian fruit growers have received no appreciable benefit. Newman, in 1908, stated that he had collected in the field during that year pupæ of *C. capitata* parasitized by the introduced parasites. In 1909 he stated, however, that the chalcid and braconid parasites, although liberated for over 15 months, had not yet produced evident results, and in 1911 he wrote that although *Syntomosphyrum indicum* had been reared and liberated in large numbers during the previous four years, it did not appear to be established and there seemed little prospect of favorable results.

In 1905 Lounsbury and Fuller investigated fruit-fly conditions in Brazil and secured parasitized pupæ of *Anastrepha fratercula*, but they were unable to reach South Africa with living parasites. Parasitized pupæ of *C. capitata* were sent from Western Australia to Durban and Cape Town during 1908, but Lounsbury reported in 1909 that the introduction was unsuccessful. Silvestri, on his return in 1913 to Hawaii from West Africa, left in South Africa specimens of Dirhinus and Galesus, but they were unable to survive the following winter according to Lounsbury. Silvestri states that although he introduced *Syntomosphyrum indicum* into Calabria, Italy, he had not been able to prove that it had become established.

INTRODUCTION OF PARASITES INTO HAWAII.

The search for and discovery, the introduction, and subsequent establishment of parasites of *Ceratitis capitata* in the Hawaiian Islands form an interesting and important chapter in the history of this worldwide pest. The writers are able to state definitely, as a result of their biological work between September, 1912, and May, 1913, that no parasites of *Ceratitis capitata* were present in Hawaii up to the time when the first introductions were made in May, 1913, if we except the *Spalangia* sp. referred to on page 80 (footnote). At the present time, January 1, 1916, all larval parasites (*Opius humilis*, *Diachasma tryoni*, *D. fullawayi*, and *Tetrastichus giffardianus*) that have been liberated are being recovered in the field, and practically every lot of larvæ reared from samples of fruit collected in the littoral regions are found to be parasitized by one or more parasites. From exceptional lots all four parasites have been reared. The two pupal parasites, the proctotrupid *Galesus silvestrii* and the chalcid *Dirhinus giffardii*, have never been recovered by the writers and will not be the subject of further discussion.

The parasites at present attacking *Ceratitis capitata* in Hawaii have been introduced by the Hawaiian Board of Agriculture and Forestry. Much credit is due Mr. W. M. Giffard, who, as president of this board, was able to make arrangements for the Silvestri and the Fullaway-Bridwell expeditions to Africa. Dr. Silvestri set out from Italy during

July, 1912, and arrived at Honolulu May 16, 1913. During this time he searched for parasites in the West African States of Senegal, French Guinea, Nigeria, Kamerun, Gold Coast, Dahomey, the Kongo, and Angola; also in South Africa and in Australia. It is needless to say that Dr. Silvestri was unable to make a complete survey of fruit-fly conditions during so short a time, yet his investigations were successful, not only because they cleared the way for the Fullaway-Bridwell expedition, but also because they resulted in the introduction and establishment of *Opius humilis* and *Diachasma tryoni*. Messrs. D. T. Fullaway and J. C. Bridwell sailed from Honolulu on the second expedition during June, 1914, and arrived at Lagos, Nigeria, on July 24. On August 19 Mr. Fullaway took the parasitized material collected by the expedition at Olokemeji, near Lagos, and sailed for Teneriffe, Canary Islands, where he was able to use *C. capitata* in rearing additional specimens of the parasites emerging from the Nigeria material. With fresh material, Fullaway sailed from Teneriffe September 27 for Hawaii via Havana, Key West, Jacksonville, New Orleans, and San Francisco, arriving at Honolulu on October 27. On arrival he had living material of *Tetrastichus giffardianus*, *Diachasma fullawayi*, *Opius* sp., and *Spalangia* sp.

Mr. Bridwell proceeded from Lagos with an excellent supply of parasitized material, particularly of what appeared to be a new opiine collected at Olokemeji during the period August to October, 1914, to Honolulu via Cape Town and Australia. Unfortunately, he was overtaken before reaching Cape Town with a severe illness which necessitated stops for recuperation in South Africa and Australia of sufficient duration to make it impossible for him to bring living parasites with him to Hawaii.[1]

It has already been stated that early in 1914 Mr. D. T. Fullaway introduced at Honolulu a species of dung-fly parasite, *Pachycrepoidius dubius* Ashm. (Pl. XX, fig. 2) which was reared in small numbers by the writers from *C. capitata* pupæ during 1915.

TETRASTICHUS GIFFARDIANUS SILV.

HISTORY.

Tetrastichus giffardianus Silv. was confused with *T. giffardii* Silv., both in the mind of its author and in those of entomologists in Hawaii. The latter species was first reared from *Ceratitis colae* by the entomologist (1912–13) of the agricultural station at Aburi, Gold Coast, Africa. These specimens were identified by Dr. Silvestri as

[1] For full accounts of these parasite expeditions one should consult: Report on an Expedition to Africa in Search of the Natural Enemies of Fruit Flies. F. Silvestri. Bull. 3, Haw. Bd. Agr. and Forestry, Feb., 1914; Report of the Work of the Insectory. D. T. Fullaway. In Rept. Div. Ent. Haw. Bd. Agr. and For., for the biennial period ending Dec. 31, 1914.

new to science. Silvestri reported having reared *giffardii* during the period November, 1912, to February, 1913, from *Ceratitis antistictica* and *C. giffardii* at Olokemeji, Southern Nigeria; from *C. giffardii* at Kotonou, Dahomey, and from *Dacus bipartitus* at Victoria, Kamerun. Silvestri was unable to keep adults alive during the passage from West Africa to Honolulu.

In March, 1915, Silvestri published the description of *T. giffardianus,* stating that previous to then he had confused the species with *giffardii. T. giffardianus* was reared by Silvestri from *Ceratitis giffardii* Bezzi, collected at Olokemeji, southern Nigeria, and at Kotonou, Dahomey.

It was *T. giffardianus* Silv. and not *T. giffardii* that was collected by the Fullaway-Bridwell expedition and introduced into Hawaii at Honolulu on October 27, 1914. This fact should be borne in mind, because much of the literature dealing with parasites of *C. capitata* in Hawaii refers to *T. giffardianus* as *T. giffardii.* References to Tetrastichus as a parasite of *Ceratitis capitata* in Hawaii should be interpreted to refer only to *T. giffardianus.*

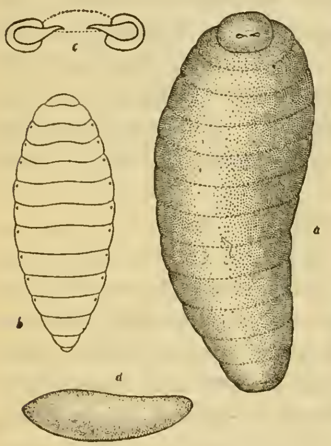

Fig. 17.—*Tetrastichus giffardianus: a,* Ventral view of mature larva; *b,* dorsal view of same, showing spiracles; *c,* mouth hooks or man dibles; *d,* egg. Greatly enlarged. (Original.)

Fullaway introduced into the Hawaiian Islands 300 living specimens of both sexes of *T. giffardianus.* By December 31, or after about two months of breeding in the laboratory, these 300 had increased to 21,431 specimens. Of these, 18,050 were liberated on Oahu, Hawaii, and Kauai by January 1, 1915. Although many thousand specimens have been liberated since December, 1914, none had been recovered as late as February, 1916, from any island except Oahu.[1] In Honolulu specimens have been reared from widely separated points, which would seem to indicate that this parasite has been established successfully. The first recoveries were made by the writers during September, 1915, in Honolulu.

DESCRIPTION.

Adult.—Both sexes of the adult are black with a slightly dark-green iridescence. The antennæ are rather dark, as are also the

[1] Exception: One lot of 46 pupæ of *C. capitata* from coffee cherries collected June 18, 1915, at Kainaliu, Hawaii, showed a parasitism of 63 per cent by *Opius humilis,* 30.4 per cent by *Diachasma tryoni,* and 2.1 per cent by *Tetrastichus giffardii.*

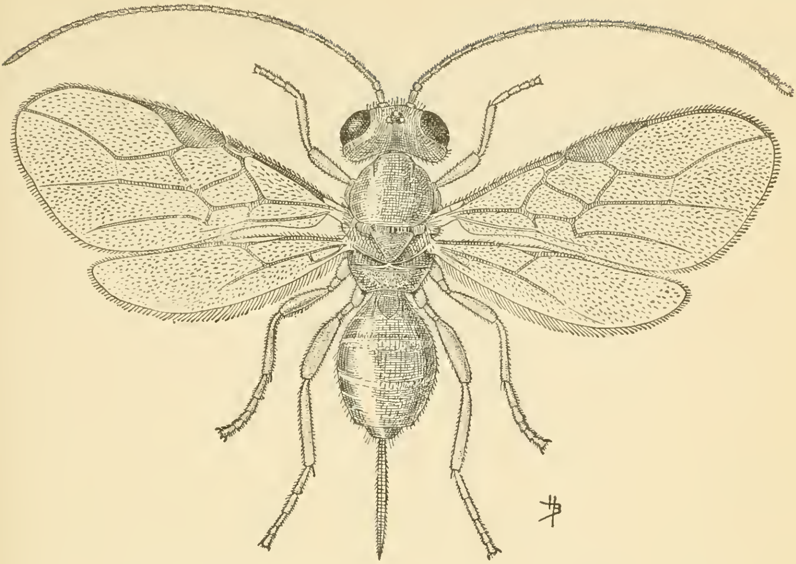

FIG. 1.—OPIUS HUMILIS: ADULT FEMALE. GREATLY ENLARGED. (ORIGINAL.)

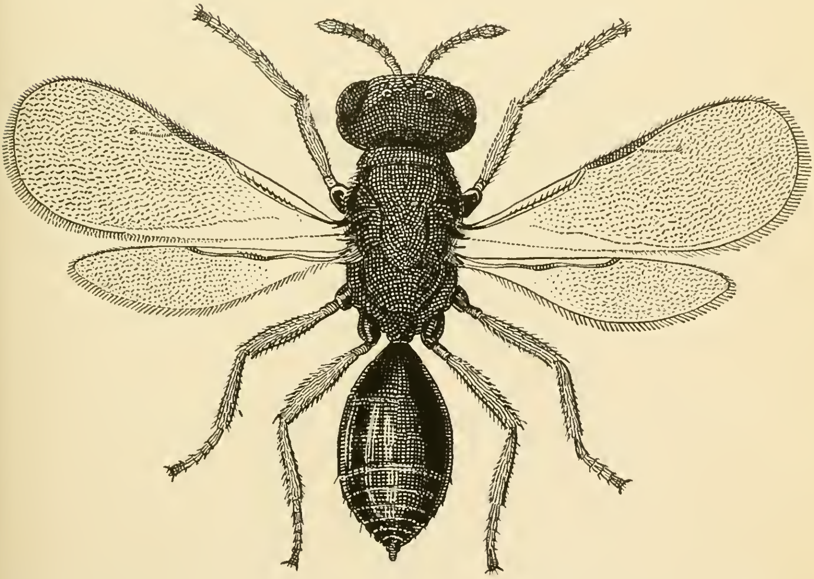

FIG. 2.—PACHYCREPOIDEUS DUBIUS: ADULT FEMALE. GREATLY ENLARGED. (ORIGINAL.)

PARASITES OF THE MEDITERRANEAN FRUIT FLY.

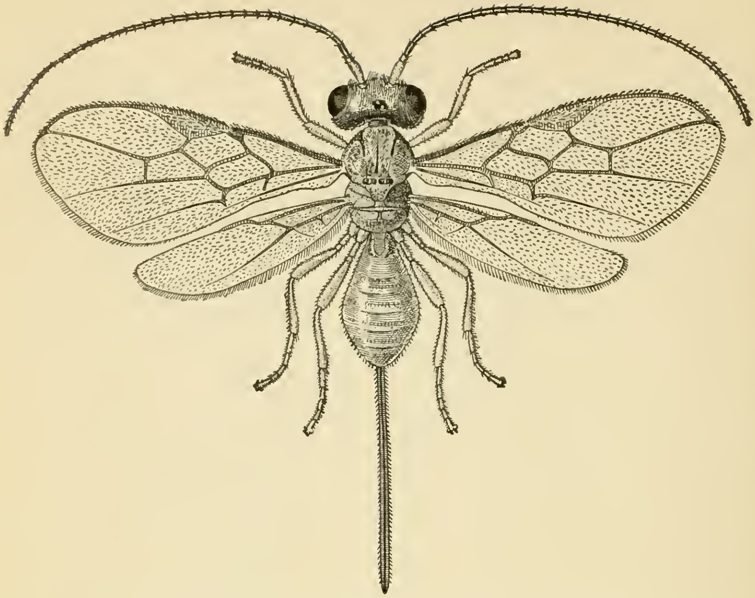

FIG. 1.—DIACHASMA FULLAWAYI: ADULT FEMALE. GREATLY ENLARGED. (ORIGINAL.)

FIG. 2.—DIACHASMA TRYONI: ADULT FEMALE. GREATLY ENLARGED. (ORIGINAL.)

PARASITES OF THE MEDITERRANEAN FRUIT FLY.

femora, but the tibiæ and tarsi are more yellowish. Length of body, about 2 mm. For the original description see Bolletino del Laboratorio di Zoologia, Portici, volume 9, page 374 (1914–15).

Egg.—The egg is pure white, about 0.11 mm. long, and shaped as shown in figure 17, *d*.

Larva.—The well-grown larva is white and grub-like, about 1.8 mm. long (fig. 17, *a*). When viewed from above, spiracles are evident on segments 3–9 (fig. 17, *b*). The mandibles are microscopic (fig. 17, *c*). When first hatched, larvæ are about 0.28 to 0.3 mm. long.

Pupa.—The pupa is about 1.9 mm. long. (See fig. 18.)

BIOLOGY.

Silvestri was unable to keep adults of *giffardii* (or *giffardianus* ?) alive for more than 15 days. His original statement that the female deposits her eggs within the eggs or young larva of the host has been proved by Fullaway and the writers to be incorrect. Oviposition by *T. giffardianus* occurs largely in the well-grown larvæ as in the case of the Opiinae. The adult parasite will enter larval chambers and breaks in the host fruit in search of fruit-fly larvæ as has been proved by the writers under laboratory conditions, and accumulating data seem to indicate that adults oviposit for the most part in larvæ within fruit already fallen to the ground. Adults are capable of beginning oviposition as soon as they emerge from the puparium of the host. The female does not necessarily make a new puncture in the epidermis of its host for each egg deposited; in one instance 41 eggs were deposited through 17 punctures. When the female comes upon a larva within a larval channel, she deposits her eggs at points about its posterior portion, but when access to the larva can be had through a thin membrane of the host fruit, she may deposit her eggs in any portion of the body. The punctures in the epidermis are evident as small dark brown depressions. Of a total of 322 adults reared from 20 pupæ, 194 were females and 128 were males; the number of adults reared from single pupæ varied from 1 to 35.

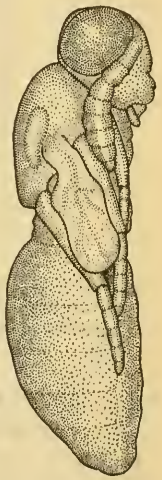

FIG. 18.—*Tetrastichus giffardianus:* Lateral view of pupa. Normal length, 1.9 mm. (Original.)

When the temperature ranges between 66° and 82° F., with a mean of about 74° F., eggs hatch in about 3 days, the larvæ become full grown in about 8 days, and the pupæ yield adults in from 11 to 15 days.

Opius humilis Silv.

HISTORY.

Opius humilis Silv. (Pl. XX, fig. 1) was first reared and described by Silvestri from pupæ of *Ceratitis capitata* collected at Constantia, Cape Colony, Africa, during March, 1913. This parasite does not appear to be an effective factor in the control of *Ceratitis capitata* under South African conditions. Silvestri reared only a few specimens of which he had only 5 representing both sexes in a living condition when he arrived at Honolulu, May 16, 1913. Although after Silvestri arrived at Honolulu he was able to rear fresh material, the danger that the progeny would be males only was so great that 3 females, with males, were liberated in the coffee fields of Kona, Hawaii, on June 12, 1913. This precaution alone saved the species from extinction in the islands, as the progeny of the specimens kept in the laboratory proved to be males. During October, 1913, large numbers of *Opius humilis* were recovered from *Ceratitis capitata* larvæ in coffee cherries in Kona, Hawaii, and it was found that the species was well established. From the specimens recovered from Kona, colonies were reared and liberated in other parts of the islands. No specimens were liberated in Honolulu until December, 1913. By July, 1914, *humilis* was found well established in the city, and by December of that year data already published [1] prove it to have become very abundant and widespread.

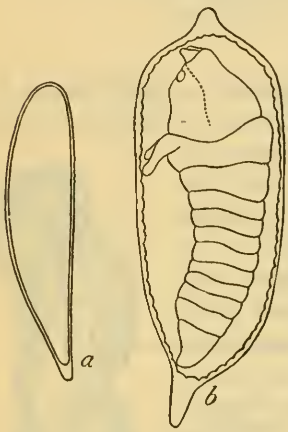

FIG. 19.—*Opius humilis: a*, Egg 1 day old, length 0.45 mm.; *b*, egg 3 days old, length 0.8 mm. (Original.)

DESCRIPTION.

Adult.—The original description of the adult by Silvestri is as follows:

♀ Body ochraceous in color, antennæ brownish-fulvous, wings hyaline with the veins brownish and the central part of the stigma ochraceous-ferruginous; legs with pretarsi brown and the posterior tarsi also in great part brown. Head scarcely more than one-third wider than long, hairy; face with a slight median carina; epistoma slightly elevated; antennæ a little longer than the body, with 35 segments; eyes a little more than twice as long as wide, their lower margin attaining the level of the superior margin of the epistoma. Mesothoracic scutum entire, smooth, with very short parapsidal furrows anteriorly; transverse prescutellar sulcus with eight small

[1] Back, E. A., and Pemberton, C. E. Parasitism among the larvæ of the Mediterranean fruit fly (*C. capitata*) in Hawaii during 1914. Rept. Hawaii Bd. Agr. and For., Dec. 31, 1914.

pits; scutellum smooth with 3 or 4 small pits and a large deep one; metanotum with a short median carina, on the submedian part shortly crenulate before the sublateral pit; propodeum with a median carina, in some specimens divided from the base into two almost contiguous parallel arms posteriorly diverging, the remainder rugose; mesopleural sulcus falveolate. Wings with venation as shown in figure [Pl. XX, fig. 1.] Abdomen with the first segment rugose on the dorsum, the remainder smooth, with a few hairs; ovipositor almost straight, a little shorter than the abdomen.

Length of body, 2.6 mm.; width of thorax, 0.79 mm.; length of antennæ, 3.3 mm.; length of front wing, 2.6 mm.; width of same, 1.15 mm.; length of third pair legs, 2 mm.; length of ovipositor, 1.15 mm.

Egg.—The egg when first deposited is about 0.45 mm. long, white and of the shape indicated in fig. 19, *a*. As the embryo develops, the entire egg increases in size until when between 2 and 3 days old (Feb., 1916) it becomes about 0.8 mm. long, and over twice as wide as when first deposited, with a protuberance at the anterior end. The developing embryo may be readily seen through the egg membranes (fig. 19, *b*).

Larva.—The white, newly hatched larva is about 1 mm. long. It has a rather large head and 12 distinct body segments. (See fig. 20.) On the anterior ventral portion of the first body segment is a pair of appendages (fig. 20, *b*, *d*), which the larva does not appear to be able to move at will or to use as an aid to locomotion. The jaws are very large and strong, being much larger in proportion than in the succeeding instars (fig. 20, *c*). The ventral portion of the head, behind the mandibles, is rather strongly chitinized, forms a support for the latter, and bears on its anterior margin two toothlike projections. On the ventral anterior portion of the head are two fleshy antennal protuberances. The thoracic appendages and large mandibles are lost after the larva molts into the second instar.

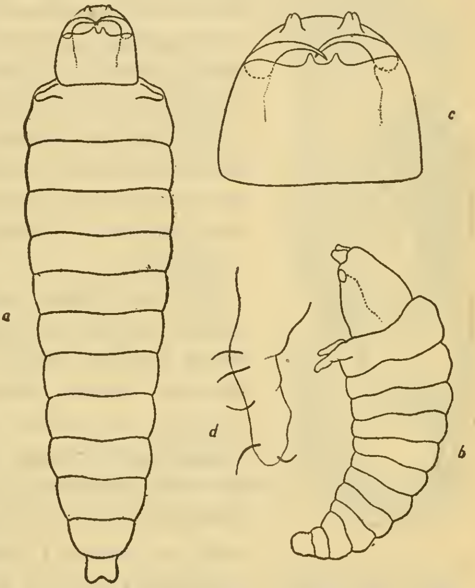

FIG. 20.—*Opius humilis*. Larva: *a*, Ventral, and *b*, lateral view of newly hatched larva; *c*, ventral aspect of head of same; *d*, enlarged thoracic appendage. (Original.)

Pupa.—The pupa is about 2.3 mm. long (fig. 21). It is very readily distinguished from the other opiine pupæ by the short ovipositor sheath.

Diachasma tryoni Cameron.

HISTORY.

Diachasma tryoni Cameron (Plate XXI, fig. 2) is primarily a parasite of the Queensland fruit fly (*Bactrocera tryoni*) and was first reared by Brooks and Gurney in New South Wales during 1908, and described as a new species by Cameron in 1911. Of 1,575 pupæ of *Bactrocera tryoni* secured by Gurney from 18 different lots of fruits during the period from January, 1910, to February, 1911, 30.2 per cent were parasitized; the highest percentage of parasitized being 52.2 per cent of 136 pupæ secured at Narara during February, 1910. During April, 1913, at Gosford the parasitism equaled 70 per cent. While *Diachasma tryoni* in Australia attacks principally the Queensland fruit fly, it has been definitely reared there from *Ceratitis capitata* under field conditions, and the indications are strong that it may attack also the island fruit fly, *Trypeta musae* Frogg. It was the opinion of Gurney that this parasite might, upon occasion, become a valuable check upon *C. capitata*.

Fig. 21.—*Opius humilis*: Lateral view of pupa. Greatly enlarged. (Original.)

While en route to Honolulu from West Africa, Silvestri, aided by Gurney, secured pupæ of *Dacus tryoni* in New South Wales. From these pupæ Silvestri reared adults of *Diachasma tryoni*, of which he succeeded in introducing at Honolulu 4 female and 3 male specimens on May 16, 1913. Silvestri soon found in his rearing experiments in Honolulu that the progeny were largely of the male sex, hence 4 females, with males, were liberated June 12 in the Kona coffee district of Hawaii, 3 females, with males, on July 4 at Waianae, and 9 females, with males, on July 11 in Kona, Hawaii. As all the progeny of the remainder of the material held at the insectary were males, the specimens of this parasite now in Hawaii are the progeny of 24 females liberated during June and July, 1913. The first recovery of *Diachasma tryoni* was made by Ehrhorn during August, 1914, from *C. capitata* pupæ from the Kona district of Hawaii. During October, 1914, a systematic collection of infested coffee cherries throughout this district proved *tryoni* to be thoroughly established. Although 3 females were liberated at Waianae, Oahu, on July 4, 1913, no specimens were liberated in and about Honolulu until early in 1915. Yet by October, 1915, this parasite was being reared [1] in small numbers from *C. capitata* pupæ obtained in various parts of the city.

[1] Back, E. A., and Pemberton, C. E., Parasitism among the larvæ of the Mediterranean fruit fly (*C. capitata*) in Hawaii during 1915. Jour. Econ. Ent., v. 9, 1916, p. 306–311.

DESCRIPTION.

Adult.—Silvestri's description of the adult is as follows:

♀. Head, thorax, first segment of the antennæ, front and middle legs testaceous-ferruginous in color; abdomen in great part brown or shining blackish brown; wings slightly infuscate, with the stigma and veins brown; third pair of legs entirely brown from apex to trochanters. Head a little broader than the thorax, about one-fourth wider than long with a slight median longitudinal ridge on the face, epistoma slightly semicircularly produced in the middle; antennæ longer than the body, with 45 segments; eyes small, twice as long as wide. Mesothoracic scutum with the parapsidal furrows smooth and deep, convergent, uniting in a deep median pit situated a little before the posterior margin; transverse prescutellar sulcus with a large pit divided into four small ones and each provided also with an incomplete posterior division; scutellum smooth; parascutellar pit with an internal scarcely visible crenulation; metanotum with a short very slight median carina flanked by two small depressions, lateral pit with an abbreviated carina; propodeum with a small anterior conical protuberance directed forward, median and submedian surface almost smooth, a little rugose at the sides and posteriorly, mesoplural sulcus crenulate. Wings with the venation shown in figure [Pl. XXI, fig. 2.] Abdomen with all the segments smooth and shining, with few hairs; ovipositor about as long as the body. Length of body, 3.5–4.5 mm.; width of thorax, 0.95 mm.; length of antennæ, 5 mm.; length of front wing, 4 mm.; width of same, 1.7 mm.; length of third pair of legs, 4.4 mm.; length of ovipositor, 4.5 mm.

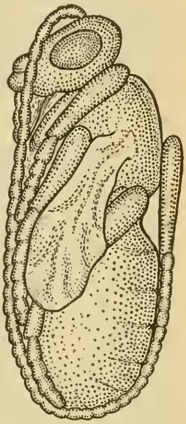

FIG. 22.—*Diachasma tryoni:* Lateral view of pupa. Greatly enlarged. (Original.)

♂. Similar to the female.

Larva.—Oval in form, whitish, with the skin smooth and apparently naked, but under strong magnification may be seen to be provided with dense, small, and slender points. Mandibles short, slightly arcuate and gradually attenuate, terminating in a point. Antennæ very short. Length of body, 3 mm.; width, 1.6 mm.

Egg.—The egg of *Diachasma tryoni* is glistening white, about 0.57 mm. long and distinctly attenuated at each end.

Larva.—The newly hatched larva, which is about 1 mm. long, is similar to that of *Opius humilis* (fig. 20, *a*, *b*) and *Diachasma fullawayi* in general shape and in the possession of two ventral appendages upon the first body segment. The proportionately large jaws are similar to those of newly hatched larvæ of *humilis* and *fullawayi* but slight distinguishing characters can be found in the large chitinous ventral plate of the head.

Pupa.—The young pupa is white in color, about 4 mm. long, 1.7 mm. wide, and may be distinguished from that of either *humilis* or *fullawayi* by the length of the ovipositor. (Fig. 22.)

DIACHASMA FULLAWAYI SILV.

HISTORY.

Diachasma fullawayi (Plate XXI, fig. 1) was first reared and described by Silvestri from pupæ formed by larvæ of *Ceratitis giffardi* collected in the fruits of Chrysobalanus on August 2–3, 1912, at Dakar, Senegal. Silvestri later reared specimens from *C. giffardi* and *C. tritea* at Olokomeji, Southern Nigeria, and from *C. giffardi* at Kokoulima, French Guinea. He was also able to rear this parasite at Dakar from pupæ formed by larvæ of *C. giffardi* parasitized experimentally during the period September 6 to 8, 1912. He was unable, however, to arrive at Honolulu with living specimens and it remained for the Fullaway-Bridwell expedition of 1914 successfully to introduce *D. fullawayi* into Hawaii from Olokomeji via Teneriffe, Habana, and the southern United States. Fullaway arrived at Honolulu on October 27, 1914, with 12 female and 19 male specimens. These had multiplied in the laboratory to 419 females and 1,000 males by December 31, and of this number 35 and 160 specimens were liberated during December at Maunawili, Oahu, and Kona, Hawaii, respectively. Although many specimens have been and are still being reared and liberated, this parasite appears to be well established on the Island of Oahu. In the Kona District of Hawaii, however, where it should have become established with greater ease, only two specimens have been reared from larvæ emerging from coffee cherries. These two specimens of *D. fullawayi* on Hawaii were reared by the writers from larvæ collected at Kainaliu on January 15, 1915, and February 13, 1916, or about 1 and 13 months, respectively, after the original liberations at this point.[1]

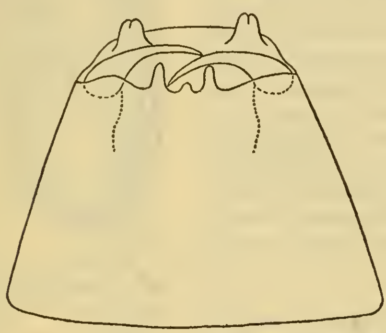

FIG. 23.—*Diachasma fullawayi:* Ventral aspect of head of newly hatched larva; greatest width, 0.3 mm. (Original.)

On Oahu, particularly in and about Honolulu, this parasite has multiplied with rapidity and was found well established in all parts of the city during September and October, 1915.

DESCRIPTION.

Adult.—The original description of the adult is as follows:

♀. Body ferruginous or ochraceous-ferruginous with the antennæ fulvous brown, the wings hyaline, with the veins fulvous brown and the stigma, in part fulvous-ferruginous, tarsi of the posterior legs slightly brownish. Head somewhat broader than long, densly covered with piliferous points, with the face slightly inflated in the middle to form a carina, antennæ longer than the body, with 44 segments. Eyes small, about twice as long as wide. Mesothoracic scutum with deep converging parapsidal furrows which meet a little before the posterior margin in a deep common pit; from this pit a median furrow proceeds directly forward, at first deep but gradually disappearing on the surface near the middle of the scutum; the entire surface

[1] Examinations made by C. E. Pemberton in Kona during May and June, 1916, found it to be established beyond question.

rather densly and closely hairy; transverse prescutellar sulcus provided with four deep pits, of which the lateral ones are deeper than the median; the scutellum is smooth and rather hairy; slightly crenulate laterally before the prealar pit; metanotum with a small median pit divided by a short carina, crenulate on the sides; propodeum strongly and irregularly foveolate. Front and hind wings with the venation shown in figure [Pl. XXI, fig. 1]. Abdomen with the first segment smooth; ovipositor straight, longer than the abdomen. Length of body, 3.6 mm.; width of thorax, 0.1 mm.; length of antennæ, 5.2 mm.; length of front wing, 3.7 mm.; width of same, 1.37 mm.; length of third pair of legs, 4 mm.; length of ovipositor, 3.5 mm.

♂. Differs from the female in having the wings more or less infuscate.

Larva.—The newly hatched larva is similar to that of *Opius humilis*, as illustrated by figure 20, *a*, *b*, as well as that of *Diachasma tryoni*, but it may be readily distinguished from that of *D. tryoni* by the possession of three instead of two toothlike projections on the anterior margin of the ventral chitinized plate of the head (fig. 23).

Pupa.—The pupa, which is about 3.2 mm. long, is most easily recognized from that of *humilis* and *tryoni* by the length of the ovipositor. (Fig. 24.)

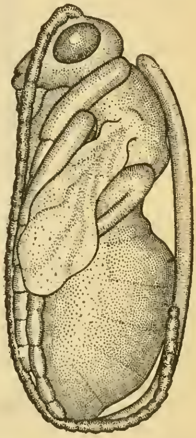

Fig. 24.—*Diachasma fullawayi:* Lateral view of pupa; normal length, about 4 mm. (Original.)

BIOLOGY OF THE OPIINE PARASITES.

Very little is known regarding the details of the life history of the three opiine parasites introduced into Hawaii. The biology of parasites now attacking *Ceratitis capitata* in Hawaii is at present being made the subject of special investigation by the junior writer. No data on the length of the various stages have been published except by Silvestri and Gurney. Silvestri's statements may be summarized as follows: That adults of *Opius humilis* emerging on April 3, 1913, were still alive on his arrival at Honolulu on May 16, when they deposited eggs from which adults developed within 14 days; that eggs of *Diachasma fullawayi*, at Dakar, Senegal, deposited on September 6 to 8, 1912, developed adults September 21 to 24, and that *D. tryoni* can complete its egg, larval, and pupal development in from 14 to 16 days. The data supplied by Gurney deal with *D. tryoni* only and will be considered later. The information of the writers is not complete and therefore is given as follows in the form of biological notes in anticipation of a more complete publication. It might be added that such data as are presented here were obtained incidental to other work.

Length of adult life.—Adults die in about 48 hours if not fed. When confined in test tubes $1\frac{1}{4}$ inches in diameter and about 8 inches long and fed daily, they live much longer, as indicated by the data in Table XXIV.

TABLE XXIV.—*Longevity records of Opius humilis and Diachasma tryoni*[1] *at Honolulu from November, 1914, to March, 1915.*

Age on date of observation.	Number of specimens dead.				Age on date of observation.	Number of specimens dead.			
	O. humilis.		*D. tryoni.*			*O. humilis.*		*D. tryoni.*	
	♂	♀	♂	♀		♂	♀	♂	♀
24	1	1	......	......	67	1	2	......	......
25	......	......	1	......	68	......	1	......	......
26	1	......	1	......	69	......	2	......	......
28	3	......	2	......	70	......	1	......	......
29	1	......	......	......	71	......	1	......	......
30	3	2	......	......	73	2	2	......	1
32	4	3	......	1	74	2	3	......	......
34	1	......	......	......	75	1	2	......	......
35	1	3	......	......	76	......	2	......	......
37	2	5	1	......	79	......	4	......	......
38	1	......	......	......	80	......	1	......	1
43	3	7	2	3	81	1	......	......	......
45	7	3	......	1	82	1	3	......	......
46	1	......	1	4	83	......	1	......	......
47	2	6	1	......	84	1	7	......	......
49	3	7	......	......	85	......	1	......	......
50	1	3	......	......	87	......	4	......	1
51	1	1	......	1	88	2	3	......	......
52	1	6	1	1	91	......	2	......	......
53	2	3	1	......	94	2	2	......	......
54	1	2	......	......	95	1	1	......	......
55	......	1	......	......	98	......	3	......	......
56	2	8	......	1	100	......	1	......	......
57	......	......	......	2	101	......	1	......	......
58	5	8	......	......	103	......	1	......	......
59	1	5	......	......	104	......	2	......	......
60	......	4	......	......	105	......	2	......	......
62	1	6	......	......	107	......	1	......	......
63	......	3	......	1	111	......	2	......	......
65	3	8	......	1	124	......	2	......	......
66	......	3	......	......	125	......	2	......	1

[1] No record was kept of adults dying during first 23 days after emergence.

Fourteen females of *Opius humilis* lived to be over 100 days old; the last two being 125 days old. One female *Diachasma tryoni* lived to be 125 days old, although this species appears to be more frail and less able to survive captivity. Unfortunately no record was kept of the number of adults of either species dying during the first 23 days after emergence.

Proportion of sexes.—A count of the sexes of 25 lots of *Opius humilis* reared from *C. capitata* developing in various fruits during September and October, 1914, showed 145 specimens to be females, and 141 males.

Mating.—Mating may occur immediately after emergence in all three species, *Opius humilis, Diachasma tryoni,* and *D. fullawayi.* Virgin females may deposit parthenogenetic eggs which, however, develop males only.

Length of life cycle.—There are no satisfactory data on the length of the life cycle under varying climatic conditions. The statement of Silvestri that the egg, larva, and pupa stages may be completed in from 14 to 16 days is a safe estimate for the minimum length required for the development of these stages. Specimens of *O. humilis,* developing from eggs deposited August 21 to 22, 1914, were already in the pupa stage when examined on August 31, and emerged as adults 13 to 16 days after the eggs were deposited. The temperature during this period ranged between 74° and 85° F., with a mean of about 79° F. In Table XXV are the summaries of emergence from 35 lots of *C. capitata* pupæ secured from various fruits, and these are presented since they demonstrate clearly that which more detailed data will prove further—that *O. humilis* passes through its immature stages more rapidly than either *D. tryoni* or *D. fullawayi*. As the eggs of the parasites are deposited within the well grown larva before it leaves the host fruits, from 1 to 4 days should be added to the duration of the immature stages indicated in Table XXV.

Three *O. humilis* emerged April 3 from *C. capitata* pupæ formed at Honolulu February 2, 1915, placed on Hualalai (temperature range, 31°–70° F.) February 11, taken to Kealakekua March 26, and to Honolulu March 29; i. e., the duration of the immature stages was increased by this combination of cool weather to about 60 days. Many records on file, not included in Table XXV, indicate that detailed data will show more convincingly that *O. humilis* is less affected by cold weather than either *D. tryoni* or *D. fullawayi*.

Dormancy.—There appears to be no tendency for the larvæ of *O. humilis* to pass through a period of dormancy. The larvæ of *D. tryoni* and *D. fullawayi* often apparently suspend activity when they become full grown and remain dormant for several months. Gurney first observed this phenomenon in the development of *tryoni*. *C. capitata* pupæ collected on February 2, 1915, produced adults of *tryoni* normally as indicated by the data in Table XXV, but two individuals emerged on May 5 and 27, respectively, or 92 and 114 days after the pupation of the host. Larvæ of *tryoni* and *fullawayi* in *C. capitata* larvæ in fruits gathered November 27, 1915, were still in the mature larva stage at the end of eight months (July, 1916). Similar data on the duration of other individuals are on file. Mr. J. C. Bridwell has stated to the writers that he has observed this same resting period among the larvæ of an undetermined African opiine, certain adults of which emerged three and four months after the pupation of the host fruit fly.

Instar of larvæ parasitized.—It is generally admitted by those rearing parasites in Hawaii that the adult parasites deposit their eggs, for the most part, in well grown third-instar larvæ while the fruits are still attached to the tree or have fallen to the ground.[1] The data in Table XXVI show a rapid decrease in the percentages of parasitism among larvæ emerging from fruits during each succeeding two or three day interval after the gathering of the host fruit.

[1] A former statement by the writers that the opiines oviposit for the most part in larvæ in fruits still attached to the tree is subject to modification. While oviposition occurs chiefly in coffee cherries attached to the tree, oviposition in kamani nuts occurs largely after the fruits have fallen.

TABLE XXV.—*Data on emergence of opiine parasites from the puparia of the Mediterranean fruit fly.*

Date.	Host and parasite.	Number of host or parasite emerging on the number of days after the formation of the puparium.																																Mean temperature.	Mean relative humidity.
		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	29	33	36	37	39	40	42	43	44	45	47	48	° F.	P. ct.
Dec., 1915 (6 lots)	C. capitata		30	139	1,202	1,982	1,341	969	69	5	1																								
	O. humilis		1	2	2	4	22	31	15	14	6	1																						73.1	72.3
	D. fullawayi				1	1	10	67	90	150	131	78	83	57	36	13	13	4	1	1															
	D. tryoni															1																			
June, 1915 (11 lots)	C. capitata		36	351	686	43	1																												
	O. humilis		10	44	70	196	243	159	58	35	13	14	6	2																				77.7–78.4	65.7–66
	D. tryoni					30	157	274	238	177	106	46	23	6	0	1	3																		
Sept. and Oct., 1915 (7 lots)	C. capitata		3	84	46	15																													
	O. humilis			13	29	45	20	8	1	0	1	1																						77.2–79	66.9–68.1
	D. tryoni				1	9	26	73	94	74	31	16	5	1																					
Dec., 1915, to Jan., 1916 (3 lots)	C. capitata							9	12	1																									
	O. humilis										4	1	0	0	0	0	1	1																73.1–71	72.3–78.5
	D. fullawayi											3	2	5	1	3	1	1	0	3	0	1	2	1	6	3	1	2	5	6	1	1	1		
Dec., 1915 (3 lots)	C. capitata				35	230	143	23																											
	O. humilis							3	2																									73.7	72.3
	D. fullawayi						3	81	103	198	164	115	60	24	13	4	0	3	0	0	1														
	D. tryoni										1	0	1	1	1																				
Nov., 1915 (5 lots)	C. capitata			3	0	55	37	20	3																										
	O. humilis					2	34	52	93	55	30	42	19	4	31	22	1																	74.6	70.5
	D. tryoni										2	7	8	2	2	1																			

TABLE XXVI.—*Percentage of parasitism among larvæ of the Mediterranean fruit fly emerging during various periods after the gathering of the host fruit (coffee).*

Locality.	Date of collection of fruit.	Date of larval emergence.	Number of pupæ yielding adults or parasites.	Percentage of parasitism.			
				Opius humilis.	Diachasma tryoni.	Diachasma fullawayi.	Total.
1752 Luso Street, Honolulu.	Oct. 21,——	Oct. 21–23..	37	78.4	0	16.2	94.6
		Oct. 23–25..	34	64.7	0	15	79.7
		Oct. 25–27..	52	20.0	0	5.4	25.4
Booth Estate, Pauoa Valley.	Dec. 8, 1915	Dec. 8–10...	256	0	0.4	92.1	92.5
		Dec. 10–13..	338	0.3	.6	78.1	79
		Dec. 13–16..	609	.6	.1	43.8	44.5
		Dec. 16–18..	258	0	0	12.8	12.8
		Dec. 18–20..	76	0	0	6.6	6.6
Kealakekua, Kona district.	Dec. 1, 1915	Dec. 1–2....	5	40	60	0	100
		Dec. 2–3....	15	86.7	13.3	0	100
		Dec. 3–4....	21	71.4	23.8	0	95.2
		Dec. 4–5....	33	66.6	21.2	0	87.8
		Dec. 5–6....	46	54.3	13	0	67.3
Kainaliu, Kona district...	June 18, 1915	June 18–19..	46	63	30.4	0	93.4
		June 19–20..	65	50.7	41.5	0	92.2
		June 20–21..	107	56	32.7	0	88.7
Kahaloa, Kona district...	Oct. 30, 1914	Oct. 30–Nov. 3.	41	80.4	2.2	0	82.6
		Nov. 3–6...	240	23.3	0.4	0	23.7
		Nov. 6–9...	125	3.7	0	0	3.7
		Nov. 9–11..	64	0	0	0	0
Hookena, Kona district...	Oct. 31, 1914	Oct. 31–Nov. 3.	52	16.7	40.7	0	57.4
		Nov. 3–6...	36	17	19	0	36
		Nov. 6–9...	86	1.2	0	0	1.2
		Nov. 9–11..	79	0	0	0	0

Resistance to cold-storage temperatures.—Indications are that *Opius humilis* can withstand greater cold for longer periods than can its host. Thus 5 *O. humilis* emerged from 2,500 *C. capitata* pupæ after they had been refrigerated for 9 days at about 26° F. Four lots of 1,200 pupæ refrigerated at the same temperature for 5, 6, 7, and 8 days yielded on removal to normal temperatures 30, 32, 8, and 4 Opius. No adult *C. capitata* emerged from those pupæ refrigerated from 5 to 9 days, but from 1,300 pupæ, refrigerated at about 26° F. for a period of 4 days, 3 adults emerged along with 40 *O. humilis*.

No adult *C. capitata* emerged from two lots of 1,900 and 4,500 pupæ refrigerated for 9 and 10 days, respectively, at 32° F., but 7 and 13, respectively, of *O. humilis* emerged. From 1,228 pupæ refrigerated for 18 days at 34° to 36° F. there emerged no adult *C. capitata* but 2 *O. humilis*.

REARING PARASITES.

In rearing parasites the writers have followed, in the main, the methods employed by the Hawaiian Board of Agriculture and Forestry as developed by Messrs. Silvestri, Fullaway, and Bridwell. The board failed to rear the opiine parasites successfully until Mr. J. C. Bridwell, then assistant superintendent of entomology, altered the procedure so that the pārasites were given an opportunity to oviposit in the larvæ within host fruits under more normal conditions. The methods previously used permitted much moisture to gather on the sides of the glass jars in which the host fruits and parasites were placed. The method now recommended by Mr. Bridwell consists in the use of two ordinary nursery flats, the boxes being 16 by 12 by 3 inches. Into one of these is placed a layer of dry sand and a wire container so arranged that it will hold the infested host fruits exposed within it clear of the sand. The second tray, the bottom of which has been replaced by fine-mesh copper wire, is used as a cover and is made sufficiently small so that it can be inverted and thrust down into the tray containing the sand and fruits as soon as vials containing the adult parasites have been unstoppered and placed upon the fruits. By pressing the edges of the covering tray well into the sand the adult parasites are prevented from escaping and ants are, temporarily at least, prevented from interfering with the experiment. When the covering tray is in place, the wire-screen top is not far from the exposed fruits; hence the parasites are forced to confine their activities where they net the best results. The Bridwell method has not only made it possible to rear large numbers of opiines quickly and without skilled labor but is largely responsible for the success of the Fullaway-Bridwell parasite expedition to Africa.

The writers have been able to rear both sexes of the opiine parasites in large numbers very easily since the summer of 1914 by merely placing in test tubes about 2 inches in diameter a number of infested host fruits and parasites. This method requires greater care and produces much sweating of the sides of the containers, but parasitic material of both sexes can be very quickly secured for experimental work, and the investigator has the advantage of being able to observe the activities of the adult parasites. The objectionable feature of excessive moisture was overcome by the use, in the summer of 1914, of a wooden box, the top and bottom of which was of fine-mesh copper wire which contained a sliding shelf made of coarse-mesh wire supported midway between the top and bottom of the box and which could be easily removed through one end of the box which was hinged. This device possessed the advantage, demonstrated by Bridwell, in that it prevented accumulations of excessive moisture and confined the parasites closely to their hosts, but was not so well adapted to the purposes of parasite work since the host larvæ which pupated on the bottom of the box could not be so readily secured. After the host larvæ have emerged from the exposed fruits the pupæ may be easily sifted from the sand beneath the fruits and held in glass jars until the adult parasites have emerged.

It was not necessary to expose adult opiine parasites to strong sunlight for a few minutes each day to hasten mating, as recommended by Bridwell, and both sexes were obtained within the laboratory without this precaution, possibly owing to the fact that the laboratories were remarkably well lighted.

Cannibalism.—Although thousands of adults representing all three of these opiine parasites have been reared during the past two years, not more than a single individual has been reared from one fruit-fly puparium. Larvæ of the Mediterranean fruit fly within coffee cherries which had been exposed to the attack of *Diachasma fullawayi* during January, 1916, were found to have been attacked in several places, and examination made of the body contents of the parasitized fruit-fly larvæ proved that as many as 8 eggs had been deposited in certain instances. It seems very probable, therefore, that in the field, under normal conditions, adult parasites do not discriminate against larvæ already parasitized when seeking a host and that due to an excessive number of parasitic larvæ within a single host a certain amount of cannibalism occurs. Cannibalism among opiine parasites was first observed by the senior writer while examining the body contents of larvæ parasitized by *Diachasma fullawayi* as previously mentioned. A newly hatched larva was observed vigorously and effectively to attack a second larva of the first instar with its large mandibles. Later examination of large numbers of fruit-fly larvæ by the junior writer have proved conclusively (1) that the last opiine parasite to hatch within a host first kills all other parasitic larvæ within the same host; (2) that the newly hatched larva is more capable of vigorous attack than one which has become engorged; and (3) that it may attack not only larvæ of another species but those of its own as well. As many as eight dead and one living first-instar larvæ have been found in a single host.

STRUGGLE FOR SUPREMACY AMONG PARASITES.

The parasites of *Ceratitis capitata* have been introduced too recently into Hawaii to warrant conclusive statements regarding the outcome of the struggle for supremacy which is clearly taking place. *Opius humilis* has an advantage among the opiines of being more hardy and of being able to pass through the immature stages more rapidly, and it is somewhat less affected by cool weather, whereas *Diachasma tryoni* and *D. fullawayi* have the advantage of possessing much longer ovipositors and are consequently better equipped to reach their host larvæ through the tissues of infested fruits. The more rapid development of the egg and larva stages of *Opius humilis* is, however, not in its favor when it is forced to compete within the same host with either *Diachasma tryoni* or *D. fullawayi*, owing to the cannibalistic habits of the newly hatched opiine larva, which impel it to seek out and destroy larvæ that have hatched earlier and already commenced feeding within the same host.

While it will probably take a number of years to determine just what advantage the longer ovipositor will afford *Diachasma tryoni* and *D. fullawayi* over *Opius humilis,* the data in Table XXVII clearly demonstrate the value of the cannibalistic habits of the newly hatched larva to the more slowly developing species.

TABLE XXVII.—*Percentage of parasitism by Opius humilis and Diachasma tryoni in larvæ of Ceratitis capitata in Kona, Hawaii.*

Locality.	Dates of larval emergence, 1915.	Percentage of parasitism.		
		Opius humilis.	Diachasma tryoni.	Total.
Kainaliu	Jan. 15–16	97.6	0.8	98.4
	Jan. 16–18	92.7	.8	93.5
	Feb. 6–8	85.3	9.3	94.6
	Mar. 15–18	92	0	92.0
	Mar. 18–19	85.1	0	85.1
	June 18–19	63	30.4	93.4
	June 19–20	50.7	41.5	92.2
	June 20–21	56	32.7	88.7
Honaunau	Jan. 19–20	82.8	3.4	86.2
	Feb. 9–10	64.2	4.7	68.9
	Mar. 19–24	73.9	.6	74.5
Honaunau	Mar. 24–26	81.2	0	81.2
	June 17–18	46.7	40.3	87.0
	June 19–20	40	49.6	89.6
	Sept. 19–20	13.9	65.1	79.0
	Sept. 20–21	10.6	69.6	80.2
Kealakekua	Feb. 6–8	79	0	79
	June 16–18	31.4	23.9	55.3
	Sept. 18–19	17.6	67.6	85.2
	Sept. 19–20	23	56.4	79.4
	Sept. 20–21	37.3	48.3	85.6

Data previously published by the writers have shown that *O. humilis* itself is capable of killing as high as 80 to 100 per cent of the larvæ of *Ceratitis capitata* developing in coffee cherries in the Kona district of Hawaii. The data secured during 1915 showed that there was a decided increase in the percentage of parasitism caused by *D. tryoni.* This increase, however, as shown by the data of Table XXVII, was largely at the expense of *O. humilis,* since the total percentage of parasitism was not in excess of that which *O. humilis* could have brought about by its own efforts. In the absence of large amounts of data necessary to the definite establishment of this point, the writers are of the opinion that similar fluctuations in the relative importance of *humilis* and *tryoni* are likely to occur each year unless *fullawayi* becomes thoroughly established, in which case it is likely to supplant *tryoni.* The gradual increase in the abundance of *tryoni* during the year is accounted for by the gradual removal, as the summer months approach, of the restrictions upon parasite development which cause a greater relative acceleration in the development of *tryoni* than in the case of *humilis.* This, aided by cannibalism, explains the ascendancy of *tryoni* during the summer and of *humilis* during the colder winter months. It would appear that *C. capitata* in the coffee sections of Hawaii would have been quite as effectively controlled had no opiine other than *humilis* been introduced.

It is doubtful if the same fluctuation in the relative abundance of *tryoni* and *fullawayi* on the one hand and of *humilis* on the other will take place in the warmer littoral regions about Honolulu where checks due to cool weather are not so effective as in Kona. A study of the data in Table XXVIII shows that *Diachasma fullawayi* gives promise of being a most efficient parasite, particularly of fruit-fly larvæ in coffee cherries, since almost unaided it produced a mortality, in one instance, of 92.5 per cent of 256 larvæ emerging from coffee cherries in Honolulu on December 8 to 10, 1915, which date was about one year after it had been liberated.

Data more recently secured by the junior writer indicate that instead of supplementing the work of the opiines, *Tetrastichus giffardianus* will prove a competitor, as its larvæ appear to be able to hold their own against opiine larvæ within the same host, usually causing their death. While both *Tetrastichus giffardianus* and *Pachycrepoideus dubius* (Pl. XX, fig. 2) have been reared during 1915 and 1916, neither is sufficiently abundant to become an effective factor in control at present.

GENERAL EFFECTIVENESS OF PARASITE CONTROL.

Only a beginning has been made in determining the effectiveness of parasites as a control factor in the Hawaiian Islands, yet the rapidity of establishment and increase of the parasites has been very gratifying. The data already published recording the percentage of parasitism secured during 1914 and 1915, together with the additional data of Table XXVIII, indicate, however, that while parasitism in such fruits as the coffee cherry is remarkably high, in fruits with a thicker pulp, such as the orange, it is very low. The data of Table XXVIII have been chosen particularly as they demonstrate that immense numbers of adult *Ceratitis capitata* are developed in spite of the excellent work of the parasites in certain host fruits. Since adult fruit flies can live many months and oviposit quite regularly as shown by the biological data, they have been able, with the aid of the unprecedented variety and abundance of host fruits growing in Hawaii, thus far to keep such an ascendency over their parasites that they cause the infestation of practically all fruits which are permitted to ripen. It would appear that unless effective pupal or egg parasites are introduced, or unless care is given to the elimination of host fruits which more thoroughly protect the larvæ from parasite attack and to the planting of fruits in which the fly is heavily parasitized, little of practical value can be expected from the parasites discussed in this paper either in rendering host fruits entirely free from attack or in raising the present quarantine against Hawaiian fruits. In Kona, Hawaii, where the percentage of parasites in coffee cherries has been phenomenally high for two years, it has been high enough merely to render an occasional fruit free from attack.[1] The control

[1] The statement of W. M. Giffard that the infestation of coffee cherries during 1914 was at least 50 per cent less than during the previous year, and that in some fields it was difficult to find any great infestation, should be interpreted as referring to the cherries which, although nearly all infested, were infested so late in development that their pulp was little affected when the fruits were picked.

executed by parasites has, however, effected a benefit to coffee growers which has probably already repaid the Territory of Hawaii for all money expended in parasite introduction, since the parasites, by greatly reducing the abundance of adult flies, have postponed the infestation of the pulp until the cherries have become quite well ripened, at which stage little loss to the coffee results.[1]

TABLE XXVIII.—*Percentage of parasitism among larvæ of the Mediterranean fruit fly developing in host fruits during November, 1915–February, 1916.*[2]

Locality.	Host fruit.	Date of larval emergence.	Total number pupæ yielding adults or parasites.	Percentage of parasitism.				
				Opius humilis.	Diachasma tryoni.	Diachasma fullawayi.	Tetrastichus giffardianus.	Total.
Hilo, Hawaii:								
Pitman Street	Coffee	Nov. 18–22, 1915	11	0.0	0.0	45.4	.....	45.4
Do	Wing kamani	Nov. 20–25, 1915	16	18.8	0	0	0	18.8
Hilo Hotel	Coffee	Nov. 19–22, 1915	5	0	0	60	0	60.0
Five Miles	do	Nov. 18–22, 1915	49	12.2	0	0.0	0	12.2
Boarding School	do	Nov. 20–29, 1915	90	1.1	0	2.2	0	3.3
Kona, Hawaii:								
Kealakekua	do	Dec. 1–5, 1915	77	71.4	22.1	0	0	93.5
Kainaliu	do	{Dec. 3–4, 1915	64	68.7	28.1	0	0	96.8
		Dec. 4–6, 1915}	119	63.9	28.9	0	0	92.8
Honaunau	do	Dec. 2–3, 1915	40	35	57.5	0	0	92.5
Honolulu:								
1560 Beretania Street	Loquat	Dec. 15–20, 1915	6	16.6	0	0	0	16.6
Do	do	Dec. 21–24, 1915	10	40	0	0	0	40
Do	do	Jan. 3–7, 1916	40	5	5	5	0	15
Waikiki	Ball kamani	Dec. 20–27, 1915	302	0	0	0	0	0
Ohua Lane	do	Dec. 22–31, 1915	75	0	0	0	0	0
Ainahau	do	Dec. 29, Jan. 1, 1916	186	0	0	0	.5	.5
Ohua Lane	do	Jan. 4–14, 1916	430	.5	0	.2	.3	1.0
Queens Hospital	C. oliviforme	Jan. 25, Feb. 2, 1916	297	2.6	2.0	2.6	0	7.2
Do	do	Jan. 27, Feb. 4, 1916	818	3.6	.6	.7	0	4.9
Do	do	Jan. 29, Feb. 9, 1916	1,954	2.4	.2	.5	0	3.1
Do	do	Feb. 4–18, 1916	870	1.4	0	.5	0	1.9
Do	M. elengi	Jan. 29–Feb. 9, 1916	1,543	.3	0	.1	0	.4
Do	do	Feb. 4–18, 1916	1,194	.5	0	0	0	.5
Do	do	Feb. 7–18, 1916	1,998	.1	0	0	0	.1
1814 Ahuula Street	Bunchosia	Nov. 24–29, 1915	45	31.1	0	0	0	31.1
Punahou Street	Chinese orange	Jan. 1–10, 1916	321	.6	.3	.3	0	1.2
Wilder and Thurston Streets.	do	Dec. 17–22, 1915	14	21.4	0	7.2	0	28.6
Do	do	Dec. 22–31, 1915	286	2.1	0	0	0	2.1
Wilder and Pensacola Streets.	do	Dec. 22–27, 1915	45	15.5	0	0	0	15.5
Upper Pauoa Valley	do	{Jan. 17–20, 1916	162	11.7	5.6	0	0	17.3
		Jan. 20–24, 1916}	817	1.2	.7	0	0	1.9
Wilder and Keeamaku Streets.	do	Dec. 17–20, 1915	143	7	0	0	0	7
St. Mary Mission	do	Dec. 16–24, 1915	316	1.5	0	.3	0	1.8
1436 Young Street	do	Dec. 13–16, 1915	5	40	0	0	0	40
Enos Lane	do	Dec. 9–20, 1915	182	3.9	0	5.5	0	9.4
Makiki and Lunalilo Streets	do	Dec. 8–13, 1915	59	0	0	3.4	1.7	5.1
Lunalilo Home	do	{Nov. 26–29, 1915	4	50	0	25	0	75
		Nov. 29, Dec. 1, 1915	43	14	0	7	0	21
		Dec. 1–6, 1915}	292	.7	.3	0	0	1.0
1571 Makiki Street	Coffee	Nov. 29, Dec. 1, 1915	54	5.5	0	85.2	0	90.7
1752 Luso Street	do	Dec. 8–13, 1915	415	1.7	.5	77.3	0	79.5
Booth, Pauoa Valley	do	Dec. 8–10, 1915	256	0	.4	92.1	0	92.5
Do	do	Dec. 13–16, 1915	611	.6	.1	43.7	.3	44.7
Upper Manoa Valley	do	Dec. 9–13, 1915	12	0	0	83.3	0	83.3
2030 Nuuanu Street	do	Dec. 11–13, 1915	22	4.6	0	81.8	0	86.4
Pauoa Valley	do	Jan. 1–3, 1916	9	11.1	0	88.9	0	100.0

[1] The losses to coffee growers due to excessive fruit-fly attack have been discussed on p. 34.
[2] Braces are used only when denoting the same lot of fruit.

While it seems evident that the favored host fruits of *C. capitata* will always be well infested if present cultural conditions persist, it is hoped that the value of the parasites may be sufficiently enhanced to free from attack such fruits as the avocado pear, which at present is infested just at the stage at which it becomes fit for harvesting.

The general effectiveness of parasite control will be increased with the discovery and introduction of a suitable egg parasite.

ARTIFICIAL CONTROL.

The only method employed at the present time in Hawaii satisfactorily to protect fruits from attack of the Mediterranean fruit fly is the covering of the fruits while they are still too green to be affected. The value of the use of cold storage as a method of rendering fruits already harvested free from danger as carriers of the pest has been demonstrated, but cold storage, of course, can have no bearing on the activities of the fruit fly in the orchard. No satisfactory substance has yet been discovered for trapping adult females, and the killing of adults of both sexes by poison sprays is not a feasible method of control in Hawaii under present cultural conditions any more than is the destruction of the immature stages by the burial, submergence, burning, or boiling of the infested host fruits. The exceptional conditions found in Hawaii make impracticable at the present time the application of any of these field methods of control, except that of covering the young fruit, notwithstanding the fact that the value of these control measures when they can be consistently, intelligently, and universally applied, has been demonstrated.

PROTECTIVE COVERINGS.

The only certain method now known of protecting fruits from attack by the Mediterranean fruit fly is to cover them when still quite young with some type of covering through which the female will not deposit eggs. During 1898 Fuller reports that about 22,000 running yards of mosquito netting were imported into South Africa for use in covering trees to protect the fruit from fruit-fly attack. The cloth was sewed into bags sufficiently large to be slipped over the trees and tied about the trunk. This method has been employed by the writers in protecting ripening peaches. Care must be taken, in Hawaii at least, to place the bags over the trees when the fruits are very small or early infestations will have already occurred which, after the coverings have been placed, will produce generations of adults that will result in the infestation of the entire crop beneath the covering.

Covering the entire tree is too expensive to be followed out on a large scale, and entirely impractical with large trees or in windy areas. Protecting fruits with individual coverings made of cloth or paper is more popular in Hawaii. Fruits inclosed in paper bags are well and cheaply protected. Coverings of cheese-cloth are often matted against the fruit by rains, thus making it possible for the female fly to oviposit in the fruit. The practice of covering mangoes with paper bags will afford protection to certain scale insects and permit them to develop and ruin the fruit.

Frequently all the fruits on a tree may be seen inclosed in paper bags. While this method of covering each fruit gives protection from the fruit fly, it involves much labor and patience and its practicability can only be determined by the value placed upon the fruit by the owner. So severe is fruit-fly attack in Hawaii that this method, in some one of its many modified forms, is the only remedy if fruits are to be brought to maturity uninfested.

CLEAN CULTURE.

Clean culture in its broadest sense includes not only the detection, collection, and destruction of all infested fruits but also the elimination of useless or unnecessary host trees or shrubs. In some one or all of its phases it has been recommended and practiced in every country where the fruit fly is a pest, and in each one of these countries the lethargy displayed by a majority of the people, no matter how much they have regretted their losses, has rendered the clean cultural methods inefficient. The effectiveness of clean culture depends upon many factors, of which cooperation among property owners, honesty on the part of inspectors, climatic and host relationships, the topography of the country, and a thorough knowledge of host fruits on the part of the director are the most important. Clean culture in the Bermudas, where conditions are exceptionally favorable for stamping out the pest, was rendered less effective, up to 1914, because there was lacking a thorough knowledge of the complete list of host fruits subject to infestation. The fruit fly has been stamped out at Blenheim, Napiers, and Davenport, New Zealand, and at Launceston, Tasmania, by the application of such clean cultural methods as the destruction of the fruits and the treatment of the soil beneath the trees with kerosene immediately after the discovery of the pest. The only other recorded instance of success attained as a direct result of clean cultural methods is that of the orange growers of the Blackall Range, in Queensland, Australia. These growers held a council and voted to grub out every kind of fruit tree except the orange, which was their staple crop. As a result of this drastic remedy the fly had nothing in which to breed during nine months of the year in this section, and therefore ceased to be a pest.

The clean-culture campaign instituted by the Hawaiian Board of Agriculture during the fall of 1911 and continued by the Federal Bureau of Entomology from October, 1912, until April, 1914, was unsuccessful from its inception, since it did not protect the fruit from attack. The main factors contributing to failure were lack of adequate police powers, adverse host and climatic conditions, and the absence, at that time, of any commercially grown orchard crop worth protecting. The impracticability of control by the clean-culture method was recognized by Mr. C. L. Marlatt, who, as a Federal representative immediately in charge of the Hawaiian investigations, was in personal touch with the problem during September, 1912. It was felt, however, that inadequate as this method had proved itself after a nine months' trial from the standpoint of alleviating the Hawaiian situation, it seemed still to offer the best-known way of safeguarding the interests of mainland fruit growers. Therefore, for the purpose of lessening the opportunities of spread to the coast, the destruction of fruits which could be carried on board ships was continued. It was not until after representatives of California,[1] Hawaii,[2] and the Federal bureau had reached the conclusion that no benefit was accruing either to the local or to the mainland interests that the campaign was discontinued.

It is doubtful if ever a clean-culture campaign against the Mediterranean fruit fly was organized so efficiently or on so large a scale as that organized by Mr. W. M. Giffard of the Hawaiian Board, to include the city of Honolulu. That this method should prove a failure under Hawaiian conditions is no reflection upon the ability of those in charge of the work. Inspectors were prohibited from gathering and destroying fruits unless they could first prove to the satisfaction of the property holder that each fruit was infested, and this restriction upon the activities of the inspectors naturally led to numerous difficulties, particularly with the poorer and uneducated classes who often exerted every effort to save their fruit. This restriction also prevented a systematic gathering of all host fruits within a given area, but necessitated many examinations for the removal, on ripening, of the fruits of each individual tree. As fruits ripen rapidly in the semitropics, it proved a physical impossibility to arrange visits by the inspectors frequently enough to prevent infested fruits from falling to the ground.

The data of Tables III to V illustrate the immense number of host trees and shrubs available for infestation in Honolulu, and the ease with which the fruit fly, uncurbed by climatic conditions, may find fruit for oviposition during any day of the year. A glance at Plates IV, VI, XII, and XIX will convince one of the absurdity of endeavoring to remove all the fruits from many of the huge host trees of the islands. The writers know of many winged kamani trees, beneath which infested nuts may be gathered each week of the year, so tall

[1] Report of Investigation of the Fruit-fly situation in the Territory of Hawaii, F. Maskew. Monthly Bul. Cal. St. Com. Hort., v. 3, 1914, p. 227-238.

[2] W. M. Giffard, Letter of Transmittal to Bulletin No. 3, Haw. Bd. Agr. and For., 1914, p. 7.

and brittle that to remove the fruits before they ripen would be impossible. To this example might be added many others in which the removal of ripening fruit would be equally impracticable.

That the campaign was successful in eliminating the bulk of the fruit ripening in Honolulu during the greater part of the year is evidenced by the inability of the Hawaiian Board to obtain any large amount for their experimental work with parasites during the period the campaign was in progress. Excepting May, June, and early July, it was not an impossibility to gather the bulk of fruits ripening in Honolulu, but during these three months tons of ripening mangoes, falling continuously, presented a situation that could not be successfully combated. (See Pls. XII and XIII.) While tons of mangoes were carried daily to the incinerator or the city dumps, except from the standpoint of city sanitation nothing of value was accomplished.

Notwithstanding the fact that the bulk of the ripening and infested fruits were collected and fruit-fly conditions were unquestionably improved from the standpoint of the numerical abundance of adult flies, the important fact remains that the number of fruit flies that succeeded in reaching maturity was sufficiently large to infest practically every fruit ripening within the city. Kerosene traps placed throughout one of the cleanest sections of the city captured large numbers of flies as proved by recorded data on file both with the Hawaiian Board and this bureau. (See Table XXI, p. 76.)

So far as the writers know, there is no way in which clean culture can be made effective in Hawaii under present conditions. There are no impelling incentives. The islands are thoroughly overrun with the fruit fly, and this applies quite as much to the guava scrubs in pastures (Pl. II), on lava flows, and in mountain valleys and ravines as within the city limits. By far the larger proportion of host trees and shrubs are grown more for protection from the semitropic heat and for their ornamental value than for their fruits (Pl. VI). Large numbers of the host fruits are not edible. The destruction of host vegetation is out of the question until it can be proved that some advantage worth while can be gained. To cut down all host trees of Honolulu at the present time would be to remove a large percentage of her prized vegetation without giving her citizens adequate compensation.

ELIMINATION OF HOST TREES.

It has been stated under a discussion of clean-culture methods that the elimination of host trees and shrubs in Hawaii is impracticable at the present time. Should the Mediterranean fruit fly ever become established in California or the Southern States, wherein there is no such wealth of host fruits and where climatic conditions would assist in control, the elimination of host trees other than the orchard cultures to be protected would play a most valuable part in control measures. Dr. Trabut found that in Algeria the infestation of oranges greatly increased after the introduction of such crops as peaches and persimmons, since these fruits furnished food for the fly during the summer and early fall months, which for the fruit fly had been starvation months previous to the cultivation of these fruits. Aided by these introduced summer crops, the fruit fly was able greatly to increase, so that when the orange crop began to ripen during the fall and winter months, the pest could attack it with increased force. The elimination of a comparatively few host trees, numerically speaking, in Bermuda would mean the elimination of breeding places over considerable areas. The destruction of unnecessary and valueless host trees serves to restrict the breeding ground, as well as to destroy the sequence of ripening hosts so that many adult flies will die while attempting to bridge the ensuing starvation periods, during which no host fruits can be found for oviposition.

SPRAYING.

It has been demonstrated that the Mediterranean fruit fly must feed for about four days after emergence in the warmer months before the females are capable of ovipositing in fruits. This feeding period may be extended to 10 days during winter in littoral Hawaii. Although the interval between emergence and oviposition is short, it offers the best opportunity to kill this pest by means of poisoned baits or sprays. Mally, in South Africa, first appreciated the vulnerability of this point in the life cycle and developed and demonstrated the value of poison sprays as a factor in the control of the Mediterranean fruit fly. Berlese, in Italy, however, working quite as independently, carried out similar experiments to check the olive fly (*Dacus oleae*). Equal credit is due Mally and Berlese for the use of poison sprays in combating fruit flies.

The results of the experimental work of Mally during 1904–5 and of Dewar during 1915 were not successful, although encouraging. The later work of Mally during 1908–9 proved conclusively the value of poison sprays under South African conditions. Mally states that "a severe outbreak of the pest in a commercial peach orchard was brought to a sudden and practically complete halt, and the fruit maturing later was marked under the guarantee of freedom from maggots," while the infestation among fruits on check trees increased until practically all fruits had become infested. These experiments lead Mally to state that *Ceratitis capitata* can be controlled most perfectly under orchard conditions by means of a light sprinkling of a poisoned sweet over the trees just before or during the ripening period of the fruit. In 1912 Lounsbury demonstrated the applicability of the poison spray under town conditions in South Africa during most unfavorable weather conditions, and concluded that if spraying is properly done this remedy is applicable under town conditions, even where the summer rainfall may be heavy.

In Western Australia Newman carried on spraying experiments during a 5½-months period (December 5, 1913, to May 25, 1914) when the fruit fly was most destructive. From the orchard at Crawly Park, in which he experimented, little or no sound fruit, other than grapes, had been picked for several years. The extreme dryness of the Western Australia summer, during which little or no rain or dew falls, affords an especially opportune time for making the best use of poison sprays. Newman estimated the cost of spraying an acre, where an application of one pint of spray was made every 12 to 14 days, to be from $1.50 to $2 per fortnight, and stated that this sum was a mere bagatelle to the loss of fruit during a similar period over a like area. His work convinced Newman that good results will follow the consistent application of poison sprays, particularly when supplemented by the proper destruction of infested fruits.

In the Hawaiian Islands there are no real orchards in which spraying experiments can be conducted under commercial conditions. Severin states that while he captured in 10 kerosene traps, hung among 400 trees, 10,239 flies during a 5-weeks period before starting spraying work, in the following 5 weeks, during which these trees were sprayed about once a week, the same traps caught only 182 flies, and of these 93 were caught during the first 6 days after the first application of spray. Inasmuch as the orchard in question is composed of small citrus trees interplanted with peach and contains a few strawberry-guava, fig, Chinese-orange and rose-apple trees, and is surrounded on one side by wild guava scrub, it is unfortunate that no data were given on the time of the year the spraying was done or on the condition of the host fruits in and about so small an orchard.

The conclusions of Weinland following his spraying experiments conducted during 1912 in dooryards of Honolulu are misleading. He used the data from 7 traps as a basis for his favorable report; had he used the data from 10 other traps in the same series of his experiments which are on file with the Hawaiian Board of Agriculture and Forestry he could have shown that on the whole his experiments were not successful, and that in several instances he caught more flies after spraying than before. The writers have demonstrated from an immense amount of data on the number of flies caught in single traps throughout a given year that even when no spraying is done there may be a sufficient falling off in the numbers of fruit flies captured to mislead one into thinking that the trees had been sprayed.

The only test of poison sprays made by the writers was in an attempt to control the Mediterranean fruit fly under adverse town conditions such as have been described on page 11. The city block in Honolulu bounded by Punahou, Beretania, Wilder, and Makiki Streets was sprayed every 2 or 3 days from July 17 to August 28, 1913. The adjoining blocks to the southeast were held as a check and the number of flies captured in 145 traps in the sprayed area and in 147 traps in the check area constituted the basis for determining the benefits of the poison spray. Knapsack sprayers only were used, and while all trees and shrubs received spray, none were sprayed more than 9 feet above ground. The average number of flies caught daily each week is recorded in Table XXIX.

TABLE XXIX.—*Number of Mediterranean fruit flies caught in 145 and 147 traps hung in sprayed and unsprayed areas, respectively; spraying begun July 17, ended Aug. 28, 1913.*

Date.	Average number of flies caught each day during week ending.		Date.	Average number of flies caught each day during week ending.	
	Sprayed area.	Unsprayed area.		Sprayed area.	Unsprayed area.
July 5	1,191	769.2	Aug. 23	215.8	561.8
July 12	881.4	722.5	Aug. 30	111.1	439
July 19	936	769.4	Sept. 6	102.7	315.5
July 26	541.2	727.2	Sept. 13	71.2	219.1
Aug. 2	472.5	904.5	Sept. 20	76.5	151.8
Aug. 9	383.8	937	Sept. 27	90	141.2
Aug. 16	269.4	762.8			

The data show that the number of flies caught in the sprayed area was greatly reduced by the spraying. The reduction in flies was not great enough, however, to save fruit of any host ripening from becoming badly infested. Similar experiments conducted during May and June, 1914, in an attempt to protect peaches ripening in town dooryards were failures. Of several thousand fruits only three reached maturity uninfested.

The composition of the poisoned-bait spray used against the Mediterranean fruit fly consists of some poison, a sweet substance attractive to the adults, and water. Mally in 1909 used the following formula: Sugar, 3 pounds; arsenate of lead, 4 ounces; water, 5 gallons. He found that from 1 to 1½ pints were sufficient for the average 10-year-old peach or nectarine tree. Lounsbury in his town demonstration work used a spray consisting of 6 pounds brown sugar, 6 ounces arsenate of lead paste, and 8 gallons water. Weinland used a spray of 3½ pounds lead arsenate paste, 10 pounds brown sugar, 5 gallons plantation molasses, and 50 gallons water. Severin used the Mally formula, but increased the lead arsenate from 3 to 5 ounces. The writers used the formula of Weinland.

The writers believe that poisoned-bait sprays if carefully applied under such commercial conditions as exist in California and Florida would prove successful. Their observations indicate that honeybees are in no way affected by these sprays. It is doubtful, however, if poisoned-bait sprays will ever be practical under present-day cultural conditions in Hawaii, where no fruit crop is grown commercially, where the majority of host fruits are either inedible or not worth the cost of spraying, and where sources of reinfestation from without are so great. The entire subject of control by spraying with poisoned baits is still open for investigation under varying conditions.

COLD STORAGE.

A discussion of the use to which cold-storage temperatures may be put as an aid in offsetting the disastrous results of attack by the Mediterranean fruit fly was published by the writers [1] in 1916. The experimental work was undertaken primarily with the hope that it would be an aid in solving the discouraging problems of local horticulturists. But whatever its value in this direction, it now appears that the results may be of much greater commercial importance in defining the conditions under which cold-storage temperatures will kill the fruit fly in stored fruits, thus rendering them free from danger as transporters of this pest from one country to another, or even from one infested district to another. It seems reasonable to conclude that sooner or later the certification of properly refrigerated fruit will be practicable. When an association of fruit growers or a community awakens to a realization of the financial value of the cold-storage treatment there is reason to believe it will result in the operation of central refrigeration plants under the supervision of officials whose guarantee will insure that all fruits sent out from the plant are absolutely free from danger as carriers of the Mediterranean fruit fly.

Experimental work in Australia, as an example, has shown that such perishable fruits as peaches and Japanese plums can be placed on the European markets in good condition if sent in cold storage, and such exports have been encouraged under Government guarantees. While cold storage can never lessen the damage already done by larvæ within fruits offered for sale or shipment, and in no way deals with the root of the trouble, as a palliative, guarding fruits against further attack while in storage or transit, it may become of inestimable value. Fruits, such as apples, that contain freshly-laid eggs or very young larvæ may be placed upon the market, provided further fruit-fly development is checked by cold storage.

For the details of the effect of cold-storage temperatures upon the eggs, larvæ, and pupæ of the Mediterranean fruit fly, as well as for

[1] Back, E. A., and Pemberton, C. E., Effect of cold-storage temperatures upon the Mediterranean fruit fly. Jour. Agr. Research, v. 5, no. 15, 1916, p. 657-666; Back, E. A., and Pemberton, C. E., Effect of cold-storage temperatures upon the pupæ of the Mediterranean fruit fly. Jour. Agr. Research, v. 6, no. 7, 1916, p. 251-260.

historical facts dealing with the use of such temperatures, one should consult the two articles to which reference has been made. Fruits of almost any variety commonly placed in cold storage are held at temperatures varying from 32° to 45° F., with preference shown to a range of 32° to 36° F. By way of general summary of many experiments, including observations upon over 26,000 eggs, 60,000 larvæ, and 173,000 pupæ to determine the effect of such temperatures as 32°, 32° to 33°, 33° to 34°, 34° to 36°, 36°, 36° to 40°, 38° to 40°, and 40° to 45°, it may be said that no stage of the Mediterranean fruit fly can survive refrigeration for seven weeks at 40° to 45° F.; for three weeks at 33° to 40° F., or for two weeks at 32° to 33° F.

EFFECT OF FREEZING TEMPERATURES UPON THE EGG, LARVA, AND PUPA.

The only freezing temperatures available in Hawaii for experimental work with eggs, larvæ, and pupæ were those found in cold-storage plants maintaining rooms for the refrigeration of fish and meat. The temperature of these rooms ranged between 21° and 30° F. though averaging close to 26° F. Out-of-door freezing temperatures have been experienced by the writers on the Island of Hawaii at an elevation of over 8,000 feet, but lasted only for a few hours at a time and occurred on mountain slopes not easily accessible.

THE EGG.

Apples in which fruit-fly eggs had been deposited on November 3, 1914, were placed in cold storage at a temperature varying from 24° to 30° F. Fruit was removed daily for 10 consecutive days and observations made on a total of 5,434 eggs contained within them. No eggs survived more than 7 days of refrigeration at this temperature. Of 507 eggs subjected to 25° F. for one day 414 hatched on removal to normal temperature; 275 of 308 eggs subjected to 24° to 25° F. for 2 days hatched after removal; 588 of 741 eggs hatched on removal after refrigeration for 3 days at 24° to 26° F.; 430 of 748, 65 of 384, 7 of 534, and 1 of 255 eggs hatched on removal after refrigeration at 24° to 30° F. for 4, 5, 6, and 7 days, respectively. All of 606, 624, and 727 eggs removed to normal temperature after 8, 9, and 9 days of similar refrigeration were dead.

In a second experiment carried out during July, 1913, peaches containing eggs were picked promiscuously in the field, and placed in storage at 26° to 30° F. The results were similar to those mentioned above, as 42 of 178, 7 of 10, and 20 of 145 eggs hatched on removal, after refrigeration for 1, 2, and 6 days, respectively; 57, 148, 82, 134, and 14 eggs refrigerated for 7, 9, 10, 11, and 12 days were dead on removal from storage.

THE LARVA.

First-instar larvæ.—A total of 2,116 first-instar larvæ were placed in cold storage at 21° to 28° F. None survived more than 5 days of refrigeration, and the following observations were recorded: 62 of 248 larvæ in refrigeration for 5 days were found living on examination after removal to normal temperature; 297 of 340 survived one day of refrigeration at 22° to 23° F.; 239 of 275 survived two days of refrigeration at 21° to 23° F.; 110 of 243, and 44 of 240 survived refrigeration at 21° to 28° F. for 3 and 4 days, respectively; 264, 132, 213, and 141 larvæ refrigerated for 6, 7, 8, and 9 days, respectively, were dead on removal from storage.

In a second room, the temperature of which ranged from 26° to 30° F., infested peaches were placed. An examination of the contained larvæ after refrigeration gave results similar to those above; 21, 9, 9, and 19 larvæ were found dead after 5, 6, 9, and 12 days of refrigeration, and 336 removed after refrigeration from 13 to 15 days were dead.

Second-instar larvæ.—A total of 3,216 second-instar larvæ were subjected to freezing temperatures with the following results: 367 of 377, 77 of 123, and 9 of 195 larvæ were found living on removal to normal temperatures after refrigeration for 1, 2, and 3 days, respectively, at 21° to 29° F. An average of 361 larvæ removed after refrigeration 4, 5, 6, 7, 8, 9, and 10 days were dead. No living larvæ were found after the third day of refrigeration.

Third-instar larvæ.—Of a total of 6,774 third-instar larvæ in kamani nuts (*Terminalia catappa*) subjected to freezing temperatures ranging between 22° and 27° F. for 1 to 9 days, 82 of 157 and 4 of 510 larvæ were found alive upon removal after refrigeration at 24° to 27° F. for 1 and 3 days, respectively. Only 3 of 524 were alive on removal after 4 days of refrigeration at 22° to 27° F. An average of 1,221 larvæ removed daily between the fifth and ninth days of refrigeration were dead.

After refrigeration at 26° to 30° F. 114, 7, 1, 12, and 124 larvæ in peaches were found dead on removal after 5, 6, 9, 12, and 15 days, respectively, of refrigeration. Ten badly infested peaches were removed to the laboratory after 3 days of refrigeration and from two of these there later emerged 1 and 9 full-grown larvæ which pupated normally and produced adults. No adults were reared from 15 peaches removed after 14 days of refrigeration.

Fourteen peaches held in refrigeration 5 days at 26° to 30° F., then successively for 24 hours each at 33° to 38° F. and 40° to 45° F., were removed to the laboratory. A total of 36 third-instar larvæ, found within the fruit, were dead.

THE PUPA.

A total of 21,450 pupæ have been subjected to freezing temperatures varying from 24° to 32° F. and averaging about 26° F. All pupæ were fatally injured before the end of the fourth day of such refrigeration. Three hundred 3-day-old pupæ, 100 2-day-old pupæ, and 200 1-day-old pupæ on removal to normal temperature after 3¾ days of refrigeration at about 26° F. produced 1, 1, and 1 adults, respectively. Under similar conditions only 2 of 100 4-day-old pupæ and 3 of 200 3-day-old pupæ produced adults after 3 days of refrigeration. Each lot of pupæ ranging from 1 to 9 days old and totaling 1,900 individuals yielded from 2 to 22, or a total of 78 adults, after 2 days of refrigeration. Even 1 day of refrigeration at 26° F. proved fatal to a large percentage of pupæ, especially the younger, as evidenced by data in Table XXX covering observations on 1,500 pupæ.

TABLE XXX.—*Effect of 26° F. upon pupal life. Pupæ placed in cold storage Oct. 27, 1914; removed to normal temperature Oct. 28.*

Age of pupæ (days).	Number of pupæ.	Number of adults emerging on—									
		Oct. 30.	Oct. 31.	Nov. 1.	Nov. 2.	Nov. 3.	Nov. 4.	Nov. 5.	Nov. 6.	Nov. 7.	Nov. 8.
9	100	5	18	4	....	....	....	....	....	....	....
8	100	1	6	42	10	....	....	....	....	....	....
7	100	....	....	5	15	12	....	....	....	....	....
6	200	....	....	....	....	45	5	....	....	....	....
5	200	....	....	....	....	....	9	1	....	....	....
4	200	....	....	....	....	....	5	7	....	....	....
3	200	....	....	....	....	....	....	14	21	....	....
2	200	....	....	....	....	....	....	....	7	3	....
1	200	....	....	....	....	....	....	....	13	2	1

During May, 1913, 500, 119, and 331 pupæ of all ages were placed in cold storage, the temperature varying from 22° to 24° F. for 5, 7, and 12 days, respectively. After removal to normal temperature all pupæ were found to be dead. During July, 1913, 2,000 pupæ of various ages were subjected to a temperature varying from 24° to 30° F. and averaging about 26° F. for 3 to 16 days; none yielded adults after removal from storage even after only 3 days of refrigeration. On June 24, 1913, 2,500 pupæ removed from storage after one month of refrigeration at about 26° F. were found dead.

Pupæ held in refrigeration 4 days at 24° to 30° F. were removed to normal temperature after being held 2 successive days at 33° to 38° F. and 40° to 45° F., respectively, but none yielded adults.

TRAPS.

The idea of exposing in infested areas a substance that will attract both sexes of the Mediterranean fruit fly is an excellent one, and may lead to the discovery of some medium which will prove an effective method of control. It was the writers' idea to simulate, in such a substance, the odor emanating from the male *C. capitata*, but the experiments proved unsuccessful. Severin exposed various oils derived from crude petroleum, but found them ineffective. He also used, without satisfactory results, turpentine, coconut oil, citronella, whale and fish oils, vinegar, and vanilla. Hooper in Western Australia experimented with naphtha and turpentine in 1907 without success, and similar results followed the exposure by Gurney in New South Wales of citronella, linseed, salad, whale, neatsfoot, and fish-oils. Howlett, in India, was able to attract males of *Dacus zonatus* and *D. diversus* by exposing citronella oil. Later he believed that he had found the actual substances which are responsible for the attraction of these two species in isoeugenol and methyleugenol. Three traps containing, in the order mentioned, eugenol, methyleugenol, and isoeugenol hung in orange trees in a badly infested area of Honolulu captured in 6 days only 2, 10, and 1 male *C. capitata*, as compared with 77, 153, and 48 males captured in check traps containing kerosene hung within 50 feet of them. These three substances were furnished the writers by Severin, who had received them in turn from Howlett.

Much of the experimental work to which reference has just been made represents but a small amount of that undertaken to determine the effectiveness of traps. It has grown out of the accidental discovery in Australia by a housewife that a coating of kerosene oil, put about a post for the protection of a glass of preserves from ants, was attractive to adult *C. capitata*. This observation led to the heralding, in 1907, of the use of kerosene as a method of control as the "best discovery against the fruit fly in years," and to regulations in Western Australia requiring fruit growers to place from one to two traps in each fruit tree. It is natural that entomologists combating this pest should carry on experiments, but the worthlessness of kerosene as a factor of control was not demonstrated until a considerable literature upon the subject had been published. Kerosene is ineffective, inasmuch as it attracts for the most part only males. Of 2,639 adults, representing four lots examined by the writers, only eight were females. Only 36 of 10,239 adults captured by Severin were females. Many thousands of adults captured in kerosene oil in connection with the present investigations have demonstrated the worthlessness of kerosene as a factor in reducing the infestation of fruit.

While the use of kerosene to trap the adults of the Mediterranean fruit fly is of no value in checking the ravages of this pest, the writers have made use of the number of males captured in traps to arrive at conclusions regarding the relative abundance of adults in any given area. The use of the kerosene trap for this purpose when supplemented by other observations has a value, provided conclusions are not attempted from too small a number of catches. The writers have data on file covering the number of flies caught in 292 traps for 16 consecutive months. As a rule traps hung in dense foliage of any sort captured more flies, while traps hung on porches and set upon stumps or in other exposed situations from 30 to 80 feet away from foliage captured only an occasional male. It would seem that in countries where host trees and shrubs are less abundant than in Hawaii the number of flies caught could be used as a basis for valuable deductions on such subjects as seasonal abundance and migrations of adults.

Description of trap.—The trap used by the writers is a simple affair consisting of an ordinary pie tin suspended by three tin strips from a tin cone through the top of which extends a wire by which the entire trap may be suspended from a branch. A trap can be made cheaply by any tinsmith. If properly painted, traps will last several seasons. The pan may be removed as often as desired. In Honolulu the oil was replenished every 2 or 3 days. In dry areas no protective covering for the pan containing the oil is needed. Oil to cover the bottom of the container to a depth of one-fourth of an inch is sufficient. The trap should be so long that no oil will spread to the bark of the tree.

SUBMERGENCE IN WATER.

Submergence of host fruits as a method of control has been recommended many times by writers and investigators of fruit flies. Harris recommended weighting sacks of infested fruit and sinking them at sea. Gurney found that larvæ in sea water in test tubes pupated at the surface against the glass and that a large percentage of larvæ in oranges submerged in cold water for 6, 8, 24, and 45 hours survived, pupated, and matured into normally healthy adults, and concluded that no casual treatment such as throwing infested fruit into a stream can be considered an effective method of destroying fruit-fly larvæ. Severin showed that many well-grown larvæ found floating on the top of a barrel of water, into which infested oranges had been thrown 24 hours previous, resumed activity within several hours after being placed on moist filter paper, in spite of the fact that they were distended and apparently dead when removed from the water. A small percentage of other larvæ taken from the water after 3 days showed traces of life, but no adults developed from the fruit submerged for 4 days.

With the temperature ranging between 67° and 80° F. the writers were able to demonstrate that well-grown larvæ placed in tightly stoppered vials of fresh water died by the end of the third day. Thus 486 of 490 larvæ survived submergence 21 hours, 96 of 100 for 24 hours, and 78 of 100 for 48 hours; two lots of 100 larvæ each submerged 70 and 74 hours, respectively, were dead. It was found, however, that larvæ live longer when placed in water in open vials. Under such conditions certain individuals may remain suspended from the surface film of water much as do mosquito larvæ and pupæ. This is made possible by the circlet of small hairs about the posterior stigmal plates. While larvæ ordinarily become rigid and apparently dead within 2 or 3 hours after submergence in water, larvæ thus suspended were found to remain active for as long as 7 days in one instance. One larva removed to fresh fruit after suspension for 5 days pupated 7 days later and emerged as an adult after 9 days in the pupa stage.

TABLE XXXI.—*Effect of submergence of host fruits in water upon the larvæ of the Mediterranean fruit fly.*

Number hours immersed.	Host fruit.	Number of fruits examined.	Dead larvæ.			Living larvæ.		
			First instar.	Second instar.	Third instar.	First instar.	Second instar.	Third instar.
23	Apple	4	4	0	64	0	106	18
41	Apple	2	104	81	0	0	4	0
72	Apple	6	0	91	32	0	0	0
94	Apple	8	0	262	107	0	0	0
4	Winged kamani	21	0	0	0	0	63	279
22	Winged kamani	22	0	0	5	0	113	448
49	Winged kamani	23	0	0	88	0	0	51
72	Winged kamani	33	0	0	179	0	0	12
96	Winged kamani	253	0	0	1,376	0	0	1
98	Winged kamani	21	0	0	142	0	0	0
120	Winged kamani	34	0	0	147	0	0	0
4	Rose apple	4	36	80	0	0	0	0
24	Rose apple	5	0	9	0	0	8	17
70	Rose apple	50	0	0	217	....	....	....
72	Rose apple	1	0	12	0	0	0	0
98	Rose apple	3	0	37	0	0	0	0
18	Chinese orange	94	0	123	189	....	72	97
45	Chinese orange	39	0	71	163	....	....	3
69	Chinese orange	34	0	0	191	....	....	....
72	Chinese orange	162	....	....	205	....	....	....
94	Chinese orange	50	....	57	98	....	....	....
116	Chinese orange	33	....	....	22	....	....	....
18	Guava	9	....	63	9	....	51	168
46	Guava	4	....	....	45	....	....	3
69	Guava	4	....	19	65	....	....	....
94	Guava	7	....	....	61	....	....	....
49	Strawberry guava	35	....	....	14	....	....	11
72	Strawberry guava	54	....	17	37	....	....	....
96	Strawberry guava	107	....	....	38	....	17	....
4	*M. elengi*	5	28	....	....	....	40	36
74	Orange	2	....	9	5	....	....	....
96	Orange	6	....	14	87	....	....	....
121	Orange	8	....	9	32	....	....	....
66	Peach	58	....	....	156	....	....	2
91	Peach	50	....	....	422	....	....	....

The examination of various host fruits submerged in ordinary tap water, when the temperature ranged between 67° and 80° F., gave the data recorded in Table XXXI. The data indicate that while larvæ are little affected after 1 or 2 days of submergence, a large percentage are dead after submergence for 3 days. Seventeen second-instar larvæ and 1 third-instar, however, were found living after submergence for 4 days. It is safe to conclude that submergence for 5 days will either kill all larvæ or incapacitate them for further development. It might be added that fruits held in water for as long as 3 to 5 days are, in Hawaii, rendered unfit as food for fruit-fly larvæ after removal from water.

TABLE XXXII.—*Effect of submergence in tap water upon pupæ of the Mediterranean fruit fly.*

Lot number.	Number of pupæ under observation.	Number of days immersed.	Date of pupation.	Date of immersion.	Date of removal.	Number of adult C. capitata emerging.	Number of adult Opius humilis emerging.	Date of emergence.
						650	3	June 27-28
						191	15	June 29.
1	1,016	2	June 14-17	June 24	June 26	4	18	June 30.
						....	16	July 4.
						....	1	July 5.
						62	0	July 1.
2	440	3	....do......	...do.....	June 27	16	3	July 2.
						1	1	July 3.
						4	0	July 1.
3	312	4	....do......	...do.....	June 28	3	0	July 2.
						0	1	July 4.
4	410	5	....do......	...do.....	June 29	0	0	
5	258	6	....do......	...do.....	June 30	1	0	July 7.
6	214	7	....do......	...do.....	July 1	0	0	
						32	0	June 29.
						207	5	June 30.
						190	7	July 1.
7	950	2	June 17-22	...do.....	June 26	156	18	July 3.
						39	8	July 4.
						6	0	July 5.
						18	2	July 6.
						64	0	July 1.
						76	....	July 3.
8	460	3	....do......	...do.....	June 27	41	....	July 4.
						16	....	July 5.
						9	1	July 6.
						3	....	July 9.
						1	....	July 1.
						25	....	July 3.
						23	3	July 4.
9	210	4	....do......	...do.....	June 28	9	2	July 5.
						17	....	July 6.
						19	1	July 7.
						1	1	July 8.
						2	....	July 3.
						19	....	July 4.
						19	....	July 5.
10	557	5	....do......	...do.....	June 29	42	....	July 6.
						18	....	July 7.
						22	....	July 8.
						5	....	July 9.
						13	....	July 7.
11	372	6	....do......	...do.....	June 30	6	....	July 8.
						3	....	July 10.
						3	....	July 12.
12	476	7	....do......	...do.....	July 1	0	0	
Total....	5,675							

Pupæ from 1 to 4 days old were submerged in vials of tap water when the temperature ranged from 72° to 85° F. A record of the emergence from these pupæ is given in Table XXXII. The data covering lots 1 to 6 show that the more mature pupæ succumbed to immersion more quickly than the younger pupæ of lots 7 to 12. Thus many of the young pupæ emerged as adults after being submerged 4, 5, and 6 days, while submergence for these periods killed nearly all the older pupæ. Submergence for at least 7 days is necessary to assure the death of all pupæ.

BURIAL IN SOIL.

Many entomologists have made statements regarding the efficacy of burying infested fruits in the soil as a method of destroying fruit flies. These references have been summarized by Severin, hence need not be considered at length here, particularly as they deal with a method that is decidedly unsatisfactory and seldom effective. Gurney found that pupæ buried 6, 8, and 12 inches below the surface of the soil produced adults that were able to escape. Severin found that adults could make their way to the surface from pupæ buried 2, 3, and 4 feet beneath dry sand, and from pupæ buried 2 feet beneath wet sand, but that no adults escaped through 2, 3, or 4 feet of dry soil. Mally found that 10 inches of soil shoveled loosely over fruits did not prevent adults from escaping later, but that no adults could reach the surface through 10 inches of well-tamped soil. No adults escaped from 20 pupæ placed in the center of a cake of mud one-half inch square taken from the heavy, tenacious soil of the vegetable gardens at Waikiki. The mud became thoroughly dry without cracks before the end of the normal pupa stage. A cake of the same soil 1½ inches square, however, on drying developed a crack through which 50 adults made their escape from 75 pupæ buried within the center of the square. While adults can not make their way through a foot of well-tamped soil, it is difficult to bury host fruits in such a manner that the soil covering will remain firm. The rapid decay and settling of fruit, if any amount be buried in the same excavation, cause cracks to develop through which adults can escape readily. While many fruit flies can be killed by proper burial, indifference and carelessness among workmen will always make possible the escape of many adults.

BURNING AND BOILING HOST FRUITS.

Burning or boiling host fruits is a sure method of destroying the immature stages of the Mediterranean fruit fly provided the work is feasible and can be done thoroughly. The usual practice of throwing fallen infested fruits into a compost pit and burning over them every few days such trash as may have accumulated is not a trustworthy method of destruction, inasmuch as the heat produced is very often insufficient to cook or burn the fruit thoroughly or to reach the pupæ in the soil beneath the fruit.

SUMMARY.

The Mediterranean fruit fly (*Ceratitis capitata*) was discovered at Honolulu in the Hawaiian Islands in 1910. Since that time it has spread to all the islands of the Hawaiian group, and because of the equable climate and abundance of host fruits, has effected a serious and permanent check to horticultural pursuits, and put an end to all export trade in fruits except that in bananas and pineapples.

Research seems to have fixed the native home of *C. capitata* in tropical Africa. Its spread has been slow but persistent throughout tropical and semitropical countries, until at the present time it is known to have become a pest in every continental area except that of North America. With the Mediterranean fruit fly now well established in Bermuda and the Hawaiian Islands, it would seem that it is only a matter of time before it will be inadvertently introduced and become established in California and the Southern States. The frequent interception and destruction of infested fruits from Hawaii at California ports, by officers of the Federal Horticultural Board, indicates the ease with which the introduction of the Mediterranean fruit fly might occur were Hawaiian fruit permitted unrestricted entry to the mainland of the United States.

No edible fruit in Hawaii, except the pineapple, escapes attack. The banana, when in good condition, is never infested, infestation having been noted only when the fruits were overripe or injured. The Mediterranean fruit fly has been reared in Honolulu from 72 species of host fruits, including the peach, plum, pear, guava, mango, orange, lemon, grapefruit, banana, etc. A large proportion of the host fruits are inedible. Throughout the littoral regions a continuous cycle of host fruits is available for infestation throughout the year; hence there are no starvation periods for the fly to survive.

With such a quantity and variety of host fruits, nuts, and vegetables in which to propagate, and enjoying an ideal climate, the mean temperatures of which vary between 68° and 79° F. for the regions in which the fly is a most serious pest, the Mediterranean fruit fly finds no check to its rapid increase. While a single generation may require as few as 17 days during the warmest weather, there are usually 15 to 16 generations a year at Honolulu, and 10 to 12 generations in areas where the winter mean drops to 68° F. There is considerable variation in the length of the immature stages, particularly during the coolest weather. Inasmuch as adults have been kept alive for 10 months and may deposit eggs in lots of a few to 32 daily quite regularly throughout life, the generations become hopelessly confused. While adults are not forced in Hawaii to pass through periods of several months when food is not available for oviposition, females deprived of host fruits for such periods will resume active and normal oviposition when the fruits become available. One female deposited 622 eggs between June 4 and September 2. The long adult life, and the ability of the female to deposit eggs regularly succeeding the period of from 4 to 8 days after emergence which is required to complete sexual maturity, make it possible for the annual progeny of a single pair of adults to reach enormous numbers.

Attempts at control by clean culture have been failures, owing largely to insurmountable obstacles placed in the way of man by a favorable climate and an unprecedented quantity of varied host fruits. Many fruits and nuts subject to attack grow on huge trees which blossom irregularly, and produce, in many instances, fruit susceptible to attack throughout the year. There is no procedure by which clean culture may be made effective under the present Hawaiian cultural methods. The islands are thoroughly overrun with the fruit fly, and this applies quite as much to the wild guava scrub in pastures, on lava flows, and in mountain valleys and ravines, as it does within the city limits. By far the larger number of host trees and shrubs are grown more for the protection they offer from the semitropical sun and for their ornamental value than for their inedible fruits. The destruction of host vegetation will not be practicable until it can be demonstrated that a distinct advantage would be gained thereby. To destroy all host trees of Honolulu at the present time would be to remove a large percentage of her prized vegetation without any compensating returns.

The ideal climatic and host conditions of Hawaii have rendered less effective and impracticable the usual artificial methods of control the value of which has been demonstrated in other countries possessing natural features less favorable to fruit-fly increase. At the present time the only hope of relief lies in the establishment of parasites. Six parasites have been introduced during the past three years and are now well established. While they have more than repaid the Territory of Hawaii for the cost of their introduction by bringing about an improved condition in the coffee-growing industry, it is doubtful whether they will effect a sufficient decrease in the proportion of infested host fruits to be considered efficient factors in control. This conclusion appears inevitable in spite of the remarkable success attendant on their introduction, unless a campaign is inaugurated for a reapportionment of host fruits; otherwise the hordes of adult flies maturing in thick-meated fruits, or in fruits protecting larvæ by other means from attack by parasites, will neutralize the effective work of parasites attacking larvæ in thin-skinned and thin-pulped fruits. There is great need of an effective egg parasite that will kill the fruit fly before the larva can do injury.

From a practical or commercial standpoint the results of the investigations reported herewith are of value (1) in furnishing data to determine the probable range of this pest should it be introduced and gain a foothold in continental United States; (2) in verifying the practicability of poison sprays; (3) in indicating the utilization of cold-storage temperatures in making safe the movement of fruits from areas which might otherwise be cut off by quarantines from outside markets; and (4) in placing upon a sound basis the banana and pineapple export trade of the Hawaiian Islands.

At 50° F. little if any development takes place, and freezing temperatures can be withstood successfully only for short periods. Accumulated data indicate that the Mediterranean fruit fly will not become a serious pest in climates where the mean temperature is below 50° F. during periods covering three months of the year.

While Hawaiian conditions are unfavorable to the use of poison sprays, the work of the writers has convinced them that these sprays can be employed as successfully in combating this pest in commercial orchards of California and of Southern States, should they ever become infested, as in Africa and Australia.

While at present cold storage is not utilized to modify existing quarantine, it is a recognized fact that, commercially used, it has been of value in safeguarding fruits from additional infestation while en route over long distances. The data set forth herewith indicate for the first time the duration of time required for various temperature ranges to kill the stages of the fruit fly within stored fruits, and from these records it is reasonable to conclude that the certification of properly refrigerated fruit is practicable. When an association of fruit growers or the people discover that refrigeration is financially worth while, there is reason to believe that it will result in the operation of central refrigeration plants under the supervision of officers whose guarantee will insure that all fruits sent out from the plant are absolutely free from danger as carriers of the Mediterranean fruit fly.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 539

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER. September 8, 1917

THE LESSER CORN STALK-BORER.[1]

By PHILIP LUGINBILL and GEO. G. AINSLIE, *Entomological Assistants, Cereal and Forage Insect Investigations.*

CONTENTS.

INTRODUCTION.

Although the lesser corn stalk-borer (*Elasmopalpus lignosellus* Zell.) heretofore has occurred in injurious abundance only in sporadic outbreaks, it now has become an insect of considerable economic importance in the Southern States, since crops grown in the poorest types of soils, or in soils lacking humus, are usually the most seriously affected. The injuries to plants by larvæ of this species sometimes resemble closely those of certain beetle larvæ commonly known as "budworms" (*Diabrotica 12-punctata* Fab.) and it seems probable that injuries frequently attributed to the latter are in reality the work of the lesser corn stalk-borer.

While engaged in other investigations early in the season of 1913 near Columbia, S. C., the senior author was informed by the authorities superintending the State farm near that city that the lesser corn stalk-borer was responsible for considerable damage to their field crops almost every year. Investigations begun immediately were continued through 1914 and 1915. The junior author, while engaged in certain investigations in Florida during the winter of 1913–14, encountered this same species in destructive numbers.

The following paper, therefore, is a compilation of the results obtained from studies made at Columbia, S. C., during the years 1913–1915 by the senior author (27)[2] and at Lakeland, Fla., in 1913–1914, by the junior author.

[1] The authors wish to acknowledge the cooperation of A. H. Beyer and H. L. Dozier in field investigations.

[2] Reference is made by number to "Literature cited," p. 25.

ECONOMIC HISTORY.

Although the lesser corn stalk-borer was originally described by Zeller (3) in 1848, and was known to scientific workers from several parts of the Western Hemisphere, it was not until 1881 that it began to have other than a purely scientific interest. In July, 1881, C. V. Riley, then entomologist of the United States Department of Agriculture, was notified that an insect (later identified as this species) was injuring corn, both old and young, in the vicinity of Augusta, Ga. Steps were taken at once to learn more of the life history and habits of the pest, and agents of the Division of Entomology spent the remainder of the year conducting investigations at these points in order that they might be able to propose remedial or preventive measures. The studies made at that time showed that this insect had not been known as a pest until about 1878, and that during the period 1878–1881 it had become of economic importance in Georgia and South Carolina, specimens being taken even as far north as Chapel Hill, N. C. The life history was partly worked out and published by Dr. Riley (8, 9, 10)[1]; but, as no further complaints were received, the investigation was suspended.

In a discussion of the corn insects of Nebraska, Prof. Lawrence Bruner (14) published a brief account of this species and its work, but did not state that it had been found in Nebraska. In 1884 (11) and again in 1893 (16) Riley listed it as injurious to the stalk of corn.

Not until nearly twenty years after the first recorded damage did it again become the object of special study by entomologists. In 1899 Dr. F. H. Chittenden, of the Bureau of Entomology, received complaints of injury to beans by the insect in Alabama and South Carolina, and also to peanuts in Georgia (19). Specimens of the insects sent to Washington were identified as *Elasmopalpus lignosellus*, and further biological studies were begun. All the available information at this time was brought together, and the results published in Bulletin 23 of the Division of Entomology by Dr. Chittenden (18). A brief note by Dr. Chittenden (21) in Bulletin 40 of the Bureau of Entomology, published in 1903, reported damage to cowpeas in Texas and Virginia, and the Yearbook of the United States Department of Agriculture for 1903 (22) records injury to cowpeas, beans, and soy beans in Texas, Alabama, and Virginia, part of these records undoubtedly being repetitions of those given in Bulletin 40. In 1904 Titus and Pratt (23) listed it as injurious to corn, beans, and peas.

Dr. S. A. Forbes (24) included this species in his monograph of the insects injurious to corn, drawing largely from Riley's account in describing its habits and methods of attack. He added the information, however, that adults had been taken in Illinois in August

[1] See "Literature cited," p. 25.

and September, but the account does not indicate that the species caused damage in the State at that time.

In 1905, as reported in the Yearbook of the United States Department of Agriculture for that year (25), sorghum, cowpeas, and crabgrass were totally destroyed in some fields near Columbia, S. C., and reports of damage were received from other localities in South Carolina and Georgia. On November 4, 1915, the junior author also found at Nashville, Tenn., a small wheat plant killed by a larva which was nearly full grown and which entirely filled the burrow that it had excavated in the stem.

SYSTEMATIC HISTORY AND SYNONYMY.

The lesser corn stalk-borer was first described by Zeller (1) from Brazil, Uruguay (Montevideo), and Colombia, South America, and a single female from "Carolina," U. S. A. In this article, aside from the specific description, Zeller describes three unnamed varieties, basing his descriptions almost entirely on color variations. No further notes are given in this account except from the localities listed. Four years later Blanchard (2) redescribed the species under the name *Elasmopalpus angustellus*, erecting for its reception the genus Elasmopalpus, which recently has been accepted as the proper position for the species. Not until two decades later is there a further reference to the species in the literature, when Zeller (3), in an article dealing with some North American moths, adds somewhat to our knowledge of its seasonal and geographical distribution, recording it from Brazil and Colombia, in South America, and "Carolina" and Texas, in the United States. At the latter place three females were taken, one on July 15 and the other two a month later. He also adds the descriptions of two varieties, *incautella* and *tartarella*, based on color variations. Each of these varieties was described from a single specimen, and both were taken at the same place and on the same date. The species as a whole is extremely variable and Zeller himself in a later publication (7) placed *incautella* as a synonym of *lignosella* though still retaining *tartarella* as a valid variety. Another variety, designated as "variety *B*," was described by Zeller (4) from material collected at Valparaiso, Chile. In 1875, Berg (5), using material taken in Patagonia and elsewhere in southern South America, supplemented Blanchard's description of *E. angustellus*, going into detail, particularly in describing the venation, and two years later, in a further paper on Patagonian insects (6), came to the conclusion that the species he had been considering Blanchard's *angustellus* was Zeller's *lignosella*. Since both the species are genotypes, the reduction of *angustellus* to a synonym of *lignosella* made Elasmopalpus a synonym of Pempelia, where it remained until revived by Hulst in 1890 (13) for this same species. In 1881 Zeller (7) gave some notes on the amount of variation in the species, basing his remarks on a collection of 25 specimens from Colombia, South America, most of them taken in September and October.

Hulst (12) redescribed this species as new, from Texas, under the name *Dasypyga carbonella*, a mistake which he later rectified in his monograph of the Phycitidae (13), in which he places *carbonella* as a synonym of Zeller's variety *tartarella*. In the same publication he redescribes *lignosellus*, places it in the genus Elasmopalpus for the first time under that name, and gives a bibliography and notes on the distribution and seasonal occurrence.

Ragonot (15) covers much the same ground as several of the previous authors, giving the synonyms, bibliography, and a description of the species and calling attention to its great variability. He also uses the name *major*, the first word of Zeller's description, for the variety *B* mentioned above and lists it as a variety of the species *lignosellus*. Smith (17 and 26) records the species from New York, and Dyar (20) lists it with its synonyms in his catalogue of the Lepidoptera of North America, giving the distribution as the Atlantic States and South America.

The junior author has gone carefully over all the descriptions given by the various authors mentioned above, examining the specimens in the United States National Museum, and has come to the conclusion that the use of all varietal names in this species may well be discontinued. The varieties that have been described are not constant in any respect either as to size, geographical distribution, or seasonal occurrence, and apparently they indicate merely individual aberrations in color, size, or markings. The synonymy, then, stands as follows:

Pempelia lignosella Zeller (1),
Elasmopalpus angustellus Blanchard (2),
Pempelia lignosella tartarella Zeller (3),
Pempelia lignosella incautella Zeller (3),
Dasypyga carbonella Hulst (12),
Elasmopalpus lignosellus (Zeller) Hulst (13),
Elasmopalpus lignosellus incautellus (Zeller) Hulst (13),
Elasmopalpus lignosellus tartarellus (Zeller) Hulst (13).

GEOGRAPHICAL DISTRIBUTION.

This species is limited in its occurrence to the Western Hemisphere. It occurs practically throughout South America, having been reported from widely separated localities in all parts of that continent. The list as given by Hulst includes Venezuela, Colombia, Brazil, Argentina (Buenos Aires), Chile, and "Patagonia." In North America (fig. 1), while its range is not so great, it may be said to occur over the entire southern half of the United States. It has been most commonly reported from the States bordering the Gulf of Mexico and the southern Atlantic coast. It has been encountered causing injury in Arizona. Dr. Forbes reports it as having been taken at various points in southern Illinois. There is a specimen in the National Museum rather indefinitely labeled "Iowa." The late Prof. F. M. Webster observed some of the moths years ago at Lafayette, Ind. In addition to the one mentioned above there are specimens in the National Museum bearing locality labels indicating that the moths have been taken at Cohasset, Mass.; Clemson College, S. C.; Miami, Palm Beach, and Lakeland, Fla.; New Orleans, La.; Dallas, Brownsville, Sabinal, Kerrville, Victoria, and Burnet County, Tex.; and San Diego, Cal. John B. Smith, in his List of the Insects of New Jersey, records it from Newark and Montclair and states that it will

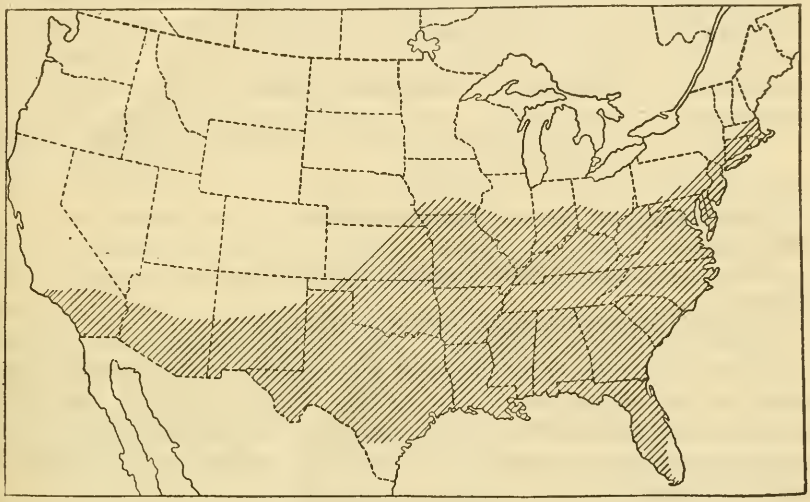


FIG. 1.—Map showing present known distribution of the lesser corn stalk-borer (*Elasmopalpus lignosellus*) in the United States. (Original.)

be found throughout the State. It undoubtedly occurs throughout Mexico and has been reported from the Bahama Islands.

FOOD PLANTS.

The following is a list of food plants upon which the larvæ of this species have been found to feed, given here with locality, date, and collector or observer:

BEANS:

Auburn, Ala., August 16, 1889 (F. S. Earle); Charleston, S. C., September 27, 1889 (H. M. Simmons).

CORN (*Zea mays*):

Augusta, Ga., 1881 (C. V. Riley); Illinois, 1905 (S. A. Forbes); Lakeland, Fla., April 25, 1913 (Geo. G. Ainslie); Columbia, S. C., 1913–1914 (P. Luginbill); Tempe, Ariz., October, 1914 (Edmund H. Gibson).

COWPEAS:

Victoria, Tex., August 30, 1902 (W. D. Hunter); Fredericksburg, Va., September 2, 1902 (G. W. Koiner); Columbia, S. C., and other points in the State, and Georgia, 1905 (F. M. Webster); Columbia, S. C., 1914 (P. Luginbill); Gainesville, Fla., July and August, 1916 (R. N. Wilson and H. L. Dozier); Boca Grande, Fla., June 29, 1916 (H. L. Dozier); Arcadia, Fla., June and July, 1916 (Joseph Crews).

CHUFA (*Cyperus esculentus*):

Arcadia, Fla., June and July, 1916 (Joseph Crews).

CRAB GRASS (*Eleusine indica*):

Columbia, S. C., other points in the State and Georgia, 1905 (F. M. Webster); Columbia, S. C., August 27, 1913 (P. Luginbill).

JAPANESE CANE:

Arcadia, Fla., June and July, 1916 (Joseph Crews).

JOHNSON GRASS:

Tempe, Ariz., November 3, 1914 (Edmund H. Gibson).

MILO MAIZE:

Tempe, Ariz., October, 1914 (Edmund H. Gibson).

PEANUTS:

Athens, Ga., September 25, 1889 (Thomas I. Todd).

SORGHUM:

Columbia, S. C., other points in the State and Georgia (F. M. Webster); Columbia, S. C., 1913–1915 (P. Luginbill).

SUGAR CANE:

New Orleans, La., June 16, 1914 (T. E. Holloway).

TURNIPS:

Athens, Ga., October, 1889 (Thomas I. Todd), feeding on the leaves.

WHEAT:

Nashville, Tenn., November 4, 1915 (Geo. G. Ainslie).

Although it would seem from the above that the larvæ are omnivorous, the investigations of the writers disclose the fact that they show a decided fondness for the Gramineæ and probably would confine themselves almost exclusively to plants belonging to this order if always obtainable.

RECENT INJURIES.

This species is particularly injurious because it shows a decided fondness for attacking plants growing in sandy soil. Soil of this type generally is deficient in fertilizing elements and also suffers very quickly from drought. Consequently plants growing in such soil are not as thrifty and vigorous as those growing in loamy soils, and when attacked they lack vitality to counteract the injury and suffer more than do those in soils of more favorable nature. It frequently occurs that only certain portions of the field are of this sandy type and in such cases infestation is confined to the sandy areas, it often being difficult to find larvæ in the rest of the field.

During the summer of 1913 about 2 acres of sorghum in a field on the State farm near Columbia, S. C., was practically laid waste by the ravages of this species. The soil in this area was almost pure sand, while the rest of the field was sandy loam. In many instances, as shown in Plate I, figure 2, no trace of plants could be found when the photograph was taken, the larvæ having killed them outright when young. Those that did survive were much dwarfed and rendered practically worthless, and in most instances were devoid of central stems.

In the latter part of April, 1913, fields of small corn near Lakeland, Fla., were being attacked and ruined by these larvæ, about 10 per cent of the plants exhibiting evidences of injury at this time. The plants continued to die for about 10 days, at the end of which time in some portions of the fields fully 90 per cent were dead and the stand everywhere was poor. The parts of the fields most lacking in humus suffered the greatest injury. During the same year considerable damage was done to cowpeas in fields near Columbia, S. C., the soil in the infested fields being very gravelly and in some places composed of almost pure sand. The injured plants, at the time of the discovery, were wilting, which made it appear as though they were suffering from want of moisture. At one place this species, together with *Diatraea zeacolella* Dyar, destroyed the greater part of a 7-acre field of corn.

In 1914 about 2 acres of corn (Pl. I, fig. 1), in a field on the State farm near Columbia, S. C., was damaged very severely by the larvæ. In many instances the plants were apparently killed outright when young, as in the case of the sorghum previously mentioned. Those that recovered were very much dwarfed, became one-sided, and gave rise to a number of suckers. The soil in this infested area is composed almost entirely of sand, while the rest of the field is a sandy loam.

Under date of October 7, 1914, Mr. Edmund H. Gibson, of the Bureau of Entomology, recorded larvæ of this species as injuring seriously corn in laboratory plats at Tempe, Ariz. Pulling up 15 stunted and withered corn plants, he found the larva in every stalk. Later in the month the larvæ were more abundant on corn and were also taken from sorghum sprouts and milo maize. On November 3 of the same year larvæ were collected from Johnson grass growing in a barley field, and about 70 per cent of the grass was injured, although the barley showed no evidence of injury.

During July and August, 1916, about 2 acres of sorghum in a field on the State farm near Columbia, S. C., was again practically laid waste by the ravages of these larvæ. The soil in this area also was of a sandy nature. Some of the badly infested plants were from 1 to 2 feet tall and without a central stem, as late as September, whereas plants uninfested were from 5 to 8 feet tall and in head.

Under date of August 19, 1916, Mr. H. L. Dozier, of the Florida Agricultural Experiment Station, informed the senior author that larvæ of this species were damaging cowpeas in plats on the station grounds.

The soil in these plats was of a sandy nature. He further stated that a report was received from Boca Grande, Fla., that 2 of 18 acres of cowpeas had been destroyed by this pest. Mr. R. N. Wilson, of the Bureau of Entomology, who was instructed to investigate this infestation more fully, confirmed Mr. Dozier's statement, young plants being injured by the larvæ boring into and upward in the stems, while in older plants the stems were girdled at or slightly below the ground. The result in both cases was that the injured plants wilted and died, although it was noted that in exceptional cases the plants, being vigorous, overcame the injury. Mr. Wilson further submitted a letter which had been received from Mr. Joseph Crews, farm demonstrator at Arcadia, Fla., stating that the "worms" injured cowpeas, Japanese cane, corn, and chufa. Cowpeas were damaged to some extent in the stiff black soil, but more serious damage was done in the sandy soil. This soil had all been well limed and heavily fertilized. Damage was done to Japanese cane planted in an old piece of land which was cleared years ago but had not been under cultivation for a number of years until the present. At least 90 per cent of the crop was damaged and the crop lost about 50 per cent in value.

While the increasing number of records of damage by this insect in the last few years is due in part to the fact that injury by it is more likely to be reported now than was the case years ago, it is also probable that the species is slowly modifying its habits to correspond with modern methods of agriculture and that, in the future, occasional outbreaks, perhaps more severe than any yet recorded, may be expected unless means are taken to check them in advance.

DESCRIPTIONS.[1]

THE EGG.

The egg (fig. 2) is ovate, circular in cross section, 0.67 mm. in length and 0.46 mm. in diameter; greenish white when first deposited, pinkish in from 18 to 24 hours, an approximate Alizar crimson with a tinge of yellow at end of incubation period; strongly iridescent. Exochorion sculptured with shallow pits pentagonal to polygonal in outline. Endochorion apparently smooth.

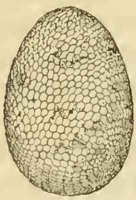


FIG. 2.—The lesser corn stalk-borer: Egg. Greatly enlarged. (Original.)

LARVAL INSTARS.

First instar.—Length 1.7 mm. Head slightly bilobed, flattened, highly polished dark brown, width 0.23 mm., about as high as wide; clypeus triangular, 0.11 mm. high. Paraclypeal pieces not perceptible, region dusky; labrum pale, tips of mandibles reddish brown, not projecting; setæ 0.11 mm. long; antennæ pale, moderate. Cervical shield almost straight in front, much rounded behind, one not quite as wide as the head. Prespiracular tubercle bears 2 setæ, the upper of the two being the shorter; subventrical tubercle also bears 2 setæ, the cephalad one being

[1] Descriptions by senior author. Measurements of all stages made from alcoholic material. That given for the length of larva in stage 5 is a little low on account of insufficient material on hand for a better average.

FIG. 1.—CORN INJURED BY THE LESSER CORN STALK-BORER IN A FIELD NEAR COLUMBIA, S. C., IN 1914. (ORIGINAL.)

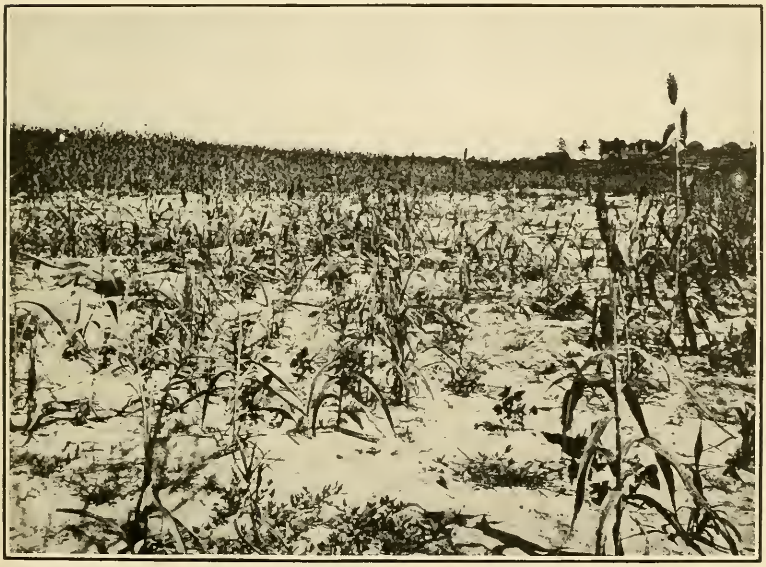


FIG. 2.—INJURY TO SORGHUM BY THE LESSER CORN STALK-BORER NEAR COLUMBIA, S. C., IN 1913. (ORIGINAL.)

DAMAGE TO CORN AND SORGHUM BY THE LESSER CORN STALK-BORER (ELASMOPALPUS LIGNOSELLUS).

the shorter. Anal plate somewhat triangular, dusky. Body pale yellowish to yellowish green; posterior portion of each segment bright red to reddish brown on dorsum; whole dorsum of joint 5 of this color. These areas are joined by faint stripes, some little distance apart, of the same color, giving the larva a longitudinally striped as well as transversely banded appearance. Segments all slightly swollen, except last. Tubercles small; "iv–v" coalescent on joints 5–13, inclusive, below spiracle on joint 5, laterad and slightly cephalad of spiracle on joints 6–12, inclusive, directly laterad of "iii" in joint 13. Setæ "iib" of joint 3 and "iii" of joint 12 0.25 mm. long, about twice as long as others. Abdominal segments except terminal crossed transversely through the middle by shallow grooves on dorsum. Thoracic feet pale, though somewhat dusky; abdominal prolegs all whitish.

Second instar.—Length 2.7 mm. Head slightly bilobed, flattened, highly polished, blackish brown, width 0.29 mm., clypeus 0.14 mm. high. Cervical shield concolorous with head, 0.26 mm. in width. Anal plate dusky. Body pale yellowish; transverse bands and stripes adjoining as in preceding stage. Tubercles "iib" of joint 3 and "iii" of joint 12 large, each supplied with a long seta as before; subprimaries present. Thoracic feet pale to dusky; abdominal prolegs same as venter of body, pale yellowish.

Third instar.—Length 5.7 mm. Head as in second instar except trifle paler, width 0.44 mm., a little wider than high; clypeus 0.20 mm. high; labrum pale amber, mandibles dark amber, almost black at tips; antennæ pale amber at tips, otherwise pale whitish. Cervical shield large, darker than head, the anterior border extending somewhat over the head lobes, wider than head, width 0.54 mm., length 0.30 mm., corneous, polished. Body pale greenish white to pale yellowish green; transverse bands and connecting stripes reddish brown to brown, sometimes only greenish white between the stripes; tapering posteriorly. Thoracic legs dusky; abdominal prolegs pale yellowish green, same as venter.

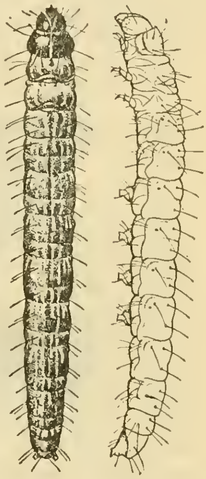


FIG. 3.—The lesser corn stalk-borer: Larva. Greatly enlarged. (Original.)

Fourth instar.—Length 6.9 mm. Head slightly bilobed, polished dark brown, 0.61 mm., about two-thirds as high as wide; clypeus 0.25 mm. high; around base of spines pale. Cervical shield concolorous with head, width 0.89 mm., length 0.45 mm. Prespiracular tubercle large, somewhat corneous, dusky; subventrical tubercle also dusky, normal. Body as in preceding stage except that venter is taking on deep green color; greenish white more conspicuous and breaking into the transverse bands, very deeply in some segments; stripes joining transverse bands wider than before. Thoracic legs and abdominal prolegs as before.

Fifth instar.—Length 8.8 mm. Head bilobed and polished as before, very dark brown black, width 0.89 mm., clypeus 0.32 mm. high, the paraclypeal pieces distinct, the sutures almost touching the beginning of the intersection point of the lobes on the vertex, whitish; labrum pale amber, mandibles amber, very dark at tips. Cervical shield darker than head, 1.02 mm. wide, 0.62 mm. long; on the meson is a pale stripe extending longitudinally from the posterior border to a point almost across the shield. Body as in preceding stage except that transverse bands are now at a point of being broken up, giving way to pale yellowish white color of the dorsum, the dark color being now confined chiefly to the longitudinal stripes, now almost continuous over the body but very irregular; in some specimens there is a whitish patch, ellipsoidal in outline, on the dorsum of joints 3 and 4; venter tinged with pale reddish. Thoracic legs and abdominal prolegs as in preceding stage.

Sixth instar.—Length 16.2 mm. (fig. 3). Head slightly bilobed, somewhat flattened, dark brownish black, highly polished, width 1.11 mm. Clypeus triangular, somewhat pale in the upper angle, extending over two-thirds of height of head (0.43 mm.). Paraclypeal pieces prominent, sutures converging at the beginning of intersection point of head lobes on vertex; setæ pale, stiff, pale around base; proximal parts of antennæ pale whitish, distal amber; labrum pale amber, width 0.32 mm.; mandibles dark red, black at tips. Cervical shield dark brown, width 1.49 mm., length 0.93 mm.; pale line on meson extending across the shield, coming to a point before; extending over head to intersection of lobes. Body Nile green, prevailing color on the dorsum greenish white, which almost breaks up completely the dark brown transverse bands; longitudinal stripes conspicuous, dark brown, somewhat broken. Tubercles "ia" and "ib" of joint 3 small, setæ short, "iia" and "iib" small, seta long; "ia" and "ib" of joint 4, small, seta short, "iia" and "iib" small, seta long, caudad of latter is dusky patch, somewhat polished; on joints 3 and 4 "iii" is caudo-laterad of "iib," distant, "iv" is cephalad and slightly laterad of "iii," distant, "v" cephalo-laterad of "iv," well separated; "iv–v" is coalescent on joints 5 to 13, inclusive, arrangement as before; on joint 13 "vi" is near "v"; on joints 12 and 13 "ii" is much nearer meson than "i," on joint 11 "i" and "ii" arranged in form of square. All segments slightly swollen except last two; transverse grooves prominent. Thoracic legs dusky; abdominal prolegs pale.

FIG. 4.—The lesser corn stalk-borer: Pupa. Greatly enlarged. (Original.)

PUPA.

The pupa (fig. 4) when freshly formed is pale green, yellowish on abdominal segments; later brown and just preceding emergence of adult uniform black; lustrous; delicate; length 8.1 mm., width 2 mm. Spiracles ellipsoidal, prominent, except on joint 12, obsolete. Dorsum of terminal segment has slight elevation or hump which slopes abruptly posteriorly and forms the obtuse tip. Anterior portion of this elevation corneous, rugose, and black. At tip is a row of six hooked spines arranged transversely, about 0.17 mm. in length. Tip of the male pupa is rounded, that of the female pupa irregular. Other sexual differences in pupal stage shown in figure 5, *a* and *b*. Abdominal segments 1 to 7, inclusive, densely and finely pitted on dorsum, very abundant and scattered almost over whole surface of first four segments, scant and restricted to anterior border of last three.

COCOON.

The cocoon is cylindrical, compact, 15.9 mm. in length, and 5.9 mm. in diameter, oval in outline, frequently supplied with exit tube at an angle of about 145°; 23.9 to 30 mm. in length and 4 mm. in diameter; lined throughout on inside very smoothly with silk and covered without with sand and dirt particles. (Pl. II, figs. 3 and 4.)

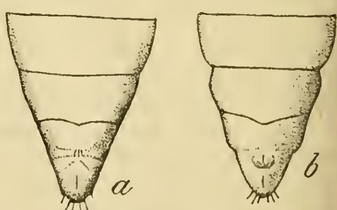


FIG. 5.—The lesser corn stalk-borer. Comparison of terminal segments of male and female pupæ showing sexual differences: *a*, Female; *b*, male. Greatly enlarged. (Original.)

ADULT.[1]

Expanse 17–22 mm. Head brown to blackish. Labial palpi erect, not recurved; somewhat longer in the male than in the female and more slender, heavily scaled, lying close together on the shining crest which is hollowed out for them; somewhat clavate toward the tip, end member very short, about one-eighth the middle; groove for the pale papillary tufts reaching almost to the apex and very deeply impressed. Basal segments pale gray outside, within bearing a longitudinal white stripe which broadens somewhat at the end of

[1] Compiled from descriptions of Zeller and Hulst by the junior author.

the second and beginning of the last segment. Maxillary palpi pencil-tufted. Proboscis long, strong, scaled. Ocelli present. Antennæ brownish, simple, bent and expanded above the base, with a heavy tuft of scales in the bend in the male; in the female more slender and without the tuft. (Fig. 6.)

Thorax ochre-brown to blackish. Legs brownish gray, darker on the outside; tarsal segments bright yellow. Forewings very narrow, much elongated, 8–9 mm. long; distal margin oblique, posterior margin waved; in male (fig. 6, *a*) ochre-brownish on posterior margin from base out, with a poorly defined median stripe of ochre-brownish reaching almost to distal margin; remainder of margin varying from a narrow edging of brown to a complete covering of wing with blackish to plumbago; disk yellow-ochreous to reddish; on subdorsal vein slightly before middle where posterior margin begins to darken lies a dense brown dot marking position of first transverse line; diagonally outwards above it upon median vein is a smaller dot and beyond a more prominent one on cross vein; both lie in the bright median space but close to yellowish-brown shading of anterior margin; distal margin marked by row of black confluent dots within which is indistinct grayish stripe dusted with whitish atoms; within this in the dark color of surface appears beginning of second cross line very close to distal

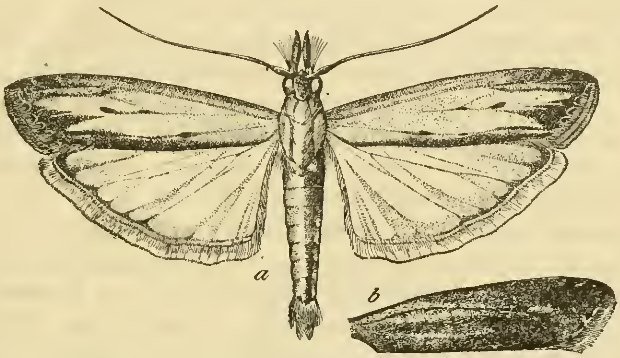


FIG. 6.—The lesser corn stalk-borer: *a*, Male moth; *b*, forewing of female moth. Greatly enlarged. (Original.)

margin and most apparent on anterior margin; fringes brownish gray, beneath shining brownish gray; in the female (fig. 6, *b*) markings are the same but generally darker than in male; dot on the subdorsal vein enlarged but not prominent, dot on cross vein somewhat more distinct. Hind wings white, pellucid, somewhat grayish or brownish along anterior and distal margins and at apex shading back into the wing for a greater or less width; fringes whitish, brownish toward apex and bearing a faint yellowish line paralleling margin; beneath along anterior margin browner than above. Venation: Forewings, eleven veins, 4 and 5 separate, 10 separate; hind wings, 2 more or less distant from angle, 4 and 5 stemmed, 6, 7, and 8 stemmed, cell rather short.

Abdomen yellowish to fuscous, darker in female; terminal tuft of male yellowish at the end and in the middle, gray laterally, darkening toward end; of female yellowish. Male genitalia: Uncus longer, more slender than usual in related genera, bifid at base; these parts arched; the spine long, harpes broad with long hairs along upper edge forming somewhat of an anal tuft; a strong bent spine at base; lower plate conical, within entrance a long, slender, bent spine; last segment of abdomen beneath with two tufts of hair.

SEASONAL HISTORY.

OVIPOSITION.

Eggs of this species have not been found in the field; but, judging from the results obtained from rearing, they are probably deposited on the stems of plants, in the axils of the leaves, or on the ground at or near the bases of the stalks. The larvæ upon hatching crawl to the stalks and begin feeding.

In rearing cages, the eggs are deposited generally on the cheesecloth which covers the lantern globe. Sometimes, however, they are deposited on bits of grass leaves or stems, pieces of cloth or other loose material placed in the bottom of the cage, on the stem of grass placed in the cage as food or, not at all infrequently, upon the cotton which holds the sprig of grass in place. Most of the eggs deposited on the cloth top are pushed through the mesh of the cloth by the female and are found on the upper side of the cloth, appearing as though they were deposited from without. Eggs are placed singly as a rule, though sometimes two or three *en masse* may be found glued securely together. In such cases they lose their individual rotundity and flatten out somewhat at points at attachment. A mucilaginous substance secreted by the female, which hardens after exposure to the air, glues the eggs firmly to the object.

The females begin to oviposit shortly after dusk and continue until the early hours of the morning. The majority of the eggs are deposited during the forepart of the night and it is probable that all of them are laid at this time under field conditions. No eggs are deposited during the day or in bright light at night. Oviposition will take place, however, in diffused light, although not as many eggs will be deposited as in total darkness.

EFFECT OF TEMPERATURE ON OVIPOSITION.

Oviposition did not take place when the temperature fell much below 80° F. Two cages containing a number of females and males were kept under normal conditions; three others, also supplied with a number of moths of both sexes, were kept in a room the temperature of which rose to somewhere between 80 and 90° F. during the day and fell gradually, reaching approximately 80° F. by early evening and practically normal by morning, as the windows were kept open all night. Eggs were obtained in all the cages kept in the room, all of them being deposited during the early part of the evening. No eggs were obtained in the cages kept under normal conditions. The same type of cage was used in both cases, consisting of a flowerpot surmounted by an ordinary lantern globe, the top of which was closed with a bit of cheesecloth held in place by a rubber band.

TABLE I.—*Incubation records of eggs of Elasmopalpus lignosellus obtained from one female at Columbia, S. C., 1913.*

Deposited.		Hatched.		Incubation period.
Date.	Number of eggs.	Date.	Number of eggs.	
				Days.
Aug. 28	50	Aug. 31	50	3
Aug. 29	57	Sept. 1	57	3
Aug. 30	40	Sept. 2	40	3
Aug. 31	49	Sept. 3	49	3
Sept. 1	36	Sept. 4	36	3
Sept. 2	30	Sept. 5	30	3
Sept. 3	26	Sept. 7	26	4
Sept. 4	17	Sept. 8	17	4
Sept. 5	7	Sept. 9	7	4
Sept. 6	3	Sept. 9	3	3
Sept. 7	4			
Total	319			
Average				3.16

TABLE II.—*Incubation period of eggs of Elasmopalpus lignosellus deposited during 1914 and 1915 at Columbia, S. C.*

Deposited.		Hatched.		Egg stage.
Date.	Number of eggs.	Date.	Number of eggs.	
				Hours.
Aug. 31, 10 p. m. to 11 p. m	1	Sept. 5, 7 p. m	1	116–117
Aug. 31, 11 p. m. to 12 m	14	Sept. 5, 8.30 p. m	12	116.5–117.5
		Sept. 6, 8 a. m	2	128.5–129.5
Sept. 1, 7 p. m	1	Sept. 6, 9 a. m	1	110
Sept. 1, 12 m	30	Sept. 5, 8.30 p. m	14	92.5
		Sept. 6, 8 p. m	16	116
Sept. 9, 8 p. m	2	Sept. 12, 10 p. m	2	74
Sept. 9, 8 p. m. to 10 p. m	23	Sept. 12, 10 p. m	21	70–72
		Sept. 12, 12 m	2	74–76
Sept. 2, 9 p. m	66	Sept. 6, 9 a. m	66	84
				Days.
Sept. 5	11	Sept. 9	11	4
Sept. 4	36	Sept. 8	36	4
Sept. 10	53	Sept. 13	53	3
Sept. 13	24	Sept. 18	24	5
June 23	27	June 26	27	3

LENGTH OF INCUBATION PERIOD.

From Tables I and II it will be seen that the egg stage varies from three days in the summer time to five days in early fall, being influenced greatly by temperature conditions. In late fall, eggs were obtained that required from six to eight days to hatch.

TABLE III.—*Number of eggs deposited by 1 female of Elasmopalpus lignosellus in 1 day and during life, at Columbia, S. C., 1915.*

Cage 15-1112.		Cage 15-1113.		Cage 15-1114.	
Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.
June 15	73	Sept. 2-3	25	Aug. 31	15
June 16	11	Sept. 4	36	Sept. 1	31
June 17	73	Sept. 5	11	Sept. 2-3	38
June 19	61	Sept. 6	5	Sept. 4-5	19
June 21	27	Sept. 8	9	Sept. (?)	60
June 22	39	Sept. 9	7	Sept. 9	22
June 23	27	Sept. (?)	20	Sept. 10	3
June 24	15	Sept. 10	9	Sept. 11	3
June 25	6	Sept. 11	12	Sept. 12	1
June 26	4				
June 28	6				
Total	342		134		192
Average per day	24.43		(?)		(?)

Cage 15-1115.		Cage 15-1116.		Cage 15-1117.	
Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.
Sept. 10	53	Sept. 8	56	Sept. 13	24
Sept. 11	56	Sept. 9	35	Sept. 14	55
Sept. 12	38	Sept. 10	34	Sept. 15	12
Sept. 13	34	Sept. 11	33		
Sept. 14	1	Sept. 12	28		
Sept. 15	9	Sept. 14	8		
Sept. 16	2				
Sept. 17	4				
Total	197		194		91
Average per day	24.63		27.71		30.30

NUMBER OF EGGS DEPOSITED BY ONE INDIVIDUAL.

The number of eggs deposited by one individual under laboratory conditions varies (as will be seen by referring to Table III) from 91 to 342, with an average of 190. The small number deposited in Cage 15-1117 was probably due to premature death of the female.

The number of eggs deposited by one individual in any one day varies from 1 to 73. The daily average computed from the daily average of the four cages in Table III is about 26.77 eggs.

In two other experiments conducted in July, 1914, 188 eggs were obtained in one cage and 311 eggs in the other.

PROCESS OF HATCHING.

Shortly before the larva is ready to emerge it can be seen very distinctly through the semitransparent shell. The brown-black head and the pinkish markings on the segments especially are conspicuous. The larva occupies a curled position inside of the shell, with its head resting on the ultimate and penultimate segments of the body. Just preceding emergence a wavelike rhythmic motion is seen, starting at the head and continuing from segment to segment slowly to the end of the body, after which the larva moves its head about and with its mandibles makes an incision large enough for it to pass through. This takes about five minutes. The larva then usually rests a few minutes, after which it begins to draw itself out of the shell.

NUMBER AND LENGTH OF INSTARS AND LENGTH OF LARVAL LIFE.

The number of instars and their length, as well as the total length of the larval life, are extremely variable, as will be noted by referring to Tables IV, V, and VI. These variations are due in part to differences of temperature. During the summer months the larvæ may molt four or five times and in fall five or six, making from five to six instars for the former and six to seven for the latter. The seventh instar in such instance resembles the sixth in color pattern and size. The second instar and sometimes the third is somewhat longer than the first during the summer months. In fall, however, the first instar is longer than any of the others, except the last one, or the one just preceding pupation, which is generally also the longest during the summer months.

The length of the life of the larva is somewhat dependent upon the number of instars. The larger the number of instars the larva undergoes, the longer the period it will take in reaching maturity, as is brought out by comparing the averages of the instars in Tables IV, V, and VI. In Table IV the larvæ having five instars reached maturity in 374.5 hours, while those having six instars reached maturity in 406.33 hours. In Table V those having five instars reached maturity in 397 hours, as compared to 453 hours for the six-instar larvæ. In Table VI the six-instar larvæ required 842 hours while the seven-instar larvæ required 906 hours to reach maturity.

The larvæ may reach maturity in the short period of 13.8 days, but generally in about 16.8+ days, during the summer months. However, one larva required as many as 20.8+ days to reach maturity. In fall, when temperatures are low, this period is considerably lengthened, varying from a minimum of 22.0+ to a maximum of 41.6 days.

TABLE IV.—*Number of instars, their length, and length of larval life of Elasmopalpus lignosellus during the months of June and July, 1914, at Columbia, S. C.*

Number of tube.	First instar.	Second instar.	Third instar.	Fourth instar.	Fifth instar.	Sixth instar.	Length of larval life.
	Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
1	56	60	48	96	144	....	404
2	44	36	48	60	144	....	332
3	44	36	60	48	72	144	404
4	44	36	48	60	84	144	416
5	44	36	48	60	48	172	408
6	56	60	48	72	172	....	408
7	44	36	48	84	144	....	356
8	44	36	60	72	84	108	404
9	44	36	48	84	72	120	404
10	44	36	48	60	84	132	404
11	44	48	36	60	72	144	404
12	44	48	36	60	84	156	428
13	44	48	36	60	84	156	428
14	44	36	48	60	48	120	356
15	44	36	60	72	144	....	356
16	44	36	60	72	120	....	332
17	44	36	48	60	84	144	416
18	44	36	60	72	72	120	404
19	56	48	84	84	180	....	452
20	44	36	48	84	144	....	356
Average	45.8	40.8	50.5	69	104	138.3	393.6

TABLE V.—*Number of instars, their length, and length of larval life of Elasmopalpus lignosellus, during the month of August, 1915, at Columbia, S. C.*

Number of tube.	First instar.	Second instar.	Third instar.	Fourth instar.	Fifth instar.	Sixth instar.	Length of larval life.
	Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
15–771	69	60	60	72	120	....	381
15–773	81	36	72	72	144	....	405
15–774	45	72	48	72	120	....	357
15–775	69	72	72	48	72	96	429
15–776	69	72	72	48	72	120	453
15–777	69	60	60	72	72	120	453
15–786	69	72	48	72	24	168	453
15–788	81	60	72	72	120	....	405
15–790	69	60	60	72	120	....	381
15–791	69	72	48	72	72	144	477
15–795	93	60	60	72	120	....	405
15–797	69	72	48	72	120	....	381
15–925	69	48	48	72	120	....	357
15–926	81	48	60	72	168	....	429
15–927	69	48	48	72	144	....	381
15–929	69	48	72	72	120	....	381
15–933	81	60	48	72	240	....	501
Average	66	59.6	58.6	69	115.8	127.6	413.5

TABLE VI.—*Number of instars, their length, and length of larval life of Elasmopalpus lignosellus, during the months of September and October, 1914, at Columbia, S. C.*

Number of tube.	First instar.	Second instar.	Third instar.	Fourth instar.	Fifth instar.	Sixth instar.	Seventh instar.	Length of larval life.
	Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
1	209	72	108	156	120	108	144	927
2	153	84	72	96	192	120	168	885
3	165	108	204	132	48	144	....	799
4	165	84	252	96	72	288	....	957
5	117	156	108	84	84	288	....	837
6	129	120	144	72	96	216	....	777
Average	156.3	104	148	106	102	194	156	863.7

DURATION OF THE MOLTING PERIOD.

During the summer months the time required for the larvæ to molt varies from 12 to 24 hours in all the instars and during the fall from 12 to 26 hours and sometimes 48 hours. The majority of the larvæ in fall require only 24 hours. Generally a longer time is required in the last instars than in the first ones.

DESCRIPTION OF ECDYSIS.

The larva when about to cast its skin becomes pale, sluggish, and usually remains motionless in tunnel or tube unless disturbed, and even then it is not as active as normally. The first real indication that molting has commenced is the appearance of a pale whitish patch in the region of the neck. This patch is the outer conjunctival layer which, having been loosened, is being unfolded to accommodate the growing larva. This patch becomes more and more evident as molting progresses. The eyes at this time can be seen through the semitransparent conjunctival layer, appearing a little distance back of the head mask. The outer layer of the cuticle, having been loosened throughout, ruptures immediately back of the head mask, first on the venter, then rapidly extending laterally and dorsally. The larva with wavelike rhythmic motions gradually draws itself out of the old cuticular layer. Just at the point when the last joint is being extricated the larva bears down with the head and frees itself from the mask.

FEEDING HABITS OF THE LARVA.

The larva of the species, as its common name would indicate, has a habit of boring or tunneling into the stems of growing plants (Pl. III, fig. 3) and feeding within. This manner of feeding is especially characteristic where young corn and sorghum plants are attacked. The larvæ in such cases tunnel into the stalks at or slightly below the surface of the ground, through and sometimes up the heart for a distance varying from 1 to 2 inches. The bud leaves of such affected plants die, having been severed from the main plant; Plate III, figure 2, shows the appearance of such a plant. The bud leaves dry up and wither away. Some of the plants may survive, but such plants remain in a dwarfed condition or become deformed and one sided.

Injury to corn in this manner resembles closely the work of the southern corn rootworm (*Diabrotica 12-punctata* Oliv.); however, *E. lignosellus* is an upland species, being found only in the driest of soils, while the corn rootworm breeds generally in the moist lowlands.

In older corn and sorghum, as well as in cowpeas, the damage consists primarily in the girdling of the stems at or slightly below the surface of the ground, but the larvæ also tunnel into the stems, thereby weakening them to such an extent that very little pressure is required to break them off, and frequently infested plants break off at this point when attempts are made to pull them up.

Cowpea plants have been found almost completely cut in two, at a point near or slightly below the surface of the ground, by the larvæ girdling the stem, while in other cases the larvæ were found tunneling into the stems as in the case of corn and sorghum.[1]

It is seldom that larvæ are found in the tunnels of the plants upon which they feed, but more often in specially constructed tubes which lead away from the entrance to the tunnel in the stalk, lying even with or slightly beneath the surface of the ground or sometimes curved around the stems. Plate II, figures 1 and 2, shows the tubes attached to the stems at the entrance to tunnels. These tubes are often 2 inches or more in length and have a number of side galleries or chambers (Pl. III, fig. 1). They are composed of particles of sand and dried excrement of the larvæ spun together with silk. They are generally rather delicate and fall to pieces unless handled with great care. The larvæ apparently use these tubes as a means of retreat when disturbed while feeding.

In young corn and sorghum not more than two larvæ have been found feeding on one plant, each from within a separate tube, and in cowpea plants never more than one. In older corn and sorghum as many as 6 larvæ have been found feeding at one time on the same plant and 13 cocoons taken from the surrounding soil. Dr. Forbes (24) reports that as many as 13 larvæ have been found feeding on a single corn plant.

In our rearing cages larvæ were fed cowpea leaves in test tubes and jelly glasess. During the first and second instars the larvæ have a habit of partially skeletonizing the leaves, devouring the epidermis of one side and the mesophyll, leaving the epidermis of the other side intact. They construct on the leaf delicate tubelike coverings made up of dried excrement spun with silk and feed from under this covering. After the second instar the larvæ begin to eat the leaves, perforating them and devouring all except the mid-veins. They persist in skeletonizing the leaves even when almost mature, and this is especially noticeable when given leaves that are somewhat tough or whose tissues have hardened. The boring habit (Pl. III, fig. 3), so characteristic of the work of the larvæ in stalks, was demonstrated even while the larvæ were feeding upon leaves, the larvæ even in their earlier stages boring into the larger veins of the leaves and petioles and constructing tubes leading away from the entrance to the tunnel. This habit was discontinued in the last stages, the larvæ feeding as do those of most Lepidoptera.

[1] Dr. Chittenden (22) makes mention of this method of feeding and illustrates it with a figure.

ACTIVITY OF THE LARVA.

The larvæ of this species, while very active, even when quite young, are much more so as they become older. They have a habit, when disturbed, of skipping and jumping about, an acrobatic feat which lasts from one to four seconds, during which time they go through all kinds of contortions, frequently throwing themselves clear of the surface upon which they have been placed. Just how this is accomplished is not definitely known, as it is done almost too quickly for the eye to follow. However, they appear to bear down with the head and posterior end of the body at the same time, with such force that the impact throws them into the air. On account of this skipping habit the larvæ are frequently but erroneously termed "skippers."

That the larvæ are resistant to rough treatment is indicated by the following ordeal through which one was put by the junior author in an effort to photograph it. It was chloroformed for 15 minutes and, being then still somewhat active, was put into 80 per cent alcohol for 15 minutes more. The next morning it had revived and, except for a loss in the brillancy of its coloring due perhaps to its enforced fast, was as active as before.

The larvæ in all stages spin a silken thread wherever they go, and the younger ones readily suspend themselves by it.

LENGTH OF PUPAL STAGE.

The length of the pupal stage varies considerably, as will be seen from Table VII, temperature conditions having a great effect upon the length of this stage. This stage varies from 7 to 11 days in July, from 7 to 10 days in August, from 8 to 18 days in September and October, and from 19 to 21 days in October and November. The general average from the records of Table VII is 10.16 + days.

It should be stated that the records obtained during the fall of the year are approximate, as it has been found that the larvæ, upon entering the pupation tubes, sometimes do not transform immediately.

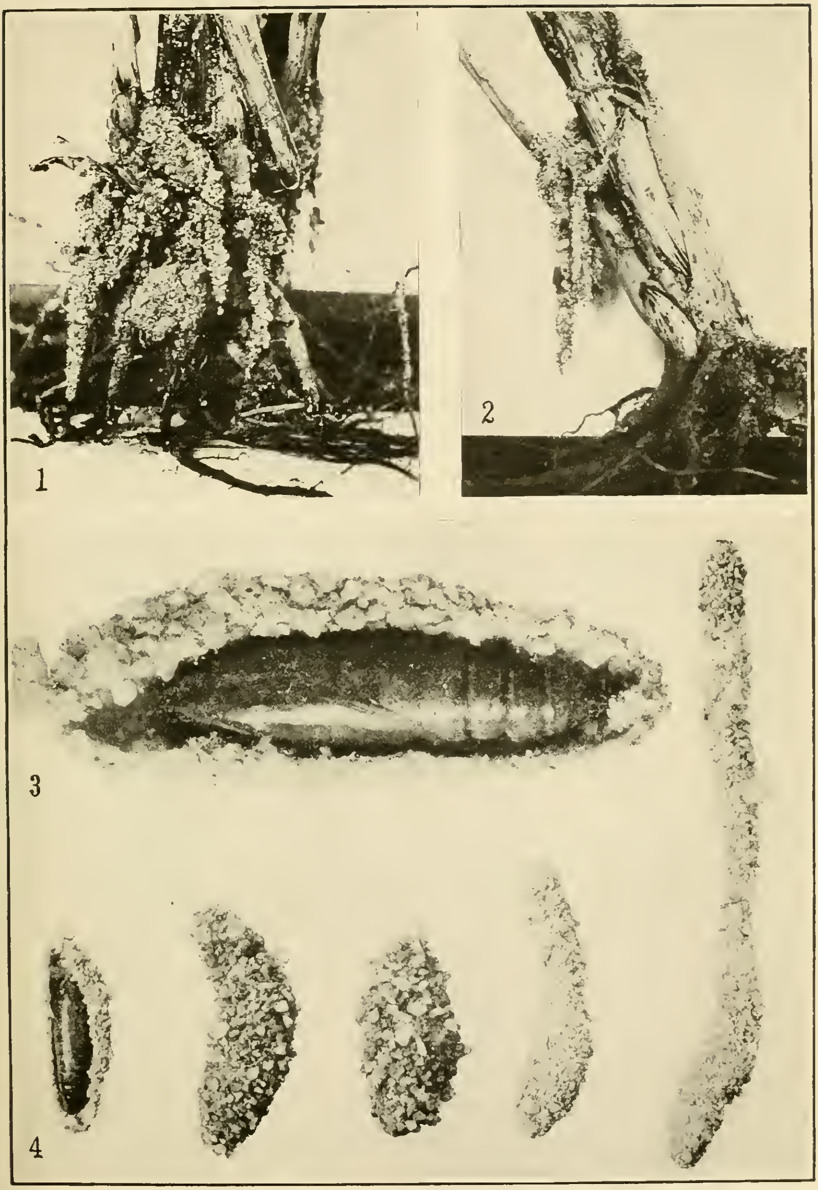
TABLE VII.—*Length of pupal stage of Elasmopalpus lignosellus. Records obtained at Columbia, S. C., in 1915.*

Number of individuals.	Date of— Pupation.	Date of— Emergence.	Days.	Sex.	
	1913.	1913.			
1	Sept. 29	Oct. 16	17	....	Male.
1	Sept. 30	...do....	16	Female....	
	1914.	1914.			
2	July 8	July 17	9	...do......	Do.
1	July 9	...do....	8	...do......	
1	...do....	July 18	9	....	
1	...do....	July 20	11	....	
4	July 11	...do....	9	2 females..	1 male.
1	July 12	...do....	8	Female....	
1	July 13	July 21	8	...do......	
1	...do....	July 20	7	....	
	1915.	1915.			
1	Aug. 16	Aug. 25	9	....	Male.
1	Aug. 17	...do....	8	Female....	
1	Aug. 18	Aug. 27	9	....	Do.
1	...do....	Aug. 28	10	....	Do.
1	Aug. 20	...do....	8	Female....	
1	...do....	Aug. 30	10	....	Do.
1	Aug. 21	Aug. 28	7	....	Do.
1	...do....	Aug. 29	8	....	Do.
1	...do....	Aug. 30	9	....	Do.
1	...do....	Aug. 31	10	....	Do.
2	Aug. 23	...do....	8	Female....	Do.
3	Aug. 29	Sept. 6	8	2 females..	1 male.
1	...do....	Sept. 7	9	Female....	
1	...do....	Sept. 9	11	....	Male.
1	Aug. 30	Sept. 7	8	Female....	
1	Sept. 24	Oct. 4	10	....	Do.
1	Sept. 25	Oct. 6	11	....	Do.
1	...do....	Oct. 9	14	Female....	
1	Sept. 27	Oct. 7	10	....	Do.
1	Sept. 28	Oct. 6	8	....	Do.
1	...do....	Oct. 7	9	....	Do.
2	...do....	Oct. 9	11	Female....	Do.
1	...do....	Oct. 12	14	...do......	
1	...do....	Oct. 14	16	...do......	
1	...do....	Oct. 15	17	...do......	
1	Sept. 29	...do....	16	...do......	
1	Sept. 30	Oct. 16	16	...do......	
2	Oct. 1	...do....	15	...do......	Do.
1	Oct. 4	Oct. 18	14	...do......	Do.
1	Oct. 6	...do....	12	...do......	
1	Oct. 7	Oct. 19	12	...do......	
1	...do....	Oct. 20	13	...do......	
1	...do....	Oct. 23	16	...do......	
1	...do....	Oct. 25	18	...do......	
1	...do....	Oct. 28	21	...do......	
1	Oct. 13	Nov. 1	19	....	Do.
1	...do....	Nov. 8	26	Female....	
1	Oct. 18	...do....	21	...do......	
2	Oct. 20	Nov. 10	21	2 females..	
59	....	....	10.16+		

Average length of pupal stage, 10.16+ days.
Maximum length of pupal stage, 21 days.
Minimum length of pupal stage, 7 days.

MATING.

Moths of this species usually mate the second day after emergence from pupæ in the summer time, and in the fall this period is somewhat lengthened. Mating probably takes place at night, although the moths have never been seen in coitu. A pair were found in copula in a cage in the morning and upon examination it was discovered that they were unable to disconnect themselves.



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2

3

4

FEEDING TUBES AND COCOONS OF THE LESSER CORN STALK-BORER.

FIGS. 1, 2.—Feeding tubes attached at entrance to tunnels, at base of sorghum stalks. FIG. 3.—Cocoon opened, showing pupa *in situ*. FIG. 4.—Cocoons, with and without exit tubes. (Original.)

DAMAGE TO SORGHUM BY THE LESSER CORN STALK-BORER.

FIG. 1.—The many-branched feeding tube attached at entrance to tunnel, at base of sorghum stalk. FIG. 2.—Sorghum severely damaged by stalk-borers, as shown by the dead bud leaves. FIG. 3.—Stem sectioned to show the borer tunnel within. (Original.)

ACTIVITY OF THE MOTHS.

The moths are very active during the night. They are positively phototrophic to bright light and even react positively to diffused light. This probably accounts for the fact that copulation and oviposition were not observed, for as soon as cages were placed in light sufficient for observation the moths became restless and began to roam around in the cages.

LENGTH OF LIFE OF ADULTS.

The length of life of the adults of this species varied from five to eighteen days in the rearing cages, as is shown in Table VIII. The average duration of this period is approximately the same in both sexes. Adult moths confined in cages and supplied with food (sugar sirup) lived longer than when deprived of it.

TABLE VIII.—*Length of life of moths of Elasmopalpus lignosellus, at Columbia, S. C.*

Male.				Female.			
No.	Emerged.	Died.	Days.	No.	Emerged.	Died.	Days.
1	June 15	July 3	18	1	June 15	July 3	18
2	July 17	July 27	10	2	July 17	July 27	10
3	July 17	July 27	10	3	July 17	July 28	11
4	July 19	July 28	9	4	Aug. 22	Sept. 9	18
5	Aug. 30	Sept. 13	14	5	Aug. 30	Sept. 13	14
6	Aug. 30	Sept. 16	17	6	Aug. 30	Sept. 12	13
7	July 17	July 24	7	7	Sept. 10	Sept. 15	5
Average			12.1	Average			12.7

POLYGAMY.

Experiments were conducted to ascertain whether polygamy exists among the moths of this species. The moths that were used in these experiments emerged from pupæ which had been placed in individual tin boxes, and there was absolutely no chance of their having mated upon issuing, before being placed in the rearing cages.[1]

The male, after the death of the female (Cage 15–1113) with whom he had mated and from whom 134 eggs were obtained, was placed with a freshly issued female (Cage 15–1117). From this female 91 eggs were obtained. All of the eggs that were obtained in both of these cages were fertile.

In another cage, the male, which had mated with a female (Cage 15–1114) and from whom 192 fertile eggs resulted, was placed (Cage 15–1116) with a virgin female. From this female 194 fertile eggs were obtained.

[1] All of these cages are recorded in Table III.

LIFE CYCLE.

The life cycles of the generations (Table IX) during summer are considerably shorter than those of the fall of the year and possibly shorter than that of the spring generation. The spring generation has not been reared but probably has about the same cycle as the fall generation. They are about as follows:

TABLE X.—*Duration of the spring and fall generations of Elasmopalpus lignosellus at Columbia, S. C.*

Period or stage.	Summer broods.	Fall broods.
	Days.	*Days.*
Time elapsing between emergence and oviposition	2	2.5
Egg stage	3.5	5.6
Larval stage	24	36
Pupal stage	9	21
Total	38.5	64.6

By comparing the two cycles it will be noticed that the time required for the insect to pass through the cycle during the summer months is only about 6.2 days more than one-half of the time required in the fall of the year.

NUMBER OF GENERATIONS.

There are probably four generations of this species in the latitude of Columbia, S. C., although it has not been reared continuously for one whole year to verify this. However, three complete generations were reared from the middle of June to the middle of October in 1913.

Some of the pupæ of the last generation gave rise to moths, while the remainder died during the winter. Some of the larvæ of this last generation, not pupating in the fall, died also during the winter, apparently from the lack of suitable food and from being kept under abnormal conditions. Otherwise they possibly would have completed their growth, pupated, and given rise to moths early in the following spring (1914).

Our collection in the spring of 1915 would seem to substantiate this. Larvæ nearly full grown were found for the first time on corn in the field during the first week in June, thus rendering it probable that the eggs producing these larvæ were placed when the corn was up, by the moths issuing from pupæ in the early spring, as the field in which they were found was winter plowed and freed from rubbish and grass, making it impossible for these larvæ to have wintered over under these conditions.

WINTERING.

In the latitude of Columbia, S. C., this species apparently passes the first part of the winter as a larva and the latter part as a pupa and possibly adult, although it has not been possible to verify this absolutely by rearing experiments.

Larvæ have been found in the field, in their burrows in the stalks, as late as the middle of November, after which time none could be found. Repeated efforts were made at various times during winter to find pupæ, and one cocoon containing a pupa was found in January which, unfortunately, died. This pupa probably would have changed early in the spring to an adult.

According to the experiments of the writers in 1915, larvæ pupating in the fall did not winter as such but gave rise to moths in early winter. These moths died within a short time, which circumstance would seem to indicate that this species does not winter in the adult stage. Larvæ have been kept alive in rearing cages under outdoor conditions up to January, at which time they died, apparently from being kept in closed receptacles, which was very favorable for the development of a fungus which killed them.

In Arizona the species probably passes the winter in the larval stage, judging from the fact that larvæ in all sizes were found as late as November 3 at Tempe, Ariz.

REARING METHODS.

In rearing the larvæ of this species a number of different types of cages were used, such as the ordinary "pot cage" surmounted by a lantern chimney covered with cheesecloth, or with a celluloid cylinder covered with cheesecloth. None of these types of cages gave complete satisfaction, for the reason that they could not be made tight enough and the larvæ, being very restless, are ever on the alert to find an opening through which they may escape.

Tin salve boxes and the ordinary low-type jelly glass with tin cover proved the most satisfactory of all cages. In rearing these larvæ, a small quantity of sand was placed in the bottom of each and kept moistened. These containers were kept supplied with fresh cowpea leaves and a number of larvæ were reared in each receptacle.

To obtain eggs, a cage, consisting of a 6-inch flowerpot saucer, lantern chimney covered with cheesecloth, and a bottle containing a small sorghum plant, in water, was employed with success.

In making a study of the different instars, small test tubes, used in bacteriological experiments, were found to be the most practical, on account of the convenient size and also because observations could be made without removing specimens.

NATURAL ENEMIES.

According to observations, the lesser corn stalk-borer apparently suffers very little from natural enemies. This condition is undoubtedly a result of the excellent protection afforded the larvæ at all times, both while feeding in their burrows and while resting in their tubes. One parasite, a hymenopteron, determined as *Neopristomerus* sp., has been reared in the laboratory at Columbia, S. C. This parasite emerged September 1, 1914, from a larva collected at Columbia, S. C.

Another parasite was reared by R. N. Wilson at Gainesville, Fla., September 11, 1916, which was determined by Mr. A. B. Gahan as *Orgilus laeviventris* Cress. Mr. Gahan believes it probable that the parasite of *Elasmopalpus lignosellus* recorded by Chittenden (18) as *Orgilus mellipes* Say was in reality *laeviventris*.

METHODS OF CONTROL.

The ravages of this insect can be reduced markedly if not entirely controlled by progressive methods of farming. Infested fields should be plowed very late in fall or early winter, after they have been freed from all remnants and waste material. The borders and terraces of the field should be gone over with a harrow to stir up the ground. This breaks up the winter quarters of pupæ and causes them to perish.

The practice of cleaning up and working these waste places is not only an excellent one for the eradication of this species but also contributes to the destruction of many other noxious insects that chance to be hibernating therein; and as usually very little attention is given to the practice of clean cultural methods and the cleaning up of such waste places, the importance of such methods can not be overemphasized.

In regions where this insect remains more or less active throughout the winter, it is advisable to plow out and destroy the infested stubble in case of corn, sorghum, etc. In all other cases fall plowing and thorough working of the ground are to be recommended.

It is also of great importance that the sandy areas of the fields be made as rich as possible. A thorough application of fertilizer should be made in order to stimulate plant growth and make the plants more resistant to the attacks of this insect.

Where it is necessary to plant corn, sorghum, and allied crops in fields subject to infestation, it is advisable to make such plantings as early in the season as possible, thus enabling the plants to get a good start before the insect begins its depredations.

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(2) Blanchard, E.

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(3) Zeller, P. C.

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Page 544. *Pempelia lignosella* Zeller. Records the species from Brazil and Colombia, South America, "Carolina," and Texas. One pair taken July 15 and two females August 15 in Texas. Also gives the original description of the varieties *incautella* and *tartarella* each from one specimen taken August 21 in Texas.

(4) Zeller, P. C.

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(6) Berg, C.

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(8) Riley, C. V.

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(10) Riley, C. V.

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1884. Catalogue of the Exhibit of Economic Entomology at the World's Industrial and Cotton Centennial Exposition, New Orleans, 1884–'85, 95 p.

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(15) Ragonot, E. L.

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(18) Chittenden, F. H.

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(20) Dyar, H. G.

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(21) Chittenden, F. H.

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(26) Smith, J. B.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 550

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief.

Washington, D. C. August 9, 1917

CONTROL OF THE GRAPE-BERRY MOTH IN THE ERIE-CHAUTAUQUA GRAPE BELT

By

DWIGHT ISELY, Scientific Assistant, Deciduous Fruit Insect Investigations

CONTENTS

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CONTROL OF THE GRAPE-BERRY MOTH IN THE ERIE-CHAUTAUQUA GRAPE BELT.

By DWIGHT ISELY, *Scientific Assistant, Deciduous Fruit Insect Investigations.*

CONTENTS.

INTRODUCTION.

Of the grape pests of the Erie-Chautauqua grape belt none is more baffling to control or more discouraging to the vineyardist than the grape-berry moth (*Polychrosis viteana* Clem.) (Pl. I). Owing to its direct attack upon the fruit, its ravages are felt at once wherever it is present in destructive numbers. It is very erratic in its occurrence, both locally and seasonally. In some years it may be practically absent from the majority of the vineyards of the belt, whereas in other years it is often not only the pest of first importance, but its ravages exceed those of all other pests combined.

To establish means of control for this pest experiments were conducted at North East, Pa., during the seasons of 1914, 1915, and 1916.[1]

[1] This investigation was conducted under the direction of Dr. A. L. Quaintance, Entomologist in Charge of Deciduous Fruit Insect Investigations of the Bureau of Entomology. At the outset the work was greatly facilitated by the temporary association of Mr. Fred Johnson, formerly of this bureau, who placed at the writer's service his extended knowledge of grape insects and conditions in the Erie-Chautauqua grape region. The writer was assisted during the seasons of 1914 and 1915 by Mr. E. R. Selkregg and in 1916 by Mr. James K. Primm. Parallel with the experiments for direct control of the grape-berry moth, a study of its parasites was made by Mr. R. A. Cushman, from whom valuable cooperation was received. To these gentlemen and the cooperating vineyardists the writer wishes to express his appreciation for numerous courtesies.

NOTE.—This bulletin will be of interest to grape raisers in New York, Pennsylvania, Michigan, and Ohio.

The results of these experiments constitute the chief subject matter of this bulletin. Only such biological data as are necessary as a basis for the remedial work are included. Various control measures which have been employed are given place in the earlier part of the paper, but chief attention is devoted to spraying, which has proved to be the most effective means of control.

FOOD PLANT.

The grape, as far as is known, is the only food plant of the larva of the grape-berry moth, and since the larvæ usually feed upon the grape berry, it is from this habit that its common name is derived. Before the berries are developed, the few early larvæ feed in the blossom clusters. In confinement larvæ may feed sparingly on grape leaves and stems.

DISTRIBUTION.

The distribution of the grape-berry moth extends throughout the United States from east of the Great Plains to the Atlantic, and from the southern portion of the Canadian Province of Ontario to the Gulf of Mexico. The States from which it has been recorded in publications and in unpublished files of the Bureau of Entomology are as follows: Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Ohio, Indiana, Illinois, Wisconsin, Michigan, Missouri, Iowa, Nebraska, Kansas, Virginia, South Carolina, Florida, Alabama, Kentucky, Louisiana, Arkansas, and Texas. Most frequent complaints of its destructiveness have come to the Bureau of Entomology from New York, Pennsylvania, New Jersey, and Ohio.

ECONOMIC STATUS.

The grape-berry moth is a major grape pest in the eastern United States, on the whole probably being exceeded in destructiveness by the grape rootworm (*Fidia viticida* Walsh) and the grape leafhopper (*Typhlocyba comes* Say). However, its exact status as a pest is uncertain. In some grape-growing regions, within the limits of distribution, its presence is ignored or even unknown to the growers. It is exceedingly erratic and local in occurrence, and the damage which it inflicts varies greatly from year to year. The history of the grape-berry moth in the Erie-Chautauqua grape belt is an example of this variation. In the western part of the grape belt, in Pennsylvania, during the season of 1916 this insect was by far the most destructive grape pest; in the eastern part of the grape belt, in New York, it was not generally regarded seriously, yet Slingerland in 1904 reported it as very destructive throughout all of this region, particularly near Brocton, N. Y., where in one vineyard as high as 90 per cent of the fruit was ruined.

The extensive grape regions of Michigan have been the source of very few complaints of loss due to the grape-berry moth. In the summer of 1915 the writer visited many vineyards in the vicinity of Benton Harbor, St. Joseph, Paw Paw, and Lawton, Mich., and found the berry moth present in practically all of them, although usually in small numbers. Its destructiveness in this region is obscured by the greater and more consistent injury by the black-rot fungus, and probably injury by the grape-berry moth is often attributed to the black-rot fungus. In contrast to this, in the Ohio grape regions it has been consistently destructive and the leading grape pest for years. Even in a region where the grape-berry moth is a recognized pest it is by no means consistent in occurrence, and may be erratic and local even within a vineyard. In the vicinity of North East, Pa., in the western part of the Erie-Chautauqua grape belt, in most seasons fully half of the vineyards are practically free from it. In others the outside rows, ends of rows, or irregular spots are heavily infested, while the rest is practically free. Yet there are many vineyards that annually sustain the loss of from one-fourth to one-half the crop.

DESTRUCTIVENESS WITHIN A VINEYARD.

The destructiveness of the grape-berry moth is underestimated greatly even in vineyards where it is recognized as the chief pest, and where the infestation is light it is usually ignored. This is due to the fact that "wormy" grapes, unless very heavily infested, will bring a price comparatively near the standard price, seldom with a reduction of more than 10 per cent. Even when the infestation approaches total, the price may be much nearer to the standard for grapes than the price for cider apples is to the standard price for apples. Because of this the vineyardist is apt to consider the reduction in price as the chief loss and largely disregard what may be a greater charge against the berry moth—the reduction in weight.

The berries infested by first-brood larvæ (see Pl. II, fig. 1) are totally lost, although if they are destroyed very early in the season this loss may be partially offset by increased weight in the rest of the cluster. Those infested by the second brood (see Pl. II, fig. 2), which the larvæ have left or in which the larvæ are well grown, lose weight rapidly; by the end of the season they are little more than dry shells and have but a fraction of their former weight (Pl. III, fig. 1). This loss varies greatly, depending upon the time when the berries are infested and upon the time of harvest.

"Wormy" grapes are of course largely excluded from the market for basket grapes, for unfermented juice, and for some wines, unless all of the "wormy" berries are trimmed out. This exclusion from certain markets may in certain years represent a considerable loss.

If the infested berries are trimmed out of the clusters the loss of their weight is total in addition to the cost of trimming.

While the berry moth is not as generally destructive as the grape rootworm or grape leafhopper, it is capable of inflicting greater losses than either to a single season's crop, and neither of these pests will appear in destructive numbers with such alarming rapidity in a vineyard which has been apparently free from them as will the grape-berry moth. When it is present at all in a vineyard it always causes a loss in weight and is a constant menace to the grape industry in that vicinity.

SUMMARY OF SEASONAL HISTORY AND HABITS.[1]

Before considering control measures, a summary of the seasonal history and habits upon which these measures are based will be given.

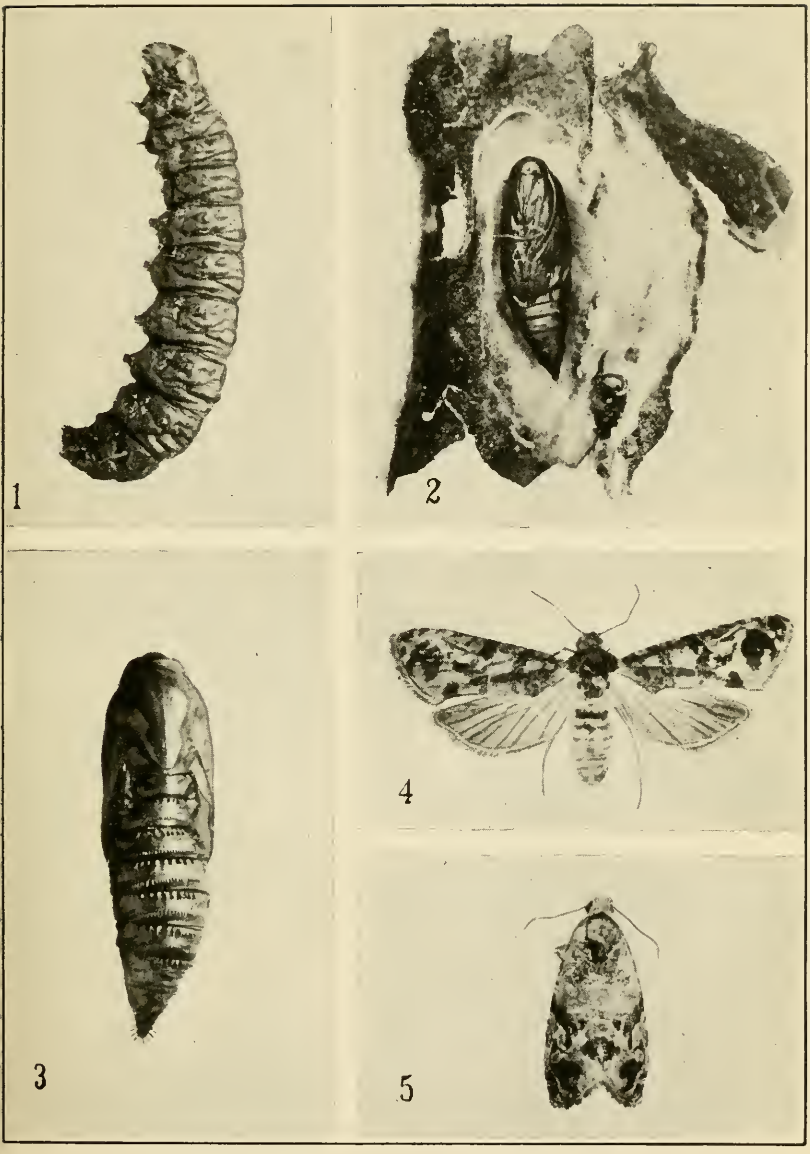
There are two broods of the grape-berry moth that must receive economic consideration. The first brood, resulting from the hibernating generation, is comparatively small, owing to high winter mortality of the pupæ. The earliest recorded emergence of moths is May 29 and the latest July 26; however, the bulk of the emergence begins between the 10th and the 25th of June, varying with the season, and usually is ended within 3 weeks. Within 4 to 6 days after emergence the moths (Pl. I, figs. 4, 5) begin depositing eggs, preferably on grape berries. Incubation requires about 6 days. Thus the hatching period of large numbers of larvæ begins from June 20 to July 5, depending upon the season, and continues for about 3 weeks.

The beginning of this period is almost coincident with the falling of the grape blossoms and the setting of the fruit. The larval feeding period averages 23 days, after which the larvæ (Pl. I, fig. 1) spin cocoons in leaves on the vine, and in an average of 13 days emerge as moths. Some pupæ (Pl. I, fig. 3), however, do not transform at this time but remain in the cocoon (Pl. I, fig. 2) until the following spring.

The earliest recorded emergence of summer-brood moths is July 12 and the latest is after the middle of September. A heavy emergence of moths begins in a normal season in the latter part of July, and in backward seasons may continue as late as the earlier part of September. Although the second brood is only a partial one, it is by far the more numerous and destructive. It may escape serious attention from the vineyardists until shortly before harvest, when the well-grown larvæ begin to leave the berries they first attacked and to enter others.

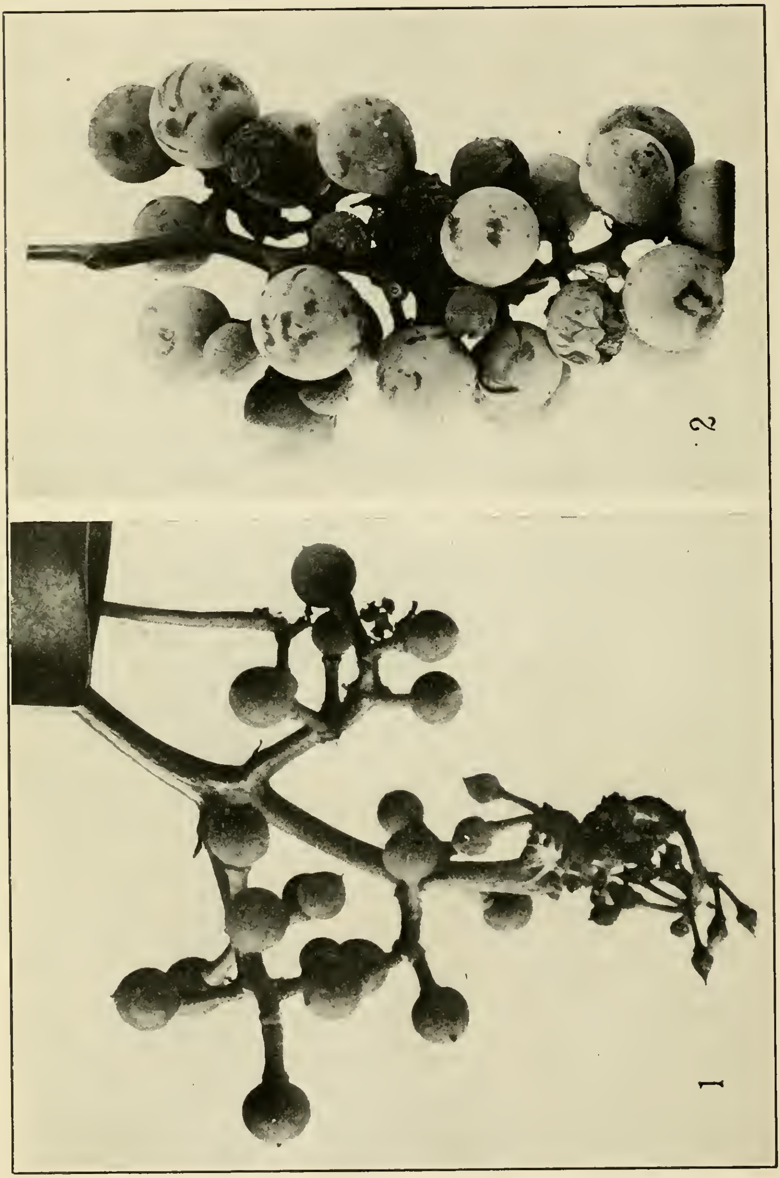
The development of this brood is slower than that of the first. In a normal season the larvæ are cocooning in large numbers by the latter part of September and by the middle of October most of them

[1] This summary is based on the life-history studies of the grape-berry moth by Johnson and Hammar, and studies by the writer and his associates, the details of which have not yet been published.



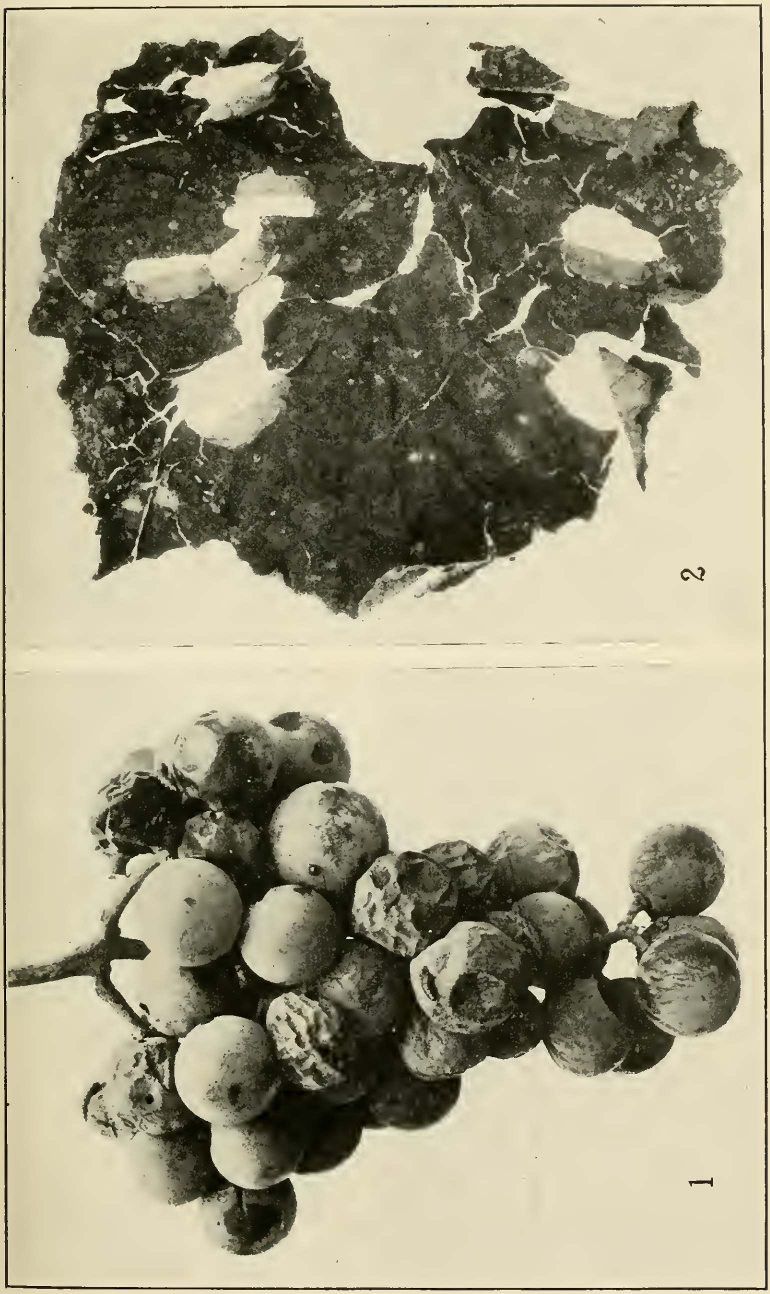
THE GRAPE-BERRY MOTH (POLYCHROSIS VITEANA).

FIG. 1.—Larva. FIG. 2.—Pupa (ventral aspect) in cocoon. FIG. 3.—Pupa (dorsal aspect). FIGS. 4, 5.—Adult. All greatly enlarged. (Original.)



GRAPE CLUSTERS ATTACKED BY FIRST-BROOD GRAPE-BERRY MOTH LARVÆ.

FIG. 1.—Injury by earliest larvæ, showing webbing of cluster. FIG. 2.—Injury by later larvæ, showing undersized, cracked, and shriveled berries which have begun to fall. Note second-brood eggs on surface of berries. (Original.)



DAMAGE BY THE GRAPE-BERRY MOTH.

FIG. 1.—Grape cluster at harvest time, heavily infested with second-brood grape-berry moth larvæ. FIG. 2.—Cocoons in sodden grape leaf under trellis. (Original.)

have left the berries. However, in the very late autumn of 1915 the majority of the larvæ did not leave the berries until after October 25.

Winter is passed in a cocoon, usually spun in a decayed grape leaf under the trellis. (Pl. III, fig. 2.)

FEEDING HABITS OF LARVÆ.

The very few early larvæ which hatch before the grape blossoms fall feed in the blossom cluster. But most of them, coming after the grapes are set, eat at once into the berry, causing the characteristic purple spotting and cracking of grape berries.

The point of entrance may be anywhere on the surface of the grape berry, but before the berries touch, about half of the larvæ enter around the stem attachment. Of 500 infested berries counted on July 14, 1916, about 12 days after setting of grapes, 266 were entered at the stem end and the other 234 from other parts of the grape berry. After the grape berries reach the stage of growth where they begin touching, the point of contact becomes the most common place of entrance.

The early larvæ, which hatch when the grape berries are still small, destroy many more berries than do larvæ which hatch after the grapes are larger.

FLIGHT OF MOTHS.

The distance which moths of this species may fly in large numbers is uncertain, but as a rule the spread of infestation is slow. In one instance serious infestation advanced from a heavily infested vineyard into an adjacent young vineyard not more than 100 or 120 feet distant. In this vineyard there could have been no previous infestation, as it had just come into bearing. Some infested berries were found 350 feet from the older vineyard, but very few. On the other hand, the following season a vineyard about 1,100 feet wide, newly in bearing, was traversed and infested heavily by a single generation. The spreading of infestation probably is much influenced by weather conditions at the time of the flight of moths. While it may be slow ordinarily, no vineyard is immune from rapid infestation in a vicinity where the berry moth is present.

HISTORY OF CONTROL METHODS.

Measures to control the grape-berry moth, since its appearance as an economic pest, have developed gradually from many sources. The first considerable advance toward a solution of the problem, however, was made by the biological and systematic studies of Slingerland (9)[1] and Kearfott (8) in which they definitely determined the limits of the species and the fact that the grape was its only food plant; and by Slingerland's field experiments, which

[1] Reference is made by number to "Literature cited," p. 42.

were the first in which spraying was attempted as a primary means of reducing its destructiveness.

Gathering and burning grape leaves in the fall, to destroy the hibernating insects, was recommended first by Walsh and Riley (1). This recommendation remained in good standing until it was questioned by Webster (5), because he was unable to rear any moths from collected leaves, and since that time it has appeared less frequently. Slingerland recognized the general futility of this practice and termed it "the least effective measure."

The bagging of clusters to prevent infestation was first recommended by Lintner (2).

Picking and destroying infested fruit was recommended by Bogue (6) in a general way. Slingerland (9) recommended the picking of grape berries infested by first-brood larvæ and also advised the destruction of the "trimmings."

Burying the hibernating pupæ by plowing was also first suggested by Slingerland (9).

Marlatt (3) first recommended spraying, but did so doubtfully, for at that time the berry moth was regarded as a general feeder. Following this both Beach (4) and Bogue (6) disparaged spraying as "of little value." Webster (5), however, observed that the pest could be controlled by spraying, and Felt (7) reported, as an incidental to rootworm control, that spraying had reduced the berry-moth infestation 50 per cent.

Slingerland's work, mentioned above, was followed by a number of important contributions. Gossard and Houser (11), in Ohio, recommended the addition of soap to an arsenical spray and the use of "trailers" in applying it. A thorough life-history study, the first upon which a satisfactory spray schedule could be based, was made by Johnson and Hammar (16) and a combination of control measures was recommended. Goodwin (19), in Ohio, recorded satisfactory results by spraying, using 3 pounds of arsenate of lead (powdered) to 50 gallons of liquid, an adhesive, and an application with "trailers." His spray schedule differed from the preceding by being directed largely against the second-brood larvæ.

CONTROL EXPERIMENTS AT NORTH EAST, PA.

Experiments to establish a control for the grape-berry moth, conducted at North East, Pa., were carried on in vineyards on a commercial scale whenever possible. Vineyards chosen for experimental work were those which had been infested heavily the previous season and as far as possible those in which the infestation had been distributed rather evenly.

To determine the degree of success of the different methods tried in vineyards, whenever it was feasible, counts were made of the sound and infested berries in the different experimental plats and in the adjacent untreated check plats. Counts of infested berries in each of the different plats were made the first season from four 40-pound crates of harvested fruit. In all plats in a single vineyard, the crates were taken from the same relative positions. During the following seasons a count was made from all of the fruit from 12 to 25 vines. These vines were taken at intervals throughout the length of each plat so as to include all conditions, and in the same relative positions in all plats in the same vineyard.

ELIMINATING VINEYARD CONDITIONS FAVORABLE TO THE GRAPE-BERRY MOTH.

Winter Exposure.

Protected situations in vineyards, along hedgerows, fences, or woodlots, and low-lying spots, are invariably more heavily infested by the berry moth than are the less protected portions of the same vineyard. On the other hand, exposed knolls seldom are infested heavily. This variability in infestation, according to Johnson and Hammar, is due to protection afforded to hibernating insects and the consequent reduction of winter mortality. Goodwin attributed the heavier infestation in low-lying spots to washing of cocoons in winter. Observations by the writer confirmed both these conclusions and also indicated that wind at the time of flight of moths is a factor, as moths drift with the wind into these low-lying spots.

Of these factors causing heavy infestation, one at least, winter protection in a vineyard, can be regulated more or less by artificial means. The importance of this factor was tested during the winter of 1915–16.

Different lots of cocoons, collected in the fall of 1915, were placed in cylindrical baskets of 20-inch wire mesh and wintered in vineyards in protected and in exposed situations, and also in the insectary yard under a covering of leaves held in place by wire screen. To forestall accidents each lot was divided into two baskets. In May, 1916, the cocoons were removed and placed in rearing jars. Table 1 shows the effect of the different conditions upon mortality:

Table 1.—*Percentage of emergence of the grape-berry moth hibernating in exposed and in protected situations.*

Lot No.	Situation.	Number of cocoons.	Number of moths emerged.	Emergence.
				Per cent.
I.	In vineyard, naturally exposed; crest of windswept knoll....	350	20	5.71
II.	In vineyard, naturally protected by brush and drifted snow..	350	86	24.05
III.	In vineyard, artificially protected by covering with 2 inches of earth..	150	45	30.00
IV.	In insectary yard, artificially protected under "leaf blanket".	350	154	44.00

The rearing records show clearly the value of winter exposure in a vineyard in reducing the number of moths that will be present the following season.

A comparison of Lot III with Lot I shows how plowing, if injudiciously practiced, may increase vineyard infestation. If a furrow is thrown up to the vines in late fall, after the larvæ have spun their cocoons under the vines, it will give the hibernating pupæ winter protection. And if the earth is plowed away before the time of moth emergence, these artificially protected insects are released.

It is obvious that the protection of hibernating pupæ should be avoided whenever practicable. Plowing to the vines in late fall after harvest should be avoided as far as possible. Hedge rows and brush along vineyards should be removed. This last coincides with good vineyard practice and is of value also in reducing danger of leaf-hopper injury.

Unnecessary Shade.

Shade in a vineyard favors the berry moth. Where the growth is vigorous and the foliage dense, or where vines have been trained so as to give an unusual amount of shade, the infestation invariably is heavier than in adjacent parts of the vineyard or in vines giving less shade. Vigorous growth is desired, of course, but when horticultural considerations do not prevent, vine training systems which give unusual shade should be avoided.

DESTRUCTION OF LEAVES IN FALL.

Destruction of the hibernating generation in the cocoon, the first control measure to be recommended, was tried in the fall of 1914. In a small block in the McDonald vineyard the writer attempted removing cocoons by raking out the leaves under the trellis. Upon examination of the leaves thus collected it was found that practically all of the cocoons had fallen out. In the following season when counts of berries infested by first-brood larvæ were made no difference between this block and the check was noted.

During the seasons of 1914, 1915, and 1916 the writer and his associates collected approximately 30,000 cocoons for rearing. No system could be devised to aid in collecting these cocoons and the work was necessarily done by hand. It was always a slow and tedious process and is impracticable as a means of control, since the cocoons are usually spun, except in very dry seasons, in leaves that are sodden and ready to fall apart, and not in fresh, crisp leaves. Frequently the cocoons are spun in the leafage of chickweed and sorrel and in other leaves which ordinarily would escape collection.

BAGGING GRAPE CLUSTERS.

The bagging of grapes immediately after the setting of fruit, to prevent infestation by the berry moth, was tried in the season of 1914 in the vineyard of the late Mr. J. L. Spofford. Clusters on 25 vines were covered with paper bags, 2 and 3 pound sizes. The bags were fastened on the clusters with long pins and a slit was cut in the bottom of each bag to drain out whatever water might collect.

The experiment was successful in so far as exclusion of the moth was concerned. Only 20 wormy berries were found in 100 clusters which averaged 32 berries to the cluster. This was a total infestation of only 0.62 per cent. However, the test was not severe, for the infestation of the grapes on the surrounding vines was light, being only 13.2 per cent. The infestation of the bagged clusters was due no doubt to oviposition which had taken place before the bags had been placed on the clusters.

The cost of bagging, however, is prohibitive in commercial vineyards in the Erie-Chautauqua grape region. Brooks (10) records, in control measures against the grape curculio, that one laborer in his employ could bag 1,200 clusters a day. This was probably exceptionally fast work. Using this as a basis and figuring 550 vines per acre, each bearing 40 clusters, or a total of 22,000 clusters, the minimum cost of bagging an acre of grapes, according to 1914 prices, would be as follows:

Applying bags	$22.91
Cost of bags, $1.15 per 1,000	25.30
Pins, $0.10 per 1,000	2.20
Total	50.41

This method of control, if followed at all, would be practicable only in a garden vineyard.

HAND PICKING INFESTED BERRIES.

Attempts to control the grape-berry moth by hand picking the fruit infested by first-generation larvæ, in order to prevent subsequent infestation, were made in the seasons of 1914 and 1915. Clear-cut comparisons between the hand-picked plats and the checks were impossible because of the flight of moths from one row to another.

Experiment in Adams and Gill Vineyard of North East, Pa., 1914.

The plat chosen for the hand-picking experiment was a narrow strip of eight rows, containing slightly more than 1 acre, located in a corner of the vineyard, and bordered by a hedgerow. This plat was from three to four times as grossly infested as was the greater part of the vineyard. After the six rows nearest the hedge, the percentage of infestation declined quite rapidly as compared with that of the rest of the vineyard, and the south end, which was lower than the rest of the plat, was even more heavily infested than the rows next to the hedge.

Hand picking of wormy fruit was done July 7 and 8 and again between July 25 and August 1. The time of the first picking occurred about 10 days after the falling of the blossoms. The actual time expended in this work was 35.5 hours for the two men employed, or a total of 71 hours. The second picking, which was more or less interrupted by rain, developed that about 12 per cent of the berries were wormy.

The counts of wormy berries taken at harvest time showed the following percentages of infestation:

	South end.	North end.
	Per cent.	*Per cent.*
Hand-picked plat	84.4	24.9
Check	68.2	25.3

This shows as a curious result that the hand-picked area was more heavily infested than the check, probably owing to the flight from the vineyard at large of moths which settled in this narrow protected area.

Experiment in Moorhead Vineyard, Moorheadville, Pa., 1914.

A plat of 16 rows, 2 acres in area, was chosen in the middle of the vineyard of the late R. E. Moorhead. The infestation was comparatively uniform throughout. Hand picking of infested fruit was done three times, July 2 and 3, again from July 17 to 21, and again from August 10 to 15. The total time occupied in treating the 2 acres was 55 hours, or 27½ hours per acre.

Counts of infested berries from four crates of grapes from the hand-picked plat were made and the same from the check plat. The following shows the percentage of infestation:

Hand picked	14.7 per cent.
Check	27.4 per cent.

Experiment in the McDonald Vineyard, North East, Pa., 1915.

The heavily infested ends of 12 rows of a vineyard section adjoining a woodlot were chosen for this experiment. The picked area extended along the rows about 70 feet. The plat was picked over once, August 5 and 6, requiring a total of 22 hours' work for approximately one-fifth of an acre.

Counts taken just before harvest from representative vines in the hand-picked plat and in the check plat showed the following results:

Table 2.—*Counts in hand-picking experiment, McDonald vineyard, North East, Pa., 1915.*

Plat.	Number of vines.	Number of clusters.	Number of berries.	Infested berries.	Infested berries per 100 clusters.	Infestation.
						Per cent.
Hand picked	12	520	13,664	2,592	498.4	18.12
Check	12	546	16,513	6,162	1,136.6	34.93

EXPERIMENT IN THE MOORHEAD VINEYARD, MOORHEADVILLE, PA., 1915.

A plat of 22 rows, comprising nearly 3 acres, part of which had been hand picked in the experiment in 1914, was chosen for experimental work. No difference in infestation was shown in the two parts of this plat, probably because the effect of the work of the previous season had been obscured by the flight of moths from one part to another. However, the cumulative results probably were of considerable value, as the infestation in this section of the vineyard was much lighter than it had been the previous season, while the infestation of the vineyard as a whole was about the same.

The plat was hand picked only once for infested berries, between July 30 and August 5, the time required being lengthened by rain. The actual labor required was 43 hours.

Counts taken just before harvest on 12 representative vines in the hand-picked plat and in the check plat showed the following results:

TABLE 3.—*Counts in hand-picking experiment, Moorhead vineyard, North East, Pa., 1915.*

Plat.	Number of vines.	Number of clusters.	Number of berries.	Infested berries.	Infested berries per 100 clusters.	Infestation.
						Per cent.
Hand picked	12	408	11,793	945	242.3	8.01
Check	12	360	11,793	1,677	465.8	14.22

DISCUSSION.

An average, from the different experimental plats, of the time required to hand pick the "wormy" berries in an acre of grapes was 55.75 hours. At 12½ cents per hour the cost per acre would be $6.97.

This method, hand picking wormy berries, was employed in a number of vineyards by the owners during the seasons of 1914 and 1915 and as a rule the beneficial results were not readily apparent. In several instances the value of the work was reduced by picking the berries after most of the "worms" had left the grapes, and in others by inefficient laborers who missed a large percentage of the "wormy" berries. In some cases the infestation probably was considerably reduced and in one instance apparently successful control resulted. In this vineyard the infestation was restricted to a narrow strip comprising a few rows which were hand picked by the owner himself about once a week.

From the experiments and observations of the two seasons, hand picking of "wormy" berries could be relied upon to reduce berry-moth infestation but not to control it. The difficulty of securing ample and efficient labor at a time when it is needed stands in the way of adopting hand picking as a general method of repression, and the ultimate cost is thus too high when only partial control may be expected. It might be of use in a garden vineyard or in a commercial vineyard where only a small area is infested, but on the whole it can not be regarded as a satisfactory remedial measure.

EARLY HARVESTING.

Early harvesting of grapes and removal of the "trimmings" remove great numbers of berry-moth larvæ which otherwise would be left to overwinter in the vineyard. This practice is limited, for the grape harvest usually continues long after a majority of the berry-moth larvæ have cocooned. However, it should be applied to the worst infested areas in the vineyard.

The degree of reduction of hibernating pupæ by comparatively early harvesting is best shown by counting cocoons under vines. During the harvest of 1915, which was an extremely late season, one part of the edge of a vineyard, where the infestation was approximately 50 per cent, was picked October 12 to 15, and all grapes were removed; the other part was picked October 24 to 26. The count of cocoons under 14 vines from each block was as follows:

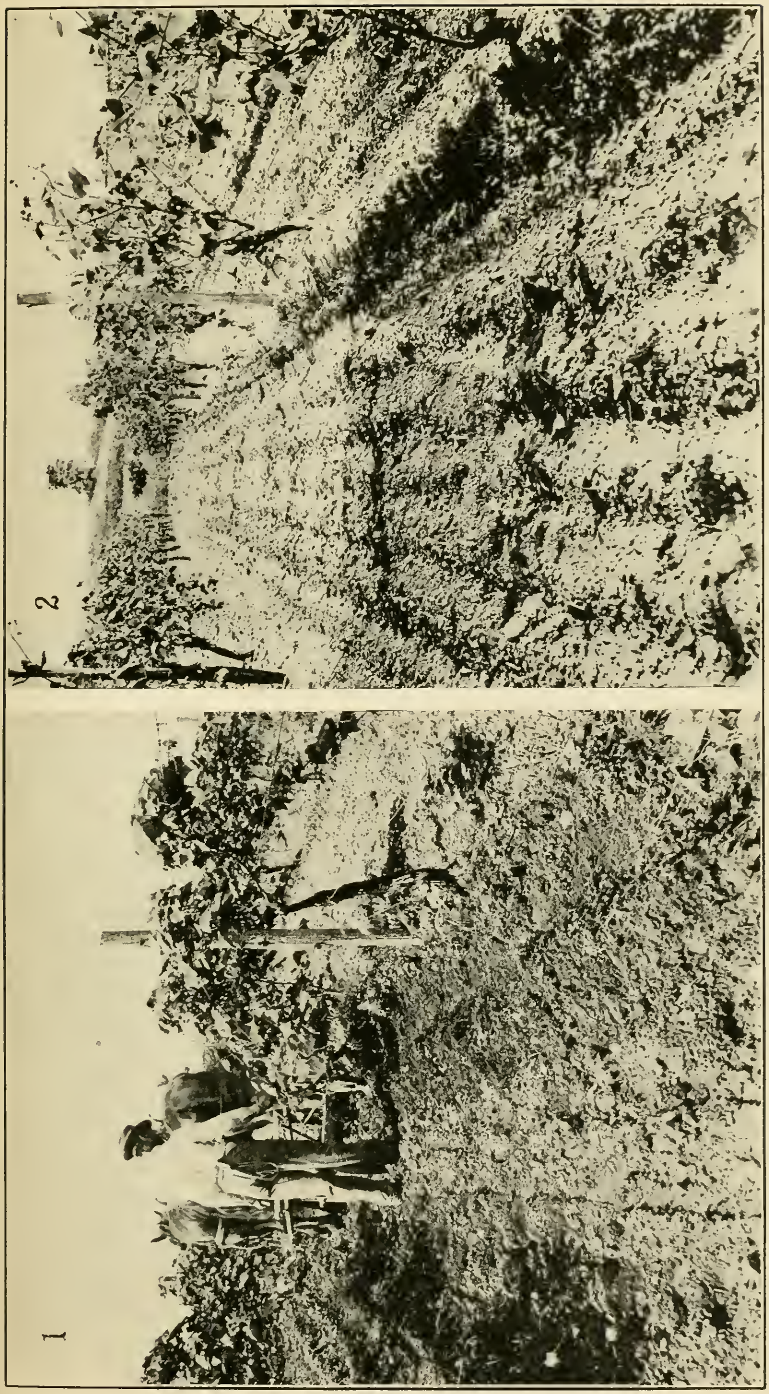
Date picked.	Number of vines.	Cocoons found under vines.	Cocoons per vine.
Oct. 12 to 15	14	92	6.59
Oct. 24 to 26	14	621	44.50

As stated, this was an exceptionally late season. During the season of 1916, according to the records, half the larvæ had left the grapes by October 4. Johnson and Hammar found that during normal seasons the majority of the berry-moth larvæ left the grapes by October 10.

Early harvesting is more valuable in avoiding loss of weight in the crop attacked than in reducing the following season's infestation. Grapes badly infested with the berry moth lose weight rapidly after the picking season begins, owing to the movement of larvæ from infested to sound berries, and to the subsequent shrinking of previously infested berries.

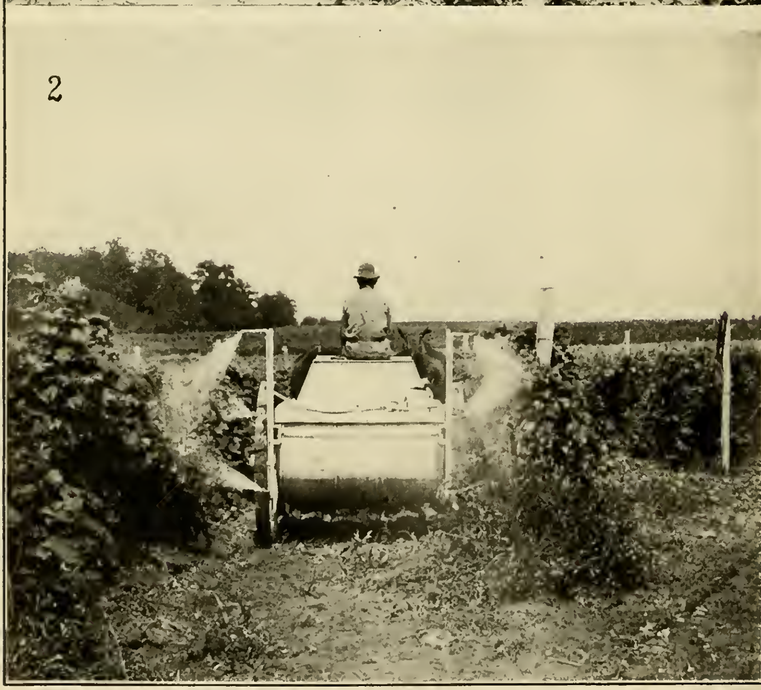
BURYING HIBERNATING PUPÆ.

"Plowing under" the hibernating generation previous to the time of moth emergence and keeping it covered during the earlier part of this period had been practiced for a number of years in the vicinity of North East, Pa., although no definite knowledge as to the effectiveness of the practice had yet been ascertained. (See Plate IV.) In late fall or early spring earth is thrown up by a plow to the vines on both sides covering the hibernating pupæ under several inches of earth. This earth is allowed to remain until after the general emergence of moths in the spring, when it is removed with a horse-hoe.



CULTURAL METHODS AGAINST THE GRAPE-BERRY MOTH.

FIG. 1.—Removing ridge of earth under trellis with horse hoe. FIG. 2.—Ridge of earth before horse hoeing. (Original.)



SPRAYING AGAINST THE GRAPE-BERRY MOTH.

FIG. 1.—"Trailer" method of applying spray. FIG. 2.—"Set nozzle" method of applying spray. (Original.)

The effect of this treatment is to prevent the moths from escaping through the covering of earth.

In a number of vineyards where this method of control has been practiced, check rows were maintained in which the earth was removed early in the season, in order to determine, if possible, the effects of the practice. No definite results were obtained. If small checks were left the flight of moths obscured the results altogether; and in larger checks variation of infestation interfered. In some vineyards the infestation appeared to be reduced greatly, but in none was it controlled.

The principle of this practice was proven correct, however, by a small experiment in the insectary yard during the season of 1916.

Three lots of 300 cocoons each, collected in the fall of 1915 and wintered in the insectary yard, were placed in 8-inch flowerpots. Two lots were covered with from $2\frac{1}{2}$ to 3 inches of earth; the third was left uncovered. The emergence record totals as follows:

From 600 cocoons buried under earth no moths emerged.
From 300 cocoons not buried 103 moths emerged.

In a number of small lots 60 cocoons were placed in glass vials where the action of the moths after emergence could be observed. These cocoons were covered with earth at depths varying from $\frac{1}{2}$ inch to 3 inches. Upon emergence none of the moths were able to work their way upward through the covering of earth. It should be remembered, however, that results as satisfactory as these can not be expected under field conditions.

"Horse hoeing" away from the vines, if done during the grape blossoming period, would also destroy grape-rootworm pupæ which are transforming at that time (13, 18).

SPRAYING.

Experiments with poison sprays were conducted during each of the three seasons. All of the vineyards but one were planted to Concord grapes, which is the standard variety for this grape-producing region. In 1916 experiments were conducted also in a single vineyard of Niagara grapes.

Weather conditions affecting spraying operations and results differed strikingly during the three seasons. Records from the Weather Bureau station at Erie, Pa., on Lake Erie, 16 miles west of North East, showed that in 1914 the months of July and August were nearly normal. The next year was colder with excessive rains during these two months, while the corresponding period of 1916 was very warm and dry. The average mean temperature for these two months in 1915 was 2.4° below normal and the rainfall was 7.95 inches above normal. In 1916 the average mean temperature was 3.7° above normal and the rainfall was 3.39 inches below normal.

In rainfall during these two months the two seasons showed a difference of 11.34 inches.

Methods of Application.

All spray applications were made with a gasoline-power sprayer. Two methods of applying the spray were used. (See Pl. V.) By the one, spray was applied to the vines by a "set-nozzle" arrangement at the rear end of the machine. From vertical pipes on each side of the machine two short spurs were directed outward, each bearing an angle nozzle which drove the spray outward and upward and as far as possible under the leaves. The lower spur was below the lowest wire of the trellis. The height of this spur could be varied somewhat to suit the trellis. A third and upper nozzle was mounted on a longer spur and projected over the trellis, the nozzle being directed downward. The "set-nozzle" method of application of spray is more generally used against the grape rootworm and mildew, because it is least expensive from the labor standpoint.

By the other method single nozzles were mounted on short rods attached to the machine by trailing hose, and the spray was directed to the grape clusters by hand. This "trailer" method has been recommended by Johnson in his investigations against the grapevine leafhopper.

The two methods require about the same amount of spray material per acre. When "set nozzles" were used about 150 gallons of spray was applied per acre; with "trailers," about 125 gallons per acre was used immediately after the falling of the blossoms, and about 175 gallons when the berries began to touch.

When applications were made with "set nozzles" the machine was driven along every row, but when "trailers" were used the machine was usually driven only along alternate rows, the rodman on each side being able to reach through the trellis and spray both sides of the row.

The spraying schedules followed in these investigations were based largely on the seasonal-history studies on the grape-berry moth made by Johnson and Hammar, modifications being made the second and third seasons.

Spraying Experiments in 1914.

From a control standpoint the spraying in 1914 was a failure, although it did bring about a consistent reduction in the numbers of the berry moths. Furthermore, results in the Phillips vineyard were of uncertain value because of the wide variation of infestation as shown by the checks. The negative results were of value, however, since they indicated the necessity of a radical revision of spraying practice.

In applying the spray, the difficulty in covering the grape clusters with "set nozzles" was apparent. It was noted also that even when the spray was applied directly to the grape clusters with "trailers" it did not adhere to the waxy skin of the grape berries, except when the solution to which soap had been added was used. These features, (1) the application of the spray directly to the grape clusters and (2) the addition of soap to the solution, were the most important changes which were suggested by this season's work.

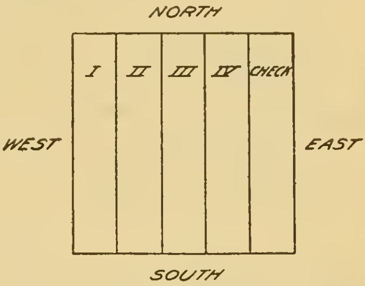


FIG. 1.—Diagram showing arrangement of experimental plats in Mr. J. M. Moorhead's vineyard, Moorheadville, Pa., 1914. (Original.)

EXPERIMENT IN THE MOORHEAD VINEYARD, MOORHEADVILLE, PA., 1914.

Experimental work in the Moorhead vineyard was conducted in a section of 38 rows, comprising about 5 acres, which was divided into 4 plats of 8 rows each and one of 6 rows, the latter used as the check plat. The arrangement of the plats is shown in the diagram (fig. 1). The vineyard was rather evenly infested throughout.

TABLE 4.—*Spray mixtures used, methods and dates of application, and percentages of infestation in experimental plats, Moorhead vineyard, Moorheadville, Pa., 1914.*

Plat No.	Dates sprayed with set nozzles.	Dates sprayed with trailers.	Arsenate of lead (paste).	Bordeaux mixture.		Laundry soap.	Water.	Infestation.
				Lime.	Copper sulphate.			
			Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Gallons.*	*Per cent.*
I	June 9, 23, and July 9		3	3	3		50	25.6
II	June 23 and July 9		3	3	3		50	26.7
III	June 23	July 9	3	3	3		50	27.8
IV	do	July 10	3	3	3	[1] 1	50	22.9
Check, unsprayed.								31.8

[1] Last application only.

Though the experiments in this vineyard showed a consistent reduction of infestation, definite control of the grape-berry moth was not established. In one plat the results appeared somewhat more favorable than in the others and offered a suggestion for further investigation. Soap was added to the spray mixture and "trailers" were used in applying it, but as these changes had been made only for the last application they could not affect the results materially.

EXPERIMENT IN THE PHILLIPS VINEYARD, NORTH EAST, PA., 1914.

Experimental work in the Phillips vineyard was conducted in a section which included 44 rows, covering about 7 acres. It was divided into 7 plats of 6 rows each. The middle row of each plat and the two rows at one side were chosen for checks. The arrangement of the plats is shown in the diagram (fig. 2).

TABLE 5.—*Spray mixtures used, methods and dates of application, and percentages of infestation in experimental plats, Phillips vineyard, North East, Pa., 1914.*

Plat No.	Dates sprayed with set nozzles.	Dates sprayed with trailers.	Arsenate of lead (paste).	Bordeaux mixture.		Laundry soap.	Nicotine sulphate.	Water.	Infestation.
				Lime.	Copper sulphate.				
			Lbs.	*Pounds.*	*Pounds.*	*Pounds.*	*Pints.*	*Galls.*	*Per ct.*
I	June 12, 26, and July 12		3	3	3			50	5.2
II	June 26 and July 12		3	3	3			50	4.5
III	June 26	July 12	3	3	3			50	7.2
Check A									8.7
IV	June 26 and July 12		3	3	3	[1] 1		50	9.5
V	June 26	July 12	3	3	3	[1] 1	[1] ¼	50	5.5
VI	June 26	July 12	3	3	3	[1] 1		50	17.9
Check B									52.4

[1] Last application only.

The infestation in this vineyard had been very heavy the previous season, but in 1914 it was light. Check plat B was much more heavily infested than the adjacent sprayed plat, whereas this plat was much more heavily infested than check plat A. While it is probable that spraying did reduce the infestation somewhat in this plat and in the one next to it, because of the wide variation of infestation in the unsprayed checks, this can not be stated definitely. The similarity of results in check plat A and the sprayed plats adjoining it indicates failure in control.

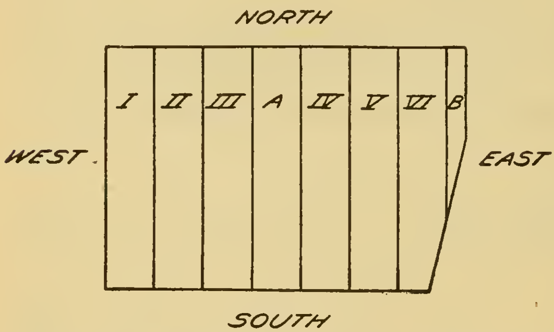


FIG. 2.—Diagram showing arrangement of experimental plats in Mr. M. D. Phillip's vineyard, North East, Pa., 1914. Sprayed plats are marked with Roman numerals, check plats with letters. (Original.)

SPRAYING EXPERIMENTS IN 1915.

The season of 1915 was marked by extremely heavy rainfall during the spraying season and during the month following. Spraying operations were interrupted frequently or delayed by rain and as a result spraying as a remedial measure was put to a very severe test. However, when the final counts were made, all plats sprayed with solutions containing arsenate of lead and soap and applied with "trailers" showed a satisfactory reduction of infestation from a commercial standpoint. The contrast in infestation between the sprayed plats and others was commented on with astonishment at harvest time by pickers who were ignorant that any remedial measures had been employed. Tables 6 and 7 will give in detail the treatments applied in the different vineyards and the results as shown by percentages of "wormy" fruit.

EXPERIMENT IN THE BARTLETT VINEYARD, NORTH EAST, PA., 1915.

Experimental work in this vineyard was conducted in a square corner section of about 2 acres which had been very heavily infested in 1914. It was divided into two large plats of 11 rows each with an 8-row check between and 2 narrow plats of 3 rows each outside of the larger ones. The adjacent vineyard also was unsprayed and used as a check. The arrangement of plats is shown in the diagram (fig. 3).

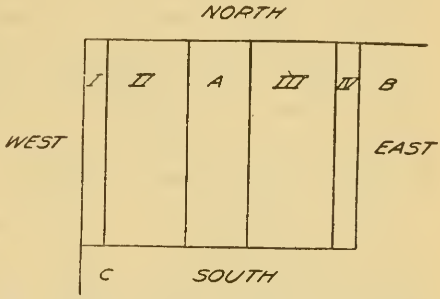


FIG. 3.—Diagram showing arrangement of experimental plats in the vineyard of Mr. A. P. Bartlett, North East, Pa., 1915. The sprayed plats are marked with Roman numerals and the check plats with letters. (Original.)

TABLE 6.—*Spray mixtures used and method and dates of application in experimental plats, Bartlett vineyard, North East, Pa., 1915.*

Plat No.	Dates of spraying.	Arsenate of lead (paste).	Bordeaux mixture.		Laundry soap.	Nicotine sulphate.[1]	Water.	Method of application.	Remarks.
			Lime.	Copper sulphate.					
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pints.*	*Gallons.*		
I........	July 6, 19	3	3	3	1	¼	50	Trailers.	Double sprayed.[2]
II........	...do........	3	3	3	1	¼	50	...do.....	Single sprayed.[2]
III........	...do........	5	3	3	1	¼	50	...do.....	Single sprayed.[2]
IV........	...do........	5	3	3	1	¼	50	...do....	Double sprayed.[2]

[1] Last application only.
[2] Plats marked "double sprayed" were sprayed twice on each date of treatment, the second spray being applied as soon as the first had dried.

TABLE 7.—*Percentage of infestation in experimental plats, Bartlett vineyard, North East, Pa., 1915.*

Plat No.	First brood.					Second brood.				
	Number of vines.	Number of clusters.	Total berries.	Infested berries.	Infestation.	Number of vines.	Number of clusters.	Total berries.	Infested berries.	Infestation.
					Per cent.					*Per cent.*
I...............	20	1,024	29,036	572	1.97	15	768	21,760	849	3.9
II...............	20	1,132	31,314	572	2.71	15	849	23,489	963	4.1
Check A.........	20	1,124	30,568	2,404	7.86	15	843	22,926	3,372	14.8
III...............	20	1,330	38,676	375	.97	15	997	29,066	313	1.2
IV...............	20	1,192	41,107	124	.30	15	894	30,830	68	.23
Check B.........	20	1,051	29,567	1,943	6.57	15	788	22,175	3,925	17.7
Check C.........	20	832	21,356	1,743	8.16	15	624	16,016	1,399	46.2

On all sprayed plats where poison with adhesive had been applied with "trailers" the control was effective. Plats I and II on which arsenate of lead (paste) had been applied at the rate of 3 pounds to 50 gallons of liquid were infested more heavily than Plats III and IV, on which arsenate of lead at the rate of 5 pounds to 50 gallons had been applied. The infestation was naturally heavier on the west side, however, as is shown by a comparison of the unsprayed plats. Double spraying appeared to reduce the infestation but not enough to offset the extra cost of application.

EXPERIMENT IN THE MILLER AND CARLBURG VINEYARD, NORTH EAST, PA., 1915.

The experimental plat in this vineyard included 64 rows covering about 10 acres. It was divided into 10 plats of 6 rows each, the 4 remaining rows being left for check. This plat was surrounded on

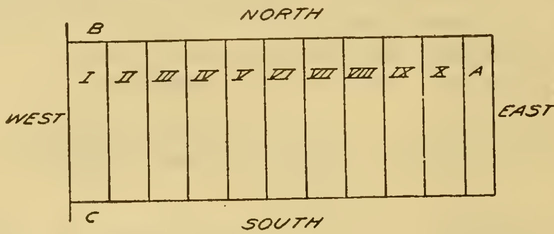


FIG. 4.—Diagram showing arrangement of experimental plats in the vineyard of Messrs. G. H. Miller and A. I. Carlburg, North East, Pa., 1915. The sprayed plats are marked with Roman numerals and the check plats with letters. (Original.)

all sides by vineyard, two parts of which were used as checks also. The arrangement of plats is shown in the diagram (fig. 4). Spraying operations for both first and second applications in this vineyard were interrupted and delayed by frequent rains.

TABLE 8.—*Spray mixtures used and methods and dates of application in experimental plats, Miller and Carlburg vineyard, North East, Pa., 1915.*

Plat No.	Dates of spraying.	Arsenate of lead (paste).	Bordeaux mixture.		Laundry soap.	Fish-oil soap.	Flour paste.	Nicotine sulphate.	Water.	Method of application.
			Lime.	Copper sulphate.						
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pints.*	*Gallons.*	
I	July 2, 15	3	3	3	1				50	"Trailers."
II	July 2, 15	5	3	3		2			50	Do.
III [1]	July 2, 15	3				2			50	Do.
IV	July 3, 16	3	3	3	1				50	Do.
V	July 3, 16	3	3	3		2		1/4	50	Do.
VI	July 3, 16	3	3	3	1			1/4	50	Do.
VII	July 3, 17		3	3	1				50	Do.
VIII	July 5, 17	3	3	3			2		50	Do.
IX	July 5, 17	3	3	3					50	Do.
X	July 5, 17	3	3	3		2			50	"Set nozzles."

[1] Rain followed immediately after the second spray application on this plat and apparently washed off most of the spray.

TABLE 9.—*Percentage of infestation in experimental plats, Miller and Carlburg vineyard, North East, Pa., 1915.*

Plat No.	First brood.					Second brood.				
	Number of vines.	Number of clusters.	Total berries.	Infested berries.	Infestation.	Number of vines.	Number of clusters.	Total berries.	Infested berries.	Infestation.
					Per ct.					*Per ct.*
I	25	601	14,028	450	3.21	20	481	10,822	847	7.91
II	25	544	12,550	414	3.29	20	435	9,640	951	9.86
III	25	492	11,235	519	4.53	20	397	9,088	2,887	31.77
IV	25	460	13,692	343	2.51	20	368	10,956	432	3.94
V	25	575	13,705	289	2.11	20	460	10,960	967	9.56
VI	25	796	19,544	479	2.45	20	637	15,625	1,188	7.60
VII	25	712	22,736	1,264	5.99	20	570	16,587	5,523	33.31
VIII	25	661	18,508	795	4.18	20	529	14,783	2,793	18.89
IX	25	561	16,269	901	5.53	20	459	13,005	2,738	21.05
X	25	716	21,480	1,024	4.53	20	513	15,441	3,152	20.41
Check A	25	695	20,850	1,013	4.86	20	556	14,430	3,958	28.80
Check B	25	792	23,882	3,533	14.87	20	634	19,135	11,803	61.67
Check C	....	....	....	....	....	10	340	9,380	4,710	50.21

In spite of the exceedingly adverse weather conditions at the time of spraying, all plats but one on which arsenate of lead with soap had been applied twice with "trailers" (Plats I, II, IV, V, and VI) showed a satisfactory reduction of the grape-berry moth from a commercial standpoint. In one plat where rain followed immediately after the second spray application (Plat III) the results must be disregarded. The rain also probably reduced the efficiency of control in Plat II, which was sprayed just before Plat III, and to a less degree may have affected others; but the results showed that when the spray had time to dry on the grape berries before rain, a fairly satisfactory control could be secured. Failure to control resulted in plats where spray was applied with "set nozzles" instead of "trailers" (Plat X), where the soap was omitted from the spray mixture (Plat IX), and where flour paste was used as adhesive instead of soap (Plat VIII). Bordeaux mixture and soap were used without arsenate of lead (Plat VII) and no effect, repellent or insecticidal, was noted. Nicotine sulphate appeared to add nothing to the effectiveness of the solution (Plats V and VI). Laundry soap (Plats I, IV, and VI) and fish-oil soap (Plats II and V) were both used apparently without distinct advantage for either. The plat sprayed with 5 pounds of arsenate of lead (paste) to 50 gallons of liquid (Plat II) was much more heavily infested than the plat sprayed with only 3 pounds of arsenate of lead (paste) to 50 gallons (Plat IV), but as the second application of spray on Plat II was closely followed by rain the infestation in this plat was probably also somewhat heavier naturally. (Compare check plats B and C with A.)

EXPERIMENT IN THE MOORHEAD VINEYARD, MOORHEADVILLE, PA., 1915.

The experimental work in the Moorhead vineyard was conducted in the same section as in 1914, but the arrangement of plats was somewhat changed. The plat that had the lightest infestation was chosen as check, while the check of the 1914 season was sprayed. The adjacent sections of the vineyard were sprayed once by the owner, soon after July 1, with arsenate of lead (paste), 3 pounds, and Bordeaux mixture, 50 gallons, to control the grape rootworm; the spray was applied with "set nozzles." Counts were made from these sections adjacent to the experimental block and they are recorded as checks, B and C. The arrangement of plats is shown by the diagram (fig. 5).

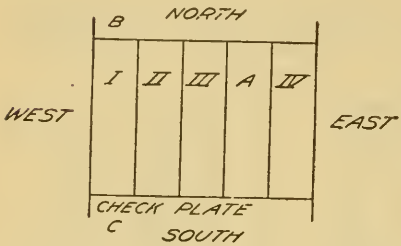


Fig. 5.—Diagram showing arrangement of plats in the vineyard of Mr. J. M. Moorhead, Moorheadville, Pa., 1915. The sprayed plats are marked with Roman numerals and the check plats with letters. (Original.)

Table 10.—*Spray mixtures used and methods and dates of application in experimental plats, Moorhead vineyard, Moorheadville, Pa., 1915.*

Plat No.	Dates of spraying.	Arsenate of lead (paste).	Bordeaux mixture.		Laundry soap.	Nicotine sulphate.	Water.	Method of application.
			Lime.	Copper sulphate.				
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pints.*	*Gallons.*	
I	July 1, 20	3	3	3	1	....	50	Sprayer ("trailer") driven in alternate alleys.
II	July 1, 20	5	3	3	1	....	50	Every alley.
III	July 1, 20	3	3	3	1	¼	50	Alternate alleys.
IV	July 1, 21	3	3	3	1	....	50	Every alley.

Table 11.—*Percentage of infestation in experimental plats, Moorhead vineyard, Mooreheadville, Pa., 1915.*

Plat No.	Number of vines.	Number of clusters.	Total berries.	First brood.		Second brood.	
				Infested berries.	Infestation.	Infested berries.	Infestation.
					Per cent.		*Per cent.*
I	20	820	29,130	90	0.31	1,099	3.77
II	20	975	34,450	112	.32	717	2.08
III	20	726	22,411	49	.22	943	4.21
Check A	20	975	25,512	903	3.54	4,860	19.05
IV	20	813	26,350	141	.54	1,070	4.06
Check B	20	785	21,951	715	3.25	4,997	22.81
Check C	20	756	22,478	822	3.65	7,736	34.86

The final counts show that the grape-berry moth had been controlled in all sprayed plats. In this respect they contrast sharply with the previous season's results in the same vineyard. The only essential differences between the treatments of this season and those of the previous one were the addition of soap to the spray mixture and the application of the spray with "trailers" instead of with "set nozzles."

The results further indicate that 3 pounds of arsenate of lead (paste) was practically as effective as 5 pounds to 50 gallons of liquid, and that no special advantage or injury resulted from the addition of nicotine sulphate to the spray mixture. Also that drawing the sprayer in every alley and each rodman spraying only one side of a row at a time had no advantage over driving up alternate alleys with each rodman spraying both sides of a row at one time.

Spraying Experiments in 1916.

Confirmation of the 1915 results was the most important feature of the season's work. Although infestation by the grape-berry moth was much heavier, the season was more favorable for work and the control measures were more effective.

EXPERIMENTS IN THE BARTLETT VINEYARD, NORTH EAST, PA., 1916.

The experimental work in Mr. A. P. Bartlett's vineyard was conducted in two sections differing in distribution of the berry moth. In both sections the rows ran north and south, but the checks were arranged differently. In the upper section the 1915 infestation was

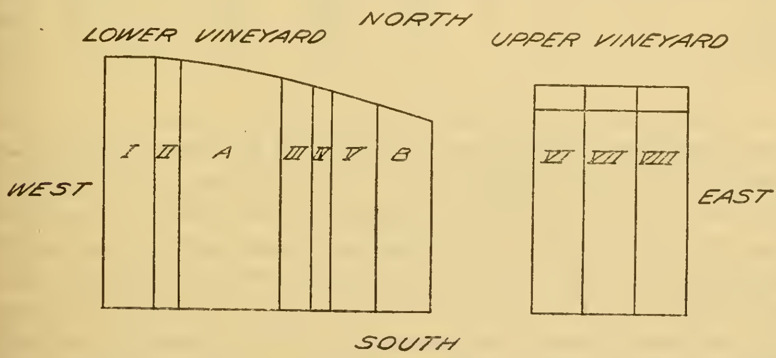


FIG. 6.—Diagram showing arrangement of experimental plats in vineyard of Mr. A. P. Bartlett, North East, Pa., 1916. In the lower vineyard the sprayed plats are marked with Roman numerals and the check plats are lettered. (Original.)

much the heavier on the west side, consequently the checks were not chosen in the usual way but instead a transverse check of the end 6 vines on all rows was left unsprayed. The arrangement of plats is shown by the diagram (fig. 6).

TABLE 12.—*Spray mixtures used and method and dates of application in experimental plats, Bartlett vineyard, North East, Pa., 1916.*

Plat No.	Date sprayed.	Arsenate of lead (powder).	Bordeaux mixture.		Laundry soap.	Resin fish-oil soap.	Potash fish-oil soap.	Water.	Method of application.
			Lime.	Copper sulphate.					
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Gallons.*	
I	July 22	1½	3	3	1	...	...	50	"Trailers."
II	Aug. 12	2½	3	3	...	1	...	50	Do.
III	July 6, 25	1½	3	3	...	1	...	50	Do.
IV	July 6, 25 and Aug. 12.	1½	3	3	1	...	...	50	Do.
V	July 5, 21	1½	3	3	1	...	...	50	Do.
IV	July 6, 21	2½	3	3	1	...	...	50	Do.
VII	July 5, 21	1½	...	...	1	...	...	50	Do.
VIII	July 5, 22	1½	3	3	...	...	2	50	Do.

TABLE 13.—*Percentage of infestation in experimental plats, Bartlett vineyard, North East, Pa., 1916.*

Plat No	Number of vines.	Number of clusters.	Total berries.	First brood.		Second brood.	
				Infested berries.	Infestation.	Infested berries.	Infestation.
Lower.					*Per cent.*		*Per cent.*
I	20	532	17,556	1,708	9.72	2,970	16.92
II	20	424	12,720	...	...	2,486	19.97
Check A	20	415	12,450	858	6.64	6,913	55.53
III	20	389	11,281	228	2.02	243	2.14
IV	20	390	11,700	...	...	81	.68
V	20	411	11,508	145	1.26	182	1.57
Check B	20	460	12,420	...	...	10,909	79.72
Upper.							
VI	20	474	15,168	320	2.11	768	5.06
Check VI	6	111	3,330	717	21.53	3,158	94.83
VII	20	681	18,068	199	1.10	724	4.01
Check VII	6	200	7,200	452	6.27	6,380	88.74
VIII	20	512	14,336	69	.48	67	.47
Check VIII	6	214	6,848	263	3.84	1,764	25.76

The final counts in this vineyard showed satisfactory results in all plats on which two applications of arsenate of lead with soap had been made (Plats III, V, VI, VII, and VIII). Where, in addition to these two applications, a third application was made, directed solely against the second brood, the percentage of infested fruit was slightly reduced, but since the result was so satisfactory with two sprays (compare Plat IV with III and V) an extra or third application was unnecessary. As an additional disadvantage, the fruit thus sprayed was badly stained at harvest time. A single application made at the time when the grape berries were just touching (Plat I) effected a marked reduction of infestation, as did a later single application directly solely against the second brood (Plat II), but in both plats the results were far from satisfactory. Any late application is open thus to objection because of staining the fruit at the approaching harvest. Three adhesives, laundry soap (Plat V), resin fish-oil soap (Plat III), and fish-oil soap without resin (Plat VIII), were used. The difference in infestation in these plats was so slight that it is not worthy of special consideration. Resin fish-oil soap solution spread rapidly and could be applied most easily. Arsenate of lead when used at the rate of 2½ pounds (powder) to 50 gallons of liquid (Plat VI) did not appear more effective than when used at the rate of 1½ pounds to 50 gallons. The solution in which Bordeaux mixture was omitted (Plat VII) was practically as effective as any other, although slight burning followed its application.

EXPERIMENT IN THE SOUTHWICK VINEYARD, NORTH EAST, PA., 1916.

A plat of 28 rows, 9 rows to the acre, was chosen for experimental purposes in this vineyard. An unsprayed check of 8 rows was left in the middle of the plat. On one side were two sprayed plats of 6 rows each, and on the other side two plats of 4 rows each. The rest of the vineyard section on either side of the experimental block, although sprayed for the grape rootworm by the owner, also served as a check. The arrangement of these plats is shown by the diagram (fig. 7).

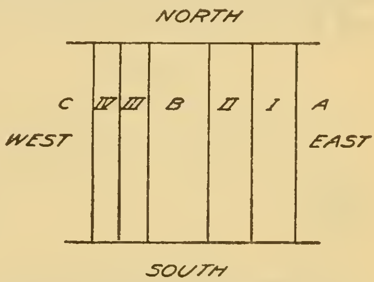


FIG. 7.—Diagram showing arrangement of experimental plats in the vineyard of Mr. B. T. Southwick, North East, Pa., 1916. The sprayed plats are marked with Roman numerals and the check plats with letters. (Original.)

During the season of 1915 this section had been heavily infested, from 30 to 40 per cent, with a tendency for the infestation to be heaviest at the north end.

TABLE 14.—*Spray mixtures used and methods and dates of application, Southwick vineyard, North East, Pa., 1916.*

Plat No.	Date sprayed.	Arsenate of lead (powder).	Bordeaux mixture. Lime.	Bordeaux mixture. Copper sulphate.	Nicotine sulphate, 40 per cent.[1]	Laundry soap.	Water.	Method of application.
		Pounds.	*Pounds.*	*Pounds.*	*Pints.*	*Pounds.*	*Gallons.*	
I	July 10, 24.	1½	3	3	¼	1	50	"Trailers."
II	....do....	2½	3	3	¼	1	50	Do.
III	July 24....	1½	3	3	¼	1	50	Do.
IV	July 10, 24.	1½	3	3	¼	1	50	"Set nozzles" first application, "Trailers" second.

[1] Last application only.

TABLE 15.—*Percentage of infestation in experimental plats, Southwick vineyard, North East, Pa., 1916.*

Plat No.	Number of vines.	Number of clusters.	Total berries.	First brood.		Second brood.	
				Infested berries.	Infestation.	Infested berries.	Infestation.
					Per cent.		*Per cent.*
Check A	20	609	16,443	2,866	17.43	11,635	70.76
I	20	570	15,960	565	3.41	1,339	8.43
II	20	638	19,778	597	3.02	835	4.22
Check B	20	623	15,575	2,129	13.61	11,706	75.16
III	20	585	14,625	1,364	9.32	4,966	33.95
IV	20	584	16,936	995	5.87	3,242	19.13
Check C	20	608	15,200	1,073	7.06	9,963	65.65

The final counts in this vineyard showed that the grape-berry moth had been controlled in the plat where two applications with "trailers" had been made, using arsenate of lead (powder) at the rate of 2½ pounds to 50 gallons with an adhesive (Plat II). This was in the face of a very heavy infestation in the checks. In contrast to the results in all other vineyards, in the plat in which 1½ pounds of arsenate of lead (powder) was used the final count was distinctly less satisfactory (Plat I). This difference was conspicuous only at the north end of the vineyard, where the infestation in the checks was practically total and where several eggs had been deposited on a majority of the berries. It should be noted that the contrast was not apparent until the second-brood counts were made, and the first-brood infestation was about the same in both plats. An unusually large percentage of second-brood larvæ found in Plat I were very late, indicating that the early second brood had failed to enter the berries. This would indicate that the two amounts of poison were equally effective for some time, but that the higher amount withstood the weathering better.

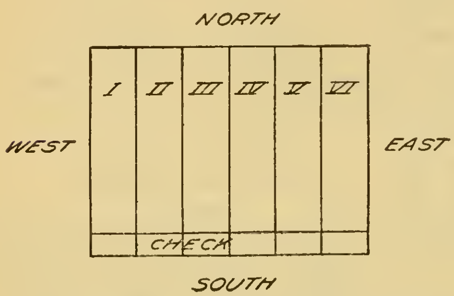


FIG. 8.—Diagram showing arrangement of experimental plats in the vineyard of Mr. J. M. Moorhead, Moorheadville, Pa., 1916. (Original.)

Two applications (1) with "set nozzles" and (2) with "trailers" (Plat IV) were partially effective, though not satisfactory. A single application with "trailers" when the berries were just touching (Plat III) was entirely unsatisfactory.

EXPERIMENT IN THE MOORHEAD VINEYARD, MOORHEADVILLE, PA., 1916.

An experimental plat of 48 rows, 8 rows per acre, was chosen in this vineyard. It was divided into 6 plats of 8 rows each. During the season of 1915 the infestation was heavy, 30 to 35 per cent of the berries being "wormy," with a tendency for heaviest infestation at the west side. Accordingly a transverse check of seven unsprayed vines at the end of each row was left. The arrangement of plats is shown by the diagram (fig. 8).

TABLE 16.—*Spray mixture used and methods and dates of application, Moorhead vineyard, Moorheadville, Pa., 1916.*

Plat No.	Date sprayed.	Arsenate of lead (powder.)	Bordeaux mixture.		Laundry soap.	Potash fish-oil soap.	Soft soap.	Water.	Method of application.
			Lime.	Copper sulphate.					
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Gallons.*	
I	July 8, 19	1½	3	3	1	....	....	50	"Trailers."
II	...do...	2½	3	3	1	....	....	50	Do.
III	July 8, 20	1½	3	3	....	2	....	50	Do.
IV	...do...	1½	3	3	1	....	....	50	"Set nozzles" first application; "trailers" second.
V	...do...	1½	3	3	....	....	1	50	"Trailers."
VI	July 20.	1½	3	3	1	....	....	50	Do.

TABLE 17.—*Percentage of infestation in experimental plats, Moorhead vineyard, Moorheadville, Pa., 1916.*

Plat No.	Number of vines.	Number of clusters.	Total berries.	First brood.		Second brood.	
				Infested berries.	Infestation.	Infested berries.	Infestation.
					Per cent.		*Per cent.*
I	20	850	29,750	243	0.81	1,752	5.88
Check I	6	253	9,108	406	4.45	3,812	41.85
II	20	675	23,625	154	.65	919	4.02
Check II	6	226	8,136	297	3.65	2,997	36.83
III	20	709	23,397	152	.64	806	3.15
Check III	6	195	7,410	340	4.57	2,848	38.43
IV	20	638	19,778	163	.82	1,307	6.61
Check IV	6	235	8,930	345	3.86	2,443	27.33
V	20	703	23,902	190	.79	4,605	19.60
Check V	6	224	8,064	174	2.15	2,741	33.99
VI	20	709	20,561	333	1.61	1,079	5.25
Check VI	6	154	4,312	86	1.99	1,010	23.39

The final counts showed satisfactory results in plats where two applications with "trailers" were made with poison and laundry or fish-oil soaps (Plats I, II, III). Fish-oil soap without resin as well as laundry soap was an effective adhesive, fish-oil soap having the advantage. A "soft soap" was also used (Plat V), but proved a very poor adhesive. Arsenate of lead at the rate of 2½ pounds (powder) to 50 gallons of liquid (Plat II) appeared to be little more effective at the increased strength than when used at the rate of 1½ pounds to 50 gallons (Plat I).

Plats where the first application was made with "set nozzles" (Plat IV) and where it was omitted altogether (Plat V) showed a fairly satisfactory reduction of infestation. It should be noted that the infestation in the checks in these two plats was not as heavy as that in the checks adjacent to Plats I, II, and III.

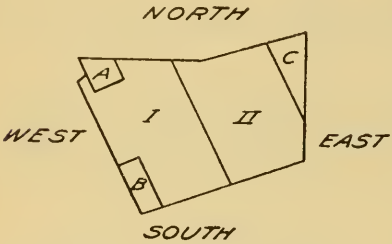


FIG. 9.—Diagram, showing the arrangement of experimental plats in the vineyard of Mr. M. D. Phillips, North East, Pa., 1916. The sprayed plats are marked with Roman numerals and the check plats with letters. (Original.)

EXPERIMENT IN THE PHILLIPS VINEYARD, NORTH EAST, PA., 1916.

This vineyard consisted of Niagara grapes, whereas in all other vineyards in which experimental spraying was done the grapes were Concords. It covered about two acres, irregular in shape, and was divided into two plats. To guard against natural irregularities of infestation unsprayed checks were left in each of the three corners. The arrangement of plats is shown in the diagram (fig. 9).

TABLE 18.—*Spray mixtures used and methods and dates of application, Phillips vineyard, North East, Pa., 1916.*

Plat No.	Dates sprayed.	Arsenate of lead (paste).	Bordeaux mixture.		Laundry soap.	Water.	Method of application.
			Lime.	Copper sulphate.			
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Gallons.*	
I	July 5 and 22	5	3	3	1	50	"Trailers."
II	July 5 and 22	3	3	3	1	50	Do.

TABLE 19.—*Percentage of infestation in experimental plats, Phillips vineyard, North East, Pa., 1916.*

Plat No.	Number of clusters.	Total berries.	First brood.		Second brood.	
			Infested berries.	Infestation.	Infested berries.	Infestation.
				Per cent.		*Per cent.*
I	400	15,200	436	2.87	479	3.15
II	400	16,000	107	.67	142	.89
Check A	200	7,200	423	5.88	5,135	71.32
Check B	200	7,600	1,186	15.61	6,114	80.45
Check C	200	8,000	289	3.11	4,034	50.43

Results in this vineyard showed that spraying will control the grape-berry moth fully as well in the very compact clusters of the Niagara grapes as in the less compact Concord. The test was thorough, as shown by the heavy infestation in the checks. Arsenate of lead used at the rate of 5 pounds (paste) to 50 gallons of liquid (Plat I) did not appear to have any advantage over 3 pounds to 50 gallons (Plat II).

The Spray Mixture.

ARSENATE OF LEAD, AMOUNT NECESSARY.

Arsenate of lead, either as paste or as powder, was the insecticide used in all field experiments. In all instances but one, when used at the rate of 3 pounds, paste, or 1½ pounds, powder, to 50 gallons of liquid, the amount was sufficient to reduce the grape-berry moth satisfactorily. During the seasons of 1915 and 1916 at least one plat was sprayed with poison at the above rate, and one other plat was sprayed under conditions as nearly the same as possible except that the amount of poison was increased to 5 pounds of paste or 2½ pounds of powder to 50 gallons of liquid. In all instances except the one referred to no distinct advantage was shown in favor of the higher amount, while in two of the vineyards the plats sprayed with the higher amount were actually the more heavily infested. The differences in results that did appear were usually slight and could be accounted for largely by variation of infestation. The comparative value of the two amounts of poison as it appeared in the different vineyards is summarized in Table 20.

Table 20.—*Relative efficiency of arsenate of lead at the rate of 3 pounds and 5 pounds (paste) to 50 gallons of liquid.*

Amount of arsenate of lead.	Treatments common to all plats.	Years tried.	Number of vineyards.	Number of plats.	Infested grape berries.					
					Best plat.	Adjacent check.	Poorest plat.	Adjacent check.	Average of all plats.	Average of all adjacent checks
					Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
3 pounds paste or 1½ pounds powder to 50 gallons of water.	Laundry soap, 1 pound, Bordeaux mixture (3-3 formula).	1915, 1916	7	7	0.89	50.43	8.43	75.16	4.12	50.03
The same as above. Poorest plat eliminated.	50 gallons applied twice with "trailers."	1915, 1916	6	6	......	......	......	......	3.41	49.17
5 pounds paste or 2½ pounds powder to 50 gallons of water.	....	1915, 1916	6	[1] 6	3.15	75.16	5.06	94.83	3.34	54.90

[1] Plat II, Miller and Carlburg vineyard, is not included in this average because the results were prejudiced by rain.

Table 20 indicates that as a rule there is practically no difference in effectiveness between the two amounts of poison. However, in the Southwick vineyard, 1916 (Plats I and II), the results in the plat sprayed with the higher amount appeared so much better in the final counts that the result could hardly be accounted for by variable infestation. Moreover, checks on either side showed that very little variation existed. In this vineyard at one end, although not throughout the vineyard, the checks showed an infestation very near to total, and probably enough moths had emerged to have totally infested a crop several times as heavy. Under such conditions of extremely heavy infestation the higher amount of poison was more effective. As previously stated in the discussion of results in the Southwick vineyard, the two amounts of poison were apparently equally effective when the first counts were made, but the higher amount withstood the weathering better and was more effectivea gainst the late second brood.

ADHESIVES.

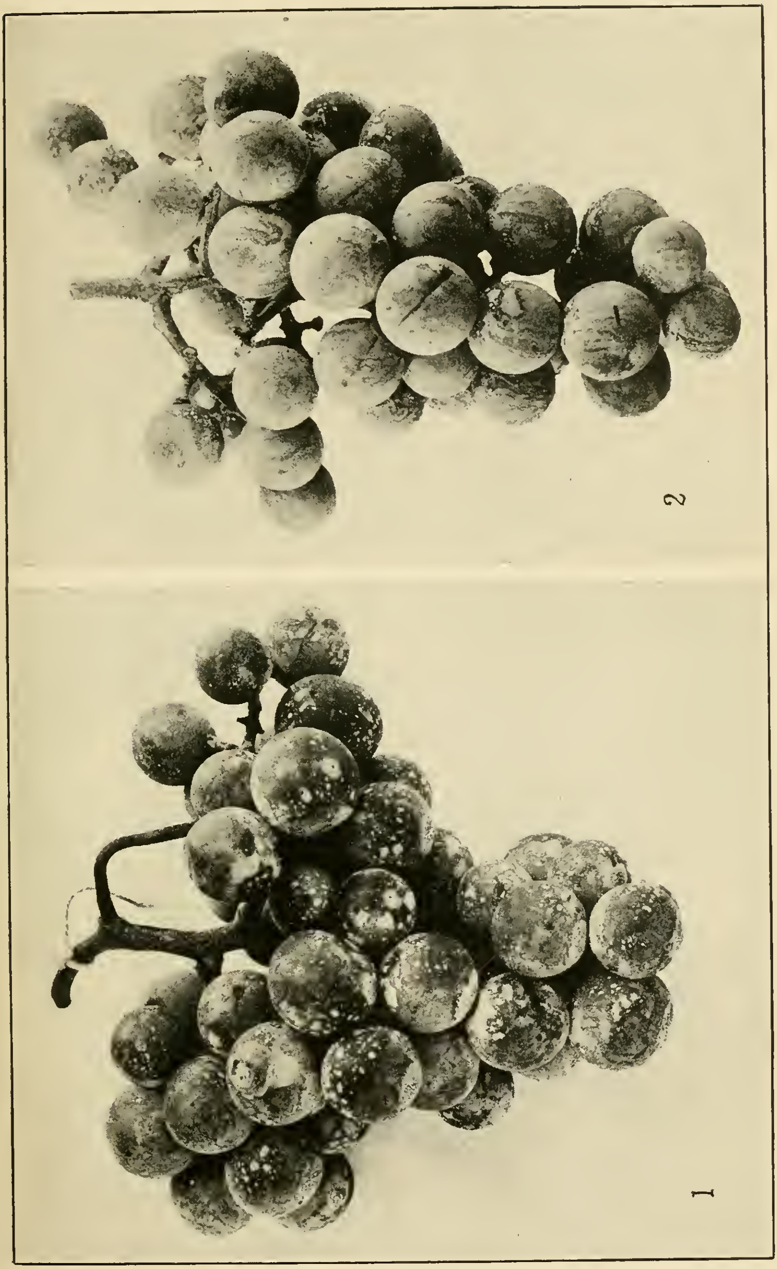
The necessity of adding adhesives to the spray mixture became apparent to the writer in the experiments in 1914. It was readily observed that the spray solutions from which an adhesive was absent did not adhere to the waxy skin of the grape berries, and this was undoubtedly one of the chief reasons for the failure to control the grape-berry moth during that season. The solutions to which soap was added appeared to adhere much better, but since this was used only in the last application a definite contrast in the final count was not shown. The counts in plats where soap had been added to the spray solution and applied with "trailers," however, when compared with counts in the nearest checks are consistently better than the others.

The effect of applying a spray mixture without adhesives was specifically demonstrated in 1915 by a comparison of the results in Plats V and IX in the Miller and Carlburg vineyard, pages 18–19.

TABLE 21.—*Relative effectiveness of spray mixtures with various adhesives and without adhesive.*

(Treatments common to all plats: Arsenate of lead, 3 pounds of paste or 1½ pounds of powder; Bordeaux mixture (3–3–50 formula) applied twice with "trailers.")

Kind of adhesive used.	Years tried.	Number of vineyards.	Number of plats.	Infested grape berries.					
				Best plat.	Adjacent check.	Poorest plat.	Adjacent check.	Average of all plats.	Average of all adjacent checks.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Resin fish-oil soap	1916	1	1					2.14	55.53
Fish-oil soap (without resin).	1916 only.	2	2					1.97	31.29
Do	1915, 1916	3	3	0.47	25.76	7.91	65.94	3.95	42.84
Laundry soap	1916 only.	4	4					4.14	61.79
Do	1915, 1916	7	7	.89	50.43	8.43	75.16	4.12	50.03
Soft soap	1916	1	1					19.60	33.99
Flour paste	1915	1	1					18.89	28.80
No adhesive	1915	1	1					21.05	28.80



SPRAYING AGAINST THE GRAPE-BERRY MOTH.

Comparative spreading qualities in spray mixture of a laundry soap (fig. 1) and a resin fish-oil soap (fig. 2). (Original.)

From Table 21 it may be seen that fish-oil and laundry soaps used in the seasons of 1915 and 1916 were both effective as adhesives and that soft soap and flour paste were unsatisfactory. (See Pl. VI.) The advantage of one soap over another, as shown in the final counts, was usually so slight that it can not be considered significant.

At the time of application resin fish-oil soap appeared at best advantage. It was a better spreader than any of the others and consequently made the work faster and easier. It was used only in the Bartlett vineyard during the season of 1916. The potash fish-oil soap without resin also spread better than laundry soap. Potash fish-oil soap was used in 1915 in the Miller and Carlburg vineyard and in 1916 in the Moorhead and Bartlett vineyards.

The following analysis of the resin fish-oil soap used was made by the Bureau of Chemistry:

Water, 25.7 per cent.
Fatty and resin anhydrides, 68 per cent.
Sodium oxide, Na_2O, 4.3 per cent.
Undetermined, 2 per cent.

Laundry soap if carefully used is practically as effective and adhesive as the fish-oil soaps, but it has two distinct disadvantages, (1) it is a slower and a poorer spreader than fish-oil soaps, and (2) different makes of soap and even different lots of soap of the same make vary. In the experimental work each brand of soap was tried on a few vines with a hand sprayer before it was used in commercial experiments. If the vineyardist finds it necessary to rely on laundry soaps for an adhesive, this precaution would be advisable.

All of the laundry soaps that proved satisfactory were yellow resin soaps. Some of the so-called white soaps containing no resin were tried with a hand sprayer but lacked adhesive qualities and were not used in any field experiments.

Cutting the laundry soap and allowing it to dry out before using it in the spray mixture seemed to impair its sticking as well as its spreading qualities seriously.

A soft soap from a rendering factory also was tried, but gave negative results both as an adhesive and as a spreader. This was observed readily at the time of application, and the result is shown clearly in the final counts. (Moorhead vineyard, Plat V, 1916.)

Flour paste although a good spreader was an unsatisfactory adhesive, because it washed off with the first rain. (Miller and Carlburg vineyard, Plat VIII, 1915.)

When soap in the spray mixture is not dissolved thoroughly, clogging of the spray apparatus is likely to follow. Hot water was found necessary for quickest results. If the sprayer engine is water cooled, hot water from the water jacket can be used satisfactorily for this purpose.

Amount of adhesive necessary.—Resin fish-oil soap or laundry soap used at the rate of 1 pound to 50 gallons of liquid gave good results as a "sticker" and spreader. Potash fish-oil soap without resin was used at the rate of 2 pounds to 50 gallons of liquid.

NICOTINE SULPHATE.

Forty per cent nicotine sulphate was utilized in sprays every year in some of the vineyards against the grape leafhopper. This substance was used at the rate of 1 part to 1,600 parts of liquid in the last grape-berry moth spray. In 1915 it was used in both of the applications against the berry moth. In none of the plats on which it was used was there any indication that nicotine sulphate added to or detracted from the value of the spray mixture, so far as grape-berry moth control was concerned.

RELATION OF FUNGICIDES.

Bordeaux mixture had no insecticidal or repellent value, so far as the grape-berry moth was concerned. (Miller and Carlburg vineyard, Plat VII, 1915.) However, the addition of this fungicide seemed to be advantageous. Besides reducing the danger of burning by the arsenate of lead and soap combination it gave to the spray mixture physical qualities which lessened the tendency to collect on the lower surface of the berry.

The relation of neutral acetate of copper to arsenate of lead and soap was tried in an experiment on a small scale. It was thought that this nonstaining fungicide might be substituted for Bordeaux mixture if an August spray were adopted. One pound of neutral acetate of copper and 1 pound of soap to 50 gallons of water were mixed and applied to a few vines. The result was unsatisfactory. No injury to the foliage resulted, but the soap and neutral copper acetate in combination stained the grapes fully as objectionably as the soap and Bordeaux combination.

It had been demonstrated previously that the Burgundy mixture should not be used in combination with an arsenical, and it was not tried.

LIME.

When for any reason it was desired to omit Bordeaux mixture from the spray combination of arsenate of lead and soap, lime was added at the rate of 1 pound to 50 gallons of liquid.

INJURY DUE TO SPRAYING.

Combinations of arsenate of lead and soap with Bordeaux mixture or lime caused no injury to foliage in any of the three seasons of experimental work. If "nicotine sulphate 40 per cent" at the rate of 1 part to 1,600 parts of liquid was added to this solution it also was applied safely. However, the combination of arsenate of lead and soap alone produced slight burning of foliage in 1916. (Bartlett vineyard, Plat VII.)

No serious staining of fruit occurred except when the second-brood spray was applied in August in 1916. This was much reduced by using the arsenate of lead and soap with lime instead of with Bordeaux mixture.

METHOD OF APPLICATION.

The first season's experiments clearly demonstrated the difficulty in covering grape clusters by the "set-nozzles" applications. This was particularly inadequate at the last application, at which time the foliage is very heavy, and pressure up to 250 pounds was not effective. The use of "trailers" on a few plats for the last application suggested the complete change of method which followed the next season.

A specific demonstration of the inadvisability of depending on "set nozzles" as a means of applying spray was shown in 1915 by the contrast between Plats I and X in the Miller and Carlburg vineyard.

The necessity of using "trailers" was so satisfactorily established in the first two seasons that during 1916 "set nozzles" were not used in both applications in any plats. However, in the Moorhead vineyard, Plat IV, and in the Southwick vineyard, Plat IV, "set nozzles" were tried for the first application. In the former, at the time of the first application, the results were reasonably satisfactory, although not the best. In the latter vineyard the foliage was very heavy when "set nozzles" were used, and the failure to cover the clusters with spray was obvious. The reduction of infestation that resulted should be credited largely to the last application, which was made with "trailers."

The relative efficiency of "set nozzle" and "trailer" methods of application and a combination of these methods is shown in Table 22.

TABLE 22.—*Relative efficiency of "trailer" and "set nozzle" methods of application.*

(Treatments common to all plats: Arsenate of lead, 3 pounds paste or 1½ pounds powder; laundry soap, 1 pound; Bordeaux mixture (3-3-50) applied after falling of blossoms and when grape berries were just touching.)

Method of application.	Years tried.	Number of vineyards.	Number of plats.	Infested grape berries.					
				Best plat.	Adjacent check.	Poorest plat.	Adjacent check.	Average of all plats.	Average of all checks.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
"Trailers," 2 applications	1915, 1916	7	7	0.89	50.43	8.43	75.16	4.12	50.03
"Set nozzles," 1 application; "trailers," 1 application	1916	2	2	6.61	38.43	19.13	65.65	12.87	52.04
"Set nozzles," 2 applications	1915	1	1	20.41	28.80	20.41	28.80	20.41	28.80

Usually when "trailer" applications were made the sprayer was driven only in every other alley between the grape rows, each rodman spraying both sides of his row on the same trip.

During the season of 1915, in the Moorhead vineyard, Plats II and IV, the sprayer was driven in every alley, each rodman spraying only one side of a row on each trip. While it was easier to cover the foliage by this method, it was slower and it showed no distinct advantage over the usual method, in controlling the berry moth. It was given no further trial. Which of the two methods is best is probably a matter of individual preference.

Careful work was an absolute necessity for successful "trailer" applications. While the responsibility rested chiefly with the rodmen, unless the driver was careful about gathering up the hose and at the same time allowing the rodmen time to finish spraying each vine the work was handicapped greatly. It was necessary also that the rodmen should make an effort to cover each cluster or the advantage of "trailers" over the strictly mechanical method was lost.

Time and Number of Applications.

The most satisfactory spray schedule was as follows: The first application to be made immediately after the falling of the bloom; and the second application about two weeks later, at the time when the berries are just touching. This proved effective both in 1915 and in 1916, and was the schedule used in the majority of plats.

A single application at the time the berries were just touching reduced the infestation greatly, but hardly offered satisfactory results. It was tried only in the season of 1916. This spray is intended for late first-brood larvæ, and enough of the poison will remain on the berries, at the time of the hatching of eggs of the second brood, greatly to reduce this brood as well. The effect of this spray against the second brood is shown by referring to the counts in Bartlett (lower) vineyard, Plat I, in comparison with the adjacent Check Plat A. Plat I was naturally more heavily infested than was Check Plat A, as the first-brood count showed that it had about 50 per cent more infested berries than did "A." On the other hand the final count showed the percentage of infestation in Check Plat A to be three times as heavy as that in Plat I. Similar final results are shown in Southwick vineyard, Plat IV. The results in the Moorhead vineyard, Plat VI, would indicate that in case of light infestation this one application might control the berry moth satisfactorily.

In 1916 a single application, made on August 12 and aimed directly against the second brood, also reduced the infestation considerably, as shown in Bartlett vineyard Plat II, although the counts did not appear as favorable as the single earlier application previously mentioned as being made when the berries were just touching. This was probably due to the fact that the absence of the early application permitted all of the first brood to enter the berries and heavier oviposition later resulted. Furthermore, dependence upon an application as late as August 12, alone, is open to objection even if the second-brood control was very good, because infestation by the first brood will usually seriously thin out the clusters, and too, the spray remains longer on the berries, leaving them seriously stained at harvest time. This application is harder to make than is the earlier one because the foliage at the later date is much heavier. The value of the application is largely that of an emergency measure, at a time when the first brood has not been controlled.

A three-spray schedule was tried in Plat IV of the Bartlett (lower) vineyard. The infestation was less than in Plats III and V, which had been sprayed twice. However, in this instance the difference was not of commercial importance and would not pay for the extra application, and the fruit was stained so badly by the last application as to reduce materially its value on the basket market. This third application could be of value in this region only under extraordinary conditions, when faulty work or lack of spray materials and labor or unfavorable weather had prevented the control of the first brood.

A comparison of the results of different spray schedules is given in Table 23. The average infestation of plats where two applications were made was distinctly heavier than was the infestation in the one plat where three applications were made. It should be noted, however, that where the plats sprayed two and three times were adjacent in the same vineyard, the difference in infestation was very slight.

It also shows that the single application may produce fair control if the infestation is light, but that on the whole dependence on a single application is unsatisfactory.

A spray application before the grapes blossomed, followed by the usual two applications after the falling of the blossoms, was tried in one plat in each vineyard in 1914. No beneficial results of this spray could be noted when the final counts were made. The importance of this spray was brought into question soon after its application, for very few larvæ were found in the clusters before the next was applied. Even had they been numerous at that time, the "preblossom spray" could hardly have been effective, as practically all of the poison that did adhere to the clusters when applied fell off a few days later with the flower caps.

This early spray was applied again in 1915 in all three vineyards, but since practically no larvæ were found until the blossoms fell, these plats were discarded.

TABLE 23.—*Relative efficiency of different times and numbers of applications.*

Time and number of applications.	Treatments common to all plats.	Years tried.	Number of vineyards.	Number of plats.	Infested grape berries.					
					Best plat.	Adjacent check.	Poorest plat.	Adjacent check.	Average of all plats.	Average of all adjacent checks.
					P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Two applications after blossoms have fallen and when grape berries are touching.	Arsenate of lead, 3 pounds paste or 1½ pounds powder; laundry soap, 1 pound; Bordeaux mixture (3-3-50), applied with "trailers."	1915, 1916	7	7	0.89	50.43	8.43	75.16	4.12	50.03
Two applications, same as above, including only plat adjacent to that sprayed 3 times.	.....do..........	1916	1	1	1.57	79.72	1.57	79.72	1.57	79.72
Three applications, 2 same as above; third 5 weeks after first.	.....do..........	1916	1	1	.68	67.52	.68	67.52	.68	67.52
One application when grape berries are touching.	.....do..........	1916		3	5.25	23.39	33.95	75.16	18.71	51.29
One application 5 weeks after falling of blossoms.	(1).............	1916	1	1	19.97	55.53	19.97	55.53	19.97	55.53

1 Same as above, except arsenate of lead, 2½ pounds, and resin fish-oil soap instead of laundry soap.

FACTORS DETERMINING THE TIME AND NUMBER OF APPLICATIONS.

The time and number of applications are determined not only by the seasonal history and habits of the grape-berry moth, but also by the development of the grape itself. Fortunately the times for spraying, most favorable in relation to the pest and also in relation to the crop, are nearly coincident. It is probable, therefore, that the vineyardist will find it most convenient to time his operations entirely by the development of the fruit.

The first spraying probably destroys the largest number of first-brood larvæ, for it is applied just before they begin hatching in numbers. Besides these, it also destroys some larvæ which hatch before the blossoms fall and are feeding in the cluster, but have not entered a grape berry. Following this application the grapes grow very rapidly and the larger part of the berry surface does not long remain covered. But as at this time the majority of the larvæ enter the berry at the stem end, where the spray always collects, comparatively few escape.

The second application is made after first-brood hatching begins to decline, but it is effective against the second brood also. As soon as the berries begin to touch, the majority of larvæ begin entering at the points of contact instead of at the stem ends. Spray which is applied at this time is especially apt to collect at these places again, at which point it may be most effective later. It also covers the berry, and since there is comparatively little growth following this, it remains over the larger part of the surface until it is weathered off, or for about two months. Thus it remains effective during the period when the greater part of the second-brood larvæ hatch. As shown by the single-spray applications in 1916, this second spraying is practically as effective against the second-brood larvæ as is one applied three weeks later, just as they are beginning to hatch.

Larvæ which succeed in entering the first berry may be poisoned upon moving to a second. Larger larvæ seldom consume enough poison to prevent their entering the grape berry, but may be found dead in the berry a day or two later, whereas those that have reached the fourth stage are seldom susceptible to poison in the amounts in which it is to be found, after weathering, on sprayed grapes.

If this schedule is followed closely, the places on the grape berry at which the majority of the larvæ would normally enter should be well covered with poison, and the surface of the berry as a whole will be covered for a longer time than by two sprayings applied at any other time. If the first application were made earlier, before the falling of the grape blossoms, most of the poison would be lost with the shedding of the floral parts, and the application would be comparatively ineffective. If the second application were made earlier, while the berries were still growing rapidly, it could not cover the surface of the berries permanently nor could it collect at the points where the berries would touch, and while it might destroy more of the first brood, it would be almost entirely ineffective against the second. Hence no variation in the time of these two applications is advisable.

Relation of Different Grapevine Training Systems to Spraying.

The system of pruning and training a vineyard must be largely determined by horticultural considerations. Nevertheless the different systems greatly affect the facility with which the grapes may be sprayed and in other ways are related directly to the control of insect pests. To determine the relation to grape-berry moth control of five of the more important systems, a small block in Mr. A. P. Bartlett's vineyard was used in 1916. In all of the other spraying experiments the vines had been trained according to the Chautauqua system. This block was trained by the owner especially for this experiment according to the Four-cane Kniffin, Munson, Umbrella, High-renewal, and Chautauqua systems.

As there may be many who are not familiar with all of these vine-training systems the following brief descriptions have been compiled from the papers of Husmann (15) and Gladwin (14).

Chautauqua system.—This is the system used most frequently in the Erie-Chautauqua grape belt. The stem reaches only to the lowest wire from which permanent arms to suppport the canes are carried right and left along the lower wire. The canes, usually about 4, are carried upward and tied to the upper wire or wires.

High-renewal system.—The head of the vine reaches only the lowest wire of the trellis, and the canes are tied right and left along this wire. The fruiting shoots growing from these canes are trained upright and fastened to the wires overhead.

Four-cane Kniffin system.—The stem is carried directly to the top wire of a two-wire trellis. Two canes about the level of each wire are tied right and left along each wire.

Umbrella system.—This system differs chiefly from the Kniffin in that two canes are left instead of four. They are started at the upper wire and the extremities are tied down to the lower wire.

Four-cane Munson system.—This system differs from the others mentioned in that it requires an overhead trellis. Across the top of each post a crossbar 20 inches long is fastened and outer wires are fastened at the ends of these crossbars, while an inner wire is fastened to the post about 6 inches lower down. A single stem is carried to the inner wire and four canes are left, one carried in each direction along each wire.

Two regular first-brood applications with "trailers" were made. Vines trained according to any of these systems could be sprayed thoroughly and the difference in final counts is not significant, but the ease with which the applications were made is of considerable importance.

The Kniffin and Munson systems were much the easier to spray. The time required was about 15 per cent less than that required for the Chautauqua system. These systems had the advantage of having no upright shoots or canes to interfere with a free action of the spray rod. The fruit, although well protected by leaves above at the time of spraying, was well exposed below. The bunches hung, in the Kniffin system in two layers, one below each wire, and in the Munson system just below the trellis, and consequently were easy to find. The Munson system had the disadvantage of producing a dense shade, and consequently favoring grape-berry moth infestation.

In contrast to this, the Chautauqua system presented the disadvantage of upright canes, which interfered with free action of the spray rod and with fruit arising from anywhere up and down these canes. The clusters were well protected by leaves and often isolated, and greater care was necessary in finding them and covering them with spray.

The umbrella system with the canes bent down from the upper wire to the lower presented a difficulty in spraying similar to that of the Chautauqua system, although it seemed slightly easier to spray. The high-renewal system was much more difficult to spray owing to the tendency of the rods to catch in the numerous upright shoots.

Summary of Important Factors in Spraying Practice.

The most important factors in spray practice to control the grape-berry moth, shown by the final counts in 28 of the 49 experimental plats of three years, are summarized briefly in Table 24. Factors of minor importance such as a complete comparison of adhesives and value of nicotine sulphate are omitted. In addition, the plats in the experiment in the Phillips vineyard, 1914, because of the erratic infestation, and the plats in the Miller and Carlburg vineyard, 1915, which were affected by rain, are excluded.

Table 24.—*Relative efficiency of spraying measures tried.*

Spray mixture, method of application, and spray schedule followed.	Years tried.	Number of sprayed plats.	Infested fruit.	
			Average in sprayed plats.	Average in adjacent unsprayed checks.
			Per cent.	*Per cent.*
I. Arsenate of lead, paste, 3 pounds, or powder, 1½ pounds; laundry soap, 1 pound; Bordeaux mixture, 3-3-50. Applied with "trailers" immediately after blossoms had fallen and again when grape berries were just touching (or about 2 weeks later)	1915, 1916	7	4.12	50.03
II. Same as I except arsenate of lead omitted	1915	1	33.31	28.80
III. Same as I except adhesive omitted	1915	1	21.05	28.80
IV. Same as I except Bordeaux mixture omitted	1916	1	4.01	88.74
V. Same as I except arsenate of lead increased to 5 pounds (paste) or 2½ pounds (powder)	1915, 1916	6	3.34	54.90
VI. Same as I except resin fish-oil soap used instead of laundry soap, 1 pound	1916	1	2.14	55.53
VII. Same as I except fish-oil soap (without resin) used instead of laundry soap, 2 pounds	1915, 1916	3	3.95	42.84
VIII. Same as I with addition of a third application 5 weeks after first	1916	1	.68	67.52
IX. Same as I (including only the plat adjacent to VI)	1916	1	1.57	79.72
X. Same as I except first application omitted	1916	3	18.71	51.29
XI. Same as I except "set nozzles" used in first application instead of "trailers"	1916	2	12.87	52.04
XII. Same as I except "set nozzles" used in both applications instead of "trailers"	1915	1	20.41	28.80
XIII. Same as I except adhesive omitted and "set nozzles" used in both applications instead of "trailers"	1914	1	26.70	31.80

This table shows that both arsenate of lead and soap are essential factors in the spray mixture, while Bordeaux mixture is of little importance. An increase in the amount of arsenate of lead is usually of little value, and variation among the three kinds of soap used is not an essential consideration. Two applications effect a practically satisfactory control so that the advantage of a third application is insignificant. The omission of the first application, or making it with "set nozzles" instead of with "trailers," furnishes on the average only a partially satisfactory measure, while complete substitution of "set nozzles" for "trailers" is entirely unsatisfactory.

Spray Combinations

A combination of sprays may be made, to control, besides the berry moth, practically all other important enemies of the grape in this region—the grape rootworm, the grape leafhopper, and the powdery mildew. These spraying recommendations for the control of enemies of the grape other than the grape-berry moth are based on recommendations of other investigators,[1] and were employed incidentally in connection with the berry-moth experiments.

The time of the first spray application for berry moth, just after the grape blossoms fall, during the seasons of 1914, 1915, and 1916, has been from 2 to 4 days before the appearance of the rootworm beetles. Without change of time or mixture this application is effective against the rootworm also. If this application is intended as rootworm control also, care should be taken to cover the upper surface of the foliage, for unless extra attention is given to this it is apt to be done less effectively with "trailers" than with "set nozzles." In exceptional instances an extra application for rootworm control may be necessary. This combination must not be attempted if it is desired to add molasses or sugar to the rootworm spray, as mixtures containing sugar are very soluble and wash off the vines readily. Furthermore, a combination of sugar with Bordeaux mixture is apt to burn foliage.

The second berry-moth spray, applied when the berries are just touching, may be made effective also against the grape leafhopper by the addition of nicotine sulphate (40 per cent) at the rate of 1-1,600 (¼ pint to 50 gallons.)

By the addition of Bordeaux mixture in these two applications, powdery mildew also can be controlled. These two applications of Bordeaux will be useful against black rot and downy mildew also, where these occur, although an additional earlier spray will be necessary for the control of these diseases.

Cost.

The cost of spraying material and labor required to control the grape-berry moth, if applied to control the berry moth alone, is about $5 per acre. In computing this cost it is assumed that an average of 6 acres are sprayed per day and that 150 gallons of liquid are applied per acre. This average may not be maintained if the water supply is inconveniently situated and the spraying machinery is not kept in condition, but delays due to these sources are not nor-

[1] See Quaintance and Shear (12), Johnson and Hammar (13), Johnson (17), and Hartzell (18).

mally necessary. These figures do not include interest on money invested in the spraying machine, depreciation, breakage, or incidental costs of operation, such as gasoline and oil, since these vary greatly. The details of cost for a single application are as follows:

Materials for 150 gallons of spray mixture:	
Arsenate of lead (paste), 9 pounds, 8 cents per pound	$0.72
Lime, 3 pounds, 1/3 cent per pound	.01
Resin fish-oil soap, 3 pounds, 6¼ cents per pound	.19
Labor, 3 men, 1/6 day at $2 per day	1.00
1 team, 1/6 day, at $3 per day	.50
	2.42

For the two applications the cost would be $4.84 per acre.

The entire cost, however, need not be charged to berry-moth control if a combination spray is used. These two spray applications are necessary in the majority of vineyards to securo the greatest possible profits, even if the berry moth is not present. In a vineyard where control measures are already employed against the rootworm, leafhopper, and powdery mildew, the additional cost per acre in controlling the berry moth would be as follows:

Extra cost of labor for using "trailers" instead of "set nozzles" in the first application.		
Labor cost with "trailers" (see above)	$1.50	
Labor cost with "set nozzles," 1 man and team 1/8 day at $5 per day	.675	
		$0.825
Arsenate of lead (paste), 9 pounds for second application, at 8 cents per pound		.72
Soap, 6 pounds (2 applications), at 6¼ cents per pounds		.375
Total		1.920

Thus, if spraying for rootworm, leafhopper, and mildew is properly done the extra cost of spraying for the grape-berry moth is only $1.92 per acre.

SUMMARY AND RECOMMENDATIONS.

The grape-berry moth can be controlled by spraying. Other methods will reduce berry-moth infestation, and some of them can be employed profitably to increase the efficiency of spraying, but none offers a dependable control in commercial vineyards.

Gathering and destroying grape leaves in the fall is of little use in berry-moth control.

Bagging grape clusters immediately after the setting of the fruit will exclude the berry moth and prevent infestation, but the expense is prohibitive in commercial vineyards in this region and may be used advantageously only in garden vineyards. Hand picking of grape berries infested by first-brood larvæ, if done by competent labor, will reduce berry-moth infestation, but except in extraordinary cases will not control it. When spraying can be employed these measures are unnecessary.

A number of other measures reduce infestation and generally may be employed as a part of vineyard practice without additional expense. When commercial vineyards are infested, the worst areas should be harvested as early as possible and the "trimmings" removed, to secure the largest weight for the crop and to remove as many larvæ as possible from the vineyard. Clearing away brush in the neighborhood of a vineyard will destroy the protection for hibernating pupæ with an ultimate reduction in infestation. When it is in keeping with cultural practice, pupæ hibernating under the vines should be covered with earth in the spring by plowing, and this covering should remain until the period of blossoming of the grapes, when it should be removed with a horse hoe. This plowing should not be allowed to interfere with spraying.

These practices, it must be remembered, while reducing infestation, will not control it, and they should not be expected in any way to take the place of spraying.

The following spraying practice has been found most satisfactory:

The spray mixture—		
Arsenate of lead—		
Paste	pounds	3
Or powder	do	1½
Resin fish-oil soap	do	1
Bordeaux mixture—		
Copper sulphate	do	3
Lime	do	3
Water	gallons	50

Method of application, with "trailers":

Spray schedule—

First application, immediately after falling of grape blossoms.

Second application, when grape berries are just touching (or about two weeks later).

Under some conditions it may be desirable to modify the spraying practice outlined above.

In case of extremely heavy infestation the amount of arsenate of lead should be increased to 5 pounds (paste) or 2½ pounds (powder), at least in the last application.

If resin fish-oil soap is not available a laundry soap containing resin may be substituted in its place. Laundry soaps, however, vary greatly in their sticking and spreading qualities, and great care should be used in selecting those best suited to this purpose. Whatever soap is used, care must be taken to have it thoroughly dissolved before adding it to the spray mixture to prevent clogging of the spraying machinery.

The use of Bordeaux mixture, while not having a direct effect upon the berry moth, is recommended, to prevent burning of the grape foliage by the combination of arsenate of lead and soap. Lime at the rate of 1 pound to 50 gallons may be substituted instead. Since it is very rarely that the fungicidal spray can be omitted with profit, the use of Bordeaux mixture is preferred.

This spraying combination should control any infestation of the grape-berry moth, such as the writer has observed during three seasons in the Erie-Chautauqua grape belt, and has been applied successfully under very unfavorable weather conditions. If, however, through faulty spray materials or work, or adverse weather at the time of spraying, these applications fail to control the first-brood larvæ, they may be supplemented by a third application five or six weeks after the first, with the understanding that the fruit is likely to show heavy staining at time of harvest. This staining may be reduced by omitting Bordeaux mixture from the solution applied and using instead 1 pound of lime in 50 gallons of water.

In case the foliage is very light at the time of the first application, expenses may be reduced somewhat by using "set nozzles" at this time and using "trailers" only for the second application. Single spray applications, either at the time the grape berries are just touching or about three weeks later, will reduce the infestation and in some instances control it. Such measures to reduce expenses of spraying, however, are dangerously likely to fail in reducing the infestation satisfactorily, and should be adopted with great caution.

Spraying operations will be facilitated greatly by training the vines so that the clusters may be reached most quickly and covered with spray. In a limited experiment the Kniffin system seemed most satisfactory for this purpose.

The applications required for the control of the grape-berry moth are so timed that they may be combined with applications to control the grape rootworm, grape leafhopper, and powdery mildew, and some of the applications for downy mildew and black rot also may be combined with them. Nothing need be added to the spray solution for rootworm control; nicotine sulphate (40 per cent) at the rate of 1 to 1,600 should be added to the second application for leafhopper control; and Bordeaux mixture should be used in both applications for fungous diseases.

The cost of spraying to control the grape-berry moth need not exceed $5 per acre. If the applications are made to control other pests as well, the charge against the berry-moth control should be considerably less.

It should be borne in mind that unless the proper spray mixture is applied at the right time and the clusters are thoroughly covered, the work is of little value.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 553

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

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THE CHICKEN MITE:[1] ITS LIFE HISTORY AND HABITS.

By H. P. Wood, *Entomological Assistant, Insects Affecting Health of Animals, Bureau of Entomology.*

CONTENTS.

In the present bulletin no attempt has been made to give an exhaustive study of the life history of the chicken mite; rather the aim has been to work out the main points in the life cycle of this pest and to discover principles upon which combative[2] measures may be based.[3]

REARING METHODS USED IN LIFE-HISTORY EXPERIMENTS.

The method of feeding the mites was simple. A large earthen jar, in which a small roost was put, was utilized for a breeding cage. The jar was set in a pan of water in order to prevent the escape of the mites, and a coarse-mesh wire screen was fastened over the top to hold the chicken in the jar. When it was desired to feed the mites they were either dropped in the bottom of the jar or else put on the fowl's back. Easy access was thus obtained to the host, and seldom if ever were hungry mites seen in the jar after being one night with the chicken. Sheets of paper were put in the bottom of the jar to collect the manure and some of the mites. Most of the fed mites were found about the roost in cracks prepared for them.

[1] *Dermanyssus gallinae* Redi.

[2] See Farmer's Bulletin No. 801, United States Department of Agriculture.

[3] To Mr. F. C. Bishopp the writer wishes to express appreciation for direction and helpful suggestions obtained in the course of the work.

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Molting, mating, and deposition took place in tubes or small vials. In case individuals were being watched, vials were used, and where many mites were confined, test tubes were used. The vials were plugged with absorbent cotton covered with a small piece of black cloth. Black cloth was used because, owing to the contrast in color, it was much easier to observe the small white eggs and larvæ. The test tubes were plugged with cotton covered with white cheesecloth. No moisture or food of any sort was added to the tubes.

In the longevity experiments varied conditions were supplied. Some of the mites were kept in tubes on moist sand, others were kept in dry tubes, and others were on roosts. In the longevity experiment, in which the mites were supplied with a hen's egg, the egg was in a lantern chimney, both ends of which were covered with a piece of black cloth.

LIFE HISTORY.

THE EGG.

In appearance the egg of the mite is a small, oval, smooth, pearly white, and somewhat iridescent object (Pl. I). Ten eggs measured showed a maximum length of 387 microns, a minimum of 373 microns, a maximum width of 265.5 microns, and a minimum width of 244 microns, the average length being 379.3 microns and the average width 255.65 microns.

Incubation during the latter part of August took place in about 48 hours. The average mean temperature at this time was 78.43° F.

THE LARVA.

The young larva (Pl. I) on hatching is white and has only three pairs of legs. At the rear of the abdomen is a small protuberance which does not appear on any other stage. The larva moves about slowly, unlike the other stages, which are very active. The length and width of the larval body measure practically the same as those of the eggs. Without ever having fed, the larvæ molt to nymphs. Molting takes place in about 24.5 hours after hatching, when the average mean temperature is 73.5° F.

THE FIRST-STAGE NYMPH.

The young nymph (Pl. I) backs out of its larval skin like a person drawing his hand out of a tight glove. It has now acquired another pair of legs, making four pairs. After a few hours of resting, to give time for the body integument to harden, it becomes very active and will now feed if given a chance. The first-stage nymph is slightly darker in color than the larva, having a brownish tinge.

With its long, piercing mouth parts the nymph sucks the blood of the fowl. It crawls from the fowl onto the roost when fully engorged, and is now bright red, owing to the ingested blood showing through the skin. The measurements of the mite (average of five) at this stage are: Length, 568 microns (abdomen only); width, 338.4 microns; thickness (average of three), 266 microns. After a period of somewhat less than 24 hours the first-stage nymph molts to the second stage. The average mean temperature during the period when the molting was observed was 82.9° F.

THE SECOND-STAGE NYMPH.

The second-stage nymph, like the preceding stage, requires a short period of rest to harden the integument. As soon as the nymph becomes active it is ready to feed. Some authors have said that the mite takes long periods of rest. The writer finds that when such rest periods are taken it is from force of circumstances and not from desire on the part of the mite. The mite before feeding measures (average of four) 538.2 microns in length and 297.9 microns in width. After feeding, the mite measures 751.9 microns in length by 461.4 microns in width (average of 10). The second-stage nymphs molt to adults (fig. 1). This is the rule, although there may be some nymphs which undergo an additional molt before reaching the adult stage. The writer found one mite which apparently had three nymphal stages. A single instance, however, can hardly be accepted as sufficient evidence for making an exception to the rule.

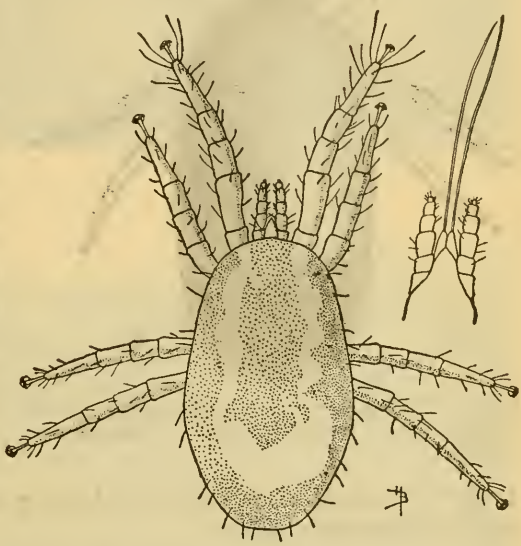


FIG. 1.—The chicken mite (*Dermanyssus gallinae*): Female mite before engorgement. Greatly enlarged. (Bishopp and Wood.)

THE ADULT.

As soon as the males crawl out of their nymphal skin they rest a short time, and are then ready to reproduce. They may clasp a nymph if no females have yet appeared, but as soon as a female appears a male will find her and clasp her, the venter of the female in close contact with the venter of the male. It is certain that fertilization can take place soon after molting and before feeding, and it can take place also after feeding. Directly after molting the females will feed, but the males will not. No doubt each male is able to fertilize several females, so that immediately after molting this is all the male desires. Normally fertilization takes place off the host, though it is conceivable that occasionally it may take place on the host. The females begin depositing eggs within about 12 hours after feeding. They will feed and deposit fertile eggs repeatedly with only one fertilization. Under observation this was done eight times. No doubt under natural conditions these females would have been visited by males several times. A single feeding during warm weather is all that is necessary for each deposition. A very small number of mites failed to oviposit after having had one good feeding. An engorged female is shown in figure 2.

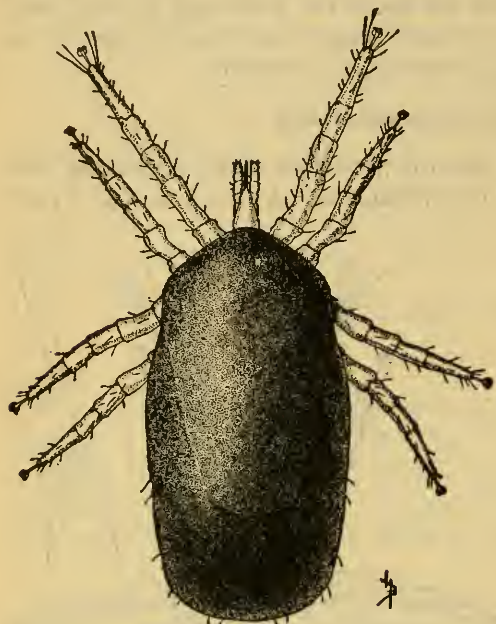


FIG. 2.—The chicken mite: Female mite engorged with blood. Greatly enlarged. (Bishopp and Wood.)

LIFE-CYCLE EXPERIMENTS.

The following outline gives an accurate record of the life cycle as worked out at Dallas, Tex.:

First-stage nymph engorgement:

August 6, 6 p. m. Several hundred first-stage nymphs put in jar with fowl.

August 7, 9 a. m. 542 engorged first-stage nymphs recovered.

First-stage nymph molting:

August 8, 7.30 a. m. Many have molted to second-stage nymphs.

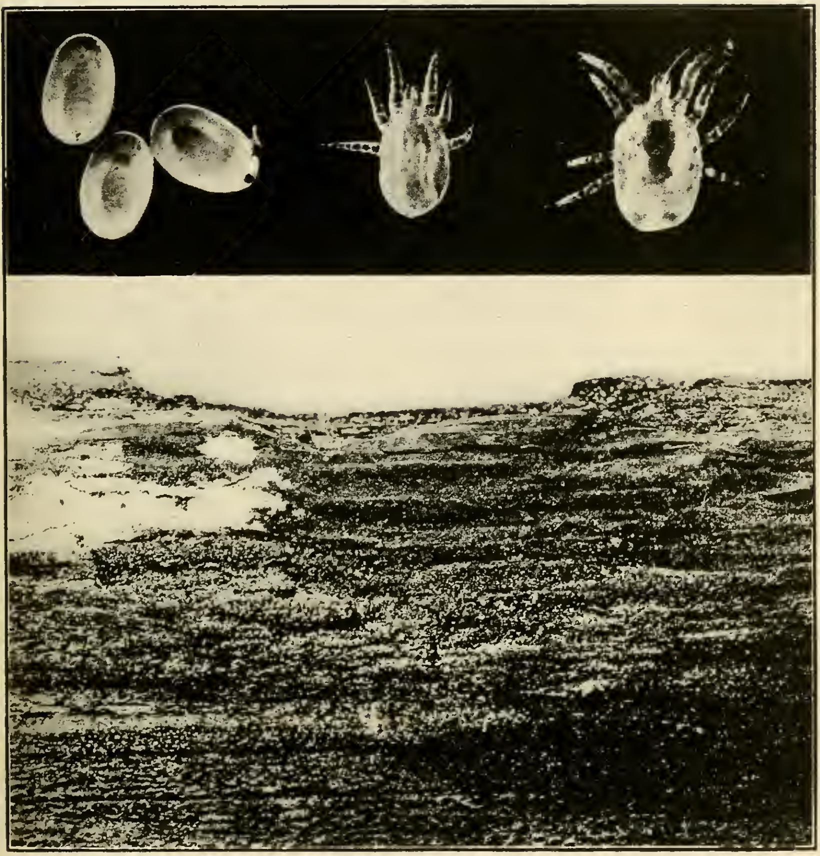
Second-stage nymph engorgement:

August 9, 5.30 p. m. All the second-stage nymphs (perhaps 50 of the 542 died) put in jar with chicken. The nymphs are very active.

August 10, 9 a. m. 263 engorged nymphs recovered.

Second-stage nymph molting and mating:

August 11, 9 a. m. Many have molted. Several pairs found to be in position of copulation.



THE CHICKEN MITE (DERMANYSSUS GALLINAE).

Upper left, eggs; upper center, larva, dorsal view; upper right, first-stage nymph before feeding; below, old roost showing spots of excrement. All much enlarged except the lower figure, which is somewhat reduced. (Original.)

First engorgement of females:

August 12, p. m. Put foregoing mites with fowl over night.

August 13, 9 a. m. 70 engorged females recovered, and about 30 unfed males. Females put in separate tubes from the males and one female in a tube.

First deposition of females:

August 13, 7 p. m. (before). Two females have begun to deposit.

August 14, 9 a .m. Five females are now depositing.

August 14, 9 a. m. Five females are now depositing.

August 15, 8.30 a. m. 52 females are now depositing.

August 15, 1.30 p. m. 61 females are now depositing.

August 15, 5 p. m. Same.

August 16, 10.30 a. m. 62 females are now depositing.

August 16, 4 p. m. 64 females are now depositing.

Hatching of eggs to larvæ:

August 16, 10.30 a. m. Some eggs from 17 of the females have hatched.

August 17, 11 a. m. 40 females now have eggs hatching.

August 17, 4 p. m. 43 females now have eggs hatching.

August 18, 10 a. m. 48 females now have eggs hatching.

(Sixteen females unaccounted for in notes.)

Molting of larvæ to first-stage nymphs:

August 16, 10.30 a. m. Some of one female's larval progeny have molted to first-stage nymphs.

August 17, 11 a. m. Some of 34 females' larval progeny now have molted to nymphs.

August 17, 5 p. m. Some of 42 females' larval progeny now have molted to nymphs.

August 18. Some of 57 females' larval progeny now have molted to nymphs.

Second engorgement of females:

(No males put with females before, during, or after feeding.)

August 20 (night of). About 60 females put with fowl.

August 21, 9 a. m. 59 engorged females recovered and put in separate vials, except seven which were not fully fed.

Second deposition:

August 22, 5 p. m.—

6 females have laid 1 egg each.
5 females have laid 2 eggs each.
24 females have laid 3 eggs each.
10 females have laid 4 eggs each.
6 females have laid 5 eggs each.
2 females have laid 6 eggs each.

August 23, 9.30 a. m.—

6 females have laid 1 egg each.
4 females have laid 2 eggs each.
10 females have laid 3 eggs each.
15 females have laid 4 eggs each.
11 females have laid 5 eggs each.
5 females have laid 6 eggs each.
2 females have laid 7 eggs each.

Totals, 53 females deposited 203 eggs.

The average mean temperature during this period was 80.8° F. No more eggs were deposited by these females until they were fed again. Two of the mites died after this deposition.

Hatching and larva molting from second deposition:

On August 23, 10 a. m., 13 eggs of this lot had hatched and one of the larvæ already had molted to a nymph. On August 24, 3 p. m., 178 eggs had hatched, and 66 of the resulting larvæ had molted. August 25, 2 p. m., all but four eggs had hatched, and 167 of the larvæ had transformed to nymphs. The following day only three eggs remained unhatched, and 190 of the 200 larvæ hatched had become nymphs.

Third engorgement:

August 26, 5 p. m., 51 females were put on a fowl for their third feeding; 49 of these were recovered on the following morning. All of these were engorged except one.

Third deposition:

Three of these females had begun depositing at 11 a. m., August 27. During the afternoon, night, and following day deposition proceeded freely. All but eight of the females had begun depositing at 5 p. m., August 27. All except 25 had completed deposition at 7 p. m., August 28. Only one egg was found after 4 p. m., August 29. It will be seen that deposition began approximately 18 hours after the mites were placed on the host and that practically all the eggs were deposited during the two days following the night of engorgement. The average mean temperature during this period was 78.43° F.

Hatching and larval molting from third deposition:

Two of these eggs had hatched by 8 a. m., August 29. All of those which completed incubation had hatched by 3 p. m. on August 31 except one, which hatched prior to 2.30 p. m. the following day. All but three eggs hatched, or slightly less than 1.3 per cent.

In a series of 10 eggs of the foregoing lot deposited between 2 and 4 p. m., August 27, six hatched between 8 a. m. and 3 p. m., August 29. Two others hatched during the next hour, and all were hatched at 10 the following morning. In another series of ten eggs deposited on August 27, the incubation period ranged from 45 to 49 hours, with an average of slightly less than 48 hours. During this period the average daily mean temperature was 78.43° F.

Molting of the larvæ which hatched on August 29 to September 1 from the eggs of the third deposition began on August 30, at 10 a. m., and was complete, with the exception of one individual, at 4 p. m., on September 2. The molting of the 10 larvæ hatched on August 29 was observed and ranged from 19 to 28 hours, with an average of 24.5 hours.

Fourth engorgement and deposition:

On the evening of September 3 the 46 remaining females were placed with a fowl for their fourth feeding. Thirty-five engorged females were recovered the following morning. On September 6 deposition was completed by all but two females. On September 8 all had finished depositing. One died without ovipositing, and three died soon after deposition was complete.

Fifth engorgement and deposition:

The remaining 32 females were put on a host for the fifth time on the evening of September 8. No males had been with them since previous to the first feeding. On September 9 22 engorged females were recovered, and all but two deposited—one of these died.

Sixth engorgement and deposition:

The sixth engorgement of the 20 females was made during the night of September 13. Fifteen of these were found engorged the following morning. Of these, three failed to deposit eggs. One of these three died.

Seventh engorgement and deposition:

During the night of September 17 12 females were placed with a host and 10 recovered. Seven of these deposited, one of the other three died, and one died soon after deposition.

Eighth engorgement and deposition:

The eighth engorgement was made during the night of September 22. All of the eight females applied to the host were engorged. Six of these deposited, beginning September 23 and finishing September 26. One female died without depositing and one failed to deposit.

On September 28, 100 per cent of the eggs deposited following the eighth engorgement had reached the nymphal stage, thus showing that fertility persisted though males were not with them since prior to the first feeding.

Ninth engorgement:

On September 28 the seven remaining females were put on a host for the ninth engorgement, but as only one was recovered the following morning the experiment was discontinued.

A summary of the depositions, with the number of eggs deposited by each female, is given in Table I.

TABLE I.—*Summary of oviposition records of Dermanyssus gallinae, Dallas, Tex., 1916.*

Depositions.	Number of females depositing 0 to 8 eggs each.									Total number of eggs.	Average per female.	Number of females depositing.	Number of females engorged.
	0	1	2	3	4	5	6	7	8				
First[1]	...	...	...	...	...	...	...	...	...	...	...	...	...
Second	0	6	4	11	14	11	4	3	0	203	3.8	53	53
Third	1	2	1	2	11	14	11	7	0	239	4.98	48	49
Fourth	2	0	2	3	10	6	9	1	2	160	4.84	33	35
Fifth	2	0	0	4	5	5	5	1	0	94	4.7	20	22
Sixth	3	1	0	5	2	1	2	1	0	48	4.0	12	15
Seventh	3	0	4	1	0	1	1	0	0	22	3.14	7	10
Eighth	2	0	1	1	2	1	0	1	0	25	4.16	6	8

[1] Not recorded.

DISCUSSION OF RESULTS OF LIFE-CYCLE EXPERIMENTS.

No attempt was made in the experiment to see how quickly the life cycle could be accomplished. In the foregoing experiment the actual time taken for the mite to pass through its life stages was 10 days. Under natural conditions in August without doubt this time would be reduced to at least 8½ days. Tables II and III show in brief the actual time taken in the experiment and the probable time in nature.

TABLE II—*Actual time taken by the mite (Dermanyssus gallinae) in experiment to go through life cycle.*

Date.	Hour.	Day.	Stage of development.
Aug. 6	9 p. m. 9 a. m.	1	First-stage nymphs fed on fowl. First-stage nymphs are all fed.
7	9 p. m. 9 a. m.	2	Second-stage nymphs molted from first-stage nymphs.
8	9 p. m. 9 a. m.	3	
9	9 p. m. 9 a. m.	4	Second-stage nymphs fed on fowl. Second-stage nymphs recovered fully fed.
10	9 p. m. 9 a. m.	5	Adults have molted from second-stage nymphs.
11	9 p. m. 9 a. m.	6	
12	9 p. m. 9 a. m.	7	Females fed on fowl. Females fully fed recovered.
13	9 p. m. 9 a. m.	8	Eggs being deposited.
14	9 p. m. 9 a. m.	9	
15	9 p. m. 9 a. m.	10	Some eggs still being deposited. Some eggs have begun to hatch to larvæ.
16	9 p. m.	11	Larvæ have begun to molt to first-stage nymphs.

TABLE III—*Probable time in nature the mite (Dermanyssus gallinae) takes to go through life cycle.*

Day.	Hour.	Stage of development.
First	a. m. p. m.	Eggs laid.
Second	a. m. p. m.	
Third	a. m. p. m.	Eggs hatched to larvæ.
Fourth	a. m. p. m.	Larvæ molt to first-stage nymphs. First-stage nymphs feed.
Fifth	a. m. p. m.	First-stage nymphs are molted to second-stage nymphs.
Sixth	a.m p. m.	Second-stage nymphs feed.
Seventh	a. m. p. m.	Second-stage nymphs molt to adults.
Eighth	a. m. p. m.	Females feed.
Ninth	a. m.	Eggs laid.

The average rate of deposition is about four eggs per day; that is, one egg in about 6.4 hours.

The rapidity with which the mite may reproduce is amazing. The possible progeny of one female in five weeks is conservatively estimated at 1,631 individuals, or, considering the duration of life of a female as eight weeks, her progeny would total 2,609 mites.

LONGEVITY.

As might be expected, since it feeds often and ordinarily does not have to wait long for a host, as do many of the ticks, the mite lives a comparatively short time in the absence of food. The experiments indicate that a certain amount of moisture and moderate temperature favor longevity, while extreme dryness and high temperatures are unfavorable factors. The mites die off much faster in the absence of food during the hot summer months than they do during the winter. The lowest temperature experienced by any of the mites under observation was 15° F., the highest 97.5° F. Adults and second-stage nymphs, during the months of July, August, September, and October, lived longest when moisture was applied—from 91 to 98 days. Under dry conditions the mites lived 56 to 85 days. During the months of August, September, October, November, and December mites under dry conditions lived from 100 to 108 days. The longest that adults which had never fed as adults lived was from 88 to 96 days; this was during the months of October, November, December, and January. All stages on a stick of wood lived 91 to 113 days in the months of September to January, inclusive. All stages in a glass chimney with a cracked egg lived more than 107 days during the same months.

First-stage nymphs have about the same period of longevity as the other stages. During the months of July to November, inclusive, this stage, when moisture was added, exhibited a longevity of 81 days under both moist and dry conditions. Second-stage nymphs seem to be the longest lived. During the months of September to January, inclusive, individuals in this stage lived 139 days. Females which had completed oviposition lived from 29 to 39 days during September and October, when kept under dry conditions. Females feeding and depositing continuously live longer than those not allowed so to feed and deposit. In the life-cycle experiment some females lived longer than 53 days.

One may therefore conclude that the mite can be starved out of a chicken house by keeping fowls and other animals away from the house for four months during the summer season and five months during the cooler season. It is probable that with uniformly cold weather, as in the Northern States, the longevity would be somewhat greater than in these experiments, all of which were conducted at Dallas, Tex.

FEEDING AND HIDING HABITS OF MITES.

FEEDING HABITS.

The usual habit of the mite is to feed at night. An experiment was conducted to determine whether mites feed and leave the fowl immediately or whether they have a particular time for dropping, such as just before daylight, as one writer claims. Two hours before dark a fowl was put on a roost containing a large number of hungry mites. Very few mites ventured far out of their hiding places at this time. A few did go to the fowl. At dark, two hours later, only four mites were found to have fed and left the fowl. One hour after dark nearly 600 mites (adults and first and second stage nymphs) had fed and left the fowl. One and a quarter hours later 535 more fed mites left the bird. Mites continued to drop in smaller numbers until after daylight. The writer finds that normal feeding takes place during the hours of darkness and that mites leave the fowl soon after feeding. All stages of mites will go on a fowl, feed, and leave it in less than two hours. In another experiment from 20 minutes to one-half hour was found to be sufficient time for complete engorgement. In one experiment about 30 per cent of a large number of mites put on a fowl in an earthen jar at 10 a. m. were full fed when observed at 2 p. m. The fact that some mites will feed day or night accounts in part for their very rapid increase about a sitting hen.

Though mites feed at night, they do not necessarily all crawl off the host before the fowls leave the roost. Both fed and unfed mites may be retained in the feathers when the fowls are running about. The number of such mites on a fowl seems to be small, but quite sufficient to infest a new place. The length of time mites may remain on a fowl after it has been on an infested roost is not certain. Experiments designed to throw some light on this point developed that nearly all mites leave the fowl by the end of the third night, but a few stragglers may persist for several days. It would be advisable for a person introducing new stock into his mite-free flock to use a little caution if he would avoid an infestation.

The author would suggest that new stock not known to be free of mites be allowed to roost the first few nights on a new roost wrapped with pieces of folded paper, preferably black. The object of using the paper is to furnish a convenient place for mites to hide. The paper may be examined, and if mites are found the fowls should be kept on this roost five or six days, or until no more mites come off of the fowls. If mites are discovered, by removing and destroying the papers and treating the roost thoroughly with kerosene or crude oil any danger of the mites getting back on the fowls can be avoided.

The ease with which mites reach the host has a decided bearing on the rapidity of increase. Hungry mites, though placed quite near a fowl, have great difficulty in finding the host unless the means of access is direct. This fact would account for the mite preferring to hide on the roost. When mites are found all over the walls the infestation must be a heavy one. To apply the above facts to aid in control work, the roosts should not be connected up with the walls of the chicken house unless some method of preventing the access of the mite to its host is used. The same may be said of the nests. The simpler and more isolated the roosts and nests, the easier it will be to eradicate the mite. (For control measures see Farmers' Bulletin 801.)

HIDING HABITS.

The direct rays of the sun act as a powerful killing agent when mites are exposed to them. Mites put on a board in the direct sun (July) were killed in a few seconds. Need of a suitable dark, protected place for deposition and molting governs the hiding habits of the mite. This may be a crack in a board or only a rough place, or it may be in the dry manure or litter. Here a place for deposition, molting, mating, and resting is provided. A very common hiding place for mites is near the nails that hold the roosts to their supports. When the mites become abundant they will overrun the roost and may be found anywhere in the chicken house. Their presence about a house may be detected by the minute black and white spots (excrement) left on the roosts. (See Plate I.) In the spring, when the weather becomes warm, mites come out of their hiding places in great numbers and, not having fed for perhaps a month, run about as tiny gray specks in ravenous haste seeking food. At this season the poultryman can tell easily whether his poultry or coops are infested with mites. A little later, in the case of light infestations, the mites may seem to disappear, but a careful search will show that they have had a feeding of blood and are hiding to reproduce. From now on they come out, perhaps only a few at a time, every night as long as the weather is sufficiently warm. It is important to clear away all manure and trash before trying to kill the mite by spraying with insecticides and to have a roost which may be removed easily, so that the underside may be sprayed.

PASSING THE WINTER.

For the mite the winter season is merely a time of lessened activity. During warm spells and in artificially heated houses the mite will feed if fowls are in reach. Since the mite may live at least four or five months, as shown by longevity experiments, there is no chance in the Southern States of cold weather lasting so long that the mite will starve from this cause. Low temperatures may kill the weaker individuals but do not destroy those with more vitality.

ENEMIES.

A small black ant (*Monomorium minimum* Buckley) has been seen to carry away recently-fed mites. Other species, notably the fire ant (*Solenopsis geminata* Fab.), destroy many. Certain spiders also have been seen to attack and destroy mites. Whether or not ants and spiders are of much importance in this respect is not definitely known. The author has found, however, that some infestations which were not quite killed out by spraying seemed to be exterminated by natural enemies.

DISPERSION.

Mites may be spread in the following ways:

(1) By infested fowls transferred to clean localities.

(2) By the use of boxes and crates in which infested fowls have been kept.

(3) Through the carrying by man of mites on his clothing, thereby starting an infestation.

(4) Through the carrying of mites by sparrows, and probably by pigeons, from one place to another in their feathers.

(5) By horses, cattle, dogs and cats, and certain wild animals, such as foxes, skunks, and weasels, which possibly act as mechanical carriers.

(6) By migration of the mites to buildings in contact or close proximity to infested premises.

The most important method of spread, without doubt, is by infested fowls. In general, it may be said that any carrier may become of greater or less importance, depending upon its closeness of association with an infestation and the degree of the infestation. Also, the danger of infestation increases the nearer clean fowls are located to infested ones.

OTHER HOSTS.

The writer has had thousands of mites crawling on his skin but has no knowledge of having been bitten by any of them; the feeling produced by the crawling mites, however, is very disagreeable. Other people testify that the mite bites them. While turkeys are attacked freely, chickens are favored, and other poultry (pigeons) are fed upon. Stock in barns abutting on chicken houses are at least irritated by mites.

FOOD OTHER THAN BLOOD.

Does the mite feed on anything besides blood? Inasmuch as a number of writers have said that the mite feeds on filth of different sorts, a few experiments were undertaken to get some evidence on the question.

Mites in different stages were put with moist and dry hen droppings, and with feed such as cornmeal and bran, and were watched closely for several days. Mites were then tried with white of egg and yolk of egg; a small quantity being put in a tube with about 50 mites. The mites did not appear to feed, nor, after several days, did they look as if they had fed on any of these substances. Mites were put in a vessel with a partially dried egg but did not appear to feed on it. Mites with access to filth, dirt, etc., lived no longer than mites without access to these substances, and they did not breed in this material.

Inasmuch as the mouth parts of the mite are fitted for piercing and sucking, a fresh egg was cracked so as to expose the amnion, to see if the mite would be able to draw nourishment from it. Careful measurements were made before and after the chance to feed on egg was offered the mites, but there was practically no change except in the case of one female which increased in length 71.75 microns and in width 100.45 microns. Some of the same mites which refused to feed on the cracked egg fed on a fowl when the chance was given them. The experiment indicates that mites rarely take nourishment in this way.

CONDITIONS FAVORABLE FOR PROPAGATION OF MITES.

The two conditions most favorable for the propagation of mites are (1) frequent direct and easy access to the fowls, and (2) numerous hiding places, such as a complicated roost, dirt, litter, etc. Other favorable conditions are the allowing of dirt and refuse to collect without removal for several weeks. Darkness and dampness without doubt help the mite to live longer in the absence of food. Even under the most sanitary conditions it is able to increase and multiply, so that cleanliness alone is not sufficient to rid premises of the mite, although it is one of the first things to be sought when an attempt at extermination is made because of the greater effectiveness of insecticides when applied.

SUMMARY OF LIFE HISTORY.

Blood is the necessary food of the mite in all stages except the larva, in which stage no food is taken.

It takes about one-half hour to one hour for the mite to get its full feeding and leave the fowl. The mite ordinarily crawls off the fowl onto the roost or other near-by place, where it finds a convenient crack or crevice in which oviposition, molting, and mating take place. Females deposit an average of four eggs each at the rate of four eggs in 24 hours. After finishing deposition the females feed again, usually at night, one engorgement nearly always being sufficient for each deposition. When full of blood the female is elliptical in outline, plump, and blood red (see fig. 2). Females will continue to feed and deposit eight times at least, and possibly many more times. The female must copulate at least once before she will deposit fertile eggs, although fertilization is not necessary before each deposition. The male does not feed immediately upon molting as does the female, but stays in the cracks, no doubt to fertilize several females. The proportion of males to females is about one to two. The eggs hatch in two days (August). The larvæ, which have only three pairs of legs, molt without feeding in about one day. The first meal is taken as a first-stage nymph. The first-stage nymph before feeding is light colored, like the larva, but is much more active. It becomes engorged with blood once and is ready to molt. One and one-half days is the length of time required by this stage. The second-stage nymph before feeding is rather grayish and, like the preceding stage, is active. With one meal of blood and a molt the second-stage nymph becomes adult. The second-stage nymph, when fed, appears much like the adult (see fig. 2), but smaller. All stages after feeding are blood red. One and one-half days is required to bring the second-stage nymph to the adult. Unfed females are slightly larger than unfed males. Mites that do not get a chance to feed may live four or five months.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 554

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. ▼ September 21, 1917

THE CRANBERRY GIRDLER.[1]

By H. B. Scammell,
Entomological Assistant, Deciduous Fruit Insect Investigations.

CONTENTS.

IMPORTANCE OF THE PEST.

The severity of the attacks of the cranberry girdler (*Crambus hortuellus* Hübner) upon cranberry vines, together with its general distribution throughout the cranberry-producing regions of the United States, marks this pest as one of prime importance to this industry.

The investigations into the seasonal history of the girdler and the observations on various methods employed to control it were made in New Jersey throughout a period covering nearly four years.[2]

Bog-management practices in New Jersey are diverse, and many opportunities have been offered to note the effects on cranberry-girdler infestations following one practice or another. Although it was stated by Smith (9, p. 21–24)[3] in 1903 that there is no such destruction of large tracts in New Jersey as in Massachusetts, it is apparent at this time that the girdler has become more of a pest each

[1] *Crambus hortuellus*; order Lepidoptera, family Pyralidae, subfamily Crambinae.

[2] During the field seasons of 1914 and 1915 the writer was assisted by Mr. H. K. Plank, of the Bureau of Entomology, and opportunity is here taken to acknowledge Mr. Plank's services, particularly in the field of insect photography. The work has been under the general supervision of Dr. A. L. Quaintance, Entomologist in Charge of Deciduous Fruit Insect Investigations, Bureau of Entomology.

[3] Reference is made by number to "Literature cited," p. 19.

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year. Smith's statement no longer holds true for New Jersey bogs, owing to the fact that many large areas of cranberry vines have been utterly destroyed by the insect in recent years.

Owing to its habit of feeding concealed in trash under the vines, the worm is very difficult to find and has been overlooked by many growers who were aware of the injury but uncertain as to the cause.

HISTORY.

The cranberry girdler has figured in entomological writings as a pest of grasses and will be found referred to in that connection as the "garden crambid" or "garden veneer." In cranberry districts it is frequently spoken of as the "girdle worm," but the generally accepted name for the species is the "cranberry girdler."

From the time of its description by Hübner (1, p. 29, pl. 7, figs. 45, 46) in Europe until the work of Scudder (5) and of Felt (6, p. 75–76, 87–88, 99–100; fig. 7; pl. 3, fig. 19; pl. 9, fig. 19; pl. 14, fig. 19) little was known of its habits. The American form was first described by Zeller (3, p. 155–156) under the name of *Crambus topiarius*, and later by Grote (4, p. 74), who stated that Zeller considered *topiarius* to represent the European *hortuellus* in the American fauna. Of late years the girdler has been the subject of considerable study in Massachusetts by Franklin (10, p. 7–8).

DISTRIBUTION.

This pest is not confined to the cranberry-growing sections, but is widespread throughout the United States, Europe, and Canada. Originally described as a European species, it is listed by Wood (2, p. 216, pl. 47, fig. 1497, *n*) from various parts of England and by Felt (6, p. 99) from St. John, New Brunswick, Canada. Felt gives the distribution as Maine, Massachusetts, North Carolina, Illinois, Nevada, and California, from which it may be noted that the species occurs practically from one end of this country to the other, and it is probable that it will be recorded eventually from every State in the Union. In the cranberry districts of Massachussetts and New Jersey it is very abundant, and in New Jersey especially it may be said that the majority of bogs show more or less injury by this species. It is common in Wisconsin, but has not become a serious cranberry pest, probably because the bog floors, as a rule, are kept wetter than those in the eastern cranberry States.

FOOD PLANTS.

The early records mention this insect as having been found commonly on grasses, but just what grasses is not specified. Fernald (7,

p. 40, fig. 1) gives sheep sorrel as a host. In later years cranberry is mentioned frequently. On cranberry the larvæ confine their feeding to the woody parts, such as the runners and the larger roots, and occasionally some of the finer roots are taken.

The investigation in New Jersey shows that a sedge, commonly called "three square" (*Scirpus americanus*), is fed upon liberally when present in cranberry bogs. This is one of the abundant bog weeds, and the larvæ attack it at the crown, sometimes forming their cocoons in this situation.

FEEDING HABITS AND DESTRUCTIVENESS.

All the injury is done during the larva stage, beginning in early June and continuing throughout the summer and fall until about mid-October. The worms are slow of growth, and the dying of the vines can not be detected readily until late August or September. During the early part of the season the worms are small and feeding is not extensive, but in late summer, when the worms are nearly full grown, they are ravenous feeders, and the lessened vitality of the vines is evidenced by the appearance of the foliage, which becomes fiery red or brown in September and October. Large quantities of the leaves drop off, and the few which remain on completely girdled vines become dry and drop during the winter, leaving areas of dead vines denuded of foliage presented to the view the following summer. Such dead areas may vary in size from a square foot to spots containing many square rods. At the close of a second year of infestation many of these dead areas will become merged, owing to the dying out of the vines in the intervening areas, by further girdler feeding. Under such conditions it is common to find areas of dead vines, leafless and very conspicuous by their black color, comprising as much as one-half acre (Pl. I). Usually the vines around the margins of the dead areas die back a little farther each succeeding year, although if the work of the girdler ceases, runners may spread out over the dead vines and tend to re-cover the area. This, however, is a very slow process, involving several years, and in the meantime the spot very frequently becomes a verdant patch of grass or sedge. In certain bogs small areas 2 or 3 feet in diameter (Pl. II, *A*) may be killed, particularly where the trash is very thick beneath the vines, as is likely to be the case in some of the corners, and the damage will not grow to alarming proportions. Such areas vary little in appearance from year to year until at some time the girdlers are exterminated, perhaps by a prolonged flooding of the bog. Then the runners push out and eventually fill in the bare spaces.

Where girdler feeding has not been severe enough completely to kill the vines, and even in those places where only slight gnawing of the runners has occurred, in a number of bogs it has been noted that such areas develop more rotten fruit than do adjacent vines in healthy condition. The weakening of the vines apparently tends to make the fruit more susceptible to fungous attack.

In severe cases of girdler feeding the vines may become so loosened, or so badly eaten and severed, that they may be rolled back with slight exertion, exposing the bare trash beneath.

Girdled vines are often found on which injured portions, where the bark has been abraded, are covered with white cottony material; these are the waxy coverings of mealy bugs (*Pseudococcus adonidum* L.), and as they are rarely found on healthy vines they should be classed as secondary pests.

The specific injury caused by the feeding worms is due to their eating through the bark of the runners into the wood, which often occurs to such an extent that the runner is completely severed. (Pl. III, *A*, *B*.) Gnawing the bark completely around a runner will also kill that part of the plant beyond, provided no other roots nourish this part. Runners are often seen which have been tunnelled for short distances by this insect, and some are eaten down to mere splinters. The fine roots as well are eaten, but to a less extent than is the woody part. Feeding marks are sometimes found on the crowns of the plants where they arise from the hills as originally set. Practically all of the feeding, however, is done by the larvæ in a concealed position—in the trash which is found beneath the vines, which consists largely of fallen leaves, pieces of vines, and other débris, and forms a mat over the runners, affording the girdlers excellent protection from parasitic insects.

The feeding marks of the cranberry girdler should not be confused with those of the cranberry rootworm (*Rhabdopterus picipes* Oliv.), which feeds on the small roots and root hairs and on the runners only to the extent of eating the bark, usually on the side which touches the ground. In general, the rootworm feeds below the surface of the ground, whereas the girdler feeds above the surface but hidden in a layer of trash. The excrement of the girdler in badly injured areas is very abundant, appearing in masses, which indicates that the larva feeds for a considerable length of time without materially changing its location. Often the excrement, intermixed with bits of trash, will be found with silken threads woven loosely through it, and these rude galleries probably constitute a protective covering for the worm during the feeding period. Scudder (5) figured a cylindrical, upright case for this larva occurring on grasses, and Fernald (8, p. 150) speaks of a vertical tube, constructed of bits of vegetable material held together by silk, but neither of these larval cases has been found on New Jersey cranberry bogs, and for this reason the larvæ are described as being naked.

DESCRIPTION OF THE CRANBERRY GIRDLER.

THE EGG.

The egg (Pl. IV, *D*) is white when first laid, becoming more and more pinkish as hatching time approaches. It is oval in outline, broadly rounded at the ends, with the end through which hatching occurs slightly more tapering than the base. The apex is divided into a number of cells of various patterns. The sides are ribbed vertically, usually regularly, but not always. These are crossed longitudinally by much finer ribs. The average size of four eggs is as follows: Length, 0.441 mm.; greatest breadth, 0.318 mm. Fifty-eight eggs laid end to end would measure about 1 inch.

THE LARVA.

The last-stage larva (Pl. IV, *A*, *B*) has a dark-brown head with ocelli, mandibles, and labrum black; the clypeus is dark brown, the thoracic shield and tip of abdomen light amber, and the rest of the body sooty white, bearing numerous long and short hairs which are black at the base and finely pointed. Its length is 12 to 15 mm., or about one-half inch.

THE PUPA.

The general color of the pupa (Pl. IV, *C*) is pale yellow with eyes becoming black before the emergence of the moth; the tip of the abdomen is dark brown, the outlines of the wings and the antennæ are brown, and the segments of the abdomen are edged with brown. The length is 8.5 to 11 mm., or about three-eighths of an inch.

THE ADULT.

Scudder (5) gives the following description of the adult (Pl. V, *A*, *B*.):

Fore-wings above of a pale straw color, growing pale buff apically heavily marked with blackish fuscous of varying shades and with silver; the latter is mostly confined to two subapical cross-bands, the upper half of the inner and the whole of the outer oblique, the inner bent just above the middle and crossing the entire wing (excepting that it fails to reach the costal margin above), the lower half at nearly right angles to the upper half and subparallel to the outer margin; the inner band is bordered interiorly with brown which extends to the costal margin; a broad stripe of silvery gray tapering apically follows the subcostal vein to the end of the cell and four fuscous longitudiual stripes reach nearly or quite to the inner silvery band, the uppermost more or less mingled with buff following the costal edge for nearly a third its length and then running a little obliquely across the upper extremity of the cell, the next tinged with silver so as to become pearl gray extending along the middle of the cell; the other two follow the median and submedian nervures; three other short longitudinal fuscous lines, much overlaid and concealed by silver, follow the nervules beyond the cell, while a supplementary brownish and oblique line intervenes between the oblique portion of the costal stripe and the inner margining of the inner silvery band; the extreme outer margin of the wing has a black line on the upper half, and on the lower half at the nervule tips three or four black points; the fringe is silvery. Hind-wings uniform silvery gray, narrowly edged on the upper half of the outer border with pale brown, the fringe silvery white. Expanse of fore wings, ♂ 15^{mm}; ♀ 17^{mm}. Described from four bred males.

The average length of 14 specimens, measuring from front of eye to tip of wing when folded, is 9.4 mm., or about three-eighths of an inch. The females are rounder of abdomen and average larger than the males.

THE COCOON.

The cocoon is composed of scraps of débris found on the floor of the bog, usually consisting of bits of dead leaves, bark, twigs, fine roots, grasses, sand, and dried excrement of the larva, with now and then a whole leaf attached loosely to the outside. This material is held together by fine strands of white silk, and the interior has a lining of white silk, parchmentlike in texture. In sandy locations the external part of the cocoon is sometimes made entirely of sand. However, for New Jersey bogs the typical cocoon is made of trash and appears dark brown in color.

The shape of the cocoon is variable (Pl. VI, *B*.). In some instances it might be described as resembling in miniature a short-handled Indian club, while others appear of a curved cucumber shape. One end is always broadly rounded, being of greatest diameter about one-third the distance to the smaller end, and tapering to a cylindrical, slightly curved neck. Some loose strands of silk are placed in the neck for protection, but the end is not securely sealed as are the walls. When pupation occurs the pupa lies with head toward the neck, and the moth is able to push its way through, leaving the pupal shell within the cocoon. One can not tell from external appearances whether the moth has emerged, because the exit hole is well concealed by the arrangement of pieces of trash which tend to fall back into position after the passage of the moth. The measurements of 13 cocoons are as follows: Length 11 to 18 mm., average 13.84.; greatest breadth 5.5 to 10 mm., average 6.88 mm.

Vertical cylindrical cases often encountered on cranberry bogs, which might be confused in the mind of the grower with those of the girdler, are those formed by larvæ of caddiceflies—harmless insects which breed in wet places. There are many styles of these caddicefly cases (Pl. VI, *A*), and they are often found projecting straight up through the trash in areas infested by the cranberry girdler.

SEASONAL HISTORY.

The seasonal-history data were secured on numerous bogs throughout the State of New Jersey and in rearing cages kept in a screened open-air insectary. Four-ounce ointment cans were satisfactory for securing the feeding, cocooning, and pupation data, while for oviposition data and caging the moths a cloth-covered lamp chimney was found to fit tightly over a 1-ounce ointment can.

ADULT STAGE.

The time of emergence in the spring and summer depends largely upon whether the bog is a dry one or a flowed one and on the date of drawing the winter flowage.

Dry-bog conditions.—Cocoons kept at the laboratory during the winter of 1914–15, under approximately dry-bog temperatures, yielded moths from May 11 to June 18. In the cranberry bog where winter flowage was removed on April 10, moths began flying June 7.

Winter flowage drawn May 10.—This represents probably the average date at which New Jersey growers remove the winter flowage. From a large mosquito-bar cage placed over an infested area of cranberry vines bared of winter flowage on the 10th of May, adult emergence was noted from June 10 to July 8. The complete record appears in Table I.

TABLE I.—*Emergence of cranberry-girdler moths on cranberry bog, Whitesbog, N. J., 1915.*

Date of removal from cage.	Number of moths.	Date of removal from cage.	Number of moths.
June 10	16	June 18	38
June 11	48	June 25	10
June 12	42	July 2	1
June 15	117	July 8	1
June 16	24		

Keeping the winter flowage on a bog until some time after May 10, in the region of New Jersey, produces a later emergence of moths. There is a date, however, which no one as yet has determined definitely, when, owing to the lateness of holding the flowage, the immature stage of the moth is killed. One observation was made in 1916 on a bog at Howardville, N. J., showing that, although the winter flowage had been held until July 12, a number of the girdlers in the immature stages were able to survive this treatment, and moths were found flying August 3.

On grassy bogs and on bogs bearing a heavy mat of vines the emergence of the moths may be prolonged over a long period. At

Whitesbog, N. J., records of late-flying moths have been kept for three years, and it is not unusual to find them flying until mid-August. The heavily shaded places, from which the flowage is slow in draining, probably retard the development of the immature forms in the cocoons and thus give rise to later issuing moths. These are the conditions which have led to the erroneous conclusion that more than one brood occurs in the course of a season.

The moths, which are strong fliers, are seldom noted in their concealment among the vines, but when disturbed they fly several rods or more, finally seeking shelter in the vines again and often running down to the trash for security. When resting, the moths fold the wings tightly around the body and are inconspicuous; at night, with the aid of a lantern, they may be seen in this position clinging to vines or the stems of tall grasses.

Proportion of sexes.—In the early summer the males and females appear to be about equal in number; for example, on June 11, 24 moths were collected, of which 12 were males and 12 were females. In late summer, however, the males are far in excess of the females, as shown by the following collections: Thirteen moths taken July 27 consisted of 11 males and 2 females, while of 23 moths collected August 10 only 5 were females.

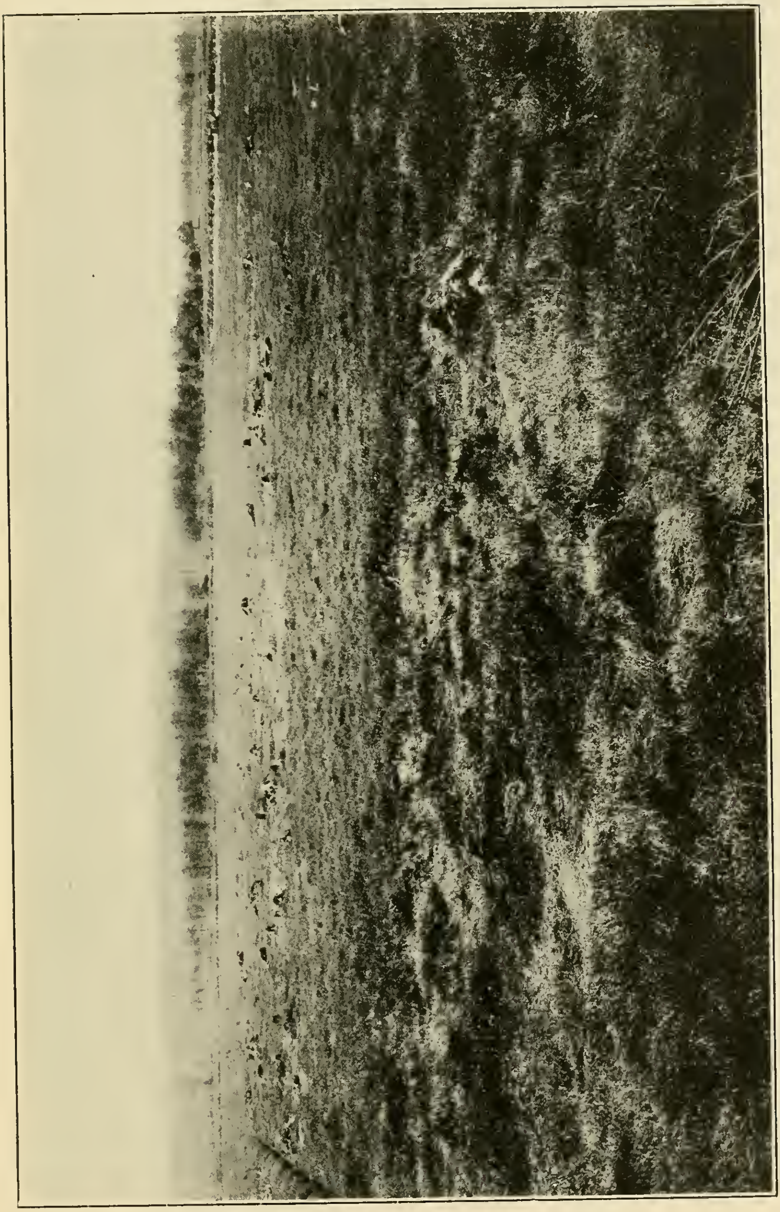
EGG STAGE.

In rearing cages the moths laid eggs from various positions, not necessarily resting on the bottom of the cage, but dropping the eggs from whatever position they happened to have assumed. No eggs were found attached to the cranberry vines or sides of the cage, but all were recovered on the cage floor. It is assumed, then, that on the bogs the eggs are laid either when the moths have crawled down to the trash or when they are clinging to vines or grasses. The eggs are so minute that there is little possibility of finding any under natural bog conditions.

The moth has been known to be a prolific egg layer. Felt (6) records one female that laid 700 eggs, 300 of them being deposited on the first day. In the course of observations at Whitesbog, N. J., a female was noted which laid 50 eggs in less than two hours.

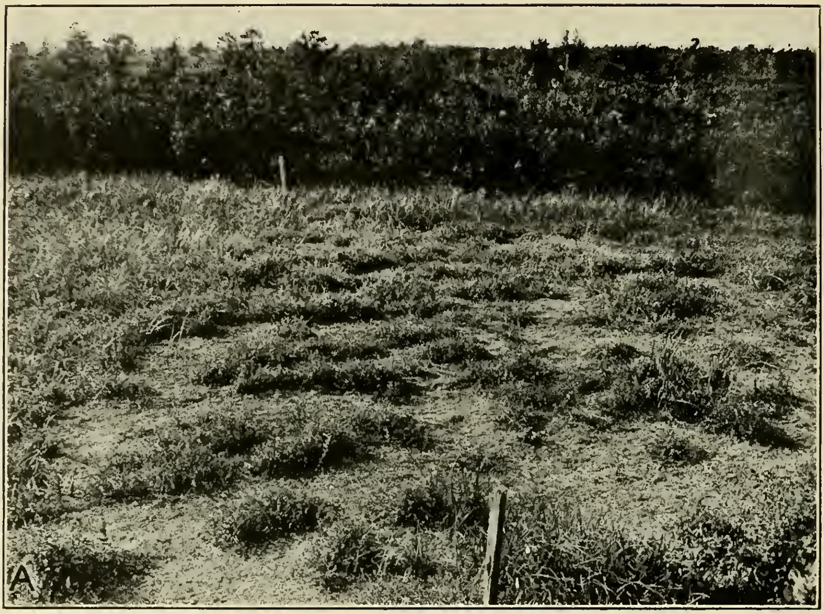
The data in Table II give the number of eggs per female secured at Whitesbog, N. J., under insectary conditions.

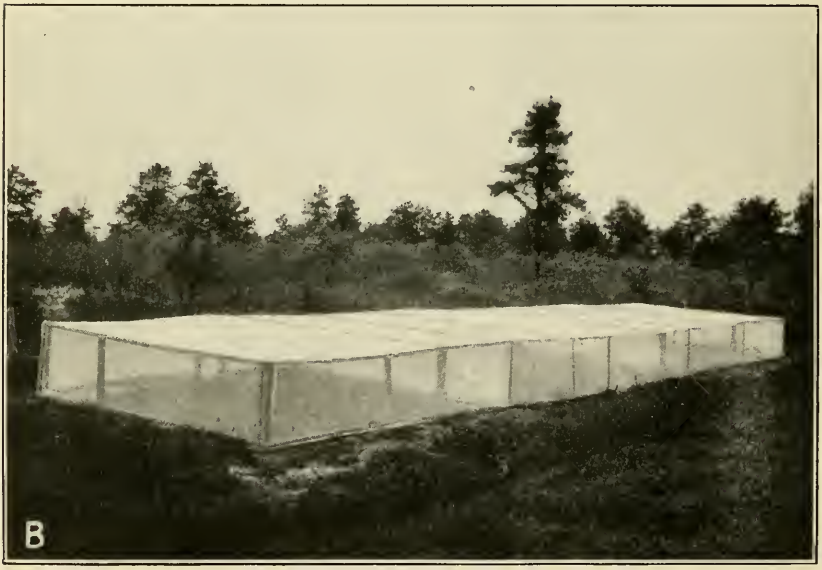
A male and female (reared) were placed in each cage and fed sugar sirup.



WORK OF THE CRANBERRY GIRDLER (CRAMBUS HORTUELLUS).

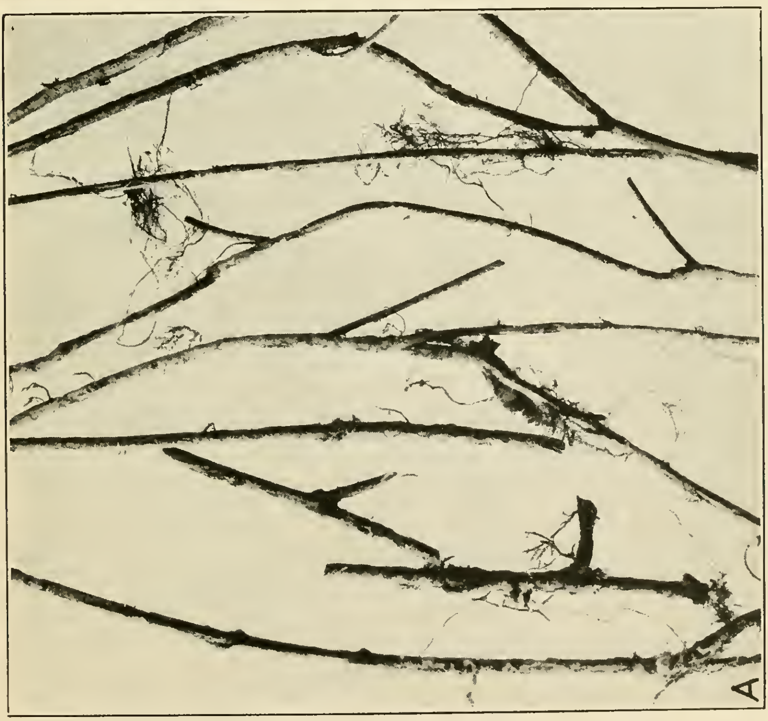
Severely injured cranberry bog, showing large dead area in foreground and smaller dead areas beyond. (Original.)





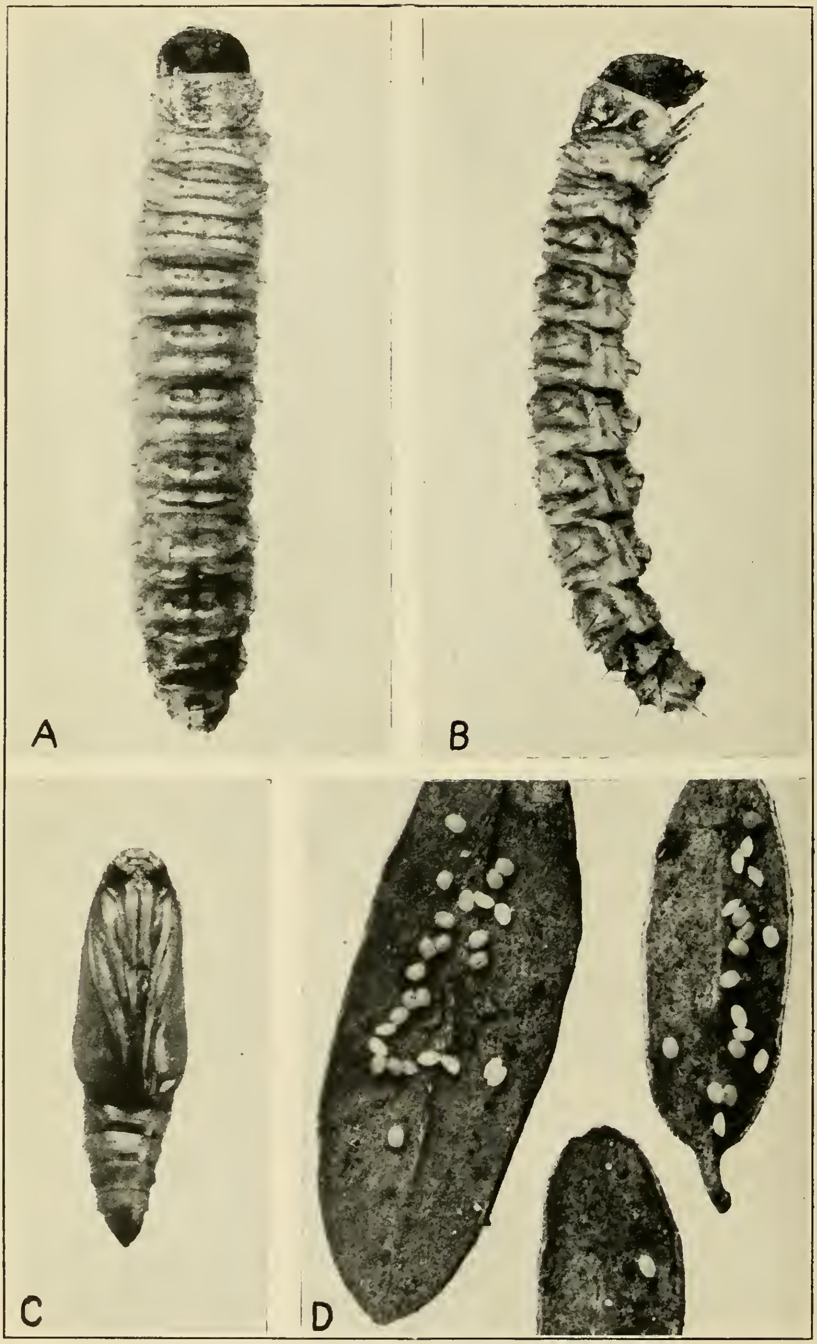
THE CRANBERRY GIRDLER.

A.—Mild case of injury to cranberry vines. B.—Cage used in sanding experiment at Whitesbog, N. J. (Original.)



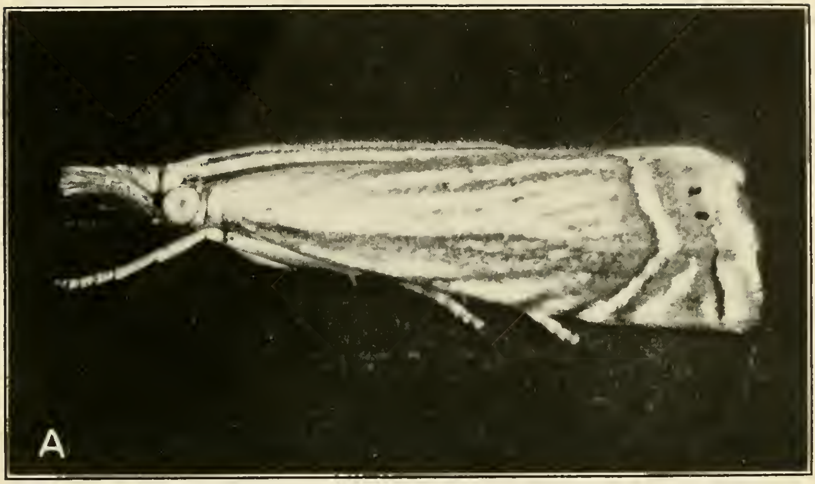
DAMAGE BY THE CRANBERRY GIRDLER.

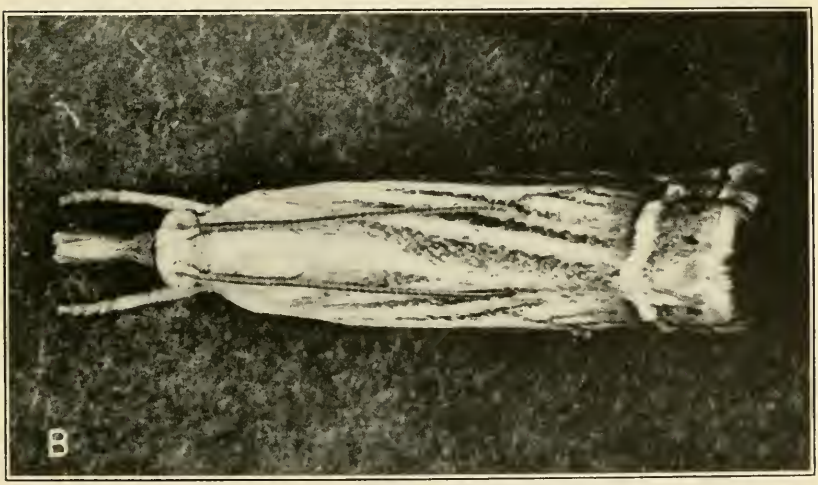
A.—Cranberry runners gnawed by the larvæ. B.—Larval feeding marks on cranberry vines in rearing cage. (Original.)



STAGES OF THE CRANBERRY GIRDLER.

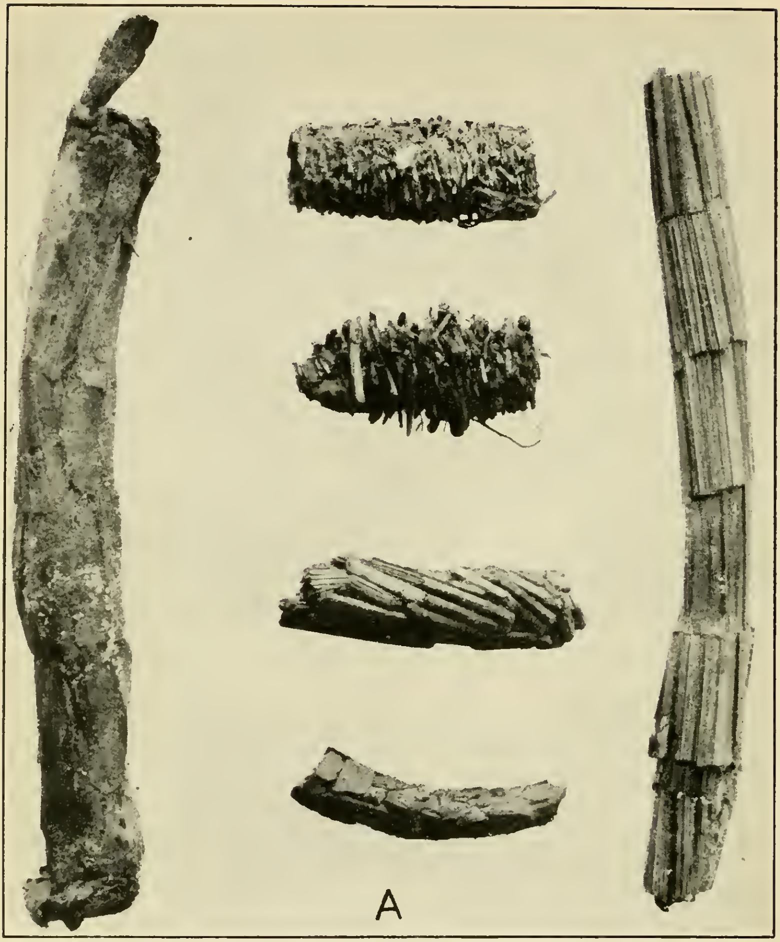
A.—Dorsal view of last-stage larva, enlarged 9 times. B.—Lateral view of last-stage larva, enlarged 9 times. C.—Pupa, enlarged 6 times. D.—Eggs on fallen cranberry leaves. (Original.)

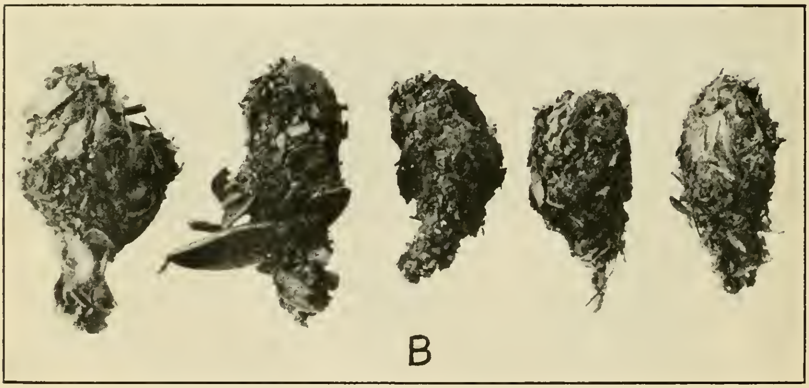




THE CRANBERRY GIRDLER.

A.—Adult moth, viewed from side. B.—Adult moth viewed from above. Photographed from life, enlarged 9 times. (Original.)





COCOONS OF CRANBERRY GIRDLER AND CADDICEWORMS.

A.—Caddiceworm cases, sometime mistaken for those of the girdler, twice enlarged. B.—Types of cocoons of cranberry girdler, twice enlarged. (Original.)

TABLE II.—*Number of eggs per female of the cranberry girdler, Whitesbog, N. J., 1915.*

Pair No. 1.		Pair No. 2.		Pair No. 3.		Pair No. 4.	
Date of deposition.	Number of eggs.	Date of deposition.	Number of eggs.	Date of deposition.	Number of eggs.	Date of deposition.	Number of eggs.
June 9	7	June 1	1	May 22	79	July 24	55
June 10	98	June 2	1	May 23	103	July 25	8
June 11	30	June 3	1	May 24	0	July 26	78
June 12	12	June 4	6	May 25 and 26	32	July 27	21
June 13	14	June 5	17	May 27	9	July 28	49
		June 6	59	May 28	12	July 29	3
		June 7	75			July 30	17
						July 31	12
	161		160		235		243

The greatest number of eggs laid in a single day by one female was 103, and the greatest number laid during the life of a given female was 243. The length of the egg stage varies with the season, those eggs deposited in May requiring a longer incubation period than do those laid in July, as shown in Table III.

TABLE III.—*Length of the egg stage of the cranberry girdler, Pemberton and Whitesbog, N. J., 1915.*

Date of deposition.	Date of hatching.	Length of stage.	Date of deposition.	Date of hatching.	Length of stage.
		Days.			*Days.*
May 21	June 8	18	July 25	Aug. 1	7
May 22	do	17	July 26	do	6
May 23	do	16	Do	Aug. 2	7
Do	June 10	18	July 27	Aug. 3	7
May 26	June 11	16	July 28	Aug. 5	8
June 9	June 17	18	July 30	Aug. 6	7
June 10	do	7	July 31	do	6
June 11	June 19	8	Aug. 7	Aug. 13	6
June 12	do	7	Aug. 9	Aug. 15	6
July 24	Aug. 1	8			

Average length of the egg stage, 9.63 days.

LARVA STAGE.

The larva leaves the egg through a hole which it cuts in the apex, or slightly to one side of the apex, and emerges as soon as the aperture is large enough to permit the passage of the head, crawling rapidly out and appearing very active at this period. In small cans the larvæ were fed fine cranberry roots, the bark and wood feeding habit being acquired apparently during later life. As remarked by Ainslie (12), some species of Crambinae defy all attempts to rear the larvæ, and *C. hortuellus* falls into this class in the experience of the writer.

Investigations conducted in this region demonstrated beyond doubt that there is only one generation annually. Field records kept on a number of badly infested bogs throughout the entire season showed only a single flight of moths from about June 10 to mid-July, after which there was no further evidence of moths until the following year. This was also demonstrated in a mosquito-bar cage covering 2.4 square rods, from which moths issued from June 10 to July 8, and although oviposition occurred in the cage, none of the larvæ pupated during that season.

Larvæ are rarely found in wet situations or in places where a lack of drainage is materially affecting the productiveness and health of the vines.

The drier locations, such as knolls, the high margins of the bogs, and well-drained areas having a considerable quantity of fallen leaves and trash under the vines are the places injuriously infested. The character of the soil is not so important a limiting factor as the drainage. Severe injury occurs on mud and peat bottoms as well as on savannas, provided a good layer of trash is present and the land is well drained.

Larvæ are never found feeding in exposed positions, but always buried beneath more or less trash. When exposed to the light, as when trash is turned over, they usually are found in a curved position and motionless. After a period of about 10 seconds the larvæ will start crawling rapidly for cover, and it is at this time that they are most easily detected. The trashy nature of the infested situations also renders their location difficult. Many growers have failed utterly to locate the larvæ, although the vines may have shown injury of an extreme type.

The amount of damage done by the cranberry girdler seems out of all proportion to the number of larvæ to be found in a given location. In one instance, however, the writer found 30 cocoons containing larvæ and 1 naked larva in an area of about 4 square feet.

What appears to be the most important point in the seasonal history of this pest from the standpoint of its control is the period when cocoon making begins. The few publications available on the seasonal history of the cranberry girdler present various statements regarding the time of cocooning. Some writers have placed the period as late as November, and others have indicated this period as beginning at varying dates in September and October. Realizing the importance of knowing more definitely when cocooning commenced, the writer has made collections of larvæ and cocoons in the fall, and from these data it may be stated for New Jersey conditions that some larvæ form cocoons in late September and the majority in early October. Records obtained from bogs in different localities are shown in Table IV.

TABLE IV.—*Cocooning records of the cranberry girdler in New Jersey, 1915.*

Date.	Number of larvæ in cocoons.	Number of naked larvæ.	Date.	Number of larvæ in cocoons.	Number of naked larvæ.
Sept. 8	0	21	Oct. 5	9	1
Sept. 14	0	15	Oct. 11	6	1
Sept. 19	0	7	Oct. 15	37	1
Oct. 1	3	17	Oct. 19	1	0
Oct. 4	0	2	Nov. 17	26	0

The foregoing figures, obtained under actual bog conditions, show that cocoons were first found October 1, although search was not made for them between September 19 and that date. Naked larvæ were abundant on October 1, but this condition soon changed, and by the 5th of October larvæ in cocoons outnumbered the naked ones.

After making the cocoon, the larva lies dormant within until spring of the following year, at which time pupation occurs. Larvæ in cocoons are able successfully to withstand the usual winter flowage, which is applied, as a rule, in December and held until the following April or May. Some few are able to withstand a flowage lasting until July, although an infestation is always greatly reduced by such late holding.

The cocoon is not impervious to water and, in fact, becomes filled with water about three days after submergence. After 24 hours' submergence in a solution tinged with red, the inner wall of the cocoon was found entirely reddened, with no free water around the larvæ. Similar results were obtained with another cocoon after 48 hours' submergence, while at the end of four days three cocoons were entirely filled with the solution.

PUPA STAGE.

Pupation occurs after the removal of the winter flowage and is dependent upon the time of this removal. On dry bogs it may occur in late April or May, and on winter-flowed bogs it may be retarded by late holding of the flowage until July. No evidence has been noted of pupation taking place while the winter flowage was on; in fact, the examination of cocoons within a day or two after the drawing of the winter flowage showed all such to contain larvæ.

After pupation has occurred the bog may be reflowed for several days without effecting the death of the pupa. On one occasion a pupa in its cocoon was found alive on the bog after submergence for between five and six days.

Pupal records have been difficult to obtain, because the opening of the cocoon for purposes of observation is disturbing to the larva and is likely to result either in its death or in delaying its transformation to the pupa. The records at hand show that the stage lasts, on the average, 21 days. (See Table V.) Under natural bog conditions, following the drawing of the winter flowage about May 10, it is very likely that the pupal period is several days shorter in duration than as stated. The pupa is always found with the head pointing toward the neck of the cocoon, eventually permitting the easy emergence of the moth.

TABLE V.—*Length of pupa stage of the cranberry girdler, Pemberton, N. J., 1914.*

Experiment No.	Date of pupation.	Date adult emerged.	Length of stage.	Experiment No.	Date of pupation.	Date adult emerged.	Length of stage.
			Days.				*Days.*
1	Apr. 28[1]	(2)	....	9	Apr. 30	(2)	....
2	Apr. 29[1]	May 11	12	10	May 2	(2)	....
3	...do....	May 15	16	11	...do....	May 18	16
4	...do....	May 18	19	12	...do....	...do....	16
5	...do....	May 20	21	13	May 7	June 5	29
6	...do....	May 27	28	14	May 23	June 13	21
7	...do....	May 29	30	15	May 29	June 17	19
8	Apr. 30	...do....	29	16	...do....	...do....	19

Average days, 21.15. [1] Approximate. [2] Died.

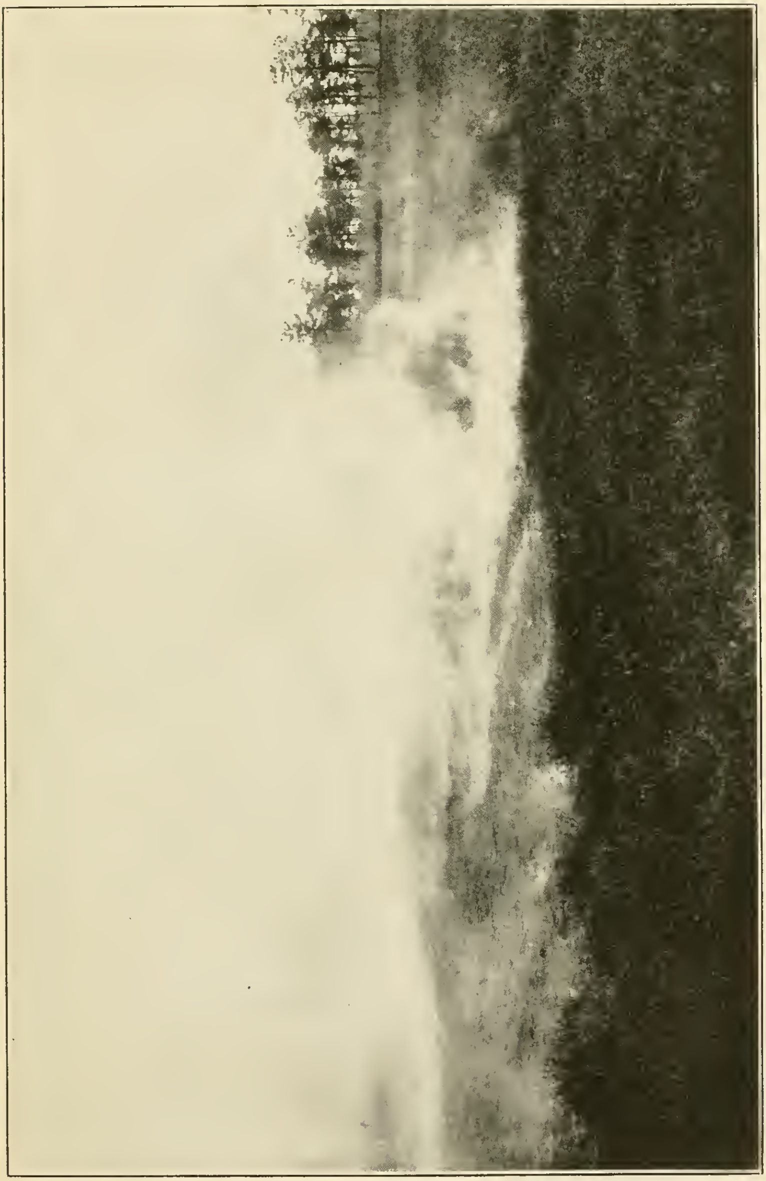
NATURAL ENEMIES.

Among the parasites there appear to be very few which attack the cranberry girdler. No parasites were obtained in the rearing cages, but occasionally when opening cocoons the remnants of a parasite in one stage or another were found. From such findings two species of Ichneumonidæ were secured. The habit of concealed feeding of the girdler larvæ must be a great protection against parasitic enemies, and the winter flowing of the bogs probably also tends to lessen the activities of parasites.

In areas of severe girdler infestation spiders have been found to be very abundant as well as have various species of ground beetles. Among the ground beetles *Harpalus caliginosus* Fab. and *Anisodactylus harrisii* Lec. have been collected.

Very often an area of vines infested with girdler larvæ will be invaded by field mice, and the burrows just beneath the surface will run throughout the entire section. While mice occasionally cut off cranberry vines which are in the line of a runway, they should be classed as minor pests of the cranberry industry. The work of mice may be recognized by the diagonal cut of the severed vine and the furrows made across the end by their teeth. It is thought, however, that the mice search for girdler larvæ and are instrumental in reducing large infestations. They nest in roundish houses built of grasses above the level of winter flowage.

Among the birds which prey on insects the swallows are perhaps the most useful in capturing girdler moths. At Howardville, N. J., a swallow followed the writer the length of one of the bogs, and as



A SEVERE REMEDIAL MEASURE AGAINST THE CRANBERRY GIRDLER.

Burning a cranberry bog, a practice occasionally resorted to in very severe outbreaks. (Original.)

the moths, frightened from the vines, rose into the air the swallow darted for them and captured many.

At present, natural enemies do not appear to be potent factors in the control of the girdler on cranberry bogs.

REMEDIAL MEASURES.

Under the heading of remedies fall such methods of treatment as spraying, the use of repellents, burning, trap lights, flooding, and sanding. Of these measures, flooding and sanding have given the best satisfaction, as indicated by the work conducted in New Jersey.

SPRAYING.

Owing to the habit of the larvæ of feeding on roots and runners under cover of the trash beneath the vines, there seems to be no hope of developing a method of combating them in which reliance can be placed on spraying. In addition to the trash which hides the larvæ, the dense mat of vines covering the bog prevents a large portion of the spray material from reaching even the trash.

REPELLENTS.

It has been suggested occasionally by growers that commercial fertilizers might act as repellents of the girdlers and at the same time stimulate the vine growth. The opportunity to study this method of treatment was afforded at Whitesbog, N. J., where fertilizer experiments on cranberry bogs have been carried on by the New Jersey experiment station for a period of four years. No fertilizer was applied to the plats the fourth year, owing to the excessive vine growth produced during the previous three years. Muriate of potash has been held by some to afford protection from certain insects owing to its repellent action, and four of the plats to which this material was applied, along with other ingredients, were kept under observation by the writer. The data in Table VI[1] show the fertilizers and the amounts applied on four plats, consisting of one-twentieth of an acre each.

TABLE VI.—*Experiment with fertilizers as repellents against the cranberry girdler, Whitesbog, N. J., 1915.*

Plat No.	Fertilizer tested.	Plat No.	Fertilizer tested.
11	10 pounds muriate of potash, 25 pounds acid phosphate, 10 pounds ammonium sulphate.	29	10 pounds muriate of potash, 15 pounds phosphate rock, 10 pounds ammonium sulphate.
13	10 pounds muriate of potash, 25 pounds acid phosphate, 20 pounds dried blood.	31	10 pounds muriate of potash, 15 pounds steamed bone, 10 pounds ammonium sulphate.

[1] Extracted from Proceedings of the 46th Annual Meeting of the American Cranberry Growers' Association.

The fertilizers listed in Table VI have been of no avail in repelling the girdlers; in fact, these plats in 1916 showed serious injury, as evidenced by the considerable areas of girdled vines found on them. In general, it may be said that the use of fertilizers tends to make conditions more favorable for girdler infestation by increasing the amount of vine and foliage production and thus in direct proportion increasing the trash on the ground beneath the vines. This, however, should not deter anyone from using fertilizers on cranberry bogs where the vines need stimulation, but should be taken as a caution that girdler infestation is likely to follow a heavy production of vines, particularly on well-drained land.

In a test to determine the repellent value of certain materials a lumpy and granular residue, said to be a by-product of a gasworks, was applied to an infested piece of land by broadcasting at the rate of 650 pounds per acre. The larvæ were not repelled and were as abundant at the time of cocooning on the treated plat as on the adjacent untreated plats.

BURNING.

Burning infested areas has been recommended in the past and occasionally has been resorted to by growers. When a bog is burned over (Pl. VII), a large quantity of the trash remains unconsumed on the bog floor, but it is probable that the heat generated is great enough to kill the larvæ, naked or in cocoons, that may have been buried in this débris. Other methods of controlling the girdler have been devised which do not entail destruction of the vines by burning, and the practice therefore is not recommended.

TRAP LIGHTS.

Capturing the moths by trapping with lights was tried for two seasons with very unsatisfactory results. On one occasion four moths were captured at a stationary light in the course of a night. The tests with lights were made in the height of the flying season, and the results showed conclusively that the moths are not attracted to lights in sufficient numbers to warrant employing this method of capture.

LATE HOLDING OF THE WINTER FLOWAGE.

By late holding of the winter flowage is meant maintaining the winter head of water over the vines from the time it is applied in December or thereabouts until some time between July 1 and August 1. Holding the flowage until July 1 does not always satisfactorily destroy girdler infestations, but if the head is maintained until July 15 much better results are obtained. Occasionally a grower is met who has kept the water on the bog until August 1, and, while this treatment is very satisfactory from the standpoint of destroying the girdlers, it may result in a very poor bud formation and a light crop of berries the following year. Some of those who have tried holding the flowage until mid-July have reported that the crop the year following yielded an increase of 100 per cent over a normal one, showing that this treatment may be used without monetary loss, provided frosts, which may destroy part of the prospective double crop, are not encountered in the cropping year.

Holding the flowage until July 14 or later results in the loss of the current year's crop, but this procedure is good practice where the girdler infestation is severe and perhaps complicated by an infestation of the blackhead fireworm (*Rhopobota vacciniana* Pack.). Considerable expense is saved the grower by allowing the bog to go one year without a crop, and the treatment always results in producing a cleaner bog, especially if the one so handled has been invested by grass and weeds.

June 18 is the latest date, in the knowledge of the writer, to which the winter flood can be held and a good crop secured the same season. This was accomplished on a deep-flowed bog of Early Black vines near Pemberton, N. J.

In the event of holding the winter flowage until July 15, or a little later, successful control of the girdler will be secured, but not extermination. A few of the insects will escape even this treatment, and at the end of three or four years the infestation again may be severe. The mistake made by many growers is in permitting the injury to assume large proportions before attempting control. The first signs of girdler injury should be noted and the remedy applied before the pest gains headway and large areas of vines are destroyed. The presence of large numbers of the moths on a bog in June and July should serve as a warning that the vines are in a fair way of being severely damaged.

FALL FLOODING.

Fall flooding affords the most satisfactory control of the girdler, and will result in practical extermination of the pest until reinfestation comes from the upland or other bogs, if it is applied at the proper time. As shown in the study of the seasonal history, the larvæ make cocoons in the fall, and if the fall flowage is applied after the cocoon is formed, the larva within will not be injured, even though this flowage lasts two weeks or more. However, if the flowage is applied before cocoon making begins, the naked larvæ will be killed certainly in a week, and it is probable that five days is ample time for submergence, although some growers prefer to hold the flowage two weeks to insure a thorough treatment.

For New Jersey, cocoon making begins in a large way the first week in October, and it is therefore essential to reflow the bog during the latter part of September. If the bog is vined with a variety of early berries it will not be difficult to have them picked early so that flooding can be done at the proper time. With late berries, such as Howes, this treatment is not in vogue and some other remedy must be attempted. It is of course essential to have sufficient water in storage to accomplish the fall flooding, and a lack of storage water at this season of the year is the stumbling block which limits the practice of fall flooding to a very few of the New Jersey bogs.

If the fall flowage is applied later than the first week in October most of the worms will not be killed, as is shown in the following notes made on a bog at Mays Landing, N. J.: On October 15 the bog was examined and was found to have been severely damaged. A search for larvæ and cocoons was made, and 30 larvæ in cocoons and one naked larva were secured. The flowage was put on October 22 and held until November 8, a period of 17 days. On November 17 another examination was made, and 26 live larvæ and 1 dead larva in cocoons were collected. This treatment was therefore entirely unsatisfactory.

At Pemberton, N. J., a newly infested bog was flooded from September 19 to October 3, a period of 14 days, with the result that the following season no further dying of the vines occurred and no flight of moths was observed. This indicated very successful control.

Fall flooding immediately after picking the crop, whether this be early or late, is a treatment to be commended, even though girdlers are not present, since it helps in the control of the yellow-headed fireworm (*Peronea minuta* Rob.), the red-striped fireworm (*Gelechia trialbamaculella* Cham.), the toad bug (*Phylloscelis atra* Germ.), the blossom worm (*Epiglaea apiata* Grote), and other insects of minor importance.

SPRING FLOODING.

Wherever opportunity offered, examinations were made of bogs after the reflowage had been removed in the spring, to determine if flooding during the pupa stage for various lengths of time had killed the pupæ. In the season of 1915 a bog from which the winter flowage had been drawn on May 10 was reflowed June 9, and a certain area, known to be infested, was watched to ascertain the number of hours it was covered by the flowage. This period proved to be 24 hours, and soon afterward two cocoons, each of which contained a live pupa, were found upon the bog. Moths issued from these pupæ on June 15 and June 19. From another area on the same bog, which had been submerged about 30 hours, 11 cocoons were collected, and these yielded 10 pupæ. Moths issued from these pupæ as follows: June 14, three; June 15, two; June 16, one; June 17, three.

During the season of 1916 a bog was observed which had the following history: The winter flowage was drawn off on April 9. The first reflow lasted 5½ days on the girdler-infested area, or from May 12 to May 18. The second reflow was held 36 hours, dating from May 31, and the third reflow was removed at the end of 18 hours, on June 9. On June 12, three days later, girdler moths were found flying over the infested area, and since no other infestation existed near by, this was ample evidence that the three reflowings had not destroyed the immature stages.

On one occasion a live pupa was collected in its cocoon where the reflow had lasted 5½ days. The winter flowage had been drawn May 10, and the reflowing occurred from June 9 to June 15. Two weeks later girdler moths were very abundant on this area. These records indicate that spring reflows occurring during or near the pupa period and when held for periods lasting as long as 5½ days do not give control of the girdler.

SANDING.

There has been considerable hostility to the practice of sanding cranberry bogs by some of the New Jersey growers, due largely, it seems, to the fear of increasing the fungous troubles of this fruit. On the other hand, there are a few growers who, while not consistent "sanders," are greatly in favor of the practice although little, if any, experimental work has been performed in New Jersey to determine whether or not the losses due to fungous diseases have increased on sanded areas. It has long been customary in Massachusetts to sand the bogs, and such treatment has a well-recognized value in the control of certain cranberry insects, notably the cranberry tipworm (*Dasyneura vaccinii* Smith) and the cranberry girdler.

Sand should be spread on the bog in the fall, winter, or early spring, preferably in late fall so as to have it become well settled around the vines by the winter flowage. Occasionally, during cold weather, sand may be spread on the ice, resulting, when thawing ensues, in an even covering of the ground. For girdler infestations a layer of sand not less than 1 inch in thickness is required, and it will be found far better on most New Jersey bogs that have not been sanded previously to apply a coat nearer 2 inches in thickness. The sand is of value in several ways: First, if the coat is sufficiently thick it prevents the emergence of the moths; and, second, it covers the trash on the bog floor, producing clean conditions unfavorable for girdler infestation. In locations where girdler injury has already occurred it covers the injured vines, causing them to throw out new roots, and invigorating them to such an extent that recovery is rapid.

For those who undertake the sanding method of controlling girdlers it should be borne in mind that there is some risk, attendant upon this practice, of increasing the fungous troubles of the fruit, and one should be prepared to spray sanded bogs with a fungicide such as Bordeaux mixture.

Experimental work is not altogether conclusive as to the thickness of the coat of sand which will prevent emergence of the moths from cocoons. Franklin (11, p. 19) found that an even covering of sand 1 inch in thickness effectually prevented moth emergence in small cages, while the writer's data, obtained in a mosquito-bar cage placed on a cranberry bog, lead him to conclude that an even coat, 1 inch in thickness, will not be obtained by the grower in the actual practice of sanding and that considerable numbers of moths will emerge through the sand.

The sanding experiment performed at Whitesbog, N. J., was essentially as follows: Three plats were laid off where the vines showed severe injury and where, in fact, they had been killed over a considerable extent. Two of the plats were sanded fairly evenly on November 23, 1914, the depth varying from an inch to an inch and a half. The winter flowage was put on in December and removed May 8, 1915. The same day three cocoons were removed from beneath the sand in plat 2, and on May 10 two cocoons were dug out, all of which contained live larvæ. A tight mosquito-bar cage (Pl. II, B) was built over the three plats a few days later, and emergence of moths was first noted June 10, 1915.

TABLE VII.—*Emergence of moths of the cranberry girdler in sanding experiment at Whitesbog, N. J., 1915.*

Date.	Number of moths emerged.		
	Plat 1, area, 173 square feet, sanded.	Plat 2, area, 248 square feet, check.	Plat 3, area, 222 square feet, sanded.
June 10	4	12	0
June 11	7	41	0
June 12	10	34	1
June 15	41	64	12
June 16	18	3	3
June 18	21	8	9
June 25	4	1	5
July 2	0	0	1
July 8	1	0	0
Total	106	160	31

Owing to the distance of the cage from the field laboratory it was not practicable to remove and count the moths each day. The data show that the greatest number of moths emerged from the unsanded plat, which was also the largest plat, but that 1.55 moths emerged per square foot in the unsanded plat as compared with 1.61 moths in plat 1, sanded. Plat 3 was known to have a lighter infestation than the others when the experiment was started.

There were one or two places, particularly around a stump, on the sanded areas where the sand had washed a little thin during the period of winter flowage, but these spots were insignificant in size, and the data presented lead to the conclusion that a 1-inch coat of sand applied under natural bog conditions with a great deal more care than would be given by the average grower is not effectual in preventing the emergence of girdler moths from their cocoons.

RECOMMENDATIONS FOR CONTROL.

The most effective control measure that the writer has seen applied for this insect is the fall flooding immediately after picking the crop, when this operation can be completed in time to apply the water before the last of September. This treatment is effective, because it comes before the worms have spun their cocoons, and a reflow lasting not more than a week is undoubtedly of sufficient duration to kill all naked girdler larvæ.

If the berries can not be removed from the vines in time to permit fall flooding before the last of September, or if the water supply is insufficient, the next best method of control is to hold the winter flowage over the vines until July 20, thereby losing one crop of berries, but gaining a clean bog and the possibility of having a crop twice the normal in quantity the following year.

In the event that the foregoing remedies can not be employed, recourse may be had to sanding and better cultural methods. It is doubtful if a coat of sand less than $1\frac{1}{2}$ inches in thickness can be relied upon to prevent emergence of the girdler moths and, while this is an expensive operation, there are many New Jersey bogs, particularly those having peat or mud bottoms, which would be benefited greatly by a thorough sanding. A 1-inch coat of sand will be found of value for invigorating injured vines and in so far as it covers the trash on the bog floor will render conditions less favorable for further infestation by the girdlers. If the fruit produced on sanded lands is less sound than it was prior to sanding, this condition may be corrected to a large extent by spraying with Bordeaux mixture in the proper season.

Pruning, along with sanding, should be practiced, and these measures, together with the removal of obnoxious weeds and grasses, constitute better cultural methods, all of which aid very materially in making cranberry vines healthier and freer from damaging insects.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 564

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. ▼ October 4, 1917

COLLECTION OF WEEVILS AND INFESTED SQUARES AS A MEANS OF CONTROL OF THE COTTON BOLL WEEVIL IN THE MISSISSIPPI DELTA

By

B. R. COAD and T. F. McGEHEE, Entomological Assistants
Southern Field Crop Insect Investigations

CONTENTS

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CONTENTS.

GENERAL STATEMENT OF EXPERIMENTS CONDUCTED.

During the cotton-growing seasons of 1915 and 1916 the writers conducted a series of studies to ascertain the value of various methods of collecting boll weevils and infested cotton forms as a means of control for the cotton-boll weevil. The experimental work was conducted in the vicinity of Tallulah, La., while more or less extensive observations were made at various points throughout Louisiana and Mississippi. The following studies apply most directly to the conditions existing in what is termed the "Delta" of Louisiana and Mississippi, but are also undoubtedly applicable to other portions of the cotton belt where a severe weevil infestation prevails.

In July, 1916, the senior writer published a preliminary report on the results of the 1915 studies [1] in order to place the information secured in a form available for use by the planters.

NOTE.—This bulletin will be of interest to entomologists and to cotton growers in the Delta region of Louisiana.

[1] Coad, B. R. Cotton-boll Weevil Control in the Mississippi Delta, with Special Reference to Square Picking and Weevil Picking. U. S. Dept. Agr. Bul. 382, July 8, 1916.

96828°—Bull. 564—17——1

The investigations of 1916 were conducted under seasonal and climatic conditions differing considerably from those of 1915 and were more extensive, so that it seems that the combined results of the two seasons' investigations may be considered as more or less conclusive. The following report presents a rather brief summary of these experiments, together with the conclusions which seem warranted by the observations.

The various field experiments were conducted by the junior writer and Messrs. W. B. Williams and T. P. Cassidy, under the direction of the senior writer.

BRIEF REVIEW OF 1915 EXPERIMENTS.

Before proceeding with a consideration of the investigations of 1916 it is probably well to review briefly the results of the 1915 studies, since the program of work for the second year was based upon these results. In 1915, plat tests of the collection of fallen forms in the cotton field gave an increased yield of 23 per cent over the untreated cotton. Similar tests of weevil collection were started and the study of weevil infestation and other observations made during the season indicated that a similar degree of control was being secured. Unfortunately, the weevil-picking test plats of that year were ruined by hail in the latter part of June, so most of the conclusions on weevil picking were based on observations made prior to the hail storm and upon comparative efficiency studies of the various means of collecting adult weevils made later in the season.

The seasonal conditions of 1915 in the neighborhood where these experiments were conducted were very peculiar. Owing to the rather severe winter of 1914–15 the emergence from hibernation in the spring of 1915 was very light and late, resulting in only a slight initial infestation. Following this, the exceedingly dry weather of July produced a very high climatic control of the weevil stages in the fallen forms. This naturally resulted in a comparatively light degree of weevil injury regardless of whether or not control measures were practiced. In view of this very unusually light degree of injury it was considered probable that different seasonal conditions would produce different results from these control measures.

One interesting feature of the investigation of 1915 was the study of different methods of collection of the weevils and infested forms. Consideration of two factors—(1) the labor supply available and (2) the labor required for the hand picking of either the weevils or the infested forms—showed these measures of repression to be impracticable under the average Delta plantation conditions, hence an effort was made to find some way of reducing the labor requirements of the picking operation. The most promising method considered in this connection was the use of the bag-and-hoop as a weevil collector. This semimechanical method, which has been explained in detail in the earlier bulletin, proved to collect more weevils in less time than did hand picking, and as an additional advantage gathered a considerable number of infested squares and bolls during the course of the shaking operation. As it was so well adapted to the type of labor available and as it considerably reduced the amount of labor required, this method appeared to give the greatest promise of success. Consequently the investigations of 1916, which largely employed the bag-and-hoop method of collection, were aimed at securing information on the exact degree of control exerted by its use in the field under varying conditions.

LINES OF INVESTIGATION IN 1916.

The experiments of 1916 may be divided into three more or less distinct lines of investigation. These were: (1) Plat tests under field conditions to determine the degree of weevil control produced by the operation of the bag-and-hoop for different periods at various time intervals between pickings; (2) intensive studies on the relation of the time interval between the pickings to the proportion of the infested forms collected in the bag; and (3) studies on the efficiency of certain mechanical collectors.

TIME INTERVAL BETWEEN BAG-AND-HOOP COLLECTIONS IN RELATION TO PROPORTION OF INFESTED FORMS SECURED.

As has been stated, one of the favorable features attending the use of the bag-and-hoop as a means of collecting weevils was the collection of the infested squares and bolls while shaking the plants for the weevils. Thus this operation to some extent combined the results secured from two operations—(1) hand picking of weevils and (2) hand picking of infested forms. However, in attempting to outline some scheme for the practical use of the bag-and-hoop in the field it was necessary to know just what proportion of the forms falling to the ground because of weevil injury would be collected at different time intervals between pickings. In other words, it seemed desirable to find just what time interval would be necessary to secure the largest proportion of the infested squares and still be feasible for use. Indirect information on this score was of course secured from the general field tests of the use of this method of control; but, in addition to these, an intensive study was conducted by Mr. Williams on Eureka plantation, near Tallulah, La. The idea of this study was not so much to secure information on the actual degree of weevil control exerted by this operation in the plats under observation, but to secure information on the forms collected in the bags and the forms reaching the ground in the different plats. As one of the larger field tests of the bag-and-hoop method was also located on this same plantation, this intensive study was termed "Eureka Experiment No. 2."

DESCRIPTION OF PLATS.

For conducting this study a small block of cotton was selected in the center of the cut. This cotton was a part of the general planting of the cut and was farmed exactly the same as the surrounding cotton throughout the season. The experimental area considered was 32 rows in width and 150 feet long. This was divided into eight plats of four rows each. The two outside plats were left untreated as checks, while plat 1 was shaken with the bag-and-hoop six times a week; plat 2, five times; plat 3, four times; plat 4, three times; plat 5, twice; and plat 6 once a week during the experimental period. These pickings were distributed through the week as well as possible. In addition to picking these plats a strip 30 feet in length beyond the end of each plat was gone over each time that the adjoining plat was picked. This was done simply to provide a buffer system which would protect the plats from an immigration of weevils from unpicked cotton.

The cotton variety used in these plats was the Simpkin's Ideal, and a good stand prevailed at the beginning of the experiment.

METHOD OF OPERATION.

The method of collection used in these plats was the ordinary system of bag-and-hoop shaking, the plants being shaken into a sack held open by a hoop sewn in the mouth.

Negro laborers were used for the work, but they were under the constant supervision of an entomologist, and care was taken to make the work very thorough. Unnecessary injury to the plants was avoided as much as possible. At the beginning of the season bags about 20 inches in diameter were used for the small plants, but these were later replaced by considerably larger ones which allowed a reasonably thorough treatment as long as the pickings were continued.

The pickings were started on June 12. The plats had been watched carefully for some weeks before that time in order to start the picking as soon as the weevils became sufficiently abundant to make the records of any value. The initial spring infestation in this particular cut of cotton was rather light, and it was not until about this date that any weevils could be located in the plats. Following this first picking the schedule mentioned was continued for nine weeks, thus making the total pickings of the different plats range from 9 in plat 6 to 54 in plat 1.

WEEVILS COLLECTED.

Throughout the experimental period a record was kept of the number of weevils gathered from each row of each plat at each picking. These records are only of incidental interest, as the extreme smallness of the plats, of course, allowed more or less of an interplat movement of weevils every day, and the records secured bear no relation to the conditions which would exist if larger tracts were picked at the different time intervals. However, the row and plat totals and plat averages for the season are of some interest and are given in Table 1.

TABLE 1.—*Total number of weevils collected, by rows and plats, Eureka plantation, Talluluh, La., 1916.*

Plat No.	Total number of pickings.	Row No. 1.	Row No. 2.	Row No. 3.	Row No. 4.	Plat total.	Average per picking for plat.
1	54	275	257	130	210	872	16.1
2	45	229	203	184	176	792	17.5
3	36	169	167	243	176	755	20.9
4	27	127	174	100	136	537	19.8
5	18	92	114	108	110	424	23.5
6	9	81	60	84	62	287	31.8

From this table it is seen that, generally speaking, the weevils per picking increased about in proportion to the increase in the time interval between pickings. However, the average number of weevils per picking in plat 6 was only twice that of plat 1, whereas plat 1 was picked six times as often as plat 6. The fact that there was an increase in the number of weevils secured per picking with the decrease in the number of pickings shows that the weevil movement within even these small plats was at least not sufficient to equalize the distribution completely throughout the plats between the pickings. This point is of principal interest in connection with the consideration of the important question of the extent and effect of the interplat movement of weevils in the larger field tests, which will be discussed later in the present report.

FORMS COLLECTED IN BAGS.

In the same way that the weevil collections were recorded the forms gathered in the sacks from each row at each picking were noted. These forms were examined each time and divided into squares and bolls; then these were redivided into those uninjured (termed "clean"), those weevil punctured, and those showing other injury, such as rot, worm injury, etc. The plat totals secured during the different pickings are shown in Table 2, and are rearranged in Table 3 to show the averages per picking for each plat.

TABLE 2.—*Total number of forms collected in bags and percentage injured, Eureka plantation, Tallulah, La., 1916.*

Plat No.	Bolls.							Squares.							Total bolls and squares collected.
	Clean.		Weevil punctured.		Other injury.		Total number collected.	Clean.		Weevil punctured.		Other injury.		Total collected.	
	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.		Total.	Per cent.	Total.	Per cent.	Total.	Per cent.		
1	1,224	44.5	770	28.0	755	27.5	2,749	1,435	33.7	2,740	64.2	91	2.1	4,266	7,015
2	800	42.9	577	31.0	486	26.1	1,863	1,362	30.2	3,073	68.0	82	1.8	4,517	6,380
3	610	37.9	481	29.8	520	32.3	1,611	1,424	32.0	2,969	66.6	64	1.4	4,457	6,068
4	633	44.4	422	29.7	368	25.9	1,423	726	25.8	2,027	72.0	63	2.2	2,816	4,239
5	171	28.1	246	40.2	195	31.7	612	686	26.4	1,813	71.4	55	2.2	2,554	3,166
6	121	35.7	118	34.8	100	29.5	339	562	30.7	1,240	67.6	32	1.7	1,834	2,173
Total	3,559	.....	2,614	.....	2,424	.....	8,597	6,195	.....	13,862	.....	387	.....	20,444	29,041
Weighted average	.....	41.4	.....	30.4	.....	28.2	.....	.....	30.3	.....	67.8	.....	1.9	.....	.....

From Table 2 it is seen that the total forms collected ranged from 2,173 for plat 6 to 7,015 for plat 1. In other words, three times as many forms were gathered in the bags in plat 1 as in plat 6. These figures show the number of forms collected per plat to increase quite rapidly with the increase in the number of pickings. In fact, the average bolls per picking increased somewhat with the increase in the number of pickings per plat. The figures on the percentage infested and clean show this increase to be largely due to the fact that more clean bolls were shaken off as the number of pickings per week was increased. This was quite probably due to the weight of the bolls breaking the stems during the frequently repeated shakings.

The square collections show different results from the boll records just noted. With the squares the increase per collection as the shakings decreased in frequency is marked, ranging from 79 for plat 1 to 204 for plat 6. This difference in results between bolls and squares is probably due to the fact that the clean squares are not broken off in such large numbers by the excessive shakings as are the bolls. In fact, the percentage of clean squares collected in the different plats ranged only from 25.8 per cent to 33.7 per cent, while the clean bolls ranged from 28.1 per cent to 44.5 per cent. Incidentally, these results seem to indicate a rather undesirable amount of loss of clean forms due to the shaking process.

The high percentage of bolls recorded as "other injury" was due to the fact that practically daily rains prevailed in the experimental area during the month of July, and consequently there was a great shedding of young, infertile or rotting bolls. This rain may have increased the natural shedding of clean forms also, and thus raised this percentage above normal. In the total of all the pickings in all plats, one-third (weighted average 33.9 per cent) of the forms collected in the bags were clean. Of course, some of these forms may have belonged to the class which shed normally for physiological causes, but this proportion seems to be very undesirably high.

The fact that the squares collected in plat 1 numbered only two and one-half times as many as in plat 6, in spite of the fact that the former was picked six times as often as the latter, is of interest. This shows that a picking at a weekly interval secures more than that day's pro rata of the squares due to fall.

FALLEN FORMS COLLECTED.

As a check on the relative number of forms collected in the bags, the number of forms falling to the ground in each row was also determined. To accomplish this all forms were picked from the ground once a week, beginning June 29. These were examined and sorted into bolls and squares, clean and injured. This sorting was continued until July 31, when it was found that so nearly all fallen forms were injured that they were divided only into bolls and squares. Unfortunately, the forms were not collected from the ground in the checks for the first four weeks. On July 25, however, all forms were cleared from the ground in the checks, and these two plats were included in the last three pickings. This makes it necessary to consider only these three pickings when comparing the picked plats with the checks.

TABLE 3.—*Forms collected in bags averaged by pickings, Eureka plantation, Tallulah, La., 1916.*

Plat No.	Times picked.	Bolls collected.		Squares collected.		Total forms collected.	
		Total.	Average per picking.	Total.	Average per picking.	Total.	Average per picking.
1	54	2,749	51	4,266	79	7,015	130
2	45	1,863	41	4,517	100	6,380	141
3	36	1,611	45	4,457	123	6,068	168
4	27	1,423	52	2,816	104	4,239	156
5	18	612	34	2,554	142	3,166	176
6	9	339	37	1,834	204	2,173	241

TABLE 4.—*Fallen forms collected. Plat totals at each collection, Eureka plantation Tallulah, La., 1916.*

Date picked.	Plat 1.						Plat 2.					
	Bolls.			Squares.			Bolls.			Squares.		
	Number.	Clean.	Injured.	Number.	Clean.	Injured.	Number.	Clean.	Injured.	Number.	Clean.	Injured.
June 29	......	......	......	34	13	21	......	......	......	42	18	24
July 3	13	......	......	40	14	26	9	......	......	16	8	8
July 10	394	108	286	248	58	190	482	152	330	375	181	194
July 17	497	17	480	227	40	187	205	16	189	200	74	126
July 25	900	219	681	465	64	401	889	364	525	431	86	345
July 31	701	......	701	692	......	692	836	......	836	1,504	......	1,504
Aug. 7	834	......	834	1,085	......	1,085	942	......	942	1,566	......	1,566
Aug. 14	204	......	204	442	......	442	431	......	431	750	......	750
Total	3,543	344	3,186	3,233	189	3,044	3,794	532	3,253	4,884	367	4,517

Date picked.	Plat 3.						Plat 4.					
	Bolls.			Squares.			Bolls.			Squares.		
	Number.	Clean.	Injured.	Number.	Clean.	Injured.	Number.	Clean.	Injured.	Number.	Clean.	Injured.
June 29	......	......	......	23	8	15	......	......	......	48	12	36
July 3	9	......	......	19	10	9	14	......	......	26	11	15
July 10	379	81	298	241	91	150	365	90	275	183	84	99
July 17	170	17	153	196	63	133	338	43	295	299	31	268
July 25	1,112	194	918	468	44	424	1,974	93	1,875	851	54	797
July 31	1,203	......	1,203	957	......	957	1,360	......	1,360	1,403	......	1,403
Aug. 7	816	......	816	1,007	......	1,007	885	......	885	1,044	......	1,044
Aug. 14	645	......	645	1,224	......	1,224	647	......	647	843	......	843
Total	4,334	292	4,033	4,135	216	3,919	5,583	232	5,337	4,697	192	4,505

Date picked.	Plat 5.						Plat 6.						Average of both checks.	
	Bolls.			Squares.			Bolls.			Squares.				
	Number.	Clean.	Injured.	Number.	Clean.	Injured.	Number.	Clean.	Injured.	Number.	Clean.	Injured.	Bolls, total.	Squares, total.
June 29	......	......	......	21	5	16	......	......	......	65	16	49	......	......
July 3	4	......	......	20	3	17	32	......	......	64	20	44	......	......
July 10	330	70	260	341	121	220	821	514	307	739	438	301	......	......
July 17	219	10	209	287	24	263	543	86	457	655	61	594	......	......
July 25	1,570	66	1,504	1,087	121	966	1,997	109	1,888	1,253	87	1,166	......	......
July 31	986	......	986	1,561	......	1,561	2,090	......	2,090	3,536	......	3,536	1,861	3,081
Aug. 7	769	......	769	1,732	......	1,732	1,177	......	1,177	2,645	......	2,645	1,233	2,248
Aug. 14	492	......	492	1,383	......	1,383	913	......	913	2,874	......	2,874	1,032	2,218
Total	4,370	146	4,220	6,432	274	6,158	7,563	709	6,832	11,831	622	11,209	4,126	7,547

TABLE 5.—*Summary of fallen forms collected from picked plats, showing percentage injured and clean, Eureka plantation, Tallulah, La., 1916.*

Plat No.	Bolls.					Squares.					Squares and bolls.				
	Number bolls.	Clean.		Injured.		Number squares.	Clean.		Injured.		Total.	Clean.		Injured.	
		Number.	Per cent.	Number.	Per cent.		Number.	Per cent.	Number.	Per cent.		Number.	Per cent.	Number.	Per cent.
1	3,543	357	10.0	3,186	89.9	3,233	189	5.9	3,044	94.1	6,776	546	7.6	6,230	92.4
2	3,794	541	14.3	3,253	85.7	4,884	367	7.5	4,517	92.5	8,678	908	10.5	7,770	89.5
3	4,334	301	7.0	4,033	93.0	4,135	216	5.2	3,919	94.8	8,469	517	6.1	7,952	93.9
4	5,583	246	4.1	5,337	95.9	4,697	192	4.1	4,505	95.9	10,280	438	4.3	9,842	95.7
5	4,370	150	3.4	4,220	96.6	6,432	274	4.3	6,158	95.7	10,802	424	4.0	10,378	96.0
6	7,563	731	9.7	6,832	90.3	11,831	622	5.3	11,209	94.7	19,397	1,353	7.0	18,041	93.0
Total	29,187	2,326	....	26,861	....	35,212	1,860	....	33,352	....	64,399	4,186	....	60,213	....
Weighted average	......	.....	7.9	......	92.1	......	.....	5.2	......	94.8	......	.....	6.5	......	93.5

TABLE 6.—*Fallen forms collected at last three collections, Eureka plantation, Tallulah, La., 1916.*

Date.	Plat 1.			Plat 2.			Plat 3.		
	Bolls.	Squares.	Total.	Bolls.	Squares.	Total.	Bolls.	Squares.	Total.
July 31	701	692	1,393	836	1,504	2,340	1,203	957	2,160
Aug. 7	834	1,085	1,919	942	1,566	2,508	816	1,007	1,823
Aug. 14	204	442	646	431	750	1,181	645	1,224	1,869
Total	1,739	2,219	3,958	2,209	3,820	6,029	2,664	3,188	5,852

Date.	Plat 4.			Plat 5.			Plat 6.			Average check.		
	Bolls.	Squares.	Total.	Bolls.	Squares.	Total.	Bolls.	Squares.	Total.	Bolls.	Squares.	Total.
July 31	1,360	1,403	2,763	986	1,561	2,547	2,090	3,536	5,626	1,861	3,081	4,942
Aug. 7	885	1,044	1,929	769	1,732	2,501	1,177	2,645	3,822	1,233	2,248	3,481
Aug. 14	647	843	1,490	492	1,383	1,875	913	2,874	3,787	1,032	2,218	3,250
Total	2,892	3,290	6,182	2,247	4,676	6,923	4,180	9,055	13,235	4,126	7,547	11,673

Table 4 shows the plat totals of fallen forms at each of the pickings, while Table 5 shows the total collections from each of the picked plats throughout the season and indicates the percentages of clean and injured forms in each lot. In order to facilitate comparison with the checks, the last three collections of fallen forms have been isolated and summarized in Table 6, together with the check records.

From these tables it is seen that the total fallen forms collected in the picked plats throughout the season ranged from 6,776 for plat 1 to 19,397 for plat 6. Thus it is seen that about three times as many forms reached the ground in the plat picked once a week as in the plat picked six times a week.

Turning to Table 6, which includes only the last three pickings, and thus affords a comparison with the checks, it is interesting to note that the checks yielded not quite three times as many fallen forms as plat 1. In other words, bag-and-hoop pickings six times a week secured only two-thirds of the squares due to fall and allowed one-third to reach the ground. It will be noted that plat 6 yielded more fallen forms than the checks. However, this is due to the fact that the check record is an average of both checks and there was a slight grading in the soil from east to west which caused the growth and fruiting of check 1 to be more determinate than that of check 2. This resulted in a much smaller number of squares forming in check 1 this late in the season and as a result this plat lowered the check average. For this reason it is more accurate to compare plat 6 with check 2 in these last three pickings, as these two plats adjoin. Comparing in this manner it is seen that plat 6 yielded a total of 13,235 fallen forms at the last three pickings while check 2 yielded 14,342. This is a total reduction of only 1,107 fallen forms due to the once a week shaking, or an average reduction of 369 per week. In this connection it is interesting to note that the forms collected in the bags from plat 6 during those same three weeks averaged 481 per week. Totaling these figures it is seen that 14,677 forms were collected in the bags and from the ground in plat 6 during these three weeks. This is 335 more than those found on the ground in check 2. This difference in totals is practically accounted for by the fact that 290 clean forms were gathered in the bags on plat 6 during these three pickings.

In connection with these studies it is of interest to compare the total forms gathered both in the bags and from the ground in each of these plats. Table 7 shows these data for the picked plats, while Table 8 shows only the final three weeks in order to afford a comparison with the checks.

TABLE 7.—*Total forms collected in picked plats throughout season, Eureka plantation, Tallulah, La., 1916.*

Mode of collection.	Forms collected.					
	Plat 1.	Plat 2.	Plat 3.	Plat 4.	Plat 5.	Plat 6.
In bags	7,015	6,380	6,068	4,239	3,166	2,173
From ground	6,776	8,678	8,469	10,280	10,802	19,397
Total	13,791	15,058	14,537	14,519	13,968	21,570

TABLE 8.—*Total forms collected from picked plats and checks during final 3 weeks, Eureka plantation, Tallulah, La., 1916.*

Mode of collection.	Forms collected.						
	Plat 1.	Plat 2.	Plat 3.	Plat 4.	Plat 5.	Plat 6.	Average, both checks.
In bags	3,935	4,369	4,027	2,847	2,146	1,442	....
On ground	3,958	6,029	5,852	6,182	6,923	13,235	11,673
Total	7,893	10,398	9,879	9,029	9,069	14,677	11,673

In Table 7 it is seen that the total for the picked plats ranged from 13,791 for plat 1 to 21,570 for plat 6. However, if plat 6 is excluded, the totals are more or less approximate.

In Table 8 it is seen that for the last three weeks the totals ranged from 7,893 for plat 1 to 14,677 for plat 6. All plats totaled less than the average check except plat 6, which was 3,004 above check. Here again the soil gradation probably distorts the results somewhat, and in considering all late season results it should be remembered that the soil graded lighter from east to west and the fruiting became more determinate, so that the figures for the various plats can not be accepted absolutely at their face value. Another factor operating at this time was the effect of the shakings on plant development. This will be dealt with in detail later in the present report.

WEEVIL INVESTATION.

Although the plats were so small that they could not represent, or even approximate, an actual test of weevil control under field conditions, the progress of the infestation was still followed very carefully throughout the season. This record was determined for each plat by examining 100 squares at each end and the middle of the two inside rows of the plat. This made a total of 300 squares for each plat and the percentage of these which had been weevil injured was noted. These records were made about once a week during the season. The detailed results secured are shown in Table 9.

TABLE 9.—*Weevil infestation, Eureka plantation, Tallulah, La., 1916.*

Date.	Plat 1.	Plat 2.	Plat 3.	Plat 4.	Plat 5.	Plat 6.	Check 1.	Check 2.
June 16	8.0	15.0	6.3	4.6	0.6	2.6	9.6	4.3
June 20	3.3	5.6	4.6	6.6	4.0	5.3	3.3	5.0
June 27	6.6	4.6	6.6	5.3	5.3	7.0	14.0	10.6
July 4	12.7	11.7	11.3	5.3	6.7	11.3	16.0	13.3
July 11	7.6	6.6	4.6	12.6	19.0	25.0	28.6	24.6
July 19	21.0	22.0	20.3	23.0	50.3	47.3	57.0	42.6
July 26	71.3	64.7	64.7	68.7	71.3	76.7	92.0	84.3
Aug. 2	90.0	83.0	91.0	94.0	93.3	90.3	95.7	94.0
Aug. 9	85.3	85.7	86.7	89.7	91.3	88.3	97.3	94.3
Aug. 15	93.3	94.3	94.7	97.7	97.0	97.0	97.7	97.0
Average of each plat	39.9	39.5	38.9	40.7	43.9	45.1	51.1	47.0

From Table 9 it is seen that a uniformly low infestation prevailed in these plats during the entire month of June, and it was not until the record of July 11 that any significant difference in the infestation of the various plats appeared. Even then the difference was rather irregular, though it showed that plats 5 and 6 and the two checks were becoming more rapidly infested than the remainder. This same condition prevailed at the examination made July 19, but by July 26 the difference had been more or less neutralized, and from that time onward the only consistent difference was the slightly higher record of the checks above the picked plats. Taking the seasonal average of the various plats, it is seen that plats 1 and 4 were practically equal, while plats 5 and 6 showed a slight increase of about 3 per cent and 5 per cent, respectively, while the two checks were slightly higher still. These figures would seem to indicate that, even in the exceedingly small plats under consideration, the pickings of three times a week or more tended to reduce the degree of weevil infestation.

EFFECT OF SHAKINGS ON PLANT DEVELOPMENT.

Rather early in the season it was observed that the shakings were apparently having a decidedly pronounced effect upon the growth of the plants in the various plats. It was noted that the plants in the most frequently shaken plats were apparently standing still as far as growth in height was concerned and that the more frequent the shaking the more pronounced this effect.

One method of measuring this effect was a series of studies on the average height of the plants, which was determined by measuring 20 plants in each row and taking the average. The first measurement was made on June 13, when it was found that the plants were more or less uniform in height, the range being only from 14.7 inches to 20.2 inches. At this time it was noted that the 15th to 18th rows (plats 4 and 5) were lower than the remainder. This was due to a slight dip in the land extending over these four rows, which had a tendency to retain standing water and thus somewhat retarded plant growth. This tended to reduce the average of these two plats, as will be noted in Table 10, which gives average heights of the plats and rows. Other than this slight difference the growth was very uniform over the series of plats.

FIG. 1.—TYPICAL PLANT IN PLAT 1, WITH LEAVES REMOVED, EUREKA PLANTATION, TALLULAH, LA., JULY 25, 1915. (ORIGINAL.)

FIG. 2.—TYPICAL PLANT IN CHECK 2, WITH LEAVES REMOVED, EUREKA PLANTATION, TALLULAH, LA., JULY 25, 1915. (ORIGINAL.)

COMPARISON OF SHAKEN AND UNSHAKEN COTTON PLANTS IN BOLL WEEVIL CONTROL.

FIG. 1.—LOOKING ACROSS END OF BUFFER OF PLAT 1, UNSHAKEN PLANTS ON LEFT, EUREKA PLANTATION, TALLULAH, LA., JULY 25, 1916. (ORIGINAL.)

FIG. 2.—DIVIDING LINE BETWEEN PLATS 1 AND 2, THE SHAKEN COTTON ON THE RIGHT, EUREKA PLANTATION, TALLULAH, LA., AUGUST 4, 1916. (ORIGINAL.)

COMPARISON OF SHAKEN AND UNSHAKEN COTTON PLANTS IN BOLL WEEVIL CONTROL.

TABLE 10.—*Average height of plants in each row and plat on June 13, Eureka plantation, Tallulah, La., 1916.*

Plat number.	Row No. 1.	Row No. 2.	Row No. 3.	Row No. 4.	Plat average.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	18.3	14.7	16.1	15.7	16.2
2	15.0	17.1	18.6	16.2	16.7
3	15.7	16.5	16.6	19.5	17.0
4	17.2	15.1	12.8	13.8	14.7
5	12.7	14.2	15.6	19.5	15.5
6	19.0	16.2	17.2	15.6	17.0
Check 1	19.8	21.4	20.2	19.5	20.2
Check 2	18.1	19.2	20.0	19.7	19.2

On July 15, just about one month later, similar measurements were made in these same plats and it will be seen from Table 11 that very different results were secured.

TABLE 11.—*Average height of plants in each plat, Eureka plantation, Tallulah, La., 1916.*

Date measured.	Plat 1.	Plat 2.	Plat 4.	Plat 4.	Plat 5.	Plat 6.	Check 1.	Check 2.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
June 13	16.2	16.7	17.0	14.7	15.5	17.0	20.2	19.2
July 15	19.8	23.1	25.4	25.5	29.2	34.7	37.4	44.3

Plat 1 was far the lowest in height, and there was a regular increase in height with the lessening in the number of shakings, the two checks being highest of all. Of course, at this time the factor of the determinate growth due to soil had become somewhat effective, and it will be noted that check 2 averaged 7 inches taller than check 1. This would tend to make the plants grade gradually in height from plat 1 to plat 6 regardless of their treatment, but the grading was far more extreme than this soil difference could explain. In fact, it will be noted that plat 6 averaged 10 inches less than check 2, which adjoined it. In the same way, plat 1 averaged 18 inches less than its adjoining check 1.

A number of photographs were taken to illustrate these differences in height of plants on July 15. Plate I, figure 1, shows a typical plant in plat 1 with the leaves removed, while figure 2 of the same plate shows a typical plant in check plat 2, thus affording a comparison of unshaken plants with those shaken six times a week. To illustrate this difference further, photographs were made showing the dividing lines between shaken and unshaken cotton. These are given in Plate II. These figures show very well the tremendous effect of the shaking operation on the height and form of the plants.

In addition to reducing the height, it was found that the shakings had considerable influence on the branching and general make-up of the plant. The most frequently shaken plants presented a bushy, compact form with exceedingly short internodes and badly deformed stalks and branches. In addition, these frequently shaken plants were much darker in color than the others, plat 1 appearing almost blackish, in fact. This color graded off as the shakings decreased until it reached the checks, which were at that time a light-yellowish green.

At the time this plant injury was noted, examinations were made in all other tests with the use of the bag-and-hoop being conducted by the writers. These were large field plats, each some acres in extent, but it was found that wherever the bags had been used the plants presented this same deformed, dwarfed appearance, and the more frequent the use of the bags the more pronounced the injury.

The exact causes of this injurious effect of the shaking operations on the cotton plant are not positively known, but it seems probable that they are produced by several different factors. In the first place, it was noted that a very large number of terminal buds were found in the bags at all shakings, and it is probable that this loss of terminal buds was very effective in producing the bushy growth noted. The loss of the terminal bud, of course, forced the formation of adventitious buds and aided in developing the very irregular branching. In addition to this, considerable injury to the stalk itself was observed, due to the bending during the shaking operation. In shaking the plants with the bag-and-hoop, it is customary to bend the stalk near the ground at a rather sharp angle in order to insert the plant into the bag before shaking it. This apparently resulted in some crushing of the tissues at the point of bending. In extreme cases noted in the most frequently shaken plats the stalk was badly scarified at the point of bending, and in some cases was actually split for a distance of several inches.

Still another effect was probably the disturbance of the root system. Whenever the plants are shaken the movement pushes the soil away from the stalk for a distance of from 1 to 2 or 3 inches below the surface of the ground. This forms a small hole all around the stalk, and it is probable that during the formation of this hole the important lateral roots, which branch out near the surface of the ground, are either very seriously injured or actually broken off. In fact, a number of plants examined showed a decidedly distorted development at the surface of the ground.

SQUARE COUNTS.

Another effect of the shaking operation on the plants is shown by the square counts which were made twice during the season. For securing these records 50 plants were examined in each plat and the total and average number of squares per plant determined. The first count was made June 13, while the second was made on August 11. The results secured are shown in Table 12.

TABLE 12.—*Square counts, Eureka plantation, Tallulah, La., 1916.*

Plat No.	June 13.			Aug. 11.		
	Number of plants examined.	Number of squares found.	Number of squares per plant.	Number of plants examined.	Number of squares found.	Number of squares per plant.
1	50	689	13.8	50	167	3.3
2	50	615	12.3	50	672	13.4
3	50	679	13.6	50	709	14.2
4	50	518	10.4	50	504	10.1
5	50	568	11.4	50	827	16.5
6	50	705	14.1	50	894	17.9
Check 1	50	896	17.9	50	367	7.3
Check 2	50	688	13.7	50	1,107	22.1

In the count of June 13 it was found that the plats were more or less uniform, ranging from 10.4 to 17.9 squares per plant. At this time check 1 averaged 17.9 squares per plant while check 2 averaged 13.7. Very different results were secured on August 11, when the determinate growth factor had become operative and check 1, which averaged above check 2 at the June 13 examination, averaged only 7.3 squares per plant, while check 2 averaged 22.1. In other words, the plants in check 1 had practically matured as far as their square formation was concerned, and were devoting themselves to ripening their crop of fruit. However, although check 1 averaged only 7.3 squares, plat 1 fell far lower still, averaging 3.3 squares per plant. Going to the other side of the experimental area, it is found that plat 6 averaged 17.9 squares per plant in comparison with 22.1 squares per plant in check 2. This shows the difference due to the once-a-week shakings. Owing to the soil variation it is difficult to compare the middle plats with either of the checks, but considering these outside records, which are strictly comparable, it seems obvious that the shaking operation greatly reduced the number of squares per plant, and on the whole the figures seem to warrant the conclusion that this reduction of square formation was more or less directly proportionate to the number of shakings which the plants received.

SPACING OF PLANTS.

In order to determine if the shaking operation had had any definite effect on the stand remaining, the total number of plants in each plat was counted on July 14. The figures secured are given in Table 13.

TABLE 13.—*Average spacing on July 14—600 feet of rows in each plat, Eureka plantation, Tallulah, La., 1916.*

Plat Number.	Number of plants in plat.	Average spacing.
		Inches.
1	349	20.6
2	336	21.4
3	342	21.0
4	363	19.8
5	332	21.6
6	423	17.0
Check 1	398	18.0
Check 2	427	16.8

From Table 13 it is seen that the checks averaged the closest spaced of all, while the average spacing increased somewhat as the number of shakings increased. This, of course, is undoubtedly due to the plants actually killed by the shaking operations and further illustrates the injurious effect of the bags.

SEED-COTTON PRODUCTION.

Owing to the small size of the plats and the soil variations existing, it was not to be expected that there would be much significance in the seed-cotton production of each, but the figures were secured for whatever value they might possess. Table 14 shows the comparison of the different pickings by plats while the row results are shown in Table 15.

TABLE 14.—*Seed-cotton production; comparison of different pickings by plats, Eureka plantation, Tallulah, La., 1916.*

Plat Number.	Seed-cotton production.		
	First picking, Aug. 17.	Second picking, Sept. 8.	Third picking. Nov. 21.
	Ounces.	*Ounces.*	*Ounces.*
Check 1	478	437	42
Plat 1	189	247	54
Plat 2	96	439	145
Plat 3	285	650	194
Plat 4	126	511	108
Plat 5	166	586	216
Plat 6	132	834	217
Check 2	74	697	391

TABLE 15.—*Seed-cotton production by rows and plats, Eureka plantation, Tallulah, La., 1916.*

Plat No.	Row No.	Seed-cotton production. First picking, Aug. 17.	Second picking, Sept. 8.	Third picking, Nov. 21.	Total by rows.	Total by plats.
		Ounces.	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*
1	1	68	78	13	159	490
	2	55	75	13	143	
	3	33	36	16	85	
	4	33	58	12	103	
2	5	20	112	30	162	680
	6	15	111	36	162	
	7	25	99	44	168	
	8	36	117	35	188	
3	9	71	160	50	281	1,129
	10	104	144	50	298	
	11	23	188	56	267	
	12	87	158	38	283	
4	13	16	195	33	244	745
	14	37	158	26	221	
	15	29	68	13	110	
	16	44	90	36	170	
5	17	42	77	28	147	968
	18	42	115	32	189	
	19	44	179	63	286	
	20	38	215	93	346	
6	21	32	222	67	321	1,183
	22	28	182	51	261	
	23	34	204	49	287	
	24	38	226	50	314	
Check No. 1	1	130	94	7	231	966
	2	106	133	14	253	
	3	129	101	7	237	
	4	122	109	14	245	
Check No. 2	1	20	206	65	291	1,162
	2	18	151	95	264	
	3	19	164	112	295	
	4	17	176	119	312	

A number of rather interesting points are brought out by these figures. It is seen that the picked plats generally increased in production from west to east—that is, with the decrease in pickings. Of course the increase in soil fertility is in the same direction, but it is far from sufficient to account for the differences between the plats. One break in this gradation is the comparatively low records of plats 4 and 5. This was due to the poor cotton in rows 15, 16, 17, and 18, which has already been mentioned. From Table 15 it is seen that these four rows yielded about the same as the other four rows of these two plats at the first picking, but at the second and third pickings there was a great loss in these four rows of poor cotton.

Another interesting feature of the production records is the late maturity of check 2. In this plat the vegetative growth was not restrained as in the shaken plats, and as a result the exceedingly wet weather of July produced a very rank plant which shaded the bolls so completely that they did not open. From Table 14 it is seen that this plat yielded far the lowest of all at the first picking, and it was not until the leaves were killed by the frost that a good portion of the crop in this plat finally opened. In fact, a considerable proportion of the bolls in check 2 never opened, as they rotted while covered with the dense foliar growth. Thus it is seen that the detrimental effect of the shaking on the fruiting of plat 6 was offset by the reduced vegetative growth (due to this same shaking), allowing a greater proportion of the bolls to open safely, and thus actually yielding more cotton than check 2, although check 2 set more bolls than plat 6. However, in a normal season this rank growth and the accompanying boll rot would not be encountered, and consequently somewhat different results would undoubtedly be secured.

In order to avoid repetition the summary of this series of studies is included in the general discussion at the end of the present report.

PLAT TESTS OF THE VALUE OF THE BAG-AND-HOOP AS A MEANS OF WEEVIL CONTROL UNDER FIELD CONDITIONS.

During the season of 1916 two series of tests were conducted to determine the value of the bag-and-hoop as a means of weevil control on the plantation. One of these tests was conducted on Hecla plantation at Mound, La., and consisted of a study of five pickings at weekly intervals on Express cotton. The principal idea of this test was to secure data on this variety of cotton, as all of the earlier work had been with the Simpkins variety and no records had been secured on the result of using the bag-and-hoop on a long-staple cotton. It was expected that there would be some difference in results between the long and short staple cottons, especially in the number of forms collected during the pickings. The long-staple cottons generally tend to retain the infested forms longer than do the short varieties, and, consequently, it seemed probable that a different proportion of the infested forms would be gathered while shaking the staple cotton.

The second test was conducted on Eureka plantation and consisted of a study of varying numbers of pickings at different time intervals on Simpkins cotton. This test is referred to as Eureka test No. 1 in order to distinguish it from the studies just described.

EXPERIMENT ON HECLA PLANTATION.

For conducting this test on Hecla plantation a small cut of cotton some 4 acres in extent was selected. This cut was comparatively new land, which had been in corn for several years and immediately adjoined heavy timber. The cotton immediately adjoining the woods consisted of a number of irregular short rows, and these were omitted from the plat, the first row of the plat proper being the third row, which extended completely through the cut. However, in order to protect the picked plat from an influx of weevils, these short rows of cotton between this plat and the timber were picked over every time the plat was picked, and in the same manner the ends of the rows extending beyond the plat lines of the picked plat were shaken each time for further protection. A buffer system was also instituted between the two plats to reduce as far as possible the influence that either plat might have on the other. This system consisted of dropping four rows from each plat immediately adjoining the dividing line when considering the plat production. As treated throughout the season the plats consisted of 22 rows each, or an area of 1.44 acres. With the four-row buffer dropped from each plat, however, the plats proper each consisted of 18 rows with an area of 1.18 acres.

The soil was of a rather heavy "buckshot" type. The drainage was fair over most of the plats, but a low area which extended across the center of both plats was rather poorly drained. The outer two rows of the check plat immediately adjoining the roadside ditch were also lower than the remainder of the plat, especially at the eastern end. In an ordinary season this difference in drainage would have made little difference in the plats, but the summer of 1916 was so exceedingly wet that the slightest difference in drainage was greatly accentuated. As a result a narrow strip across the middle of the picked plat and a wider strip through the check, as well as a considerable area in the southeast corner of the check plat, suffered from an excess of water. This tended to throw the plats "off balance," as a much greater area in the check was injured than in the picked plat. This fact of course should be borne in mind in considering the results secured.

PICKINGS.

The idea of this test was to start the pickings as soon as the weevils became sufficiently abundant to make the operation worth while. In order to determine this time, regular examinations were made at different points throughout the plats, beginning with May 8. On this date 2,100 plants were examined, and no weevils were found. On May 13, one thousand plants yielded eight weevils, but on the 19th the same number yielded four weevils. On May 24, twelve weevils were found on 1,000 plants. These records were made in belts extending along the plats parallel to the timber line. After this time, however, separate records were secured for the two plats. The observations were made at both ends and the middle of each plat. In the examination of June 1 it was found that plat 1 averaged one weevil to 55 plants, while plat 2 averaged one weevil to 33 plants. On June 5 both plats averaged one weevil to 75 plants. From these observations it is seen that a fairly heavy infestation was being developed rather gradually in this field, and it was not until the middle of June that a considerable increase in the number of weevils was noted. Consequently, the plat was first picked over on June 16, at which time 129 weevils per acre were collected. This was a rather large number and is apparently due to a sudden emergence of a great number of weevils at about this time. This plat was picked five times in all on the following dates, June 16, 22, 29, July 10 and 17. This made the pickings extend over a total period of 32 days, the average time interval being eight days.

At the time of the first picking the stage of plant development was determined by a series of square counts and plant-height measurements distributed over the two plats. From these it was found that there was an average of 3.1 squares per plant and the average height of the plants was 11.4 inches at this time.

The time required to make the various pickings is shown in Table 16.

TABLE 16.—*Labor involved in weevil picking; Hecla plantation experiment, Mound, La., 1916.*

Date.	Area.	Per plat.		Per acre.	
		Hours, labor.	Cost of labor at 7½ cents per hour.	Hours, labor.	Cost of labor at 7½ cents per hour.
	Acres.				
June 16	1.44	7.5	$0.56	5.2	$0.39
June 22	1.44	4.5	.34	3.1	.24
June 29	1.44	8.0	.60	5.6	.42
July 10	1.44	7.0	.53	4.9	.37
July 17	1.44	9.0	.68	6.2	.47
Total		36.0	2.71	25.0	1.89
Average				5.0	.38

Both men and women were used for this purpose, and as the work was about equally divided between the two the value of the labor is figured at the rate of 7½ cents an hour, which represents a fair average. From this table it is seen that an average of five hours per acre was required for each picking. Figuring on the basis of a 10-hour day this would mean 2 acres per day per hand on the average. This is a slightly higher average than has been secured from most of the figures on area covered per hand per day and is probably due to the fact that with the number of hands used and the small size of the plats only a few hours were required for the picking. It is quite probable that the laborers would not have maintained this same rate of speed if they had been working all day. The cost figures show an average of 38 cents per acre per picking, or a total of $1.89 per acre for the five pickings.

In connection with these same labor observations, a comparison was made of the relative efficiency of different individuals. Three men were selected, two of whom were fast workers and the third a very slow hand. Separate records were kept of these individuals while the fast hands were covering eight rows each and the slow man picked six. It was found that while the fast men took much less time for a row than the slow one, they averaged 8.1 and 10.9 weevils to the row, whereas the slow one averaged only 4. Thus it is seen that the efficiency of the individual largely determines not only the speed of the operation, but also its thoroughness. This same observation has been made a number of times and it was found that the individuals varied even more widely than the figures just given would indicate.

The weevils collected at the various pickings are shown in Table 17.

TABLE 17.—*Weevils collected with bag-and-hoop, Hecla plantation experiment, Mound, La., 1916.*

Picking.	Date.	Number weevils collected.	Weevils per acre.
First	June 16	185	129
Second	June 22	178	124
Third	June 29	160	111
Fourth	July 10	159	110
Fifth	July 17	163	113
Total		847	587

From this it is seen that the pickings ranged from 110 to 129 weevils per acre, with a total of 587 weevils per acre for the five pickings. It is interesting to note that the highest number was collected at the first picking. The range, however, was comparatively small.

The forms collected in the bag-and-hoop are shown in Table 18.

TABLE 18.—*Forms collected per acre with bag-and-hoop, Hecla plantation experiment, Mound, La., 1916.*

Date.	Forms collected per acre.			Clean.	Punctured.
	Total.	Clean.	Punctured.		
				Per cent.	*Per cent.*
June 16	285	17	268	5.8	94.2
June 22	346	45	301	13.1	86.9
June 29	414	59	355	14.3	85.7
July 10	894	355	539	39.8	60.2
July 17	506	139	367	27.6	72.4
Total	2,445	615	1,830		
Weighted average				25.2	74.8

At the first three pickings only squares were secured, but at the fourth and fifth both squares and bolls were collected. A total of 2,445 forms were collected at the five pickings, of which 1,830 were punctured and 615 were clean. Thus it is seen that practically one-fourth of the forms collected in the bag-and-hoop were clean. While making these collections it was noted also that a considerable number of terminal buds were broken off and gathered in the sacks.

In order to see if these injured forms collected in the bags were reducing the number reaching the ground to any extent, one collection of fallen forms was made in both plats on July 14. For this purpose a strip 20 feet long and three rows wide was laid off in the middle and each end of each plat, and all fallen forms were gathered from these strips. As the rows averaged four and a half feet in width, the total area examined in each plat was 820 square feet. The strips were selected so that no skips in stand were included, and the cotton as nearly as possible represented the average growth of that portion of the plat. As the preceding bag-and-hoop collection had been made on July 10, this fallen form collection was four days after a picking. The results secured are shown in Table 19.

TABLE 19.—*Fallen forms collected in Hecla plantation experiment, Mound, La., July 14, 1916.*

Plat.	Forms gathered.		
	Squares.	Bolls.	Total.
Check	447	23	470
Picked	234	21	255

From Table 19 it is seen that while the boll collection differed very little, there were 213 more squares collected from the check than from the picked plat. If these figures are taken as a criterion, they show that the bag-and-hoop pickings reduced the forms reaching the ground by 47 per cent. This is a considerably greater reduction than has been found in most of the tests with the 7-day interval, but this difference may well be due to the varietal differences in the cotton. As has already been mentioned, this test was conducted with a long-staple variety which tended to retain a considerable proportion of the infested squares. Even the squares which were going to fall were probably sufficiently attached to the plant to remain somewhat longer than would be the case on a short-staple variety, and consequently their chance of being collected in the bags was increased.

One important question in connection with this type of plat work concerns the influence of one plat upon another and also the influence of any near-by untreated cotton on the treated plat. This point, of course, is of primary importance in determining just how nearly such plat tests represent the conditions which would prevail if an entire field was treated in the same manner as the plat in question. In an effort to secure some information on this point the records of the bag-and-hoop collections of weevils and forms were made by rows as well as by plats. The rows in the picked plat were numbered from 1 to 22, beginning with the row adjoining the check, and the record for each row was kept separate throughout the five pickings.

TABLE 20.—*Row records of weevils collected with bag-and-hoop, Hecla plantation experiment, Mound, La., 1916.*

Row No.	Weevils collected.							
	June 16.	June 22.	June 29.	July 10.	July 17.	Row total.	Average per row in 5-row blocks.[1]	Average per row of outside and inside blocks.
1	8	7	4	8	17	44	43.3	43.3
2	5	7	4	5	7	28		
3	8	12	2	14	11	47		
4	9	14	18	8	8	57		
5	9	16	5	5	6	41		
6	10	6	14	5	8	43		
7	6	1	7	6	13	33	42.0	39.0
8	8	8	6	13	10	45		
9	6	2	10	7	8	33		
10	25	11	8	11	8	63		
11	8	14	5	5	4	36		
12	6	5	5	12	8	36	36.0	
13	14	6	3	7	4	34		
14	3	14	14	5	6	42		
15	4	2	8	8	7	29		
16	9	5	12	6	7	39		
17	8	10	0	3	9	30	32.5	32.5
18	2	9	2	5	3	21		
19	13	11	9	7	9	49		
20	4	6	4	6	3	23		
21	11	7	9	3	5	35		
22	9	5	11	10	2	37		

[1] Outside blocks each consist of 6 rows.

The weevil collection records are shown in Table 20. Owing to the variations produced by the individual efficiency of the pickers, it does not seem advisable to compare the various rows at a single picking, but this factor should be more or less averaged out in the five pickings, and to reduce this error further the rows have been averaged together in blocks. It will be noted that the first average of this type divides the plat into four blocks, the outside blocks consisting of six rows each and the two inside blocks consisting of five rows each. From this grouping it is seen that rows 1 to 6 averaged 43.3 weevils per row, while rows 7 to 11 averaged 42; rows 12 to 16 averaged 36 and rows 17 to 22 averaged 32.5. Thus it is seen that there is a more or less regular decrease in the infestation of the picked plat as the distance from the check plat is increased. However, the highest record for any single row was row 10, which was very nearly in the center of the plat. These figures would seem to indicate that picking cotton beyond the ends of the picked plat and to the north of it prevented the plat from receiving an infestation of weevils from those sides. It is also seen that there was apparently some migration of weevils from the check plat into the south side of the picked plat. However, this was not of grave importance and is probably largely counteracted by the later omission of rows 1 to 4 as buffers.

TABLE 21.—*Row records of infested squares collected with bag-and-hoop, Hecla plantation experiment, Mound, La., 1916.*

Row No.	Infested squares collected.							
	June 16.	June 22.	June 29.	July 10.	July 17.	Row total.	Average per row in 5-row blocks.[1]	Average per row of outside and inside blocks.
1	22	23	19	47	71	182		
2	8	14	19	33	40	114		
3	13	28	6	5	43	95	144.0	144.0
4	32	29	36	70	29	196		
5	13	12	23	36	38	122		
6	18	11	28	64	33	154		
7	19	19	27	31	18	114		
8	28	26	15	48	30	147		
9	13	8	28	19	14	82	127.0	
10	25	33	24	48	24	154		
11	44	28	35	26	4	137		
12	8	18	14	28	23	91		118.8
13	24	23	22	44	11	124		
14	15	18	29	29	18	109	110.6	
15	10	23	21	26	16	96		
16	24	23	51	26	9	133		
17	9	18	19	11	20	77		
18	9	23	11	30	13	86		
19	18	22	20	22	14	96	83.1	83.1
20	14	16	19	44	2	95		
21	9	20	30	7	12	78		
22	12	12	15	23	5	67		

[1] Outside blocks each consist of 6 rows.

Table 21 shows the row collections of the infested squares in the same manner. An analysis of this table by blocks shows the square collections to correlate very well with the weevil collections, the number of infested squares decreasing with the increase in distance from the check plat. In this connection it is interesting to note that the highest record was in row 4, while the second highest was in row 1, so it is seen that the most highly infested rows were included in the 4-row buffer which was dropped.

Considering these row records on the whole it is seen that the only outside influence affecting the infestation of the picked plat was apparently the migration of the weevils from the check plat. This was sufficient in extent to increase slightly the infestation of the side immediately adjoining the check and would undoubtedly have some influence on the results secured. However, this migration appears to have been comparatively unimportant, and consequently its only effect on the results would be in the degree. That is, it would not offset any beneficial effect from the bag-and-hoop collections, but probably would lessen the gain somewhat.

INFESTATION.

The infestation of these various plats was followed throughout the season in the usual manner. As has been mentioned, the weevil abundance was determined from May 8 to June 5 by plant examinations, the figures secured expressing the ratio of the weevils to the plants. After June 5, however, the squares became sufficiently abundant to allow square-infestation records. This type of record was begun on June 15 and continued at weekly intervals until August 9. At the first three examinations 100 squares were examined in each corner and the center of each plat, making a total of 500 squares to the plat. Beginning with July 4, however, the records were made in the center of each end and the middle of each plat, 200 squares being examined at each point, making a total of 600 squares to the plat.

Table 22 shows the figures secured at these examinations.

TABLE 22.—*Weevil infestation, Hecla plantation experiment, Mound, La., 1916.*

Date of examination.	Infestation.	
	Picked plat.	Check plat.
	Per cent.	*Per cent.*
June 15	65.6	49.0
June 20	43.8	47.8
June 27	34.0	38.6
July 4	39.0	25.5
July 10	25.7	24.7
July 17	47.0	50.2
July 26	48.2	53.2
Aug. 1	71.0	67.8
Aug. 9	87.8	89.8
Weighted averages	51.5	49.9

From Table 22 it is seen that there was no significant regularity in the comparative infestation of the two plats. In fact, in the weighted average for the season there was a difference of only 1.6 per cent in the infestation of the two plats. These infestation records failed to show any effect whatever from the pickings, as there was no apparent reduction in the infestation of the picked plat at any time.

Averages of the infestation records at each of the points of observation throughout the season give the following:

	Per cent.
Picked plat:	
West end	54.4
Center	47.4
East end	52.1
Check plat:	
West end	49.4
Center	50.8
East end	49.2

From these averages it is seen that the infestation was very evenly distributed over the two plats, as the extreme range was only from 47.4 per cent to 54.4 per cent. It is interesting to note that both of these extremes were located in the picked plat. The averages at the points where the infestation was determined are further evidence of the failure of the picking operation to reduce the weevil infestation in the picked plat.

EFFECT ON PLANTS.

After the first few shakings it was noticed that this operation was having a decided effect on the growth of the plants. The shaken plants were becoming much shorter than the check plants and were more bushy and compact in growth. This became so pronounced that on August 1 the height of 200 plants in each end and the center of each plat was measured. These 600 plants in the picked plat averaged 48.6 inches in height, while those in the check plat averaged 58.6 inches in height. Thus the plants in the check plat averaged 10.3 inches higher than those in the picked.

BOLL COUNTS.

In order to secure some index to the fruit being set in these two plats, 100 plants were examined in each end of each plat on July 17 and the bolls counted. At this time it was found that the picked plat averaged 3.9 bolls to the plant, while the check plat averaged 5.4 bolls to the plant. These observations were checked very carefully by a thorough examination of both plats, and it seemed obvious that the check plat, generally speaking, was fruiting better than the picked plat. However, the factor of drainage had become operative at this time, and it was seen that portions of the check plat were injured seriously by the drowning of the plants in poorly drained areas.

PRODUCTION.

The seed cotton matured in these plats was picked on October 30. The amounts secured are shown in Table 23.

TABLE 23.—*Seed-cotton production in Hecla plantation test, Mound, La., 1916.*

Plat and treatment.	Area.	Seed-cotton production.	
		Per plat.	Per acre.
	Acres.	*Pounds.*	*Pounds.*
1. Picked	1.18	591	501
2. Check	1.18	541	458

From Table 23 it is seen that the picked plat exceeded the check in production by 43 pounds of seed cotton per acre. This was a gain of 9 per cent over the check. At first glance this result seems rather surprising in view of the result of the boll counts and other observations made on the relative fruiting of the two plats, which showed the check plat to be leading the picked plat by a considerable margin. In fact, the boll count showed the check plat to have a 38 per cent margin over the picked plat. Of course, such boll counts are not absolutely accurate, but they usually prove fairly representative. However, other factors than the weevil picking itself were operating to influence the production of these two plats. The factor of drainage has been mentioned as seriously injuring a portion of the check plat. In fact, this injury probably was sufficient practically to account for the results secured. In addition to this, the factor of boll rot must be considered. The exceedingly wet weather of July caused an excessively rank plant growth on all highly nitrogenous land, such as that on which these plats were located, and this resulted in the rotting of many of the lower bolls which could not be reached by the sunlight. It has been shown that, while the shaking operations were reducing the fruiting of the plants, they also tended to prevent a rank plant development. As a result, there was little or no boll rot in the picked plat, while the check was injured seriously by this factor. Consequently it is seen that, while the shaking operation actually reduced the fruit set in the picked plat, the reduction in foliar development served to offset this by preventing boll rot.

Taking these two factors of boll rot and poor drainage of the check plat into consideration, it is possible to understand why the check matured less cotton than the picked plat in spite of the fact that it actually set more bolls per plant on the poorly drained portions of the plat. To check the production record a bur count was made in both plats by examining 500 plants in each on October 31. At this time it was found that the check plat averaged 7.4 burs per plant, while the picked plat averaged 8.7 per plant. Thus it is seen that the bur count corresponded fairly well with the production record of the two plats. This tends to place further emphasis on the probable accuracy of the boll count.

At any rate, regardless of the explanation of the weights secured, the fact remains that the difference in favor of the picked plat was so small as to constitute an economic loss, and the utter absence of evidence of a reduction of the infestation of the picked plat due to the pickings makes this test decidedly unfavorable to weevil picking as a means of control.

EUREKA PLANTATION EXPERIMENT NO. 1.

The more extensive Eureka test was located in a cut of cotton extending along Walnut Bayou. The series consisted of five plats, each plat extending at right angles to the bayou. The soil on which these plats were located was a rather light sandy loam on the bayou front, grading off heavier toward the back of the cut. As practically all soil gradation in this cut was from north to south, and as it was fairly uniform from east to west, the plats should have been reasonably comparable as regards the soil, since each extended through the extreme variation. To safeguard further against soil variations two check plats were selected, one on the east side of the series and the other on the west. In most cases in the following report the average of the records made on these two check plats is given instead of the individual records of the two, as this average should compare best with the conditions existing between the two checks. Three treated plats were arranged between these two check plats. The first of these, plat 2, was picked once a week for six weeks; plat 3 was picked twice a week for six pickings, while plat 4 was picked once a week for four weeks.

As considered during the period of treatment, each plat was 22 rows in width and 380 feet long. This made the area of each plat exactly 1 acre. However, it was recognized that there would probably be some interplat effect at the dividing lines, so a buffer system was arranged between each two plats at the time of picking in order to absorb as much as possible of this interplat effect. This system consisted of omitting four rows on each side of each dividing line. As the checks adjoined plats on only one side, this resulted in four rows being dropped from each check, while eight rows were dropped from each picked plat. Thus the checks finally considered consisted of 0.82 of an acre each, while the picked plats each consisted of 0.64 of an acre. However, all figures given in the present report, with the exception of those of production, are based on plats of 1 acre each, and, of course, the production was reduced to an acreage basis. In order to protect the plats further from outside influence a buffer system across the ends of the picked plats was maintained throughout the picking period. For this purpose the pickings were extended about 30 feet beyond the plat lines at each end each time a plat was picked.

This cut was planted in corn and peas during 1915, and a very heavy growth was turned under. This resulted in the land being in excellent condition with the exception of a rather spotted infestation of nut-grass extending along the back of the cut. However, the back end of the plats was moved forward sufficiently to avoid this grassy area almost entirely. The drainage throughout all plats was very good, and there was no apparent water injury at any time, in spite of the excessive rains during July. The cotton was the Simpkins Ideal variety, which had been planted on April 5. A very good stand was secured over all the plats.

PICKINGS.

As in the case of the Hecla experiment, the idea was to begin the pickings as soon as the weevils became sufficiently abundant to make the operation worth while. Plant-infestation studies were made in the same manner as those already described for Hecla plantation. On May 10, 1,000 plants were examined and no weevils found; on May 17 three weevils were found on 1,000 plants, while on May 23 one weevil was found, and on May 30, two weevils were found to 1,000 plants. On June 6 the plant examinations were separated by plats and 50 plants were examined in each end and the center of each plat, making a total of 150 plants to the plat. At this time only two weevils were found, one in plat 1 and one in plat 3. From these figures it is seen that the emergence of weevils into these plats was exceedingly light and late. However, by about June 12 a rather heavy general emergence of weevils was taking place over the parish, and it was considered advisable to begin picking these plats, in spite of the fact that only a small number of weevils had been found in this cut. Consequently, the first picking of all of the plats was made on June 13. At this time plat 2 yielded 10 weevils to the acre, plat 3 yielded 13, and plat 4 yielded 6. This is quite different from the first picking made three days later on Hecla plantation, when 129 weevils per acre were collected, and shows the light initial infestation of this series of plats.

In order to determine the exact stage of the cotton plants at the time of this first picking the squares were counted on 20 plants at 10 different points in the series of plats. These 200 plants averaged 7.5 squares per plant. A similar study of the plant heights showed them to average 13.1 inches at this time.

The labor involved in these pickings is shown in Table 24, figured on the same basis as in the Hecla test.

TABLE 24.—*Labor required for picking weevils, Eureka plantation, Tallulah, La., 1916, experiment No. 1.*

Plat No.	Picking.	Date.	Labor per acre.	Cost of labor per acre, at 7½ cents per hour.
			Hours.	
2	First	June 13	6.4	$0.48
	Second	June 20	5.5	.41
	Third	June 27	6.0	.45
	Fourth	July 5	9.0	.68
	Fifth	July 11	15.0	1.13
	Sixth	July 22	10.0	.75
	Total		51.9	3.90
	Average		8.6	.65
3	First	June 13	6.4	.48
	Second	June 17	4.5	.34
	Third	June 20	5.5	.41
	Fourth	June 23	6.5	.49
	Fifth	June 27	6.0	.45
	Sixth	June 30	8.0	.60
	Total		36.9	2.77
	Average		6.1	.46
4	First	June 13	6.4	.48
	Second	June 20	5.5	.41
	Third	June 27	6.0	.45
	Fourth	July 5	9.0	.68
	Total		26.9	2.02
	Average		6.7	.51

From this it is seen that the cost per acre ranged from 46 to 65 cents for picking in the different plats. Of course, the average per picking increases as the season progresses, and consequently the greater number of pickings cost more per picking. The hours of labor per acre ranged from 6.1 to 8.6. From the total cost figures it is seen that the four pickings at an interval of one week cost $2.02, while 6 pickings at the same time interval cost $3.90. The six pickings given twice a week cost $2.77. These records show a uniformly higher cost for the pickings on Eureka than on Hecla, and, judging from the general observations which have been made, it is probable that the Eureka figures more nearly represent average conditions.

The weevils collected from these plats at the various pickings are shown in Table 25.

TABLE 25.—*Weevils collected per acre with bag-and-hoop, Eureka plantation, Tallulah, La., 1916, experiment No. 1.*

Plat No.	Picking.	Date.	Number of weevils collected.
2	First	June 13	10
	Second	June 20	11
	Third	June 27	25
	Fourth	July 5	63
	Fifth	July 11	82
	Sixth	July 22	470
	Total		661
3	First	June 13	13
	Second	June 17	11
	Third	June 20	6
	Fourth	June 23	13
	Fifth	June 27	27
	Sixth	June 30	20
	Total		90
4	First	June 13	6
	Second	June 20	9
	Third	June 27	27
	Fourth	July 5	43
	Total		85

From Table 25 it is seen that if the sixth picking in plat 2 is excluded, the highest number of weevils collected per acre at any picking was 82. However, there was a tremendous increase at the sixth picking of plat 2, and 470 weevils per acre were collected at this time. This increase was due to the effect of climatic conditions on the multiplication of the weevils. As has been mentioned, the month of July was exceedingly rainy, the plats being subjected to a shower almost every day in the month. This, of course, produced a great reduction in the climatic control of the weevils in the fallen forms and, as a result, although the initial infestation of these plats was very light, the July-bred weevils multiplied so rapidly that this was quickly changed to an excessively heavy infestation. Considering the totals collected from the various plats, it is seen that only 85 weevils were secured from plat 4, while 90 were picked from plat 3. The high number secured at the sixth picking brought the total for plat 2 up to 661.

The forms collected in the bags from the different plats at the various pickings are shown in Table 26.

TABLE 26.—*Forms collected per acre with bag-and-hoop, Eureka plantation, Tallulah, La., 1916, experiment No. 1.*

Plat No.	Date.	Forms collected.			Clean.	Punctured.
		Total.	Clean.	Punctured.		
					Per cent.	*Per cent.*
2	June 13	123	48	75	39.0	61.0
	June 20	116	43	73	37.1	62.9
	June 27	338	159	179	47.0	53.0
	July 5	472	271	201	57.4	42.6
	July 11	1,309	990	319	75.6	24.4
	July 22	2,196	419	1,777	19.1	80.9
	Total	4,554	1,930	2,624		
	Weighted average				42.4	57.6
3	June 13	108	33	75	30.6	69.4
	June 17	156	68	88	43.6	56.4
	June 20	127	43	84	33.9	66.1
	June 23	83	42	41	50.6	49.4
	June 27	231	105	126	45.5	54.5
	June 30	223	109	114	48.9	51.1
	Total	928	400	528		
	Weighted average				43.1	56.9
4	June 13	76	28	48	36.8	63.2
	June 20	98	25	73	25.5	74.5
	June 27	223	99	124	44.4	55.6
	July 5	330	224	106	67.9	32.1
	Total	727	376	351		
	Weighted average				51.7	48.3

One interesting feature of the figures shown in Table 26 is the extremely rapid increase in the number of forms collected at the later pickings. For example, in plat 2, 2,196 forms were collected at the sixth picking, while a total of only 2,358 were collected at the other five pickings from this plat. Another important feature is the high percentage of clean forms collected in the bags. This varied from 42.4 to 51.7 in the different plats and averaged 45.7 over the entire series. From this it is seen that almost one-half of the total forms collected in the bag-and-hoop during this series of tests were perfectly clean. In addition to this destruction of clean squares the same loss of terminal buds which was noted in the other tests was observed in this experiment.

It is interesting to compare the form collections of plat 2 with those made on the Hecla test about the same time. This comparison is shown in Table 27.

TABLE 27.—*Comparison of Hecla and Eureka, Madison Parish, La., tests in forms collected in bags.*

Date.	Forms collected per acre.	
	Eureka plat 2.	Hecla.
June 13	123	
June 16		285
June 20	116	
June 22		346
June 27	338	
June 29		414
July 5	472	
July 10		894
July 11	1,309	
July 17		506
Total	2,358	2,445

In the Hecla test it is seen that during a total of five pickings extending from June 16 to July 17, 2,445 forms per acre were collected, while on plat 2 of the Eureka test the five pickings extending from June 13 to July 11 yielded a total of 2,358 forms per acre. Thus through this period the total forms collected in the two tests were approximately the same. However, a study of the individual pickings shows these totals to have been reached by quite different records. There was a comparatively slight increase on the Hecla test from the first to the fourth picking, and then the fifth picking decreased somewhat. In the Eureka test the first four pickings yielded less than the same number of the Hecla test, but the fifth picking increased several hundred per cent. Two factors undoubtedly influenced this difference of results in the two tests. These were the degree of weevil infestation and the cotton variety. The higher initial infestation of the Hecla test resulted in a greater number of squares being collected on that plat in the early pickings, but the comparative lack of prolificacy and the determinate fruiting of this long-staple variety of cotton was becoming effective by the picking of July 17, and consequently there was an actual reduction in the number of forms collected. On the other hand, the light initial infestation of the Eureka test resulted in low records at the first few pickings, but the rapid increase in this infestation and the enormous abundance of squares caused the later pickings to yield large numbers.

Unfortunately no collections of fallen forms were made in the Eureka plats, so it is impossible to compare the two tests on this point.

TABLE 28.—*Row records of weevil collection in bags, Eureka plantation, Tallulah, La., 1916, test No. 1.*

Plat.	Row	Weevils collected in bags.										
		June 13	June 17	June 20	June 23	June 27	June 30	July 5	July 11	July 22	Row total.	Row average in blocks.
	1							1	5	19	25	
	2	1		2				1	3	23	30	
	3	1		1		1		3	5	28	39	
	4					3		4	5	15	27	31.1
	5					3		3		23	29	
	6					2		9	6	20	37	
	7					1		2	6	36	45	
	8					2		4	3	14	23	
	9			1				2	3	25	31	
	10	1				2		2	4	29	38	
2	11							1	4	30	35	
	12	1		2		2		9	9	30	53	33.9
	13	1				1		2	7	10	21	
	14	1				1		3	5	25	35	
	15			1		3			7	26	37	
	16			2		1		3	3	12	21	
	17	1						1	3	9	14	
	18	1				1		5	2	17	26	
	19									22	22	
	20	1				1		2		27	31	22.5
	21							2		13	15	
	22	1		2		1		4	2	17	27	
	1		1			1	2				4	
	2	1	2	1	1						5	
	3					2					2	
	4	1	1				1				3	3.1
	5						1				1	
	6	1			1	1	1				4	
	7		2			1	1				4	
	8	1			1	2					4	
	9				1	6	2				9	
	10	2			1	3	2				8	
3	11	1		1	2						4	
	12	2	3	1		2	4				12	5.8
	13					1					1	
	14					2	2				4	
	15				1						1	
	16		2	2	4	1	2				11	
	17					1					1	
	18	1			1		1				3	
	19	1									1	
	20	1		1		1					3	2.1
	21					1	1				2	
	22	1				2					3	
	1			2		3		1			6	
	2			1				10			11	
	3							1			1	
	4					1		1			2	3.6
	5							1			1	
	6					1					1	
	7			2		1		1			4	
	8					3		1			4	
	9			2		2		5			9	
	10	1						3			4	
4	11	1						4			5	3.6
	12	1									1	
	13					2		1			3	
	14			1		1					2	
	15					2					2	
	16			1		1					2	
	17					1		1			2	
	18											
	19	1				3		2			6	
	20	1				1		3			5	4.5
	21	1				1		5			7	
	22					4		3			7	

TABLE 29.—*Row records of square collection in bags, Eureka plantation, Tallulah, La., 1916, test No. 1.*

Plat.	Row.	Squares collected in bags.										
		June 13.	June 17.	June 20.	June 23.	June 27.	June 30.	July 5.	July 11.	July 22.	Row total.	Row average by blocks.
	1	1	......	1	......	7	......	5	12	87	113	
	2	2	......	3	......	8	......	7	25	97	142	
	3	2	......	5	......	4	......	17	15	81	124	145.6
	4	3	......	2	......	7	......	10	10	109	141	
	5	9	......	3	......	5	......	13	19	134	183	
	6	5	......	1	......	4	......	12	16	133	171	
	7	4	......	4	......	5	......	12	30	67	122	
	8	1	......	8	......	7	......	7	13	83	119	
	9	6	......	13	......	10	......	16	24	89	158	
	10	5	......	2	......	9	......	8	15	138	177	
	11	6	......	4	......	21	......	5	5	83	124	122.9
2	12	2	......	4	......	13	......	13	15	71	118	
	13	3	......	6	......	12	......	5	13	44	83	
	14	2	......	1	......	16	......	11	12	98	140	
	15	8	......	2	......	4	......	8	12	74	108	
	16	2	......	2	......	20	......	9	9	38	80	
	17	1	......	3	......	5	......	5	7	69	90	
	18	3	......	1	......	6	......	17	7	50	84	
	19	......	......	2	......	6	......	5	2	93	108	
	20	3	......	2	......	......	......	5	1	72	83	78.8
	21	3	......	2	......	......	......	2	3	27	37	
	22	4	......	2	......	10	......	9	6	40	71	
	1	1	5	4	2	3	6	......	......	......	21	
	2	6	4	10	4	2	3	......	......	......	29	
	3	......	2	3	1	5	4	......	......	......	15	20.1
	4	1	2	1	5	4	5	......	......	......	18	
	5	......	3	......	1	2	4	......	......	......	10	
	6	1	5	4	......	6	12	......	......	......	28	
	7	2	3	8	3	3	4	......	......	......	23	
	8	3	5	3	4	4	9	......	......	......	28	
	9	3	6	7	......	8	5	......	......	......	29	
	10	6	10	10	4	9	11	......	......	......	50	
	11	7	9	5	2	5	8	......	......	......	36	
3	12	16	5	4	......	9	7	......	......	......	41	29.0
	13	......	1	4	1	5	6	......	......	......	17	
	14	7	8	......	1	12	2	......	......	......	30	
	15	6	4	1	1	4	1	......	......	......	17	
	16	......	3	2	7	5	2	......	......	......	19	
	17	4	1	2	......	12	1	......	......	......	20	
	18	5	4	1	1	3	5	......	......	......	19	
	19	4	3	......	......	5	5	......	......	......	17	
	20	1	2	4	2	7	7	......	......	......	23	19.5
	21	2	......	3	2	8	3	......	......	......	18	
	22	......	3	8	......	5	4	......	......	......	20	
	1	2	......	7	......	9	......	6	......	......	24	
	2	11	......	6	......	12	......	7	......	......	36	
	3	4	......	2	......	4	......	3	......	......	13	
	4	......	......	4	......	6	......	6	......	......	16	22.0
	5	3	......	1	......	2	......	4	......	......	10	
	6	8	......	3	......	13	......	9	......	......	33	
	7	2	......	6	......	4	......	1	......	......	13	
	8	1	......	8	......	6	......	2	......	......	17	
	9	......	......	......	......	4	......	7	......	......	11	
	10	1	......	2	......	4	......	10	......	......	17	
	11	......	......	2	......	......	......	10	......	......	12	
4	12	3	......	4	......	6	......	5	......	......	18	12.8
	13	2	......	5	......	3	......	3	......	......	13	
	14	1	......	......	......	7	......	1	......	......	9	
	15	1	......	2	......	1	......	8	......	......	12	
	16	1	......	2	......	3	......	......	......	......	6	
	17	2	......	4	......	3	......	3	......	......	12	
	18	2	......	......	......	7	......	7	......	......	16	
	19	2	......	......	......	5	......	3	......	......	10	15.1
	20	......	......	7	......	10	......	5	......	......	22	
	21	1	......	1	......	5	......	5	......	......	12	
	22	1	......	7	......	10	......	1	......	......	19	

Row records of the weevil and square collections were made in this test in the same manner as that already described for the Hecla experiment. These are tabulated in Tables 28 and 29. The row totals are averaged by blocks in much the same manner as in the Hecla test. Of course, in this case unpicked cotton adjoined only two of the blocks. These were the outside blocks of plats 2 and 4. From Table 28 it is seen that the outside block of plat 4 averaged slightly higher in weevils collected than the remainder of the plat, but that the outside block of plat 2 averaged less than the middle block of the same plat. From Table 29 it is seen that the square collections presented exactly reversed conditions. From these square collections it would seem that the outside block of plat 2 was more highly infested than the inside, while the rows 1 to 6 of plat 4 yielded a higher average than any of the remainder of the plat. These results are rather contradictory, but at any rate they seem to indicate that if the unpicked cotton had any effect on the picked plats it was comparatively slight and should have been largely eliminated by the buffer system employed.

WEEVIL INFESTATION.

The infestation of the various plats of this series was followed throughout the season in the same manner as in the Hecla test. The general rule for determining this record was an examination of 100 squares in each end and the middle of each plat. The records secured are shown in Table 30.

TABLE 30.—*Weevil infestation, Eureka plantation, Tallulah, La., 1916, Test No. 1.*

Date of examination.	Infestation.			
	Plat 2.	Plat 3.	Plat 4.	Plats 1 and 5: average of both checks.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
June 12	7.3	10.7	6.7	8.0
June 19	5.3	13.3	8.0	11.2
June 26	8.7	7.3	7.0	10.7
July 3	9.2	5.7	4.3	9.0
July 10	12.3	12.7	9.8	12.2
July 17	42.2	35.0	40.7	44.8
July 24	81.8	46.5	57.8	67.7
Aug. 1	76.3	78.2	81.7	81.8
Aug. 8	91.0	92.8	80.5	85.2
Aug. 14	96.2	96.3	97.0	96.2
Weighted average	50.6	46.1	46.2	49.7

From these figures it is seen that starting with a practically equal infestation these three treated plats and the two checks varied back and forth somewhat, but never showed any significant regularity in the difference between the various individual plats. In fact, the range in the seasonal averages of the five plats was only 4.5 per cent and the seasonal average infestation of the three picked plats was 47.6 per cent while that of the two checks was 47.9 per cent.

EFFECT ON PLANTS.

The same effect of the picking operation on the plants was observed in this test as in all other bag-and-hoop experiments. It was observed that the shakings were reducing the size of the plants and were causing the typical bushy growth. One thousand plants were measured in each of the plats to determine the average height on July 19, 200 plants being examined at five different points in each plat. The results secured are shown in Table 31.

TABLE 31.—*Average height of plants on July 11, Eureka plantation, Tallulah, La., 1916, Test No. 1.*

Plat No.	Treatment.	Average height.
		Inches.
1	Check	42.7
2	Shaken	35.4
3	do	37.9
4	do	37.5
5	Check	40.6

From this it is seen that the two checks averaged 40.6 and 42.7 inches in height, while the next highest plat was 3, which averaged 37.9 inches; plat 4 was practically the same height, averaging 37.5 inches, while plat 2 showed the greatest effect of all, averaging 35.4 inches. These differences had been more pronounced earlier in the season, but, following the cessation of shaking, the picked plats had recovered a portion of the lost height by a rapid terminal growth.

The difference in height between plats 1 and 2 is illustrated photographically in figure 2 of plate 2, which shows the dividing line between these two plats.

From these figures showing the effect of the shaking of the plants it is seen that plat 2 was the most seriously injured of the series, while plats 3 and 4 were affected practically the same. This would seem to indicate that it is the duration of the pickings rather than the number which determined the effect on the plants. For example, plats 2 and 3 received the same number of shakings, but the interval was twice as long in plat 2 as in plat 3, so they extended much later into the season and the result was that in the fall plat 2 showed a much greater injury. Plat 3 received two more pickings than plat 4 but the time intervals differed so that the pickings extended over about the same period in the two plats and the resultant effect on the plants was much the same.

SEED-COTTON PRODUCTION.

The cotton produced on these plats was gathered in three pickings, August 24, September 14, and November 21. The amount secured is shown in Table 32.

TABLE 32.—*Seed-cotton production, Eureka plantation, Tallulah, La., 1916, test No. 1.*

Plat.	Seed cotton produced per acre.			
	Aug. 24.	Sept. 14.	Nov. 21.	Total.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
2	286	478	123	887
3	172	458	175	805
4	167	562	212	941
Average of 1 and 5	297	449	119	865

From Table 32 it is seen that the total range of the plats was from 805 to 941 pounds of seed cotton per acre, or a range of 136 pounds of seed cotton per acre. In this series the checks ranked about midway between the extremes. Plat 4 ranked highest of all, while plat 3 ranked lowest. In view of these rankings and the results of the various studies conducted on these plats during the season it seems impossible to attach any significance to the differences of the yields of the various plats. The total range constituted only 18 per cent of the production of the lowest plat and the plat giving the highest yield logically should have shown less benefit than at least one other plat, if the picking operations had been effective. In fact, one of the check plats yielded 849, while the other yielded 881, showing a difference of 32 pounds between the checks themselves. Consequently, it seems probable that the yield differences were of no significance whatever. At any rate, they fail to show any important beneficial effect from the picking operation. The boll-rot factor which was discussed in connection with the Hecla test was likewise operative in this test, as the checks produced an enormously rank growth, but the reduction in fruiting due to the shaking operation balanced this, so that the yield from the checks was practically equal to that from the picked plats.

STUDIES ON THE VALUE OF A MECHANICAL COLLECTOR OF BOLL WEEVILS.

Among the many methods of weevil control advocated and advertised by various individuals throughout the cotton belt are several mechanical collectors of the weevils. These machines vary widely in form and manner of construction, but most of them are similar in the principle involved. Usually they consist of some type of pan arrangement passing along beneath the plants while at the same time the plants are agitated more or less violently, the idea being to shake the weevils into the pan. A number of different types of these machines have been examined by the writers, and several of the most promising were tested at Tallulah during the season of 1915. The one of these which gave the best results during that season was selected for more intensive studies during 1916. These studies were of two types, (1) plat tests of the machine under field conditions, and (2) comparative efficiency studies to determine the relative weevil-collecting ability of this machine when compared with the bag-and-hoop.

PLAT TEST.

The plat test was arranged in somewhat the same manner as the Hecla test which has been described. The experimental principles involved were much the same, and the same methods of arranging the plats and buffers were followed. A very uniform strip of light sandy soil was selected, and the plant growth over the entire experimental area was rather unusually uniform. The light soil was selected in order to secure plants of comparatively small size, since the machine had shown a tendency to break larger plants rather severely. Two plats were arranged, each 20 rows wide and 740 feet in length. One of these was picked with the machine, while the other was left unpicked as a check.

PICKINGS.

The first picking was made on these plats on July 1. Originally it was intended to start this picking somewhat earlier, but delay in securing the machine postponed it until this date. However, as has been mentioned, cotton of small size was secured, and the light and late weevil emergence into this cut was such that only a slight infestation was present on the 1st of July. Consequently, the conditions more or less approximated those which would usually prevail about two weeks earlier in a more severely infested cut of richer soil.

Table 33 shows the detailed results of the various pickings conducted.

TABLE 33.—*Pickings with mechanical collector, Tallulah, La., 1916.*

Date.	Weevils collected.	Bolls collected.		Squares collected.		Time required.	
		Clean.	Infested.	Clean.	Infested.	Hour.	Minutes.
July 1	40			103	112	1	
July 11	156	15	115	364	665		
July 24	450	7	362	21	1,700	1	
July 31	1,117		296		2,281	1	10
Aug. 7	1,299		397		2,238		45
Aug. 15	2,445		301		1,363		45
Aug. 21	2,037		457		2,037		45
Aug. 27	1,064		231		1,079		45
Total	8,608	22	2,274	488	11,475		

From this it is seen that a total of eight pickings was distributed over the period from July 1 to August 27. The weevils per picking ranged from 40 to 2,445, and a total of 8,608 were collected during the experimental period. As the plat consisted of 1.53 acres, the weevils collected per acre thus ranged from 26 to 1,600 at the different pickings, with a total per acre of 5,626. During this same time 2,274 infested bolls and 11,475 infested squares were collected in the pans with the weevils. During the first three pickings a record was kept of the number of uninjured forms knocked off by the machine, and this was found to total 22 bolls and 488 squares. After that time the forms collected were so highly infested that they were considered as all injured. The time required for covering the plat ranged from 45 minutes to 1 hour and 10 minutes. This would make the average time in the neighborhood of 40 minutes to the acre. However, this did not include the time spent in emptying the pans. Studies on the operation of this machine over larger areas have shown that it may be expected to cover an average of 10 to 12 acres per day when operated on a plantation basis.

BROKEN PLANTS.

The greatest difficulty which was found in the operation of this machine was the breakage of plants. It was found that if the machine was adjusted so that the plants were not broken it failed to catch an appreciable number of weevils, while if it was adjusted so that it collected a considerable number of weevils the plant breakage was very high. Consequently, in adjusting the machine, an attempt was made to strike a happy medium between these two extremes.

Following each picking, the plat was gone over and the number of broken plants counted. It was found that the number per picking ranged from 37 plants to 704 plants. The number decreased rapidly as the season progressed, owing to the fact that nearly all of the larger plants had already been broken down. During the course of the eight pickings a total of 1,827 plants were broken in the plat.

FALLEN FORM COLLECTIONS.

In order to determine whether or not the forms collected in the picking machine decreased the number reaching the ground to any appreciable extent two collections of fallen forms were made. For this purpose an area 3 rows wide and 20 feet long was selected at each end and the middle of each plat. This made a total of about 750 square feet for each plat. Care was taken to locate these points where the stand was as nearly perfect as possible and where the plant growth represented about the average of that portion of the plat. The results of these collections are shown in Table 34.

TABLE 34.—*Fallen form collections in machine-picked test, Tallulah, La., 1916.*

Date.	Picked plat.			Check plat.		
	Squares.	Bolls.	Total forms.	Squares.	Bolls.	Total forms.
July 27	1,385	516	1,901	1,371	805	2,176
Aug. 5	1,436	372	1,808	2,581	984	3,565
Total	2,821	888	3,709	3,952	1,789	5,741

From this table it is seen that on both occasions considerably more forms were gathered from the ground in the check plat than in the picked plat. In the two pickings a total of 3,709 fallen forms were gathered from the picked plat and 5,741 from the check, thus giving a reduction of 2,032 in favor of the picked plat.

INFESTATION.

The degree of weevil infestation in the two plats was followed through the season in the usual manner in order to determine the effect of the picking operations. Table 35 gives the results of these observations.

TABLE 35.—*Square infestation, Tallulah, La., 1916.*

Date.	Picked plat.	Check plat.
	Per cent.	*Per cent.*
July 1	14.3	14.3
July 7	21.4	17.2
July 13	47.7	38.0
July 21	60.3	57.2
July 27	66.8	75.0
Aug. 2	85.3	85.3
Aug. 8	88.8	90.3

From this it is seen that at the beginning of the experiment the two plats averaged exactly the same infestation. At the next examination, however, the picked plat increased slightly above the check plat and retained this position until July 27. The seasonal average of the check plat was 53.9 per cent, while that of the picked plat was 54.9 per cent. Thus these records fail to show any decrease in the infestation due to the weevil collections. In fact, the averages are remarkably nearly equal. Studies on the seasonal average infestation of the various points of observation show this infestation to have been evenly distributed in the various plats.

EFFECT ON PLANTS.

The plant breakage due to the operation of the machine has been mentioned. By the latter part of the season it was quite obvious that this was going to have a very detrimental effect on the picked plat. The picked cotton looked as if it had been topped, and it was easy to distinguish the last picked row at a glance, as this row was a foot or more shorter in height than the adjoining unpicked row.

PRODUCTION.

The seed cotton produced in these two plats was picked on August 24 and October 26. The amounts secured are shown in Table 36.

TABLE 36.—*Seed-cotton production, mechanical picker test, Tallulah, La., 1916.*

Date picked.	Seed cotton per acre.	
	Check plat.	Picked plat.
	Pounds.	*Pounds.*
Aug. 24	216	182
Oct. 26	190	109
Total	406	291

From this it is seen that the check yielded considerably more than the picked plat each time and in the total of the two pickings there was a loss of 115 pounds of seed cotton per acre in the picked plat. This amounts to a loss of 28 per cent below check and shows quite well the injurious effect of the picking operations with this machine.

COMPARATIVE EFFICIENCY STUDIES.

As a further check on the efficiency of the machine it was tested in comparison with the bag-and-hoop simply on the basis of efficiency in operation.

The first test was conducted on July 13. A uniform strip of cotton 14 rows wide and 645 feet in length was selected. The method followed was to pick two of these rows with the mechanical picker, then two with the bag-and-hoop, then two with the mechanical picker and so on until eight rows had been picked with the mechanical picker and six with the bag-and-hoop. Records were kept of the number of weevils and forms collected by each of these methods, and the time required was likewise noted. This test was repeated in an identical manner on the same cotton August 3. The results of these two tests are shown in Table 37.

TABLE 37.—*Comparative efficiency tests, mechanical pickers, Tallulah, La., 1916.*

Date.	Mechanical picker (per row).						Bag-and-hoop (per row).					
	Weevils collected.	Squares.		Bolls.		Time required	Weevils collected.	Squares.		Bolls.		Time required
		Punctured.	Clean.	Punctured.	Clean.			Punctured.	Clean.	Punctured.	Clean.	
						Min.						*Min.*
July 13	2.6	9.6	5.9	1.0	0.25	2	9.9	37.0	15.3	16.0	3.8	20
Aug. 3	48.4	163.1	......	14.7	......	3	77.5	280.6	......	25.0	......	20

From Table 37 it is seen that at the first test the mechanical picker averaged 2.6 weevils per row while the bag-and-hoop averaged 9.9. At the second test the averages were 48.4 and 77.5, respectively. This shows definitely that the mechanical picker does not even approach the bag-and-hoop in the number of weevils collected from any given area and, since the bag-and-hoop certainly does not collect all present, the mechanical picker must leave a very high percentage. The observations on the infested forms collected likewise show the bag-and-hoop to be very much superior to the mechanical picker. It is only in the time required that the mechanical picker shows an advantage over the bag-and-hoop. These figures show the bag-and-hoop to require about 20 minutes per row, while the mechanical picker required only from two to three minutes per row.

One interesting observation was made on the comparative efficiency of different individuals when using the bag-and-hoop. While conducting the test on July 13, it was noted that one of the negroes operating the bag-and-hoop was very fast, while the other one was very slow. Consequently, separate records were kept for these two women. It was found that the faster woman took just one-half the time to the row that the slower one did, and the faster woman averaged 14 weevils per row while the slower one averaged 4. This is an excellent example of the variation in the efficiency of the individual pickers.

GENERAL CONSIDERATIONS AND SUMMARY.

The studies described in the preceding pages, together with those of the season of 1915,[1] seem to warrant some conclusions on the subjects dealt with and a general consideration of their relation to the planter.

Two points stand out preeminently in the results of the studies of 1916. These are (1) the complete failure of the picking operations to exert any appreciable beneficial effect on the weevil infestation, and (2) the injurious effect of the use of the bag-and-hoop upon the plants themselves. All points considered in connection with these studies, such as the degree of weevil infestation, plant fruitage, and actual yield, have shown consistently that the bag-and-hoop treatments were not reducing the weevil infestation within the treated plats to any extent. The control exerted by the collections of the weevils seems to have been completely overcome by the number of weevils escaping capture. In this connection it is interesting to compare the results of 1915 with those of 1916. It will be recalled that studies on the collection of fallen forms conducted in the face of the light weevil infestation prevailing during 1915 resulted in a definite

[1] U. S. Dept. Agr. Bull. 382.

weevil-control reaction, though this control was by no means complete. In 1916, however, with a rapid multiplication of weevils and a heavy infestation, no evidence of control was secured from the weevil collection. The question of the relation of the degree of infestation to the effect secured from practicing these control measures has been raised frequently, and apparently it has a very definite bearing on the difference in the results secured during the two years. It might appear that if a certain amount of benefit is to be derived from the control measures during a year of light infestation, this benefit will be increased proportionately in a year of heavy infestation. The results secured do not support this idea, however, and it seems to the writers that a year of light infestation, such as prevailed during 1915, presents the optimum conditions for securing the maximum degree of control from the picking operation. It must be conceded that the most thorough picking operation will not secure all the weevils present; say, for the sake of discussion, that 75 per cent are secured. If 100 weevils per acre are present in the field at the time of the picking (as would be the case during a light infestation), 25 would be left, and this number would be below that required to produce serious injury to the crop. On the other hand, assuming that there were 1,000 weevils per acre in the field and 75 per cent of these were collected, 250 would still remain, which would be sufficient to produce great injury to the crop, if not the maximum injury. It must be recognized that the degree of weevil injury in the field is not always directly proportionate to the number of weevils present; that is, the amount of injury per weevil decreases considerably with the increase of the number of weevils per acre, owing to the lessened chances of each individual for injury and what might be called the "duplication of effort" in the repeated puncturing of the same form. With the average degree of infestation reached in the Delta during midsummer, there is a great excess of weevils for producing the maximum injury to the crop, and a considerable number of these can be removed from the field without increasing the crop secured to any appreciable extent.

In addition to this consideration, the actual effect of this collection of over-wintered weevils in relation to their propagation is of interest. Under normal conditions, the percentage of squares punctured during the period when the weevil pickings are practiced is comparatively low. The normal shedding of forms in upland cotton is so high that the squares punctured by these hibernated individuals simply serve to take the place of a portion of those which would be shed normally. Consequently, these over-wintered weevils do not injure the cotton crop directly; their only effect on the crop itself in such a case lies in the progeny they produce and the activity of these progeny. Therefore, the only beneficial effect secured from collecting these hibernated weevils would be the reduction of their progeny. In practice it is found that two factors serve to prevent the complete elimination of these progeny. These are the eggs deposited by the weevils before capture and the percentage of hibernated individuals actually escaping capture. As has been stated, if undisturbed, the weevils in the Delta usually will produce more than sufficient progeny to cause a maximum crop injury by midsummer. In view of the results of the control experiments under heavy infestation conditions, it seems that enough weevils were missed and sufficient eggs were deposited before collection by those actually captured to develop sufficient progeny for a maximum infestation of the crop.

In view of these considerations, it seems to the writers that in a year of light infestation a slight degree of benefit may be secured from the picking operations, but that in a year of average or heavy infestation this benefit is completely lost. This conclusion is borne out by the experiences of various planters which have come under the observation of the writers, and is especially discouraging in view of the fact that in a year of heavy infestation the control measure is most needed.

Another point of primary importance in connection with the plantation use of these control measures is the labor problem. This requires a consideration of the labor supply available on the average Delta plantation, the labor requirements of the ordinary plantation operations, and the labor requirements of the weevil-picking operation. In the first place, it is advisable to consider the organization of the labor by which these picking operations are to be conducted. These measures are practiced only on a tenant basis, where a "family" takes care of a certain quantity of land. This land usually is divided between cotton and corn, the greater portion being in cotton. In addition to the labor involved in caring for this land it is necessary for the plantation to levy upon the male members of these families for a certain amount of wage labor to be used in the care of the oat and hay crops, which are handled only on a wage basis.

RELATION BETWEEN LABOR SUPPLY AND MALARIA.

The Bureau of Entomology is conducting an investigation on the Hecla plantation, the estate where one of the writers' tests was conducted, on malaria mosquitoes and their control. In determining the exact relation of malaria to crop production, Dr. D. L. Van Dine made a detailed analysis of the available and required labor on this plantation. In his published account[1] of this work, Dr. Van Dine gives a chart showing the duration of each of the operations involved

[1] Van Dine, D. L., "The relation of malaria to crop production." *In* The Scientific Monthly, November 1916, p. 431–439.

Van Dine, D. L., "The losses to rural industries through mosquitoes that convey malaria." *In* Southern Medical Journal, Vol. VIII, No. 3, p. 184–194. March, 1915.

in the production of cotton, corn, and oats and a table showing the labor requirements of each operation for each crop. From these the writers have prepared figure 1. This diagram shows not only the period of each operation for each crop but also, by the block system, the labor requirements of each crop.

In this chart the writers have added a block showing the labor requirements for weevil picking in the same manner. This was figured on a basis of four pickings with the bag-and-hoop, extending

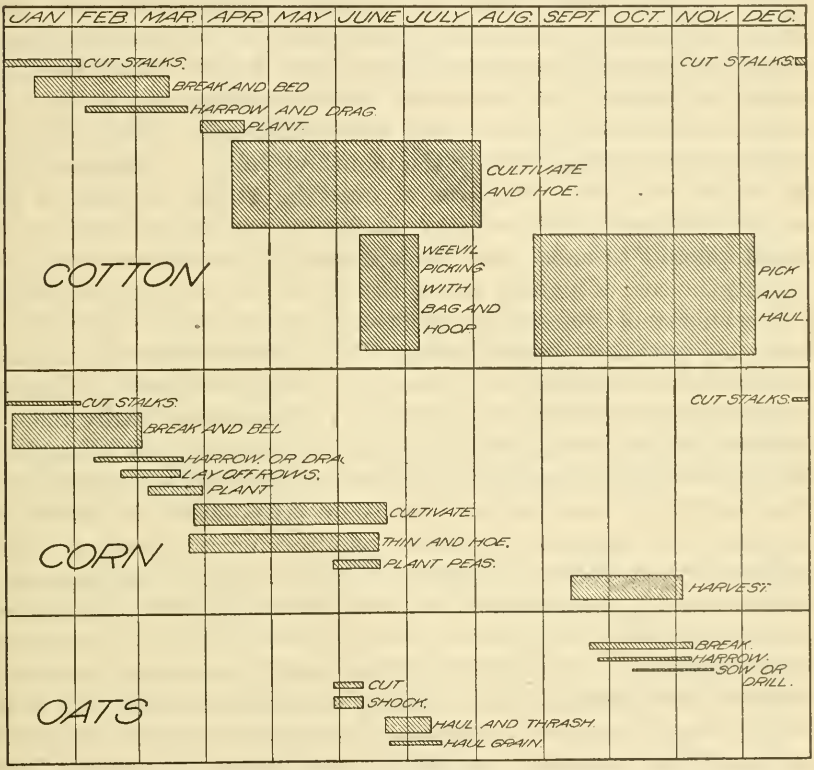

FIG. 1.—Seasonal distribution of field labor in northern Louisiana. Based on 823 acres of cotton, 657 acres of corn, and 200 acres of oats. (Original.)

over the period from June 10 to July 8, making the time interval between pickings about one week. The total acreage in cotton was 823 acres. Of course, all of this would not be picked over under normal conditions; particularly since the work would be more or less concentrated on the more heavily infested portions. Consequently, it was assumed for the sake of conservatism that only two-thirds of this acreage would be treated, or 548 acres. Extensive observations on the time required for the operation of the bag-and-hoop have shown that about the best which can be expected is an average of one and one-fourth acres per hand per day. However, these calculations were made on a basis of one and one-half acres per hand per day. At this rate, each picking of the 548 acres would require 365 labor days, making the four pickings require a total of 1,460 labor days.

In his paper Dr. Van Dine shows that the labor requirements of the ordinary plantation operations (excluding boll-weevil control) on this plantation during the month of June were 1,814 days. He also showed that the available labor days during this same month were 1,719. In other words, there was an actual shortage of 95 labor days during this month. Considering that three of the weevil pickings would fall during the month of June, a total of 1,095 June labor days would be required for conducting this operation, and as there is already a deficit of 95 labor days, this would make a total of 1,190 days of labor shortage during the month of June. Consequently, if the weevil control is practiced it must be at the expense of the neglect of some of the ordinary plantation operations. In fact, it would amount to about two-thirds neglect of these operations. In figuring the cost of malaria to the plantation Dr. Van Dine has shown that each day of crop neglect produced a loss of $5.11. Since every labor day put in at weevil picking would mean a labor-day neglect of the other operations, it is seen that, while no direct outlay for wages might be involved, the 1,460 days required would really amount to an expenditure of $7,300 at the rate of $5 per day loss for neglect. While this may be reduced by reducing the number of pickings, that would still not relieve the labor crisis which is shown in Diagram I, as the amount of labor required for each picking would still be the same unless they were conducted at longer time intervals. It is interesting to note that this same Hecla plantation attempted a thorough and systematic control of the weevils by the bag-and-hoop collection of the weevils in 1914, and this resulted in such a complete derangement of the ordinary operations without any benefit with regard to weevil infestation being shown, that the attempt has never been repeated. Although these figures of available labor are based on this plantation only, this plantation certainly is as well supplied with labor and as well organized as any in the district in which it is located.

The writers have had the opportunity of examining the original data upon which Dr. Van Dine's figures are based. Table 38 is a summary of the figures obtained on Hecla plantation in 1914 on the age, sex, and numbers of the 74 tenant families, giving the total number available for field work, the theoretical equivalent in man days, and the actual man days available for field work.

TABLE 38.—*Available labor by sex and age groups on Hecla plantation during 1914.*

Age groups	Male.				Female.				Total.
	0 to 7	8 to 12	13 to 18	19 up.	0 to 7	8 to 12	13 to 18	19 up.	
Number individuals present.	19.0	14.0	29.0	82.0	24.0	18.0	26.0	87.0	299.00
Reduced to theoretical man-days labor	....	4.5	14.5	82.0	....	2.25	6.5	43.5	153.25
Actual man-days labor	....	2.38	7.68	43.4	....	1.19	3.44	23.03	81.12

It will be observed from Table 38 that after determining the actual individuals of the various sex and age groups present on Hecla plantation this was reduced to a basis of the theoretical number of man days of labor in each of these groups. However, it is quite obvious that this theoretical figure does not represent the available labor actually present. Certain factors operate on all plantations to reduce this theoretical labor. Again referring to the study made by this bureau on the relation of malaria to crop production, the following estimate has been made of the reduction in the available labor supply:

In 1914, 138 persons in the tenant families out of a total of 299 suffered from malaria. Dr. L. O. Howard is the authority for the statement that the efficiency of a person suffering from malaria is reduced 25 per cent. Not taking account of the cases in children under 8 years of age and reducing the ages of those above 8 years to an equivalent of adult time, an equivalent of the time of 18.5 adult men was lost during the season of 1914 through inefficiency due to malaria.

It is a fact that the negro is incapable of maximum continuous effort during an entire day when at work, and aside from illness or other demands on his time will not under the tenant system work in the field every day when field work is possible. It is necessary to figure not a man day but a negro-man day, and this falls far short of what may be expected when continuous effort is made during the entire day and full advantage taken of working in the field on all days when field work is possible. Thirty days can not be counted on in every month for field work, since account must be taken of Sundays, holidays, and the weather conditions. The error would be as great to figure as available all labor not necessarily detained at home. Account must be taken of the class of labor upon which dependence is placed. It is considered that 25 per cent must be deducted from the total adult time available for this reason. Of the labor available on Hecla in 1914, this would be equivalent to the time of 38.31 adults.

OTHER CONSIDERATIONS CONNECTED WITH LABOR.

It is estimated that a further reduction of 10 per cent in the available labor must be made, to allow for the "pensioners" on the plantation, for those suffering from diseases other than malaria, for the care of infants and the cooking on the part of the women, and for absences from the field on account of funerals and other interruptions. This is equivalent to the time of 15.32 adults. The actual total adult time available, then, is only 81.12 instead of 153.25 adults. In Table 38 this available time has been reduced to adult time in the various groups arranged by age and sex.

Based on averages of 50 plantations in northern Louisiana, the Office of Farm Management of this department estimates that there are 19.1 days in June when field work is possible on a plantation. Taking this as a basis the various age groups shown in Table 38 have been reduced to available labor for the entire month of June. This is shown in Table 39.

TABLE 39.—*Total man days available of different types of labor on Hecla plantation during June, 1914.*

	Male.			Female.			Total.
Age groups	8 to 12	13 to 18	19 up.	8 to 12	13 to 18	19 up.	
Theoretical labor days available.	85.95	276.95	1,566.2	42.97	124.15	830.85	2,927.07
Actual labor days available	45.45	146.68	828.94	22.72	65.70	439.87	1,549.36

Taking the figures shown in Table 39, it is possible to determine just what classes of labor could be used in this weevil-picking work on the basis of three pickings requiring 1,095 labor days during June. Taking the actual labor days available in the different classes, it is seen that there are 22.72 in the group of females from 8 to 12 years of age, 65.7 females from 13 to 18, and 439.87 females of 19 or older. Consequently, the total man days of labor available of the female sex on Hecla plantation during June is 528.29. It is obvious that it would be necessary to take some male labor as well for the picking operation. There are 45.45 labor days of boys from 8 to 12 years of age. Adding this to the female labor makes only 573.74 labor days. There are 146.68 labor days of males from 13 to 18. Adding this to the preceding total gives 720.42 labor days, which is still 374 days short of the number required for the weevil-picking work. In other words, if all the female labor and all of the male labor under 19 years of age were devoted to weevil picking there would still be a shortage of 374 labor days for the picking operation. As the only labor left available is the males of 19 years or older, some of these must be utilized on the picking work. There are approximately 829 labor days of this group available. Consequently, if we subtract the labor required for the picking operation from that available during June there are only 455 labor days remaining. However, it was found in the malaria investigations that 199 labor days were lost directly because of malaria during June, and subtracting this number from the 455, the reare only 256 labor days left for conducting all ordinary plantation operations during the month of June, and it has been shown that these ordinary operations require a total of 1,814 labor days.

Going back to Table 39, it is of interest to calculate just what proportion of the theoretical labor would be required. If the three groups of female labor and the males from 8 to 12 are totaled, it is found that 1,093.92 days result. In other words, even on the basis of the theoretical labor, which is far from the actual labor available, it would require all of the females and all of the males up to 13 years of age to conduct the picking operations.

These observations on labor requirements and available labor seem to show definitely the impracticability of the systematic use of the bag-and-hoop on the plantation. Since comparative efficiency observations have shown that the bag-and-hoop requires only one-fourth as long as the hand picking of weevils and collects twice as many to the acre, the outlook for hand picking is very discouraging to say the least. As the labor available is not sufficient to conduct the bag-and-hoop collections, it certainly is not sufficient for the hand pickings, which would require four times as much labor. In addition, if the proportion of weevils collected with the bag-and-hoop is not high enough to benefit materially an average or heavy infestation, there seems to be little chance of securing a benefit from hand picking one-half this number of weevils. Still another method of control is the hand collection of fallen squares. Observations on the labor requirements of this have shown that the best which can be expected is one acre per day per hand. Thus this operation would require one-third more labor than the operation of the bag-and-hoop and is eliminated in the same manner.

The type of labor available for this weevil picking and the type required are also of interest. In view of the general labor shortage prevailing in the Delta, it is necessary for the women to assume the responsibility of all operations possible. This naturally results in their use as hoe hands in restraining the grass growth in both cotton and corn, particularly cotton. In case of a rain delaying operations and causing an excess of grass growth, it falls to their lot to save the cotton crop by hoeing, while the men are attempting to catch up with the strictly masculine operations. This condition is met at some time practically every season in the Delta and shows the importance of the women in the labor complex of ordinary operations. Under such conditions (and these are normal conditions in the Delta) the only labor left available for weevil and square picking operations without taking hands from some other operations is that of the children who are too small to hoe.

In this connection it is necessary to consider the type of labor required for the control operation. It would seem that the children and such women as might happen to be available should be able to reduce the weevil infestation somewhat by picking, but this is not the case. As a general rule negro children working alone will accomplish nothing. Their only incentive for effective work lies in the continued presence of older people who will force them to work properly and continuously. This would of course involve the presence of at least a few women with each group of children, and when the family is the unit the mother would be forced to neglect the hoeing and work with the children. Even this would be practicable under some conditions if it were not for the attitude of the women. It is generally recognized that negro women are very unsatisfactory workers at many plantation operations without the presence of men to keep them at work. This is particularly true of the weevil-picking operation, as this work is very distasteful to them and they wish to slight it. Of course this is due to the fact that the incentive for performing arduous and distasteful labor is not as great with the women as with the men because, generally speaking, the women are not as much concerned as the men in securing a successful crop. As a result it is generally found that to secure a picking which in any way approaches thoroughness it is necessary to have a certain number of men with each force of laborers. At any rate, regardless of the necessity of the presence of men, a small amount of child labor is in reality the only surplus labor available, and this is certainly far from sufficient to produce any effect upon the weevil infestation. Any addition to this labor only depletes the ranks of those employed in the ordinary plantation operations, and must result in some neglect.

The discovery of the injurious effect of the use of the bag-and-hoop on the plant is of great importance. Owing to the seriousness of the labor problem concerned in these operations, the first studies of the use of the bag-and-hoop looked very encouraging, as it was certainly a great advance over hand picking in both speed and efficiency of operation. However, the studies of the past season have shown definitely that the use of this semimechanical picker can not be recommended.

The studies on the infested forms collected by the bag-and-hoop are considerably reduced in practical importance by the discovery of the injurious effect of this collector on the plants. However, the general tendency of these studies is to emphasize this injurious effect, as from 25 to 50 per cent of the forms which were collected in the bags proved to be uninfested. Of course, a certain percentage of these were uninjured forms which would shed normally, but a considerable number undoubtedly were good forms which were broken off by the shaking process.

The comparison of the two varieties of cotton was not sufficiently complete to allow any general conclusions, but the most important point seems to be that the bag-and-hoop collects a higher proportion of the infested squares on the long-staple variety than on the short.

The failure of the mechanical picker to give satisfactory results is very discouraging, as such a picker seems the only solution of the labor problem involved in the collection of weevils and squares. As has been mentioned, the picker tested was the most promising which had come under the observation of the writers, but proved to miss a sufficient number of weevils practically to prevent any reduction in the infestation. In addition, this picker was so injurious to the plants that it actually reduced the crop considerably.

The information secured on the interplat movement of the weevils in the various field experiments is of considerable importance in the interpretation of the results of such tests. It is seen that in each case there was a more or less increased infestation in the picked rows immediately adjoining the unpicked cotton. However, this was usually slight and extended only a short distance, so it was certainly not sufficient to prevent the control measures from producing a beneficial effect in the treated plats, if they would do so under field conditions. This conclusion is borne out by the fact that identical tests where the control measure tested proved effective have shown a quite definite control reaction within these comparatively small plats. It is probable that the small size of the plats would somewhat reduce the extent of the gain in production from any beneficial treatment owing to the immigration of the weevils from unpicked cotton late in the season, but it seems fair to assume that when applying these results to field conditions this factor would be at the very least counterbalanced by the greater thoroughness of the picking operations in these plat tests. It should be remembered that a limited number of pickers were used in all of these plat tests and that they were under the constant supervision of one or more of the entomologists. As a result, the operations were conducted far more thoroughly than would be possible under field conditions.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 566

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. ▼ June 18, 1917

THE EUROPEAN EARWIG[1] AND ITS CONTROL.

By D. W. JONES, *Scientific Assistant.*

CONTENTS.

The European earwig (fig. 1) was first noted at Newport, R. I., in 1911 and is now present there in vast numbers. While it is not

FIG. 1.—The European earwig (*Forficula auricularia*): Adult males at left, adult females at right. (Original.)

considered of great economic importance in Europe, it has increased so rapidly in Newport that it has become a serious pest and caused

[1] *Forficula auricularia* L.

NOTE.—The first visit to Newport to study the habits of this insect was made by the writer in August, 1915. Eight trips of this kind, averaging four days each, were made during the summer and fall. Work was resumed May 6, 1916, and experiments were under close observation through the entire season. Mr. T. Suffern Tailer, a resident of Newport, whose grounds are in the heart of the area infested by this insect, gave financial support to cover expenses of the control measures and furnished the writer a large room to be used as a laboratory. With his cooperation and the help of his head gardener, Mr. William Edward, many facilities for the study of this insect were provided. Cooperation was also secured from other owners and gardeners, and Mr. Perez Simmons, a graduate of the Massachusetts Agricultural College, assisted in the application of control measures. The photographs used were made by Mr. Harold A. Preston of the Gipsy Moth Laboratory.

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much annoyance. It is not unreasonable to suppose that this insect will spread to other sections of the country and cause great annoyance to farmers.

A much smaller colony, which, however, has increased rapidly, was reported from Seattle, Wash., in 1915. Other reports of the occurrence of this earwig in the United States appear to have originated from one or two cases in which isolated specimens were captured on imported plants.

This earwig is found all over Europe, but is seldom present in extreme numbers. It is impossible to say from which of the European countries the colony at Newport originated, or how the first individuals were imported. Quantities of nursery stock arrive from abroad each year upon which the importation may have been made.

DESCRIPTION AND SEASONAL HISTORY.[1]

THE EGG.

The female earwig lays from 50 to 90 shining white eggs (fig. 2) in the ground, the eggs being about one-twentieth inch in length. Forty females were mated and placed in separate cans of soil for observation. One deposited 82 eggs between November 6 and 10. On December 26 a second examination showed that 30 of the females (75 per cent) had deposited eggs. These females do not die at once, but hibernate, and in the spring attend the larvæ in their early stages. During the previous year in a few cases eggs were deposited in the spring, but failed to hatch.

Fig. 2.—Eggs of European earwig. Enlarged twice. (Original.)

Mellow garden soil with a southern exposure is a favorite place for egg deposition. Many hibernating females and their eggs have been found from 2 to 3 inches below the surface of the lawns.

THE LARVA STAGES.

The young earwigs, or larvæ, may be found in the ground, or at night on the soil surface, about May 5. They resemble the adults in general form, but have no wings and only delicate, simple forceps or pinchers on the posterior extremity of the body. At first they are pure white, but the color slowly darkens to a delicate olive green which has a peculiar shiny appearance. About June 9 they appear very dusky olive green, or even steel gray, with almost transparent

[1] The season during which these notes were gathered was rather peculiar. The entire spring was so cold and wet that foliage and insects were retarded in their development approximately one week. The summer was nearly normal, but was followed by a long dry fall. No killing frost occurred until the second week in November, and no real freezing of the soil took place until after December 1. The larval development in an ordinary season would be approximately one week ahead of the dates given for 1916, while the fall dates for hibernation and egg deposition usually would be from one to four weeks ahead of those in 1916.

legs and a dull-brown head (fig. 3). There are four larva stages which gradually approach the adult in size and color. The change from the fourth larva stage to the adult form takes place about July 18.

FIG. 3.—Larva of European earwig. Enlarged twice. (Original.)

When first hatched the larvæ leave their underground nests, most noticeably on warm nights about two hours after dark. They swarm over the ground, but usually stay within 2 or 3 feet of the entrance to their nest. On cold nights few can be found. As they grow older they are active even on cold, wet nights.

Young larvæ feed on very tender green shoots such as clover and grass, and possibly portions of grass roots. Later they feed extensively on green shoots such as Lima-bean (fig. 4) or dahlia plants (fig. 5 in comparison with fig. 6). By July 1 dahlia buds begin to appear and the blossoms of sweet William and early roses are plentiful. These are damaged greatly by the young earwigs. The bases of the petals and the stamens are eaten and the old taste for green shoots disappears if favorable flowers are near.

FIG. 4.—Lima bean plant partially eaten by young earwigs. (Original.)

THE ADULT.

The adult is rich reddish brown, with the wing covers and legs dull yellow brown, and the wings completely developed. From head to tip of forceps it is about three-fourths of an inch in length. The forceps of the male are curved into a semicircle, or slightly elongated, with a tooth at the point of divergence. In the female the forceps are nearly straight.

The adults feed almost entirely on the petals and stamens of flowers, although many other kinds of food, such as clover, grass, terminal buds of chrysanthemums, and other fall flowers, are eaten. They kill and eat certain unprotected, sluggish larvæ, dead flies, and the dead or dying of their own species.

In late summer the adults congregate in large numbers in crevices or behind vines (fig. 7), near a good food supply. This concentration of large numbers of earwigs in favorable hiding places is due entirely to the mating instinct.

FIG. 5.—Dahlia plant defoliated by young earwigs. (Original.)

HIBERNATION.

Adult males seldom live over winter in Newport, R. I. Nearly all of them die after copulation, which occurs in the fall, before cold weather sets in. An occasional male is found in the ground with a female in the late fall; these males usually die before spring.

Adult females hibernate in the ground from 2 to 8 inches below the surface. Any well-drained soil is suitable, either in gardens or under the sod of the lawns. In some cases, as has been explained, they deposit eggs just before hibernating, so that this insect passes the winter in both the egg and adult stages.

Emergence from hibernation is dependent on the temperature. In 1916 females did not leave their hibernation quarters until the last week in April.

No migration appears to occur in the spring, except individual search for food. Apparently only a very small percentage of the total number of adult females is able to live over winter successfully.

DISAGREEABLE HABITS OF CONCEALMENT.

The adult earwigs hide very quickly if disturbed by a sudden light or some unusual noise. During the day they hide in any crevice, fold of clothing, or even behind a convenient leaf which offers protection. Thus one finds them in large numbers on the porches, behind the chair cushions, under the rugs, and in folds of awnings. On one estate, each morning when the porch awnings were let down, over a quart of earwigs dropped out and were swept up and burned. The writer has seen at least 300 adult earwigs in one of the servants' halls at Newport. They were behind the cushions in the chairs, in

FIG. 6.—Normal, uneaten dahlia plant. (Original.)

folds of lace curtains, and even on the table. Bedrooms and bathrooms of the finest houses may be invaded by occasional adults in spite of careful watchfulness and screens. They are decidedly repulsive when found crawling rapidly over the walls or furniture at night. The stories about bodily harm done by these insects are all without foundation.

AREA INFESTED.

The evidence at hand regarding the area infested previous to 1914 is very meager. It consists of data drawn from conversations with gardeners of the various estates. In almost every case they are men of education and trained powers of observation.

1911.—Mr. T. Suffern Tailer owns the estate where the first earwigs were noted. His gardener believes that a very few were present in 1911.

1912.—Mr. Tailer and his gardener state definitely that earwigs were present in 1912. Specimens were sent to Washington, D. C., by Dr. A. E. Stene, of the Rhode Island State College.

1913.—The infestation in 1913 had spread to adjoining estates. Large numbers were found on Mr. Tailer's estate and his men attempted certain control measures.

FIG. 7.—A typical congregating place for adult earwigs. (Original.)

1914.—About 1 square mile was heavily infested in 1914. Mr. Richard Gardener, of Newport, wrote to the Bureau of Entomology at Washington, asking for information regarding the insect.

1915.—The infestation during 1915 was so heavy that letters requesting information about methods of control were sent to Washington and to the State college at Kingston, R. I. A careful scouting conducted by the writer showed that about 9 square miles were heavily infested. This area is bounded on three sides by water. On the fourth side, 2 miles of territory in addition to that infested in 1915 had small scattered colonies. One isolated colony was located about 6½ miles northeast of this infested area, on the estate of the late Alfred Gwynn Vanderbilt, of Portsmouth.

1916.—About 10 square miles were heavily infested in 1916 and many new small colonies were found outside of this area. The small colonies of the previous year showed considerable growth. In some cases hundreds of earwigs were present on estates where only a few were found the year before.

METHODS OF DISPERSION.

This species rarely if ever spreads by flight: in fact, experimental efforts to induce these insects to use their delicate and complex wings were unsuccessful.

Many cases have been noticed where adult earwigs have been carried long distances in folds of clothing. Visitors to Newport may spread the insect to near-by cities in this way. Several isolated colonies located at a distance from the main infestation are at points where automobiles frequently stop while their owners walk about the extensive grounds.

These insects may be spread while hiding in the packing material or the soil of shipments of plants and general nursery stock. One dead specimen was found by J. J. Pillsbury, assistant State entomologist of Rhode Island, in a shipment of plants from Holland. The writer has noted these insects in the fall between the toes of dahlia bulbs.

NATURAL ENEMIES.

A parasitic, threadlike worm has caused the death of approximately 10 per cent of the earwig larvæ under close observation in the laboratory. This worm[1] lives free in the body cavity of full-grown larval and adult earwigs. The average measurements of five of these parasites was 3¼ inches by $\frac{1}{48}$ inch.

Various other parasites are reported as having been reared from this species of earwig in Europe, but at Newport those so far dissected have been free from parasites except in the case of one small unidentified larva and the worm just referred to.

Toads eat earwig larvæ readily, but are not common at Newport.

Hens devour adult earwigs ravenously. One hen ate 10 of these insects thrown to her in as many seconds. Under natural conditions these insects are hidden away so carefully through the day that fowls can hardly be considered as economically important in the sense of controlling the insect.

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[1] *Filaria locustae.*

CONTROL OF THE EARWIG.

NEED FOR SPECIAL CONTROL MEASURES.

In Europe this insect appears to be held in check by parasites and other natural agencies, and it is very rarely present in large numbers. Gardeners who raise prize dahlias, chrysanthemums, and flowers of that class are the only ones who consider the earwig an actual pest. As a result control measures have developed slowly. Their aim has been simply to protect a small area from the depredations of a comparatively small number of earwigs. Various methods of trapping have been developed which satisfy the need, so no better methods have been worked out.

At Newport, as has been stated, this insect occurs in vast numbers. The lack of parasites and other natural enemies, together with the favorable conditions met with at every stage of the life history, has made this rapid increase possible.

The control measures offered in this paper have been developed through laboratory tests and later have been tested in field trials on a large scale.

POISONED BAIT.

For early spring control, May 15 to June 15, poisoned-bread bait has proved extremely effective. In fact, it gave far better results than any other mixture that was tried. This method would prove cumbersome and expensive for the average farmer, but its extreme effectiveness makes it the best to recommend at this time. Stale bread was secured in 1916 for approximately 2 cents per pound. The bait is prepared as follows:

Stale white bread	pounds	16
Paris green	pound	1
Water.		

Grind the bread up fine in a meat-chopping machine and mix the Paris green with it while dry. Stir the mixture thoroughly, slowly adding water enough to make a mixture which will run through the fingers, and one which, when thrown broadcast with some force, will break up into small particles. The addition of cheap honey to the mixture increases its effectiveness, but is not necessary.

This bait should be spread broadcast between dusk and 9 p. m. in gardens and on lawns near vines and shrubs. It should be thrown with considerable force in order to break the bait up into smaller pieces. If the infestation is heavy or was heavy the previous year, three applications covering about 10 days may be necessary. Warm evenings should be selected if possible, as on such nights the larvæ are more active.

SONG BIRDS AND THE POISONED-BREAD BAIT.

The danger to song birds from the poisoned bread is very slight in the spring. After the 1st of July, especially in dry seasons when worms are not plentiful, this danger probably would increase. On May 11 an attempt was made to see if song birds would feed on this poisoned-bread bait. A narrow, recently spaded garden was selected which was south of a small greenhouse and east of a high privet hedge, where various birds were plentiful. Bits of this poisoned bait, the size of a pea, were placed 2 feet apart and 4 inches from the grass border, around the entire edge of the garden. The next morning the writer seated himself inside the greenhouse before daylight and watched the birds from 3.15 until 5.45 a. m. Ten robins were noted hopping along parallel to or crossing the lines of bait. They confined themselves entirely to feeding on earthworms. A pair of chipping sparrows were feeding on the soil surface nearly all the time, and a pair of purple grackles stalked across the lines of poisoned bait. In no case did these birds pay the slightest attention to the conspicuous bits of green bread, and after two days none of the particles were missing. No such experiment was tried in the late summer when worms were less plentiful. Probably it would be dangerous to use this mixture on ground where hens had free range.

POISON SPRAYS.

Poison sprays are not effective after July 1 because of the habit developed by this insect of feeding on protected parts of flowers and the very new shoots of various plants. During the early stages, when larvæ concentrate their feeding on certain varieties of plants, these plants should be sprayed with arsenate of lead, 6 pounds to 50 gallons of water, care being taken that the young leaves especially are covered.

As this insect is known to feed somewhat on grass and clover it might be advisable to spray infested portions of lawns carefully with arsenate of lead, but more tests are necessary to show the effectiveness of this treatment.

CONTACT SPRAYS.

Contact sprays which would burn foliage or would be objectionable near the houses on account of their odor were discarded. Any spray used on plants when they are in full bloom tends to make the petals of the blossoms fall. A contact spray which has given very good results in experimental work at Newport is made as follows:

Soft potash soap	ounces	30
Water	do	96
Nicotine sulphate, 40 per cent	teaspoonfuls	20

Dissolve the soap in a little of the water over a fire, then add the rest of the water and the nicotine sulphate. This makes 1 gallon of stock solution at an approximate cost of 50 cents. Use 1 part to 22 of water.

Common laundry soap	pound	½
Water	gallons	4
Nicotine sulphate, 40 per cent	teaspoonfuls	5

The soap must be shaved fine and dissolved in about one-third of the water, then the rest of the water and the nicotine sulphate are added. This mixture is applied without further dilution and is therefore practical only on a small scale. It does not give as good

FIG. 8.—Flowerpot traps for earwigs. Shorter supporting stakes proved to be of advantage. (Original.)

results as that containing potash soap. Fish-oil soap also was tried in this formula but burned foliage after several applications.

The foregoing two, being contact sprays, must actually hit the insects and hit them well or death is not assured. For this reason thorough spraying must be done at night, the insects being hit with a *fine mist* as they crawl over the plants, vines, and grass. To supplement this night spraying it is well to treat with a stream of the same material any crevices where insects are plentiful through the day. If necessary, the spraying of heavily infested areas should be repeated at intervals of three nights until the results are satisfactory.

TRAPPING.

Trapping is the chief method of control recommended by European authorities. The best trap (fig. 8) appears to be a 3-inch flowerpot, with excelsior in the bottom, inverted over a 9-inch stick set in the ground close to plants or vines where earwigs are most numerous. The earwigs hide in the excelsior and should be shaken into a pail of water which has a thin film of kerosene oil on its surface. Pieces of bamboo, piles of straw, strawberry boxes, and in fact anything that offers shelter may be used; but these substitutes are either less effective or less easily handled than flowerpot traps.

MISCELLANEOUS.

In cases of extreme abundance earwigs may be kept from a porch by surrounding the porch completely with a 1-inch band of a suitable sticky substance. This sticky material prevents the invasion of earwigs unless some crevice exists under the band or some vine furnishes a bridge over it. To be effective this material should be applied by June 15, and its surface must be brushed over with a wire brush by July 15, and possibly once more during the season.

EFFICIENCY OF CONTROL MEASURES.

Experiments in the field with poisoned-bread bait in May were on a rather small scale. Several flower beds and small isolated lawns which were literally swarming with young earwigs were treated with this bait. The results were surprising. Very nearly 100 per cent of the larvæ were killed with one application of bait in each case.

Five estates were partially treated with this bait on June 22, 1916, and again three days later. The young earwigs at that time were passing rapidly into the fourth stage. As has been stated, the habits rapidly become similar to those of the adult. At this late date flowers such as sweet William and roses furnished food, and many of the earwigs had left their nests in the ground. Thus they were harder to reach with the poisoned-bread bait. It is estimated that over 75 per cent of the larvæ on these five estates were killed by these two late applications of bait. Far better results could be expected earlier in the season on favorable nights.

Spraying with contact sprays at night was done on a large scale after July 1. Mr. Simmons and an assistant used a barrel pump for this work, equipped with a Bordeaux nozzle. They planned to spray every three nights the same area, namely, the vines near the houses, and a 10-foot circle of lawn around each house. In this way the houses were kept free from the insect. This spraying was continued for over a month, although far less than 1 per cent of the usual number of earwigs could be found on these estates after July 20. A few continued to crawl in from surrounding estates, especially late in the fall.

Six flowerpot traps were placed near some dahlia plants throughout the season. These gave good results; but they are valuable only where the earwigs are scarce. They take care of the "crawl-in" after a garden has been treated with poisoned bait and contact spray.

Sticky substance was applied around the porches of one house. This is necessary only in extreme cases where no control measures have been applied and adult earwigs are causing annoyance in the houses.

SUMMARY OF RECOMMENDATIONS FOR CONTROL.

MAY 15 TO JUNE 15.

Spread poisoned-bread bait broadcast over the lawns and gardens. Select a warm evening about May 15 and apply the bait just before dark. Give one or two more applications of this bait at intervals of three or four nights.

Spray plants which show signs of having been eaten, using 6 pounds of arsenate of lead to 50 gallons of water, and being very careful to cover the young leaves with the spray.

AFTER JULY 1.

If the earwig has not been controlled in the spring, spray at night with a contact spray, covering the insects well as they crawl over the grass and plants. Repeat every three nights until the numbers are sufficiently reduced.

To supplement the night spraying look for crevices where earwigs commonly hide through the day. Squirt contact spray into these cracks every other day.

Place flowerpot traps every 10 or 12 feet along borders or near vines. Remove earwigs from the traps each day by shaking the excelsior over a pail of kerosene and water.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 571

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER December 15, 1917

THE PECAN LEAF CASE-BEARER.[1]

By JOHN B. GILL, *Entomological Assistant, Deciduous Fruit Insect Investigations.*

CONTENTS.

INTRODUCTION.

Because of the increasing importance of the pecan industry the Bureau of Entomology in 1913 established a field station at Monticello, Fla., for the purpose of studying pecan insects under the most advantageous conditions. The writer was placed in charge of the investigations, under the direction of Dr. A. L. Quaintance. In the spring of 1914 Mr. A. I. Fabis was detailed to assist in the work of this station. Extensive investigations, covering a period of nearly four years, have shown the value of certain repressive measures for the control of some of the more injurious pecan insects and have resulted in the compilation of considerable data on their life histories and natural enemies. One of the principal insect pests with which the pecan grower has to contend is the pecan leaf case-bearer (*Acrobasis nebulella* Riley). The present publication is intended to give the information now available concerning the life history and control of this insect.

The writer wishes to thank the various pecan growers who have rendered assistance in this work.

[1] *Acrobasis nebulella* Riley; order Lepidoptera, family Pyralidae.

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HISTORY.

The pecan leaf case-bearer (*Acrobasis nebulella*) was first described by Riley in 1872 (1),[1] under the name *Phycita* (*Acrobasis*) *nebulo* Walsh var. *nebulella*, from a single specimen reared from wild crab (*Crataegus* sp.). In 1887 Ragonot (2) described this insect as a "new species," naming it *Acrobasis palliolella*, and in the following year Hulst (3) also described it as "new to science," under the name *Acrobasis albocapitella*. In 1890, in Hulst's article on "The Phycitidae of North America" (4), *albocapitella* Hulst is listed as a synonym of *palliolella* Rag., and Riley's original description of this insect is given under the name *Mineola indiginella* Zell., var. *nebulella*. Ragonot (5), in 1893, in his "Monographie des Phycitinae et des Galleriinae," treated Riley's *nebulella* as a variety of *Acrobasis indiginella* Zell., and *Acrobasis palliolella* as a distinct species, giving *albocapitella* Hulst as a synonym. The same classification is given in Dyar's "List of North American Lepidoptera" (7), except that the species *indiginella* is placed in the genus *Mineola*. In Florida, in 1901, Gossard, then State entomologist (6), mentioned injury to pecans by *Mineola juglandis* and *Acrobasis caryae*, but the writer is of the opinion that some of this injury, if not all, should have been attributed to the pecan leaf case-bearer (*Acrobasis nebulella* Riley). In 1902 Gossard (8) again made brief mention of what was undoubtedly this species under the name "pecan bud-worm." Fiske (9), in 1902, under the caption "Notes on certain injurious insects in Georgia," gave life-history notes and suggested remedies for the pecan leaf-crumpler, which was presumably the insect discussed in this publication. The following year (1903) Chittenden (10) reported damage to pecan buds in Georgia by this species, and Herrick (11), in 1904, referring to Chittenden's report of injury in Georgia during 1902, gave notes on *Acrobasis* sp. It would appear that the life-history notes given in Herrick's article pertain to the pecan bud-moth (*Proteopteryx bolliana* Sling.) and not to the pecan leaf case-bearer. In 1905 Gossard (12), still the Florida State entomologist, gave an extended account of this insect, but unfortunately confused some of his notes and photographs on this species with those of the pecan bud-moth. In 1909 Herrick (14) published a bulletin on this species, giving remedies and incomplete life-history notes, as based on its occurrence in Texas. During the same year (1909) Dyar (13), under the caption "Notes on the species of Acrobasis, with descriptions of new ones," gave notes on both *A. palliolella* Rag. and *A. nebulella* Riley, stating that he "expects it will be found that *palliolella* is not more than a variety of *nebulella* Riley."

Worsham (15), in 1910, made a brief mention of this species as an important pest of pecan in Georgia, and in the following year (1911)

[1] Reference is made by number to "Literature cited," p. 27.

Chittenden (16) included it in his paper entitled "Insect enemies of the pecan." Gossard (17), in 1913, under the caption "Various insects affecting nut trees," gave a short account of this species and stated that errors crept into his publication (12) on insects of the pecan, with regard to the pecan case-bearer and the pecan bud-moth. The life history and habits of the pecan leaf case-bearer were given by the writer in a paper read during the meeting of the Florida State Horticultural Society in 1914.

The foregoing paragraphs include the more important references to this species in so far as the writer has been able to determine them.

SYNONYMY.

Dr. Dyar's position on the synonymy of certain species of Acrobasis is defined in the following advice under date of August 4, 1914, given in answer to an inquiry of the writer:

> *Palliolella* is the male, *nebulella* the female of one species I believe. The males are generally whiter over thorax and base of wings. *Nebulella* (1872)=*palliolella* (1887).

The synonomy of *Acrobasis nebulella* Riley is as follows:

Phycita (*Acrobasis*) *nebulo* Walsh var. *nebulella* Riley, Fourth Ann. Rept. Ins. Mo., 1872, p. 41.
Acrobasis palliolella Ragonot, Diag. N. A. Phyc., 1887, p. 4.
Acrobasis albocapitella Hulst, Ent. Am., 1888, p. 116.

It seems advisable to note that in 1909 Dyar (13) made the following statement concerning *Acrobasis nebulella* Riley:

> This name is listed as a variety of *Mineola indiginella* Zeller, but Riley's type before me is clearly an *Acrobasis* and differs from *palliolella* only in the gray color of thorax and base of forewings. *Minimella* Rag., made to replace Hulst's *nigrosignella* by Ragonot and referred to the synonymy of *caryae* Grote by Hulst, will find place here as a synonym.

DISTRIBUTION.

The pecan leaf case-bearer is a native insect and is distributed more or less over the same territory as is its preferred hosts, the various hickories. The following records show that it is quite widely distributed throughout the United States. The distribution for *Acrobasis nebulella* Riley and *Acrobasis palliolella* Rag., along with certain notes as given by Dyar (13), is as follows:

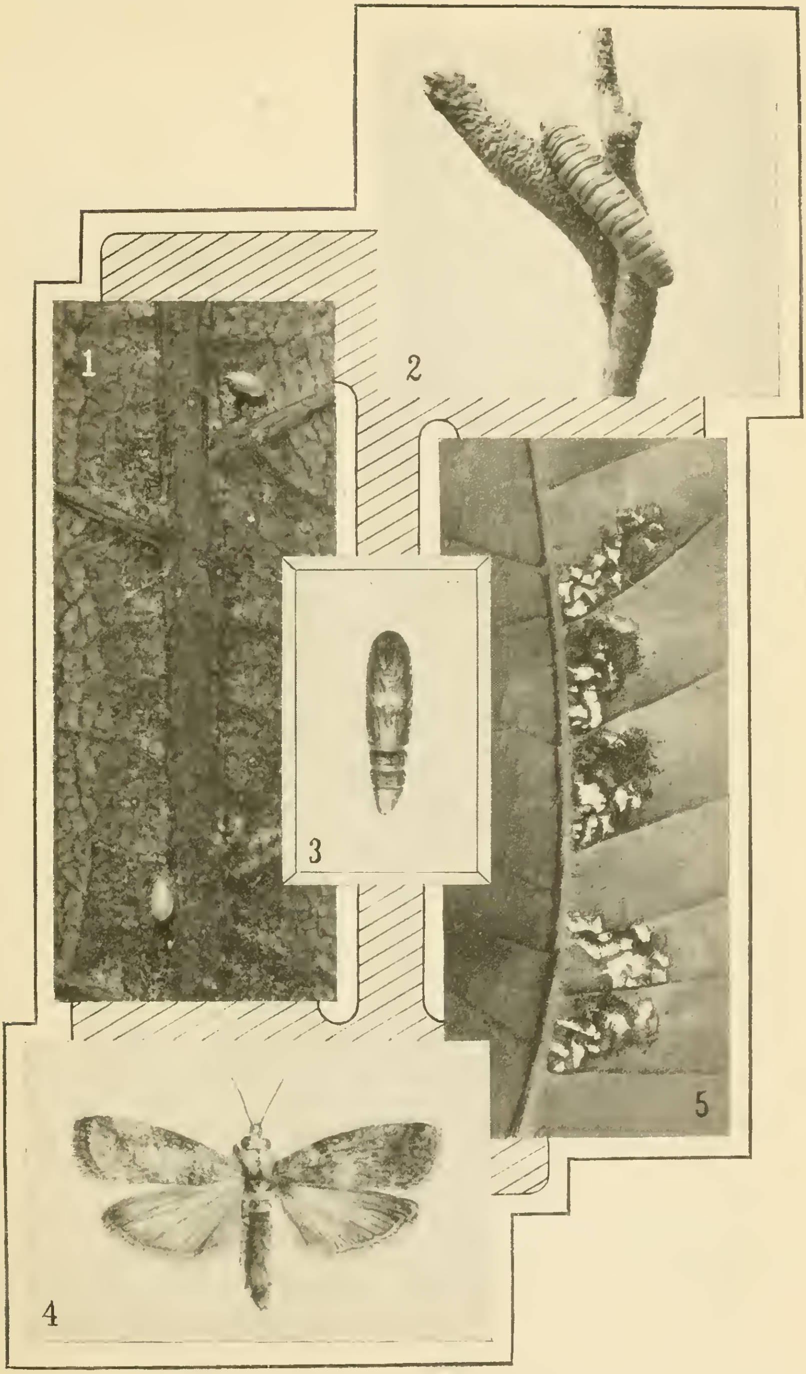
> Palatka, Fla., on pecan, issued May 27, 1903; Olustee, Fla., June, 1904; Black Jack Springs, Tex. (through Dr. Wm. Barnes); Cairo, Ga., issued June 7, 1903; Blackshear, Ga., on pecan, issued May 28, 1902 (W. R. Williams); Washington, D. C., on walnut, issued June 7, 1903 (August Busck); Chicago, Ill., July 1900 (Coll. W. B. Kearfott); Atlanta, Ga. (W. M. Scott); Kerrville, Tex., at light, May 30 to June 1, 1906 (F. C. Pratt); Blackshear, Ga., on pecan, issued June 12, 1902 (Dept. Agr. No. 8637); Rhinebeck, N. Y., July 27, 1888 (H. C. Dyar), the last a female and the reference, therefore, less certain.

H. M. Russell reported this species as reared from pecan on May 18 and 20, 1908, at Orlando, Fla. (Chittenden No. 348), and D. K. McMillan, at one time connected with the bureau, recorded it on May 25, 1908, from pecan at Brownsville, Tex. (Chittenden No. 1045). The material on which Riley based his description was probably collected in Missouri, and the material on which Hulst (3) described this insect under the name *Acrobasis albocapitella* was taken in Canada (Ontario). Fiske (9) reported it from Georgia, Gossard (12) from Florida, and Herrick (14) from Texas (Cuero and College Station). The writer has seen it occurring in injurious numbers on pecan in Florida, Georgia, Alabama, Mississippi, Louisiana, and Texas. It has been reported to be injurious in South Carolina, and it is also known to occur in North Carolina and Virginia, but in these States apparently it does only minor damage. So far as is known, this insect ranks as a serious pest only in the southern part of the pecan-growing area, but from the foregoing records it can be seen that the species is quite widely distributed over this country.

FOOD PLANTS.

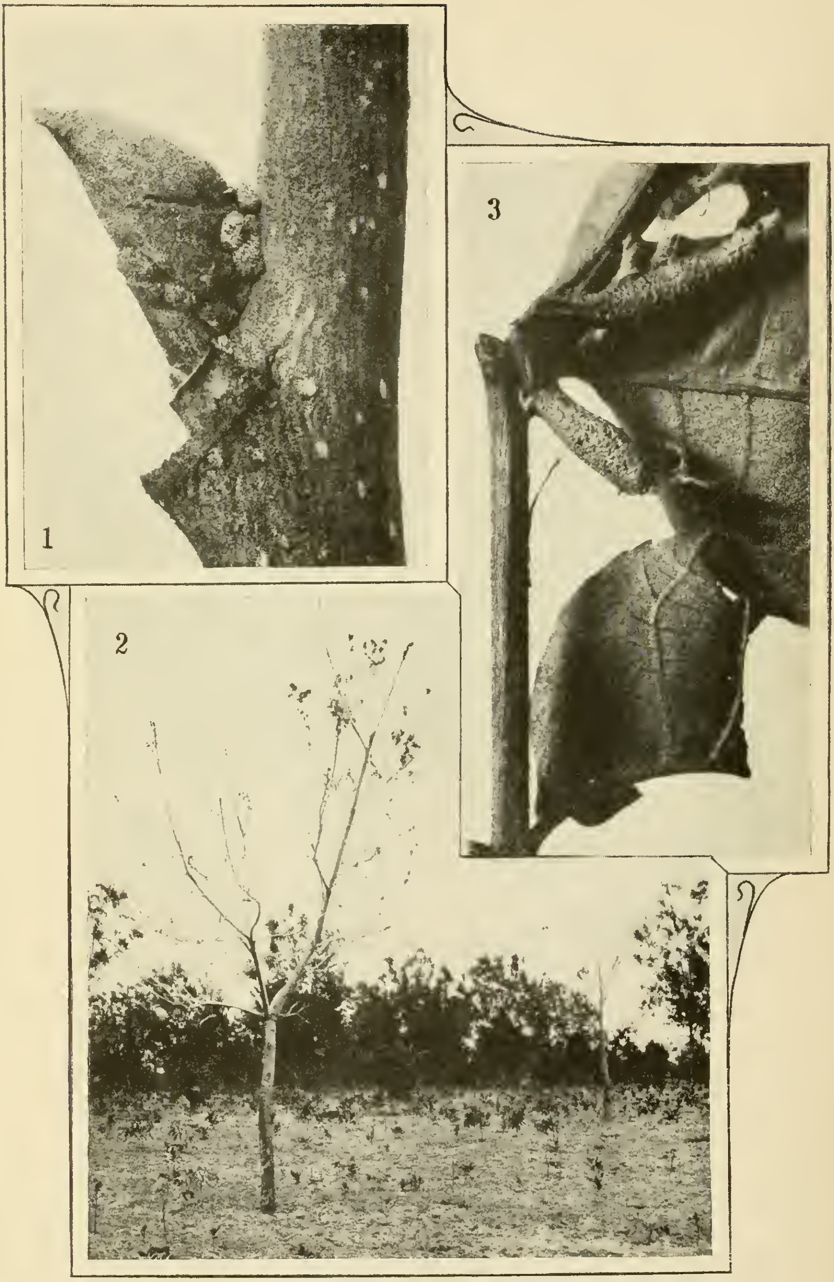
In his original description, Riley (1) gave wild crab (*Crataegus* sp.) as the food plant from which a single specimen was reared. Dr. Dyar (13) made the following statement: "I have 23 specimens before me, 4 bred by Dr. Riley on hickory and walnut, including the type of *nebulella*," and he also gave numerous records of its occurrence on pecan. Dr. Dyar (13) also gave a record made by Mr. August Busck in which this insect was reared from walnut on June 7, 1913, at Washington, D. C., and Mr. M. M. High (14) found it on wild hickory near College Station, Tex. Gossard (12) reared it in abundance from the pecan in Florida, and Herrick (14) states that he "reared many specimens from pecan at Cuero, Tex., where it was very abundant and doing serious damage." There are also many other records of this species occurring on pecan. So far as the writer's experience goes, the larvæ have been observed feeding upon hickory, Japanese walnut, and pecan, and moths have been reared from material collected on pecan and hickory. The writer has not yet found the black walnut to be attacked, although not infrequently that species has been found growing in close proximity to badly infested pecan trees. According to the writer's observation and experience it is very difficult to find larvæ on various species of Hicoria other than *H. pecan*, even in sections where this species ranks as a pest in pecan orchards. This species shows a decided preference for the pecan, and in many sections of the South it is the most injurious insect affecting the culture of this nut.

In making observations in pecan orchards in localities where this insect occurred in injurious numbers, an apparent varietal resistance



STAGES AND WORK OF THE PECAN LEAF CASE-BEARER (ACROBASIS NEBULELLA).

FIG. 1.—Eggs. FIG. 2.—Larva and case. FIG. 3.—Pupa. FIG 4.—Adult, or moth. FIG. 5.—Larval cases on pecan leaflet during the summer. All enlarged. (Original.)



WORK OF THE PECAN LEAF CASE-BEARER (ACROBASIS NEBULELLA)

FIG. 1.—Hibernacula, or winter cases, around pecan bud. FIG. 2.—Pecan trees defoliated by larvæ in the spring. FIG. 3.—Completed larval cases where pupation takes place. Figs. 1 and 3, enlarged; fig. 2, reduced. (Original.)

WORK OF THE PECAN LEAF CASE-BEARER (ACROBASIS NEBULELLA).

FIG. 1.—Pecan buds injured by larvæ in the spring. FIG. 2.—Larval cases on compound pecan leaf during the summer. FIG. 3.—Work of nearly matured larvæ on pecan foliage. FIG. 4.—Work of larvæ on pecan foliage at blossoming time. All slightly reduced. (Original.)

to its attacks was noticed. Such varieties as the Frotscher, Van Deman, Nelson, Pabst, Schley, Delmas, Stuart, and Success were badly infested, while the Mobile, Georgia, Havens, Teche, Waukeenah, Moore, Moneymaker, and Curtis were slightly infested. No reason can be given for this apparent varietal resistance, but it may be stated in general terms that pecan trees with very small leaves seem less likely to be heavily infested by this insect. Unfortunately, many of the best commercial varieties of pecan are subject to attacks by this pest.

CHARACTER OF INJURY.

The most serious damage to pecan occurs during the early spring. The larvæ feed voraciously upon the unfolding buds and leaves, as is shown in Plate III, figure 1. Just as the buds are bursting, the little overwintering "worms" gnaw their way out of their hibernacula (winter cases), which invariably are to be found snugly packed around the buds. Usually they migrate immediately to the tips of the swelling buds, upon which they partake greedily of their first meal. Upon leaving hibernation quarters some larvæ have been observed eating directly through the side of the buds, instead of entering at the tip as is usually the case. As these larvæ begin to work very early in the spring it takes but little feeding to inflict serious injury. On badly infested trees it is not uncommon to see from three to five larvæ, and sometimes more, entering a single bud. Under these conditions there is little chance for even partial development of the foliage. As the larvæ when in sufficient numbers are capable of eating the green foliage as rapidly as it appears, it is not unusual for the trees to remain defoliated for a considerable length of time. The writer has seen pecan trees kept in this condition for several weeks solely because of the attacks of this pest. On such trees the buds turn brown as a result of the feeding of the larvæ, and a block of badly infested trees takes on the appearance of blight by fire. (Pl. II, fig. 2.) When the infestation is less severe the larvæ web and tie the tender leaves together into masses, which soon become unsightly due to the wilting of the leaves and the presence of particles of excrement and larval cases with which they are united. (Pl. III, figs. 3, 4.) Late in the spring, when about half grown, the larvæ attach their cases to the leaf petioles, draw the leaflets together, and feed freely. (Pl. II, fig. 3.)

After having kept the trees in a defoliated condition for some time and, therefore, when pressed for food, these insects occasionally attack both blossom and leaf buds by burrowing directly into the ends. When thus deprived of their foliage the trees are fairly certain to become so devitalized as to be unable to make proper growth during the remainder of the season or to form fruit buds for the following season. Indirectly the trees suffer by becoming much more susceptible to attack by certain wood-boring insects and less able to withstand drought in summer.

During the summer and early fall the larvæ, then very small and feeding but little, will be found attached to the underside of the leaflets in brownish, minute, tortuous, and winding cases (Pl. I, fig. 5; Pl. III, fig. 2), which greatly resemble at a glance brown spots such as might be caused by certain fungi. These tiny cases are enlarged only as it becomes necessary for the larvæ to build their way to new feeding areas. A detailed description of the larval cases as they appear during the summer and fall months is given on page 7. So far as the writer has observed, the injury caused to the foliage during the fall is so slight that the leaves do not fall prematurely.

DESCRIPTION.

THE EGG.

The egg is elliptical in outline, somewhat convex above and flattened below. Viewed with the hand lens the surface is quite smooth, but under higher magnification it is very faintly punctate. When first deposited the egg is white with a slight greenish tinge, translucent, and iridescent in some lights. The empty shell is white. The average size of five eggs was found to be 0.55 by 0.33 mm. (0.0216 by 0.0129 inch). The eggs are deposited singly on the underside of the leaflet and usually at the junction of the veins with the midrib. Moths confined in rearing cages (battery jars) have been noticed sometimes ovipositing upon the upper surface of the leaves, but in no case has the writer observed such oviposition under natural conditions. (Pl. I, fig. 1.)

THE LARVA.

Upon hatching the larva is a little less than a millimeter (0.039 inch) in length. The head and prothoracic shield are brown in color, while the rest of the body is of a much lighter shade of brown. When extended the full-grown larva averages about 14.5 mm. (0.5708 inch) in length by 2.0 mm. (0.0787 inch) in greatest width. The head is round, shiny dark brown or blackish in color, and slightly rugose. The general color of the body is very dark green, except the prothoracic shield, which is somewhat lighter. The shape of the larva is nearly cylindrical, tapering slightly at both ends, but more posteriorly than anteriorly. The body is sparsely covered with fine long hairs and on either side of the dorsal surface of the second thoracic segment is a small well-defined tubercle, from the black center of which arises a fine hair. The skin, especially in the thoracic region, is quite wrinkled, there being a pair of crescentic folds on the dorsum of the second and third segments. Rudiments of these folds are evident on the other segments, but they are not prominent. The first four pairs of prolegs are quite short, only about one-half the length of the anal pair. The pedal end of each proleg is armed with two concentric ridges of minute claws or hooks. The thoracic legs are brownish, with a tinge of olive green, and each terminates in a single claw. (Pl. I, fig. 2.)

THE LARVAL CASES.

When first hatched the larva begins to feed upon the leaf surface about the egg. Soon after it constructs a brownish case out of excrementitious grains and a lining of grayish-white silken threads. The base of the summer case, as is shown in Plate I, figure 5, is invariably placed near the midrib. The case is enlarged by building away from the midrib in whatever direction the larva may chance to feed, and as the larva extends its feeding pasture in one direction and then in another the case soon assumes a very tortuous course. Throughout its entire length the case is securely attached to the under surface of the leaflet. It is composed of a rather flimsy texture of silken threads and pieces of excrement or frass, with the larger end open, and under this protection the larva extends its feeding area unnoticed. While the larva confines its attacks to the underside of the leaf, the upper surface becomes deadened and presents a brown patch, which becomes disintegrated, due to the effects of the weather. (Pl. III, fig. 2.)

In the autumn, before the foliage begins to drop, the larvæ migrate to the buds, where they construct very small, oval, brown cases (hibernacula), measuring about 1 mm. (0.039 inch) in diameter, in which they pass the winter. (Pl. II, fig. 1.) These brown cases are lined smoothly with whitish silken threads, and are covered with excrementitious particles and bits of bark and bud scales which render them rather difficult of detection upon superficial examination.

The cases of the matured larvæ as they appear in the spring are made of particles of frass, or grains of excrement, which are very closely woven together by means of fine silken threads, and are lined inside with a smooth surface of grayish-white silk. (Pl. II, fig. 2.) The finished case averages about 18 mm. (0.70 inch) in length, and is slightly enlarged in the middle. It is always attached to the petiole of the leaf by means of a foot stalk of grayish-white silk. The larva, as a rule, draws down and fastens two or more leaflets about its case, usually feeding upon the tips of these leaflets from this shelter. At first the case is rather loosely woven and slightly curved, but before the larva reaches maturity the case becomes straight with the unattached end larger than the attached one. The completed case, which is of a brownish-gray color, is so compactly constructed and tough that it can be torn only with great difficulty. Just before the larva pupates it seals the distal end of the case with a rather flimsy layer of silk.

THE PUPA.

The pupa (Pl. I, fig. 3) is of the usual form and without conspicuous markings. When first formed it is of a dark-brown color, with a tinge of olive green, but with age it changes to deep shiny mahogany brown. The dorsal surface of the abdomen is finely punctate. The average size of five individuals was found to be 8.1 mm. (0.318 inch) by 2.26 mm. (0.088 inch). The pupa is formed within the case, and the pupal skin is not extended upon emergence of the moth.

THE ADULT OR MOTH.

The pecan leaf case-bearer was first characterized and named in 1872 by Riley (1) as *Phycita* (*Acrobasis*) *nebulo* Walsh variety *nebulella*. The original description is as follows:

I have bred a single specimen from wild crab (*Crataegus*) which differs in some essential features from the normal form, but which nevertheless can only be considered a variety of it, as I observed no larval differences. It differs in the more uniform and subdued tone of the front wings, the markings being more suffused and indistinct; but principally in the relative narrowness of the space outside the transverse posterior line, the greater consequent width of the middle area, and smallness of the triangular brown spot—the space it occupies on the inner margin being scarcely one-half as wide as that between it and the transverse posterior line. The discal spots are also separated. Described from one good specimen.

A less technical description of the moth is as follows:

The moths measure from 14 to 18 mm. (0.55 to 0.70 inch) across the expanded wings, and they present a wide variation in color. The head, palpi, thorax, base of forewings and legs are distinctly snow-white in the specimens of males, while in the females these parts are more or less dusky gray. The abdomen is more or less white, washed with fuscous. The outer two-thirds of the forewings are gray with blackish patches, or spots, which vary to some extent. The discal spots are invariably separate and distinct. Not far from the base of the forewings is a reddish-brown stain, which is very faintly evident in some of the lighter colored forms. The hind wings are ashen gray and darker toward the outer margin. (Pl. I, fig. 4.)

SEASONAL HISTORY AND HABITS.

The seasonal-history records were obtained at Monticello, Fla., during 1913, 1914, and 1915 in an open-air insectary, in which glass jars were used as rearing cages. In all rearing work pertaining to life-history studies pecan foliage was employed.

THE ADULT AND EGG STAGES.

The time of emergence.—From material under observation during the season of 1913 it was determined that moths emerged from May 9 to July 12, inclusive. The cages, upon which the general emergence records are based, were examined daily. The dates of issuance of 269 individuals are shown in the following table:

TABLE I.—*Time of emergence of moths of the pecan leaf case-bearer during 1913 at Monticello, Fla.*

Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.
	1913.		1913.		1913.		1913.
1	May 9	3	May 30	4	June 14	7	June 29
1	May 11	3	May 31	7	June 15	8	June 30
1	May 12	4	June 1	4	June 16	4	July 1
1	May 13	5	June 2	6	June 17	9	July 2
3	May 15	4	June 3	9	June 18	2	July 3
2	May 16	1	June 4	16	June 19	4	July 4
2	May 21	1	June 5	9	June 20	4	July 5
5	May 22	6	June 6	4	June 21	3	July 6
1	May 23	9	June 7	8	June 22	2	July 7
7	May 24	10	June 8	7	June 23	2	July 8
2	May 25	12	June 9	4	June 24	2	July 9
1	May 26	2	June 10	3	June 25	3	July 10
6	May 27	7	June 11	7	June 26	4	July 11
5	May 28	3	June 12	6	June 27	3	July 12
1	May 29	3	June 13	6	June 28		

As is shown in Table I, the time of emerging of all moths varied from May 9 to July 12. The greatest number of moths to emerge on any one day was 16, and these individuals issued on June 19. There was no marked period when the vast majority of adults came forth, as is sometimes the case with certain species. A summary of Table I shows that 45 emerged from May 9 to 31, 78 from June 1 to 15, and 104 from June 16 to 30, making in all for June a total of 182; and 42 from July 1 to 12. Most of the moths issued during the month of June, and somewhat the greater number during the latter half of the month. In pecan orchards moths were not commonly seen until the early part of June, and by the middle of July they were rarely observed; but belated individuals were met until the last days of July.

Rearing cages to determine the emergence of moths during 1914 were examined daily, except on June 7, 14, 16, 21, 28, July 5, 12, 19, 26, and August 2. The dates of issuance of 385 individuals are shown in Table II.

TABLE II.—*Time of emergence of moths of the pecan leaf case-bearer during 1914 at Monticello, Fla*

Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.
	1914.		1914.		1914.		1914.
1	May 15	4	June 4	3	June 22	8	July 8
4	May 18	2	June 5	20	June 23	4	July 9
3	May 20	2	June 6	38	June 24	5	July 10
2	May 21	3	June 8	22	June 25	6	July 11
4	May 22	3	June 9	14	June 26	1	July 13
1	May 23	5	June 10	13	June 27	5	July 14
6	May 25	7	June 11	22	June 29	4	July 15
2	May 27	7	June 12	13	June 30	2	July 16
2	May 29	8	June 13	14	July 1	5	July 17
2	May 30	13	June 15	9	July 2	1	July 21
2	May 31	6	June 17	15	July 3	4	July 27
7	June 1	2	June 18	13	July 4	2	July 29
6	June 2	3	June 19	11	July 6	2	Aug. 4
4	June 3	7	June 20	5	July 7	2	Aug. 5

As is shown in Table II, the first moths of the season issued on May 15 and the last adults appeared on August 5, making a period of 82 days for the emergence of all individuals. The maximum emergence for a single day occurred on June 24, when 38 moths issued. A summary of Table II shows that 29 moths emerged from May 15 to 31, 238 from June 1 to 30, 114 from July 1 to 31, and 4 from August 1 to 5. Out of 238 moths to issue in June, 71 came forth during the first half of the month, while 167 emerged during June 15 to 30, which marks the period of maximum emergence. It is to be noted also that of the 114 moths issuing during July 100 emerged from July 1 to 14. So far as the records go, the last moth observed in the field was on August 1. From July 20 to the close of the month there was an extremely sudden decrease in the number of adults in the various pecan orchards in which observations were made.

During the season of 1915 rearing cages to determine the emergence of moths were examined daily, except on June 13, 15, 17, July 6, 13, 15, and 22. The dates of issuance of 591 individuals are shown in Table III.

TABLE III.—*Time of emergence of moths of the pecan leaf case-bearer during 1915 at Monticello, Fla.*

Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.
	1915.		1915.		1915.		1915.
2	May 22	6	June 5	31	June 21	6	July 4
3	May 24	20	June 6	31	June 22	13	July 5
1	May 25	11	June 7	24	June 23	22	July 7
1	May 26	5	June 8	12	June 24	7	July 8
4	May 27	7	June 9	6	June 25	6	July 9
2	May 28	8	June 10	14	June 26	10	July 10
10	May 29	22	June 11	11	June 27	13	July 11
1	May 30	22	June 12	16	June 28	5	July 12
2	May 31	33	June 14	16	June 29	10	July 14
16	June 1	12	June 16	6	June 30	3	July 16
5	June 2	12	June 18	16	July 1	1	July 17
21	June 3	16	June 19	10	July 2	2	July 21
6	June 4	28	June 20	22	July 3	2	July 23

As shown in Table III, the first moth of the season issued on May 22, and the last adults appeared on July 23. A summary of Table III shows that 26 moths emerged from May 22 to 31, 417 from June 1 to 30, and 148 from July 1 to 23. Out of 417 adults issuing during June, 235 appeared from June 16 to 30, which period marks the time of maximum emergence. It should be noted also that of 148 moths emerging during July, 140 issued from July 1 to 14.

The habits of moths in pecan orchards.—When the moths are at rest the wings are folded rooflike on the abdomen and the head and anterior part of the body are held in a somewhat elevated position. During the day the moths prefer to frequent the weeds at the base of the trees, but they are also to be found hiding in the dense foliage of the lower limbs. When disturbed they fly rather reluctantly from their places of concealment, but their flight is usually so rapid that it is quite difficult to follow them, although the distance traveled may be only a few feet. When alarmed, moths hiding in the débris around the base of trees often work their way into the dead leaves rather than take wing, and because of their protective color they are likely to escape detection.

Length of life of moths.—The average length of life for 26 adults was found to be 4.8 days, the maximum 10, and the minimum 2. Data bearing on the length of life are insufficient to give any generalization.

Oviposition and the length of egg stage.—It was very difficult to get reared specimens of moths to oviposit in confinement, but moths collected in pecan orchards laid eggs rather freely in some instances in rearing cages, upon both surfaces of the leaves. Under natural conditions moths oviposit only upon the underside of the leaflets. The greatest number of eggs recorded as having been deposited by a single individual was 182, which were laid by a moth collected in the field on July 20, 1916. The eggs were deposited as follows: 157 on July 21, 22 on July 22, and 3 on July 23. The records show that a period of from three to five days elapsed between the time of emergence of moths and the time of oviposition. Tables IV and V show the length of the egg stage.

TABLE IV.—*Length of egg stage of the pecan leaf case-bearer at Monticello, Fla.*

Date moths were placed in cage.	Date of oviposition.	Date of hatching.	Length of egg stage.
			Days.
June 15, 1913	June 17, 1913	June 24, 1913	7
Do	June 18, 1913	June 25, 1913	7
Do	June 19, 1913	do	6
Do	June 20, 1913	June 26, 1913	6
June 30, 1914	July 2, 1914	July 7, 1914	7
July 13, 1914	July 16, 1914	July 24, 1914	8
Maximum			8
Minimum			6

As shown in Table IV, the length of the egg stage was from 6 to 8 days. The moths used in obtaining these records were collected in the field, and from data on hand it is impossible to compute the average length of the egg stage. Upon emerging from the eggshell the larva feeds upon the leaf surface at the place where the egg is deposited.

TABLE V.—*Length of egg stage of the pecan leaf case-bearer at Monticello, Fla., in 1915.*

Number of eggs from which larvæ emerged.	Date of oviposition.	Date of hatching.	Length of egg stage.
	1915.	1915.	*Days.*
1	July 17	July 23	6
1	...do....	July 24	7
4	July 18	July 26	8
18	July 24	Aug. 1	8
1	...do....	Aug. 2	9
7	July 31	Aug. 6	6
60	...do....	Aug. 7	7
2	Aug. 4	Aug. 11	7
23	Aug. 5	Aug. 12	7
1	...do....	Aug. 13	8
Maximum			9
Minimum			6
Average for 118 individuals			7.14+

It will be noted from Table V that the average length of the egg stage for 118 individuals was 7.14 days, the maximum 9, and the minimum 6.

THE PUPA STAGE.

Of the larvæ under observation that transformed to pupæ during 1913, the first pupated on April 20, while during 1914 and 1915 the first pupæ did not appear until May 5. During the season of 1914 the actual time of earliest pupation was, perhaps, a trifle earlier than recorded, since in cages in which only the daily emergence of moths was observed the dates of pupation were not taken, and some moths from the cages issued as early as May 15. It is very likely that some larvæ in these cages transformed to pupæ during the last few days of April.

During the year 1913 the length of the pupa stage was determined for 66 individuals, as is shown in Table VI:

TABLE VI.—*Length of pupa stage of the pecan leaf case-bearer at Monticello, Fla., during 1913.*

Number of individuals.	Date of— Pupation.	Date of— Emergence.	Days as pupa.	Number of individuals.	Date of— Pupation.	Date of— Emergence.	Days as pupa.
	1913.	1913.			1913.	1913.	
1	Apr. 20	May 13	23	1	May 21	June 8	18
2	Apr. 25	May 15	20	2	...do....	June 9	19
1	...do....	May 16	21	3	...do....	June 11	21
1	May 2	May 21	19	1	...do....	June 12	22
2	...do....	May 22	20	1	...do....	June 13	23
1	May 4	May 24	20	2	May 22	June 11	20
2	May 6	...do....	18	2	...do....	June 12	21
2	May 8	May 28	20	1	...do....	June 13	22
1	May 9	May 27	18	1	May 23	June 15	23
1	...do....	May 31	22	2	May 27	June 17	21
1	May 11	May 30	19	2	May 29	June 19	21
1	...do....	June 1	21	1	May 30	June 20	21
4	May 12	June 2	21	3	May 31	...do....	20
1	May 13	...do....	20	1	June 1	June 21	20
3	May 14	June 3	20	1	...do....	June 23	22
1	...do....	June 5	22	2	June 2	...do....	21
1	May 15	June 3	19				
5	May 19	June 7	19				
2	...do....	June 8	20	Average			19.89
3	...do....	June 9	21	Maximum			23
3	May 20	June 6	17	Minimum			17
1	...do....	June 8	19				

As is shown in Table VI, the average length of the pupa stage during 1913 was 19.89 days, the maximum 23, and the minimum 17.

Table VII shows the length of the pupa stage for 45 individuals for the season of 1914.

TABLE VII.—*Length of pupa stage of the pecan leaf case-bearer at Monticello, Fla., during 1914.*

Number of individuals.	Date of— Pupation.	Date of— Emergence.	Days as pupa.	Number of individuals.	Date of— Pupation.	Date of— Emergence.	Days as pupa.
	1914.	1914.			1914.	1914.	
2	May 5	May 25	20	1	May 23	June 8	16
1	May 10	May 30	20	2	...do....	June 9	17
1	May 11	...do....	19	3	May 25	June 10	16
1	...do....	May 29	18	3	...do....	June 11	17
1	May 12	May 31	19	1	...do....	June 12	18
1	...do....	June 1	20	1	...do....	June 13	19
1	May 13	May 31	18	1	...do....	June 11	16
1	...do....	June 1	19	2	May 26	June 12	17
1	May 14	June 2	19	1	...do....	June 13	18
1	May 15	...do....	17	1	May 27	...do....	17
2	...do....	...do....	18	2	May 28	June 15	18
1	...do....	...do....	17	1	May 29	...do....	17
1	May 16	...do....	18	2	June 9	June 26	17
1	...do....	June 4	19				
2	May 18	...do.....	17				
2	...do....	June 5	18	Average			17.66
2	...do....	June 6	19	Maximum			20.
1	May 19	June 8	20	Minimum			16.
1	May 22	June 10	19				

During 1914 the average length of the pupa stage was determined to be 17.66 days, the maximum being 20 and the minimum 16.

Table VIII shows the length of the pupa stage for 109 individuals for the season of 1915.

TABLE VIII.—*Length of the pupa stage of the pecan leaf case-bearer at Monticello, Fla., during 1915.*

Number of individuals.	Date of— Pupation.	Date of— Emergence.	Days as pupa.	Number of individuals.	Date of— Pupation.	Date of— Emergence.	Days as pupa.
	1915.	1915.			1915.	1915.	
3	May 5	May 22	17	1	May 25	June 11	17
3	...do....	May 23	18	1	...do....	June 12	18
1	May 6	May 22	16	2	May 28	June 16	19
1	...do....	May 23	17	1	May 29	...do....	18
2	...do....	May 24	18	1	May 31	...do....	16
4	May 7	...do....	17	1	...do....	June 18	18
3	...do....	May 25	18	5	June 1	...do....	17
1	May 8	...do....	17	3	June 2	...do....	16
1	May 9	...do....	16	12	...do....	June 19	17
1	...do....	May 27	18	3	...do....	June 20	18
1	May 13	May 30	17	4	June 3	June 19	16
1	May 19	June 5	17	8	...do....	June 20	17
5	May 20	June 6	17	7	...do....	June 21	18
2	...do....	June 7	18	1	June 13	July 1	18
2	May 21	...do....	17	2	June 14	June 30	16
1	...do....	June 8	18	2	...do....	July 1	17
1	May 22	June 9	18	2	...do....	July 3	19
2	May 23	June 8	16	5	June 16	...do....	17
2	...do....	June 9	17	1	June 17	...do....	16
1	...do....	June 10	18				
1	May 24	June 9	16				
5	...do....	June 10	17	Average			17.15
2	...do....	June 11	18	Maximum			19.
1	May 25	June 10	16	Minimum			16.

THE LARVA STAGE.

During the season of 1913 eggs were found to hatch from about the middle of May until the last days of July, and during the season of 1914 and 1915 from the latter part of May until the first few days of August. The period over which the eggs are hatching depends, of course, upon the time of emergence of moths, and it will be noted in Tables I, II, and III that there was some variation in the issuance dates of adults during 1913, 1914, and 1915. When the young larvæ gnaw their way out of the eggshells they commence feeding upon the portion of leaflet immediately adjacent to the place where oviposition occurred. Throughout the summer and during the early fall the larvæ feed very sparingly upon the foliage, and as they extend their feeding quarters they enlarge the little winding or spiral cases which afford them protection. Although the larvæ may feed for nearly three months or even longer in some instances, they hardly attain a length greater than six one-hundredths of an inch. During the latter part of September these larvæ begin to seek hibernating quarters around the buds, where they construct small, compactly woven, oval hibernacula, and by the middle of October practically all larvæ will have left the foliage and may be found snugly protected in the hibernacula. These little "worms" very wisely abandon the compound leaves upon which they have been feeding, just a short time before the foliage begins to drop in the autumn, in order to attach the winter cases securely to the buds and twigs.

The larvæ remain in hibernation until the latter part of March or the first days of April, at which time the buds on pecan trees usually begin to open. Just as the buds are opening, the larvæ emerge from their hibernacula and attack the unfolding leaves. The pernicious feeding habits of the larvæ at this time result in serious injury to the foliage and in greatly reducing the yield of nuts. During the year 1913 the larvæ reached full growth from about April 20 until the latter part of June, but the majority pupated between May 10 and June 10. During the seasons of 1914 and 1915 the majority of the larvæ were about a week to ten days later in reaching maturity.

NATURAL ENEMIES.

Three species of birds—the blue jay (*Cyanocitta cristata*), the mockingbird (*Mimus polyglottos*), and the orchard oriole (*Icterus spurius*)—have been observed feeding upon the larvæ of the pecan leaf casebearer. These birds, as well perhaps as those of other species, do much to check the ravages of this pest, and their protection in the pecan orchard should be encouraged. The blue jay very likely is more beneficial than harmful to the pecan grower. In the writer's opinion the good that this bird does in feeding upon injurious pecan insects more than offsets the injury that it is accused of doing in the fall of the year, when it may take a few nuts from the pecan trees.

The writer has reared a number of parasitic insects from the larvæ and pupæ of this case-bearer, as follows: *Itoplectis conquisitor* Say, *Triclistus apicalis* Cress., *Calliephialtes grapholithae* (Cress.), and *Pristomerus* sp., belonging to the family Ichneumonidae; *Macrocentrus delicatus* Cress., *Meteorus* sp., *Habrobracon variabilis* Cush., and *Orgilus* sp., belonging to the family Braconidae; and *Secodella acrobasis* Cwfd., which has been described as a new species by Mr. J. C. Crawford (19), of the U. S. National Museum, and *Cerambycobius* sp., belonging to the superfamily Chalcidoidea. Two species of Tachinidae were reared from this case-bearer and were identified by Mr. W. R. Walton, of the Bureau of Entomology, as *Leskiomima tenera* Wied. and *Exorista* near *pyste* Walker. This last he considers as probably a new species. Gossard (12) reported rearing *Spilochalcis vittata* (Fab.) and *Itoplectis conquisitor* Say from this host. It is interesting to note that on one occasion specimens of *Trichogramma minutum* Riley were reared from the eggs of the pecan leaf case-bearer. Of the numerous parasites preying upon this pest, the most effective is the small chalcidoid, *Secodella acrobasis* Cwfd., which was reared in great abundance from the overwintering larvæ.

METHODS OF CONTROL.

DIPPING AND SPRAYING TESTS FOR THE DESTRUCTION OF LARVÆ IN HIBERNATION.

In order to determine the effect of various spray materials on the larvæ in their hibernacula, a series of tests was made. For this work small twigs that were badly infested were selected for the treatment, which consisted in immersing the twigs in the materials used. After the treatment had been effected the twigs were kept in separate glass jars. The results of this series of experiments are shown in Table IX.

TABLE IX.—*Dipping tests with sprays for destruction of hibernating larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1913.*

Experiment No.	Number of twigs treated.	Material used.	Date of application.	Per centage of larvæ emerging from hibernacula.
I	25	Miscible oil (1:12)	Feb. 11, 1913	18
II	25	Miscible oil (1:15)		15
III	25	Miscible oil (1:18)		20
IV	25	Miscible oil (1:20)		20
V	15	Miscible oil (undiluted)		2
VI	25	10 per cent kerosene emulsion		15
VII	25	20 per cent kerosene emulsion		15
VIII	25	Commercial lime-sulphur solution (1:8)		10
IX	25	40 per cent nicotine sulphate (1:32)		10
X	25	Check; untreated		50

For some reason, presumably because the twigs were kept in too dry a condition, many larvæ failed to emerge from hibernacula that were not treated, as is shown in Table IX. The best results were obtained with undiluted miscible oil, while strengths ranging from 1:12 to 1:20 gave considerably less benefit for the treatment, as was also the case when 10 and 20 per cent kerosene emulsions were employed. Commercial lime-sulphur solution at 1:8 and 40 per cent nicotine sulphate at 1:32 ranked second in effectiveness.

Further dipping tests were made with commercial lime-sulphur solution on March 26, 1914. The strengths employed were 1:8 and 1:10, in which thirty heavily infested pecan twigs were dipped, and after the treatment the twigs were caged immediately in jars and placed in the out-of-doors insectary. By March 31 many of the larvæ were emerging from their hibernacula and feeding upon the developing buds. Further observations showed that lime-sulphur at these strengths was not effective in preventing many larvæ from emerging from winter quarters.

Table X shows further dipping and spraying experiments with lime-sulphur and miscible oil.

TABLE X.—*Dipping and spraying experiments for destruction of hibernating larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1916.*

Experiment No.	Treatment.	Date of application.	Result.
I	Dipped twigs in commercial lime-sulphur solution (1:8), testing 32° Baumé.	Mar. 7, 1916	Many larvæ emerged and destroyed every bud.
II	Sprayed twigs with commercial lime-sulphur solution testing 32° Baumé.	.....do........	Many larvæ emerged and destroyed most of the buds.
III	Sprayed twigs with miscible oil at 1:15.	.....do........	Many larvæ emerged and destroyed practically every bud.
IV	Check; twigs untreated................	....	Larvæ emerged and readily destroyed every bud.

The twigs used in these experiments were kept in water or moist soil in order to insure the proper development of the buds. The first observations were made on April 17, 1916, and results as shown in Table X indicate the condition of the foliage. It will be noted that the lime-sulphur and miscible oil failed to destroy the larvæ.

SPRAYING EXPERIMENTS[1] FOR THE DESTRUCTION OF LARVÆ IN HIBERNATION.

A series of spraying experiments was conducted with several of the standard winter sprays to find out their effect upon larvæ in hibernation, and in all cases the material was applied thoroughly by means of a gasoline-power outfit.

[1] The spraying was done in bearing pecan orchards belonging to the Standard Pecan Co. and the Summit Nurseries, both of Monticello, Fla., and to Mr. Charles E. Pabst, of Ocean Spring, Miss.

The results of these experiments are as follows:

TABLE XI.—*Spraying experiments for the destruction of hibernating larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1913.*

Plat No.	Number of trees.	Treatment.	Date of application.	Results.
			1913	
I	11	Commercial lime-sulphur solution, testing 33° Baumé, at 1 gallon to 8 gallons of water.	Mar. 3	40 per cent of the larvæ emerged from hibernacula. Buds and foliage very seriously damaged by larvæ.
V	10	Miscible oil at 1 gallon to 20 gallons of water.	Mar. 25	75 per cent of the larvæ emerged from hibernacula. Buds were badly damaged by larvæ.
VII	14	Check; untreated		Practically all larvæ emerged. Nearly every bud was either totally or partially destroyed. Some trees were completely defoliated.

Neither the lime-sulphur solution nor the miscible oil gave satisfactory results, but of the two, lime-sulphur was the better. In this series of experiments a proprietary insecticide consisting of distillate oil, tobacco, and soap, and another one consisting principally of oil were tried at dormant strengths in Plats II, III, and IV, which are not included in Table XI, and both of these were found to be ineffective against the hibernating larvæ.

On February 15, 1913, in the Pabst orchard at Ocean Springs, Miss., fifteen 10-year-old trees were sprayed with commercial lime-sulphur at 1 gallon to 8 gallons of water, and on the same date six 10-year-old trees were sprayed with miscible oil at the rate of 1 gallon to 15 gallons of water. Since it was impossible for the writer to make observations on these sprayed trees because of stress of work at Monticello, Fla., Mr. Chas. E. Pabst, of Ocean Springs, Miss., was requested to report the results of these experiments. In his report he stated that there seemed to be a slight benefit derived from the lime-sulphur treatment, but so far as could be determined the miscible-oil-sprayed trees were as badly infested with larvæ as the trees that were left untreated.

In order to obtain additional information on the two most common dormant season sprays, a series of spraying experiments was conducted at Ocean Springs, Miss., and another at Monticello, Fla. The results of this work are shown in Tables XII and XIII.

TABLE XII.—*Spraying experiments for the destruction of hibernating larvæ of the pecan leaf case-bearer at Ocean Springs, Miss., in 1914.*

Plat No.	Number of trees.	Treatment.	Date of application.	Result.
			1914	
I	32	Commercial lime-sulphur solution, testing 33° Baumé, at 1 gallon to 8 gallons of water.	Mar. 9	Very slightly benefited. Sufficient number of larvæ emerged to do considerable damage to buds and foliage.
II	17	Commercial lime-sulphur solution, testing 33° Baumé, at 1 gallon to 10 gallons of water.	...do.....	Very slight benefit. A large percentage of larvæ emerged from hibernacula and severely injured the buds and foliage.
III	10	Check; unsprayed...........	....	Practically all larvæ that were not parasitized emerged from hibernacula. Buds and foliage were severely injured.

TABLE XIII.—*Spraying experiments for the destruction of hibernating larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1914.*

Plat No.	Number of trees.	Treatment.	Date of application.	Results.
I	12	Commercial lime-sulphur solution at 1 gallon to 8 gallons of water.	Mar. 22, 1914	Slight benefit, but a sufficient number of larvæ emerged to do much damage to buds and foliage.
II	10	Commercial lime-sulphur solution at 1 gallon to 10 gallons of water.	.....do.......	Slight benefit, but many larvæ emerged from hibernacula and did considerable damage to buds and foliage.
III	8	Miscible oil at 1 gallon to 20 gallons of water.	.....do.......	Practically no benefit derived from the treatment.

The results, as will be noted in Tables XII and XIII, show that the lime-sulphur solution at 1:8 and 1:10 gave a slight benefit, but that miscible oil was a decided failure. The number of larvæ destroyed by the lime-sulphur treatments was not sufficient to combat this pest satisfactorily. Although it has been suggested and advised by certain entomological writers that this pest can be controlled by the use of lime-sulphur during the dormant season, the results of all the experiments show conclusively that the treatment can not be depended upon as a remedy for the pecan leaf case-bearer.

SPRAYING EXPERIMENTS AGAINST OVERWINTERED LARVÆ.

EXPERIMENTS AT MONTICELLO, FLA.

The work at Monticello, Fla., was conducted in the pecan orchards of the Summit Nurseries and the Standard Pecan Co. For the spraying regular orchard gasoline-power outfits were used and the spray material was applied very thoroughly at a pressure ranging from 175 to 200 pounds. The results of the experiments are shown in Tables XIV and XV.

TABLE XIV.—*Spraying experiments against the larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1913.*

Plat No.	Number of trees.	Treatment.	Date of application.	Results.
VI	55	Paste lead arsenate at 3 pounds plus Bordeaux mixture 4-5-50.[1]	Apr. 18, 1913	Not controlled satisfactorily. About 50 per cent of the larvæ were destroyed, but the buds were badly injured.
VII	14	Check; unsprayed..........	....	Most buds were infested by larvæ. Some trees were nearly defoliated.

[1] Bordeaux mixture was used for fungicidal purposes.

TABLE XV.—*Spraying experiments against the overwintering larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1914.*

Plat No.	Number of trees.	Treatment.	Date of application.	Results.
IV	10	Commercial lime-sulphur solution at 1 gallon to 40 gallons of water.	Apr. 2, 1914	Not controlled. Some few larvæ killed, but the majority continued to feed upon the buds and foliage.
V	10	40 per cent nicotine sulphate at 1 part to 700 parts of water.	.....do.......	Not controlled. Much damage done to the buds and foliage.
VI	25	Paste lead arsenate at 3 pounds to 50 gallons of water (2 applications).	Apr. 2 and 10, 1914.	Not satisfactorily controlled. Many larvæ killed, but sufficient numbers escaped to inflict serious injury to buds and foliage.

As shown in Table XIV, a single application of paste arsenate of lead at 3 pounds to 50 gallons of Bordeaux mixture, made on April 18, 1913, failed to control the pest, although there was considerable benefit in favor of the sprayed over the check trees. Table XV shows that on trees treated with commercial lime-sulphur solution at 1:40 and 40 per cent nicotine sulphate at 1:700 on April 2, 1914, at which time the larvæ were emerging from their hibernacula, little or no benefit was derived from the treatment. Compared with the checks, the trees in Plat VI, which received two heavy applications of paste lead arsenate at 3:50 on April 2 and 10, showed that there was much in favor of the treatment, but sufficient numbers of the larvæ escaped the poison to do serious damage to the buds and foliage.

On account of the manner in which the larvæ feed upon the buds, it was found to be difficult to kill a large proportion of them before considerable damage had been done to the foliage. Results show that spraying with lead arsenate during the spring can not be relied upon as an effective remedy for this pest.

SPRAYING EXPERIMENTS AGAINST LARVAE IN THE SUMMER.

EXPERIMENTS AT MONTICELLO, FLA.

After discovering the manner in which the larvæ attack the foliage during the summer, spraying experiments were conducted to find out if the case-bearer could not be controlled practically at this stage of its life cycle. The results of this line of work are embodied in the following tables. Table XVI shows the effect of the treatment of 113 ten-year-old pecan trees in the orchard of the Summit Nurseries.

TABLE XVI.—*Spraying experiments against the larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1913.*

Plat No.	Number of trees.	Treatment.	Date of application.	Results.
I	113	One application of paste lead arsenate at 3 pounds to 50 gallons of water.	Aug. 14 and 15, 1913.	Very satisfactory control. Nearly all larvæ were killed and only a very few remained to construct hibernacula in the autumn. Was exceedingly difficult to detect any hibernacula. No appreciable amount of damage was done by the few overwintering larvæ to the buds during the spring.
II	12	Check; untreated......	....	As many as 12 hibernacula were found around a single bud; the average was about 3 hibernacula to the bud. During the spring the larvæ appeared in numbers and seriously damaged the buds and foliage. Some trees were nearly defoliated.

The results obtained on Plat I, as shown in Table XVI, were highly satisfactory, since most of the larvæ were killed by the arsenical application. By destroying the larvæ during the late summer or early autumn, the trees were protected from attacks during the subsequent spring, at which time very serious injuries occur to the buds and tender foliage through the peculiar manner of the feeding of overwintering larvæ. During the following spring (1914), the trees on Plat I put forth their foliage in perfect condition, but on account of the ravages of the case-bearer larvæ the unsprayed trees (Plat II) were kept in a state of partial or total defoliation for several weeks, and this condition interfered seriously with the setting of nuts. A slight arsenical injury was done to the foliage, but in no case was the damage so severe as to cause the leaves to drop.

More extensive spraying experiments were carried out with lead arsenate in 1914 than in 1913. Table XVII shows the series of experiments conducted in the Abe Simon orchard.

TABLE XVII.—*Spraying experiments against the larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1914.*

Plat No.	Number of trees.	Treatment.	Date of application.	Result.
			1914	
I	22	Powdered lead arsenate at 2 pounds to 50 gallons of water.	Aug. 13......	Practically perfect control. Scarcely any larvæ succeeded in escaping the poison to construct hibernacula. Foliage rather seriously injured by the heavy application of arsenical.
II	4	Check; unsprayed..........	....	Trees were badly infested, as was determined by the great abundance of hibernacula and the prevalence of larvæ in the buds during the following spring.
III	18	Paste lead arsenate at 3 pounds to 50 gallons of water.	Aug. 14......	Practically perfect control. Scarcely any larvæ succeeded in escaping the poison to construct hibernacula. Foliage rather seriously injured by the heavy application of arsenical.

On Plats I and III the case-bearer was satisfactorily controlled, while on Plat II, which was left untreated, very serious damage was done during the spring by the overwintering larvæ. Rather serious injury was done to the foliage on Plats I and III, owing in part to the showery weather that followed the spraying, which made conditions favorable for the suspension of free arsenic on the leaves. The sprayed trees shed their foliage a little sooner than the checks, but defoliation did not take place so early as to cause the trees to bud out again.

A series of dosage tests with lead arsenate was carried out for the purpose of determining the proper strength necessary to control effectively the pest under orchard conditions. The results of this work are contained in Table XVIII.

TABLE XVIII.—*Spraying experiments against the larvæ of the pecan leaf case-bearer to determine the most effective dosage of lead arsenate; Monticello, Fla., 1914.*

Plat No.	Number of trees.	Treatment.	Date of application.	Results.	
				Degree of infestation.	Arsenical injury to foliage.
I	26	Powdered lead arsenate at 1½ pounds to 50 gallons of water.	1914 Aug. 20	Practically none.	Serious.
II	16	Powdered lead arsenate at 1 pound to 50 gallons of water.	...do.....	.....do...........	Rather serious.
III	31	Powdered lead arsenate at ½ pound to 50 gallon of water.	...do.....	Light infestation	Slight burning.
IV	6	Check; unsprayed....................	...do.....	Very heavy infestation.	
V	37	Paste lead arsenate at 1 pound to 50 gallons of water.	...do.....	Light infestation	Slight burning.
VI	24	Paste lead arsenate at 1½ pounds to 50 gallons of water.	Aug. 22	Very light infestation.	Somewhat pronounced.
VII	21	Paste lead arsenate at 2 pounds to 50 gallons of water.	...do.....	Practically none.	Rather serious.
VIII	18	Paste lead arsenate at 2½ pounds to 50 gallons of water.	...do.....	.....do...........	Serious.
IX	26	Paste lead arsenate at 3 pounds to 50 gallons of water.	...do.....	.....do...........	Do.
X	24	Two pounds of paste arsenate of lead plus 4 pounds of lime to 50 gallons of water.	...do.....	.....do...........	Only a trace of burning.

As is shown in Table XVIII, the powdered lead arsenate at ½ pound (Plat III), and paste form at 1 pound (Plat V), as well as 1½ pounds (Plat VI), to 50 gallons of water were found to be too weak for effective work, while the powdered lead arsenate at 1 pound and 1½ pounds and the paste form at 2, 2½, and 3 pounds gave very satisfactory control. It was discovered that pecan foliage was quite susceptible to arsenical injury, for on all plats there was some burning. The worst burning occurred on Plats I, VIII, and IX, where the stronger dosages of lead arsenate were used; but where the weaker dosages were employed the injury was considerably lessened. The foliage on Plat X, sprayed with lead arsenate to which lime was added, was in the best condition, as only a trace of burning occurred.

Spraying experiments were conducted during the summer of 1915 for the purpose of determining the effects of various forms of lead arsenate on pecan foliage. The pecan trees selected were 12 years old and of a good size for their age. The spray material was very thoroughly applied by means of a gasoline-power outfit, using a pressure of about 200 pounds. Table XIX shows the results of this work.

TABLE XIX.—*Spraying experiments against the larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1915.*

Plat No.	Number trees.	Treatment.	Date of application.	Results.	
				Degree of infestation.	Extent of arsenical injury to foliage.
			1915.		
I	18	Powdered lead arsenate 1½ pounds, plus 3 pounds of lime to 50 gallons of water.	Aug. 24	Practically none.	Foliage in good condition; no appreciable burning.
II	18	Powdered lead arsenate 1 pound, plus 3 pounds of lime to 50 gallons of water.	...do.....	.....do..........	Do.
III	12	Paste lead arsenate 3 pounds, plus 3 pounds of lime to 50 gallons of water.	Aug. 25	.....do..........	Burning of foliage was rather serious.
IV	12	Paste lead arsenate 2 pounds, plus 3 pounds of lime to 50 gallons of water.	...do.....	.....do..........	Margin of leaves rather severely burned; but the trees did not shed their leaves prematurely.
V	5	Paste triplumbic lead arsenate 2 pounds, to 50 gallons of water.	...do.....	.....do..........	Foliage rather seriously burned, especially margin of leaves.
VI	7	Paste triplumbic lead arsenate 2 pounds, plus 3 pounds of lime to 50 gallons of water.	...do.....	.....do..........	Foliage in good condition; no appreciable burning.

As shown in Table I, the pecan leaf case-bearer was controlled satisfactorily on all plats, but only on Plats I, II, and VI was the spraying accomplished without appreciable arsenical injury to the foliage. Maximum burning of foliage occurred on Plat V, where triplumbic arsenate of lead paste alone was used; but even in this case the injury was not severe enough to cause premature defoliation. Plats III and IV, which received 3 pounds and 2 pounds, respectively, of paste arsenate of lead plus 3 pounds of lime to each 50 gallons of water, showed rather serious arsenical injury to the margins of the leaves, while Plats I and II, which received 1½ pounds and 1 pound, respectively, of the powdered form of arsenate of lead plus 3 pounds of lime to 50 gallons of water, showed no appreciable injury to the foliage. From these observations the powdered form of lead arsenate appears less likely to cause injury to the foliage than does the paste form.

Under no circumstances was it found safe to use effective dosages of lead arsenate (triplumbic or diplumbic) in either the paste or powdered form on pecan foliage without the addition of 3 or 4 pounds of stone lime per 50 gallons of water. The work with arsenicals indicates that the pecan is practically as susceptible to burning as is the peach and that the same precautions must be used in order to prevent serious injury to its foliage.

FUMIGATION EXPERIMENTS AGAINST HIBERNATING LARVÆ.

Experiments Against Larvæ on Pecan Nursery Trees.

As the pecan leaf case-bearer may be freely distributed through the medium of nursery stock as larvæ in hibernacula about the buds, it was considered advisable to obtain some data in regard to fumigation. A specially constructed box, measuring 10 feet long, $3\frac{1}{3}$ feet high, and 3 feet wide, was used for this work. The box was so made as to be practically air-tight. In order to test the effect of fumigation on the larvæ as well as on the plant itself, a number of infested, grafted, or budded pecan trees, ranging from 3 to 5 feet in height, were used. In order to have the trees in the best possible condition, they were dug from the nursery during the afternoon of the day before fumigation, and immediately after the fumigation experiments were completed the trees were set out in the laboratory yard at Monticello, Fla. The method and results of these experiments are shown in Table XX.

Table XX.—*Fumigation experiments on pecan nursery trees for destruction of over-wintering larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1916.*

Experiment No.	Number of trees.	Treatment.	Date of fumigation.	Results.
			1916.	
I	8	Fumigated for 1 hour with 1 ounce of sodium cyanid[1] per 100 cubic feet, using formula 1-2-3.[2]	Feb. 25	Larvæ were not killed, and these larvæ destroyed the buds. Trees were not injured by fumigation.
II	8	Fumigated for 1 hour with $1\frac{1}{2}$ ounces of sodium cyanid per 100 cubic feet, using formula 1-2-3.	...do....	All larvæ were killed. No apparent injury to trees by fumigation.
III	8	Check; untreated	....	Larvæ emerged in numbers and buds on the trees were badly damaged.

[1] Sodium cyanid used was equivalent to 129 per cent potassium cyanid.
[2] Formula: 1 ounce (avoirdupois) sodium cyanid, 2 fluid ounces of sulphuric acid, 3 fluid ounces of water to 100 cubic feet of space.

It will be noted in Table XX that in experiment I, where 1 ounce of sodium cyanid per 100 cubic feet was used, the case-bearer larvæ were not killed, while in experiment II, where $1\frac{1}{2}$ ounces of cyanid was used, the results were very satisfactory, as no larvæ emerged from the hibernacula. On May 1, 1916, it was found that the buds on trees in experiments I and III were badly damaged by the larvæ and that the buds and foliage on trees in experiment II were not injured. So far as could be determined, the fumigation had no effect whatever on the trees, as both the check and fumigated trees made practically the same amount of growth during the course of the season.

Further fumigation experiments were conducted during March, 1916, and are reported in Table XXI. Only badly infested pecan twigs were used in these experiments, and after being fumigated, they were placed in water bottles in order to insure proper development of the buds.

TABLE XXI—*Fumigation experiments on larvæ of the pecan leaf case-bearer at Monticello, Fla., in 1916.*

Experiment No.	Number of twigs.	Treatment.	Date of fumigation.	Results.	Remarks.
			1916.		
I	12	Fumigated for 1 hour with ½ ounce of sodium cyanid [1] per 100 cubic feet.	Mar. 4	Larvæ emerged from hibernacula.	All buds destroyed by larvæ.
II	12	Fumigated for 1 hour with ¾ ounce of sodium cyanid [1] per 100 cubic feet.	Mar. 3	......do............	Nearly all buds were destroyed by larvæ.
III	12	Fumigated for 1 hour with 1 ounce of sodium cyanid [1] per 100 cubic feet.	...do....	A number of larvæ emerged from hibernacula.	Some buds were damaged by larvæ.
IV	12	Fumigated for 1 hour with 1 ounce of sodium cyanid [2] per 100 cubic feet.	...do....	......do............	A good many buds destroyed by larvæ.
V	12	Fumigated for 1 hour with 1½ ounces of sodium cyanid [1] per 100 cubic feet.	...do....	No larvæ emerged from hibernacula.	Buds did not unfold well.
VI	12	Check; not fumigated...............	...do....	Larvæ emerged from hibernacula.	All buds were destroyed by larvæ.
VII	15	Fumigated for 1 hour with 1½ ounces of sodium cyanid [1] per 100 cubic feet.	Mar. 29	No larvæ emerged from hibernacula.	No injury to buds from fumigation.
VIII	15	Fumigated for 1 hour with 2 ounces of sodium cyanid [1] per 100 cubic feet.	...do....	......do............	No injury to buds from fumigation.
IX	15	Check; not fumigated...............	...do....	Larvæ emerged from hibernacula.	All buds destroyed by larvæ.

[1] Used formula 1–2–3. [2] Used formula 1–1–3.

It will be noted in Table XXI that strengths of sodium cyanid of ½, ¾, and 1 ounce per 100 cubic feet failed to destroy the larvæ after one hour of exposure, while strengths of 1½ and 2 ounces per 100 cubic feet killed all larvæ. It is to be regretted that in these experiments a strength of 1¼ ounces was not used, as it was found that while 1 ounce was not enough, 1½ ounces destroyed larvæ while in the winter cases. Although the maximum strength used (1½ ounces per 100 cubic feet of space) is considerably in excess of that commonly employed in the fumigation of ordinary nursery stock, these experiments indicated that, while in a dormant condition, the pecan was perfectly capable of enduring the greater strength without injury.

In fumigation for the pecan leaf case-bearer materials should be used according to the following formula: 1–1½–2. This means that 1 ounce (avoirdupois) of sodium cyanid, 1½ fluid ounces of sulphuric acid, and 2 fluid ounces of water should be used to each 100 cubic feet of space inclosed. In purchasing sodium cyanid it is essential to obtain a high-grade product, 96 to 98 per cent pure, or, in other words, one that contains not less than 51 per cent of cyanogen. Commercial sulphuric acid, specific gravity 1.84 (66° Baumé), which is approximately 93 per cent pure, should be used for fumigation in order to obtain the best results.

SUMMARY.

Although the pecan leaf case-bearer is preyed upon by a number of parasitic insects and several species of birds, it was found during a course of studies extending over a period of three years that neither the parasites nor any other natural checks could be relied upon to control it, but that certain artificial measures were successful.

It was found impossible successfully to control the pecan leaf case-bearer during the dormant season, at which time the larvæ were in hibernacula around the buds. Of the various spray materials tried for the destruction of hibernating larvæ, commercial lime-sulphur solution at the strength of 1 : 8 and 1 : 10 gave the best results, but this method failed to destroy a sufficient number of the larvæ to justify its use. Tests with miscible oils at 1 : 12, 1 : 15, 1 : 18, and 1 : 20, and 10 and 20 per cent kerosene emulsions applied during the dormant season were found to be ineffective.

Because of the manner in which the larvæ feed upon the buds and foliage, the pecan leaf case-bearer in the active larva stage during the spring was not satisfactorily controlled. Spraying experiments, using a single application of arsenate of lead (paste) at 3 pounds to 50 gallons of water, 40 per cent nicotine sulphate at 1 : 700, and commercial lime-sulphur solution at 1 : 40, were tried on orchard pecan trees as the larvæ emerged from their hibernacula, at which time the buds were beginning to unfold, but none of these materials proved effective. Two applications of arsenate of lead (paste) at 3 pounds to 50 gallons of water were made on large pecan trees, the first as the larvæ emerged from their winter cases and the second eight days later. This treatment destroyed many larvæ but was not entirely effective.

Experiments in spraying with certain strengths of lead arsenate, conducted during the summer (August), gave very satisfactory results in the control of this pest, as it was discovered that the young larvæ might be destroyed readily at this stage. Based on a large series of dosage tests with lead arsenate, conducted on orchard pecan trees, it was found that no strength weaker than 1 pound of the powdered form or 2 pounds of the paste to 50 gallons of water could be relied upon to control the case-bearer. Paste lead arsenate at 1 pound and 1½ pounds or the powdered form at ½ pound to 50 gallons of water did not give satisfactory results, but the case-bearer was controlled equally as well with 1 pound of the powder or 2 pounds of paste as with 1½ pounds of the powder or 2½ or 3 pounds of the paste to each 50 gallons of water.

In conducting extensive spraying experiments it was soon discovered that pecan foliage is more or less susceptible to arsenical burning. Experience showed that it was unsafe to spray pecan trees with lead arsenate without adding at least 3 pounds of stone lime to each 50 gallons of water.

Fumigation experiments on the hibernating larvæ on pecan twigs and pecan nursery trees demonstrated that the larvæ could be destroyed by fumigating for one hour with 1½ ounces of sodium cyanid per 100 cubic feet of space inclosed.

RECOMMENDATIONS FOR CONTROL.

Experimental work extending over a period of more than three years has shown conclusively that no matter how badly an orchard may be infested, the pecan leaf case-bearer can be controlled successfully by a single application of an arsenical solution combined with lime, if made during the latter part of summer. Experiments have shown that the best results are obtained by using 1 pound of the powdered, or 2 pounds of the paste arsenate of lead and 3 pounds of freshly slaked lime to each 50 gallons of water. Under no circumstances should arsenate of lead be used without the addition of lime, as more or less injury to the foliage and nuts is likely to follow. It is evident that spraying may be done with equal effectiveness at any time between the first of August and the middle of September. Spraying earlier than August 1 is not to be relied upon as being fully effective, since all of the eggs will not have hatched by this time, and during the course of the spraying it is considered advantageous to the work to have all larvæ feeding upon the foliage. There is also some danger in delaying the spraying in the fall, as observations have shown that some larvæ seek hibernation quarters toward the latter part of September, although the majority of them do not construct winter cases until the first week or so in October. It should be borne in mind that only the larvæ which feed on poisoned foliage are killed, and those escaping pass the winter in hibernacula around the buds and come forth in the spring to feed upon the buds and young leaves. Therefore, all who would combat successfully the pecan leaf case-bearer must realize the importance of thorough and timely spraying.

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By

W. E. DOVE, Scientific Assistant
Insects Affecting Domestic Animals

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By W. E. Dove, *Scientific Assistant, Insects Affecting Domestic Animals.*

CONTENTS.

INTRODUCTION.

In compliance with requests from farmers and horse breeders of the Dakotas and Montana regarding "fly annoyance" to horses, a survey of conditions was made in the autumn of 1914 by Mr. F. C. Bishopp. Under the direction of Dr. W. D. Hunter and the supervision of Mr. Bishopp, investigations were undertaken in the following summer upon the European *Gastrophilus haemorrhoidalis*, commonly known in that section as the "nose-fly."

The preliminary investigations in the summer of 1915 revealed the fact that the concentration of horses in pastures had rendered breeding conditions practically ideal for bot-flies, and that a most serious fly nuisance had developed which implicated three species of Gastrophilus. This concentration of horses in pastures may be attributed in part to the advent of gas engines, automobiles, and tractors, and to maximum prices, which has encouraged the breeder

[1] Mr. H. B. Bradford made the drawing illustrating the eggs of Gastrophilus, and Mr. W. N. Dovener made those illustrating the larvæ and dorsal aspects of the adults. Many of the photographs were made by Mr. A. K. Pettit.

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to meet the great demand for army horses. Within the nose-fly district is to be found one of the largest horse-sale points in the world.

BRIEF LIFE HISTORY OF GASTROPHILUS.

Our knowledge of the life histories and habits of these insect pests, which is always essential to successful control, is confined for the most part to the classical accounts of Bracy Clark in 1797 and subsequently, although later writers have added important details.

When the female of *Gastrophilus intestinalis* (*G. equi*) becomes sexually mature it is most often observed hovering near the inside of the knee of a horse, where by preference the eggs are deposited. After a few days, when the larvæ develop within the eggs, the horse by scratching the forelegs with the teeth provides sufficient moisture and friction to remove the operculum or small cap of the eggs and inadvertently the larvæ are taken within the mouth. The empty eggshells remain attached to the hairs of the legs, whereas the larvæ are carried with the food or water to the stomach, where attachment to the stomach walls takes place. Here they undergo development during the autumn, winter, and spring months, and later are passed from the horse with the manure. At this stage pupation ensues and adult flies are produced.

The other species of bots also spend similar larval periods in the animal, but have habits peculiar to the particular species.

HISTORICAL.

The literature containing historical references to the Oestridae carries one to a most remote time. The ancient Greeks and the Latins refer to "an unspeakable fright of cattle," though later writers are not agreed as to whether it was produced by an oestrid or a tabanid. It is certain, however, that Aristotle knew the forms found in the throats of deer.

The Greek veterinarians Theomnestus and Absyrtus give us the earliest record which could be referred to Gastrophilus when they write of the "biting worms which fix themselves to the anus of the horse." In order to destroy them it was recommended that they be torn from the anus with the fingers and covered with hot ashes and pulverized salt.

Malpighi in 1697 gave the first description of a gastrophilid larva taken from the stomach of an ass. According to Joly, it belonged to the species *G. intestinalis* De Geer, while to Brauer it was *G. flavipes* Olivier. Gaspari published an erroneous opinion that *G. haemorrhoidalis* deposited its eggs in the rectum of the horse during defecation, and that the larvæ migrated to the stomach until about fully developed. Vallisnieri and Réaumur made the same erroneous diagnosis.

Linnaeus, Fabricius, and De Geer occupied themselves with the early classification, and not until 1797, with Bracy Clark, does the natural history of the Oestridæ truly commence. To this historical work of Bracy Clark a few additions, many of which are cited in the bibliography, have been made by subsequent writers.

In conformity with the rules of nomenclature and following the reestablishment of the Linnaean designation "*intestinalis*" by Guyot, "*Gastrophilus intestinalis*" is given preference rather than "*Gastrophilus equi.*"

Aside from priority, the specific name "*equi*" is not reliable, since there are several species of Gastrophilus which infest the horse; moreover "*intestinalis*" has been adopted by a number of dependable authorities.

Fig. 1.—*Gastrophilus nasalis:* Female. Oviposits commonly under the jaws of horses. Greatly enlarged. (Original.)

SPECIES DIFFERENTIATION.

The eggs, larvæ, and adults are so easily distinguishable in this genus that it does not require a study of detailed descriptions to enable a student to determine the species. (Figs. 1, 2, 3.) Prof. Garman's key to the wing venation, a reliable index to the species, is here quoted.

Key to Wing Venation of Gastrophilus Spp.

1. Discoidal cell not closed by a cross vein _____ *G. pecorum.*
   Discoidal cell closed by a cross vein _____ 2
2. Wings marked with brown _____ *G. intestinalis.*
   Wings not marked with brown _____ 3
3. Anterior basal cell nearly or quite equal to the discoidal cell in length _____ *G. nasalis.*
   Anterior basal cell markedly shorter than the discoidal cell _____ *G. haemorrhoidalis.*

The cloudy wings of *G. intestinalis* and its habit of depositing upon any convenient portion of the horse where it is not disturbed, but most commonly on the forelegs, will enable one to distinguish it most readily.

G. nasalis is smaller than *G. intestinalis*, densely hairy, with the thorax yellowish red or rust colored. Its most common place of oviposition is under the jaws, but it is sometimes observed to oviposit upon the flanks or forelegs of the animal. Unlike *G. intestinalis*, it does not remain near the animal prior to the deposition of a second egg.

G. haemorrhoidalis is easily distinguished by the bright orange red on the tip of the abdomen. The thorax above is olive gray and hairy, with a black band behind the suture. The base of the abdomen is whitish and the middle blackish, which is in strange contrast with the orange red of the end. It deposits only upon the small hairs on the lips of horses and mules.

FIG. 2.—*Gastrophilus haemorrhoidalis:* Female. Oviposits only upon the small hair on the lips of horses, preferably the portions moistened by saliva. Greatly enlarged. (Original.)

The males of *G. intestinalis* and *G. haemorrhoidalis* are often found awaiting the approach of females to the horses, and when they arrive the flies copulate.

The species characteristics of the eggs of the three species occurring in the United States can best be observed by referring to the illustration (fig. 3). While *G. intestinalis* is usually attached about one-half its length to the hair, *G. nasalis* is attached almost its entire length. *G. haemorrhoidalis* is always found attached to the base of a hair on the lips. These hairs are so small that one does not observe them with the naked eye. It is the only Gastrophilus depositing here. The egg is black in color and the stalk is partially inserted in the pore of the skin at the root of the hair.

Fourth-stage lavæ, as can be seen in the illustration (Pl. I), vary in size when fully developed. In all specimens the eleventh ring is completely deprived of spines, but upon the other rings the variations are often misleading. However, the key given herein will assist in identifying fully developed larvæ.

KEY FOR THE IDENTIFICATION OF FULLY DEVELOPED LARVÆ OF GASTROPHILUS SPP.

1. Spines arranged in two alternating rows, the first more developed than the second ---------- 2
   Spines in one row ---------- *G. nasalis.*
2. Spines long and prominent, lacking only two to three pairs on dorsal center of the ninth row ---------- *G. intestinalis.*
   Spines short and segments prominent. Completely deprived or possessing only two to three pairs of spines on either side of the dorsal center of the ninth ring ---------- *G. haemorrhoidalis.*

DISTRIBUTION IN THE UNITED STATES AND PROBABLE DISPERSION.

Recently Mr. F. C. Bishopp, in communication with a large number of horse breeders, has determined some facts on the distribution and other points, especially in regions adjoining the district where *G. haemorrhoidalis* is known to occur. This information will be published later. It will suffice to say here that *G. haemorrhoidalis* occurs in sufficient numbers to warrant the adoption of control measures in the Dakotas, Montana, and northern Wyoming. According to Dr. C. Gordon Hewitt, Dominion Entomologist, the species extends over a considerable area in the Dominion of Canada. Two of the species, *G. intestinalis* and *G. nasalis*, are found throughout the United States where horses are present. *G. pecorum* is not known to occur in the United States.

The constant migration of the larvæ of *G. haemorrhoidalis* to the region of the anus and their dropping, which occurs over a long period, indicates that the principal means of dispersion is through the movement of infested horses. During the past few years large numbers of horses, which have been purchased in the infested district for European army purposes, were concentrated at certain points until more could be assembled for shipment. This occurred at times when larvæ were normally dropping and allowed ample time for this species to become established. Although the adults may not have appeared in sufficient numbers to attract attention in new districts, this will undoubtedly occur in the near future.

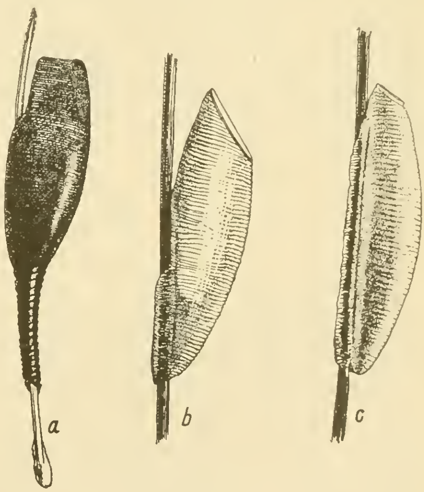


FIG. 3.—Gastrophilus eggs attached to hairs: *a*, *G. haemorrhoidalis* and hair removed with root; *b*, *G. intestinalis*; *c*, *G. nasalis*. Greatly enlarged. (Original.)

The comparatively short duration of adult life and the functions of the adults restricted to depositing eggs indicate that little dispersion takes place by actual flight. In the nose-fly district there has been a slow but gradual spread of the species each year, as verified by hundreds of statements from farmers and horse breeders.

LARVAL COLLECTIONS AND REARING TECHNIQUE.

An insectary was located in Aberdeen, S. Dak., where all types of farm and city operations concerned with the use of horses could be observed, and at the same time easily accessible to a rendering plant where post-mortem examinations could be made. Horses in pasture were available in all directions, and livery barns were located within a mile and could be conveniently visited.

Horses of many types, representing every locality in the immediate vicinity, could be observed in the livery barns, and it was from these horses that breeding material of *G. haemorrhoidalis* was obtained. While examinations of droppings were made, most of the larvæ utilized were removed from their places of attachment about the anus. These were sufficiently developed to pupate and produce adults, and did so even though they were not handled carefully with the forceps in removal. The number of horses in the liveries varied, but usually from 30 to 100 were observed daily. In order to obtain an ample supply of larvæ additional collections were made when near-by farmers came in with teams.

In rearing adults, the larvæ were placed in tin boxes upon moist sand in California parasite-rearing boxes, or in bread trays upon grass sod. These were usually kept in cages 18 by 18 by 18 inches, each of which was fitted with a door of sufficient size to permit the removal of trays for examination. When adults emerged it was necessary to confine them in tightly fitted cages which excluded sunlight, and to keep them supplied with grass sod or green foliage to lessen activity. Sunlight has an unusually great attraction for adult flies. They are very active and will damage their wings against the screen or crawl into a cage crevice and die. More especially has this been noted with *G. haemorrhoidalis.*

LARVAL INFESTATION AND INJURIES.

REVIEW OF OPINIONS.

In reviewing opinions on the economic importance of bot-flies, one naturally encounters the ideas of Bracy Clark, which have been passed from one to another since 1798. He believed that larvæ by irritating the membranes of the stomach and intestines often relieved a general disorder of the system, but mentions that, however useful a few of these natural stimuli may be, they result in large infestations which should at all times be prevented. He indicates in this paper that the infestations coming under his observation did not greatly exceed 100 larvæ, and for the most part not more than a half dozen were to be found.

We find the following statement by R. S. MacDougal (1899):

> Opinion differs a good deal as to the harmfulness of these bots. In conversations with veterinary surgeons I find there is a tendency to minimize the evils that may attend bot presence. There are authenticated records, however, which place the possibility of grievous harm beyond all doubt. Inflammation, ulcers, interference with digestion, interference with the free passage of food or exit of waste matters, loss of appetite and condition, have been frequently

Warburton (1899) says:

The irritation they set up can not fail, however, to be detrimental to the horse's health even where no ill effects are obvious. The fact seems to be that a horse in good condition and well fed can endure the presence of numerous bots in the stomach without great inconvenience, but if the animal is in poor condition gastric enteritis, perforation of the stomach, and death may result.

In Miss Ormerod's report of 1890, Dr. Hy. Thompson, of Aspatria, Cumberland, England, says:

I have never seen the stomach entirely perforated, but the irritation induced by the development of the larva causes in many cases a great wasting of flesh in the horse.

Perroncito (1902) describes lesions caused by Gastrophilus larvæ, some of which resulted in perforation of the stomach walls and death of the animals. Cases of Flohill, Numan, Conti, and others, as well as cases coming under his personal observation, are mentioned.

Kröning (1906) reports having observed cachexia accompanied with colic in young colts during the previous five years, and attributes this to infestations of bots.

Lahille (1911) makes mention of larvæ causing death of animals and cites the possibility of infection in the lesions.

Velu (1913) reports that a drought greatly favored attacks in Morocco and more than 1,000 larvæ were usually found in post-mortem examinations. All three of the more common species were present, but *G. nasalis* caused lesions which resulted in death of the animals.

The universal distribution of *G. equi* and *G. nasalis* has familiarized persons in every locality to some extent with bots of horses, yet their opinions are naturally varied as to the economic importance of the larvæ. There are some who believe that there are no ill effects; others think that they are beneficial; while some even believe that a horse will die if the bots are removed. Such conceptions are most prevalent among "horse doctors" who are not in possession of an effective treatment for the removal of bots. On the other hand, it is a difficult matter to convince a horse breeder that bots are beneficial when his yearling colts kept in pastures have a rough coat, fail to grow or fatten, show no symptoms of disease, and at the same time possess a good appetite. Many breeders have made post-mortem examinations of horses for their personal satisfaction. The finding of hundreds of well developed larvæ with conspicuous lesions conveys vivid impressions and greatly emphasizes the importance of bots. Others, without a knowledge of the development of bots within the horse, often make examinations after numbers have been passed and the lesions healed; or when the larvæ are small and probably not observed by an untrained eye they are regarded as less detrimental. It is only by careful post-mortem examinations of large numbers of horses that conclusions can be drawn, and these may be erroneous if one is not familiar with the various species, their usual points of attachment, and phenomena peculiar to each.

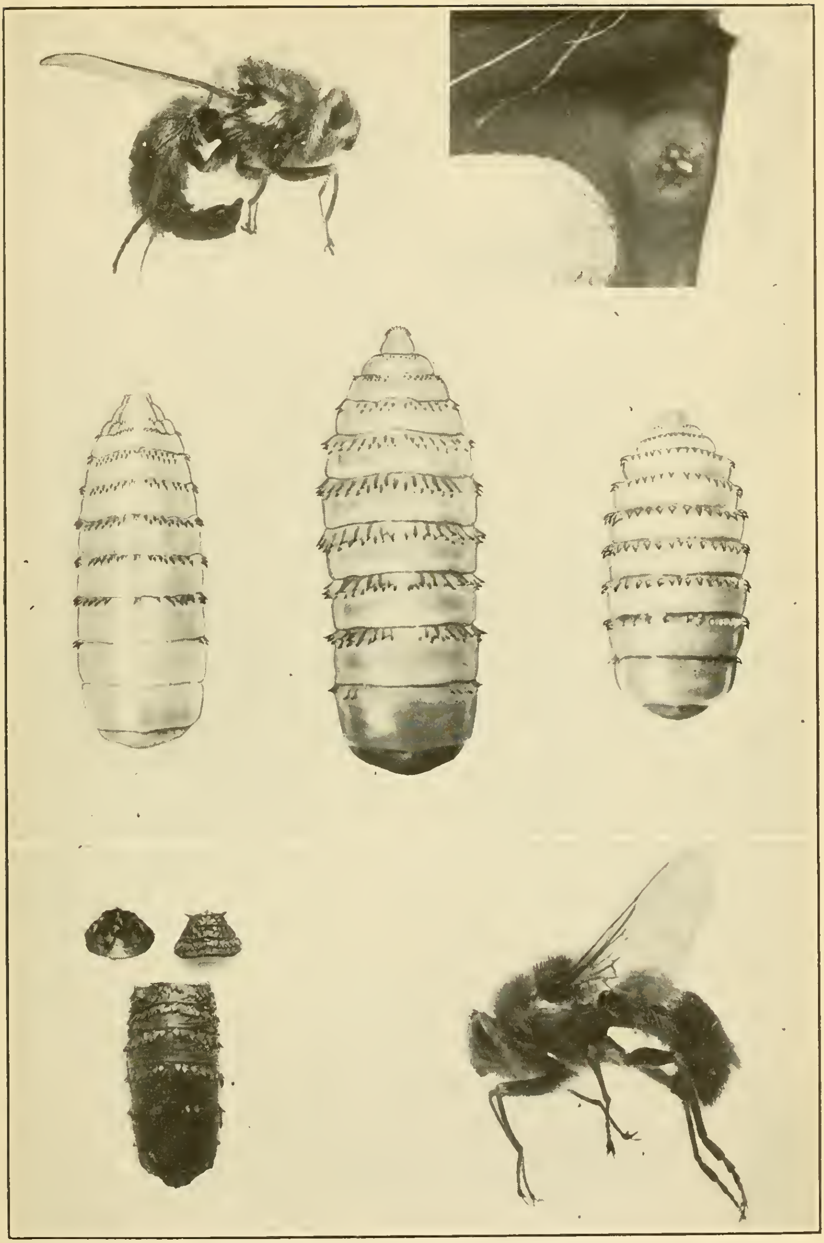
SPECIES IMPLICATED.

Gastrophilis intestinalis, "the common bot," attaches ordinarily in the stomach, has been taken in the duodenum, but has never been found permanently attached in any other regions (Table I, p. 10). Rarely it may become temporarily attached in the rectum, but is not present with an alveolus or lesion.

G. nasalis, "the throat bot," attaches by preference in the duodenum, is often found in the stomach, and is the only known species which attaches in the pharynx. Due to the attachment in the throat, it not only becomes a species of vital importance when the bots congregate in sufficient numbers to hinder or cut off the breathing of the horse or cause an infection, but in this location they can not be removed by an internal treatment. In the duodenum the infestation may be sufficient to hinder or stop the passing of excreta. Table I (p. 10) shows the comparative abundance in the stomach and duodenum during the period that larvæ are well developed and naturally drop from the host.

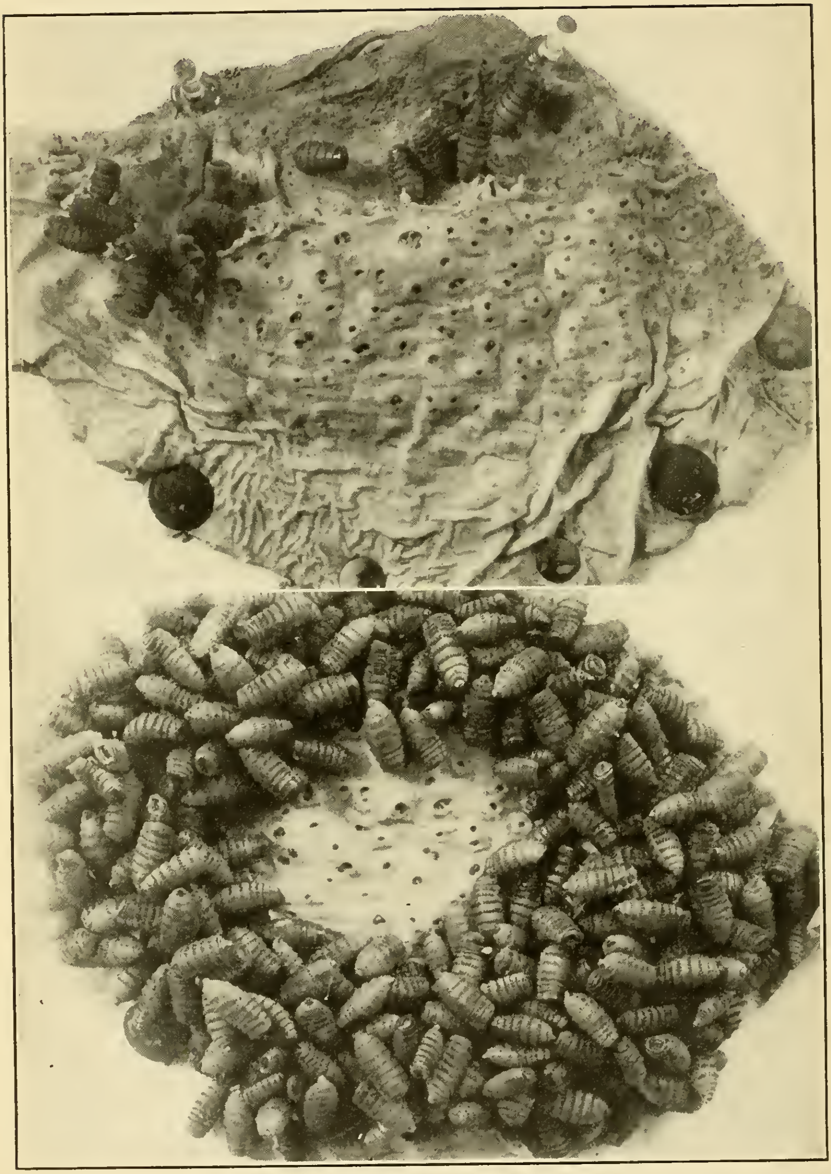
Various cases are on record in which this species has been removed from the pharynx, in all of which the authors considered it a serious detriment to the horse. While larvæ which were not sufficiently developed to be determined with authenticity have frequently been removed from the pharynx, 8 larvæ of *G. nasalis* were collected in the throat of a dray horse by J. L. Webb at Reno, Nev., on August 29, 1916. In numerous cases, both at Aberdeen, S. Dak., and at Dallas, Tex., the author has found lesions present in the pharynx, indicating that the larvæ had become fully developed and had passed out of the horse. In making post-mortem examination of horses to determine the attachment of young larvæ in the pharynx extreme care should be exercised, as young meat-infesting larvæ may be confused with Gastrophilus. Upon hatching they migrate from the light into the nostrils and may be found in the pharynx and other locations in the throat.

Dr. Buffington (1905), of Brooklyn, Iowa, gives a valuable history of a case in which a mare died as the result of an infestation of *G. nasalis* in the pharynx. This animal had experienced difficulty in eating for more than a month, and was unable to take food for a week prior to November 26, 1903. At this time she would drink water, but after masticating food a very little, would drop it out. The symptoms were those of paralysis of the muscles of deglutition and there was a very offensive odor about the head. Four days later, when the animal died, the nasal, pharyngeal, laryngeal, and upper portion of the œsophageal mucous membranes were found to be gan-



STAGES OF THE BOT FLIES, GASTROPHILUS.

Upper left.—*Gastrophilus haemorrhoidalis:* Female, side view. Upper right.—*G. haemorrhoidalis.* Larvæ attached to margin of anus of horse. Left of center.—*G. haemorrhoidalis:* Last-stage larva. Center.—*G. intestinalis:* Last-stage larva. Right of center.—*G. nasalis:* Last-stage larva. Lower left.—*G. intestinalis:* Puparium, showing cap split off by fly in emergence. Lower right.—*G. haemorrhoidalis:* Male, side view. (Original.)



LARVÆ OF THE BOT FLIES, GASTROPHILUS.

Upper.—Attachment of last-stage larvæ and alveolar lesions upon the mucosa of the left sac of the stomach. Lower.—Infestation of 317 last-stage larvæ, with lesions in the center. (Original.)

grenous and the source of the offensive odor. From the pharyngeal walls 12 or 15 larvæ were removed, 6 of which the present author obtained. Three of these larvæ were determined as *G. nasalis*, and it is reasonable to believe that the other larvæ, which were not sufficiently developed for identification, were of the same species.

The larvæ of *G. haemorrhoidalis*, "the nose-fly," as is shown in Table I, may be found in the stomach, duodenum, or rectum, and also attached about the margin of the anus, where they change in color from pink to a greenish, become accustomed to the atmosphere, and later drop to the soil for pupation. During the early stages they attach within the stomach and duodenum, but later loosen themselves and reattach in the rectum, from which they gradually move to the anus. The attachment of clusters of these larvæ in the rectum has been known to stop the passage of excreta and to cause abnormal protrusions accompanied by much suffering.

About June 1, 1915, a horse breeder in Montana experienced a case of obstruction of the rectum in a yearling colt. On three different occasions within one week the animal was observed lying down in the pasture with the rectum greatly protruded. Each time it was washed with warm water and replaced, but the larvæ causing it were not observed until the third time. The exact number of bots removed by hand was not ascertained, but upon their removal and replacement of the rectum the animal gradually recovered.

Table I records a maximum of 1,032 bots removed from a 2-year-old colt. The infestation consisted of 695 *G. intestinalis*, 248 *G. nasalis*, and 89 *G. haemorrhoidalis*. This was the greatest number obtained during any of the autopsies. Colts are always the most heavily infested, especially when they come from summer pastures, and in this case the animal was greatly emaciated, possessed a dull coat, and, in spite of a good appetite and an abundance of food during the previous winter, failed to grow or fatten. It had suffered from a broken shoulder, the result of a kick, which ordinarily would have healed promptly at this age, but instead it remained for months a cripple. The owner, believing that it would never thrive, caused the animal to be killed, and the post-mortem examination revealed no abnormal condition, except the bot infestation and the broken shoulder. It appeared that so much vitality was sapped through the inroads of bot infestation that the colt had no recuperative surplus.

At the date of the post-mortem examination 89 *G. haemorrhoidalis* larvæ had migrated to the rectum and attached. They were not sufficiently developed to pass out and were attached at this point with lesions characteristic of those usually found in the stomach.

In Table I many of the infestations noted were comparatively small when the post-mortem examination was made, and attention should be called to the fact that all of these examinations were made during the time when larvæ were naturally dropping with excreta. The numbers do not show the maximum infestations of larvæ that may have been present. Many of the dead horses examined had been subjected to various environments prior to the autopsies and are not representative of infestations found when horses have spent the entire previous summer in pastures.

Table I.—*Gastrophilus findings in post-mortem examinations of horses at Aberdeen, S. Dak., 1915–16.*

Horse died.	Spent summer.	Larvæ in stomach.				Larvæ in duodenum.				Larvæ in rectum, G. haemorrhoidalis.	Total number larvæ.
		G. intestinalis.	G. nasalis.	G. haemorrhoidalis.	Gastrophilus sp. small.	G. intestinalis.	G. nasalis.	G. haemorrhoidalis.	Gastrophilus sp. small.		
1915.											
June 7		295	11	21						9	[1] 337
July 8		158		12						14	184
July 14		103		1		11	1				116
July 21		58	290	3							351
July 26	Driven on streets	33								1	34
Aug. 12	do	18									18
Aug. 23	do	6			10						16
Aug. 23	In pasture, 1915				67						67
Aug. 26		9	1		35						45
Aug. 26	In pasture, 1915	5			71						76
Aug. 26					42						42
Sept. 13	Country and town driving				217						217
Sept. 17					101				71		172
Sept. 20	Driven on streets								22		22
Sept. 21	do	1			4				13		18
Oct. 1	Farm work	6			50				82		138
1916.											
May 20	do	123	15	7							145
May 20		7									7
May 29		56	1	10							67
May 29		44	10	35			22				111
June 7		64					5	2			71
June 8		18		5			19				42
June 16		16		1							17
June 21	Driven on streets	3									3
June 26	In pasture, 1915	687	70			7	178			89	[2] 1,032
June 28	do	72	2	26			137				237
July 11	Farm work	116	2				19	1			138
July 17	do	92	5				144				241
July 24	In pasture	461					149				610
Aug. 3	Farm work	151	1	1							153
Aug. 4		39	16	4		4	30				93
Aug. 7		20					25	2			47
Aug. 6					13		1				14
Aug. 11		24									24
Aug. 11		29	14	1			4				48
Aug. 23		1			6				26		33
Aug. 23		44		8	8		26		16		102
Aug. 26		23					1		12		36
Sept. 1		1			20						21
Sept. 8		2		1	1				14		18
Sept. 11		5				1					6
Sept. 16		2			37				31		70

[1] Includes 1 *G. intestinalis* temporarily attached in colon.
[2] Includes 1 *G. intestinalis* temporarily attached in rectum.

LARVAL MOVEMENTS WITHIN THE HORSE.

When a post-mortem examination is made. the larvæ usually are found quiescent, although occasionally some may be observed to move the posterior end slightly. The smaller larvæ show more activity than do well-developed ones.

Other than *G. nasalis*, which sometimes attaches in the pharynx, the first-stage larvæ attach to various portions of the stomach and duodenum. In the stomach young larvæ have been removed from various locations, including both the cardiac and pyloric portions. The last-stage larvæ of all three species are found in the various portions. *Gastrophilus intestinalis* is confined for the most part to the mucosa of the left sac, though this species has been taken in the right sac and in the duodenum (see Table I). In the early stages some of the larvæ either change places of attachment or pass out of the horse undeveloped. With last-stage larvæ the indications are that, excepting *G. haemorrhoidalis*, they remain attached at one place continuously during feeding, as in early spring the number of larvæ and lesions upon the mucosa is the same.

During the early spring or perhaps even in winter the larvæ of *G. haemorrhoidalis* move from the stomach and duodenum to the rectum where they may be found permanently attached in clusters. It is evident that they feed in this position, as lesions are sometimes present. Later when they move to the margin of the anus no lesions are present and apparently the larvæ only pause to become accustomed to air temperatures before dropping.

There is no definitely periodic larval migration of *G. haemorrhoidalis*, as some last-stage larvæ are found in the stomach and duodenum until early fall. Through the courtesy of Dr. L. Van Es, of the North Dakota Experiment Station, some post-mortem examinations were made at Fargo, N. Dak., and larvæ preserved according to their location within the animal. During the winter these larvæ were found in the stomach, and on July 10, 1916, 3 larvæ; July 14, 1916, 16 larvæ; and August 18, 1916, 2 larvæ were fully developed and in the same regions. This coincides with the findings at Aberdeen, S. Dak., although one last-stage larva was found in the stomach on September 8, 1916.

POINTS OF LARVAL ATTACHMENT.

When an opened stomach of a horse is examined, one is impressed by the contrast in the left and right portions. Around the entire organ a line of demarcation is represented by a prominent sinuous crest. In the left portion, which is often called the left sac, the mucosa is white, dry, resistant, and covered by a thick layer of epithelium. This covering is identical with that of the esophagus and may be considered as a widening of the esophageal canal.

Dr. Guyot, in describing the mucosa of the left sac, says the structure is analogous to that of the skin. It is dermo-papillary, with epithelium of the Malpighian type, but possesses a muscle, the *muscularis mucosae*, which is peculiar to it. The structure of the right sac differs in having a soft membrane with an epithelium formed by a single layer of cells.

G. intestinalis larvæ are practically always found attached in the left sac, and it is the opinion of Dr. Guyot that this portion affords the most stable point for larval attachment. He thinks that cases are exceptional in which larvæ maintain themselves in the right sac. This, however, does not explain the attachment of *G. nasalis* in the duodenum and to the walls of the pharynx, nor does it account for the attachment of *G. haemorrhoidalis* in the right sac of the stomach, in the duodenum, or in the rectum. As has been mentioned by Dr. Guyot, the reason for attachment in certain regions of the digestive tract will remain a mystery until the manner in which larvæ are nourished is ascertained.

Various investigators have been unable to discover white or red corpuscles of the horse in the pharynx and other alimentary portions of the larvæ. Clark believed their food was probably the chyle, but Guyot rejects this explanation, as larvæ in the pharynx are located where this could not possibly be utilized. As *Oestrus ovis* larvæ nourish themselves with the mucus secreted by the mucosa of the nose and frontal sinuses of sheep, and as those of Hypoderma utilize the pus of the abscesses which they create by their presence in cattle, he believes it permissible to suppose that those of Gastrophilus find nutriment in the inflammatory products of the gastric mucosa.

It would appear, from observations, that Gastrophilus larvæ sometimes feed upon the blood of the animal, although they are not dependent upon it for subsistence. The red and maroon color of *G. intestinalis* and *G. hæmorrhoidalis*, with their attachment upon points other than the mucosa of the left sac, would bear out this hypothesis, which is further supported by the fact that *G. haemorrhoidalis* when fully developed in the rectum still retains a pinkish color.

THE ALVEOLAR LESIONS OF THE STOMACH.

In Dr. Guyot's examinations of lesions caused by the attachment of larvæ to the mucosa of the left sac, the muscular coat was not damaged. The condition found was merely a localized inflammation around the point of larval attachment, in which the derma had been invaded by leucocytes. He assumes that this is only the common inflammatory reaction which would be normally produced around any foreign body.

In following these studies Perroncito found that the bottom of the alveolus varied in size and became the seat of a more or less remarkable inflammatory process. This produced a thickening of the walls of the stomach and finally the disappearance of the muscular tissue, which becomes hard and compact, preventing the normal functions of the stomach. He mentions cases of perforations, lacerations, and ruptures of the stomach observed by Flohill, Numan, Conti, and Brusasco, and calls attention to alveolar lesions which are naturally more predisposed to induce various infective diseases. (See Plate II.)

GASTROPHILUS AND SWAMP FEVER.

Aside from the lesions which may induce the entrance of organisms of infectious diseases, the Seyderhelms, of Strassburg (1914), report results which they think implicate Gastrophilus larvæ in the causation of swamp fever. It is believed by them that the larvæ excrete a specific toxin which is the cause of the disease, for by administering extracts of these larvæ symptoms typical of swamp fever have been observed. The coincidental distribution of Gastrophilus with that of this disease would appear to bear out the hypothesis. It is said that the most virulent reactions were obtained in these experiments with *G. haemorrhoidalis* larvæ.

BOT-FLY ANNOYANCE.

In those portions of the country where the nose-fly does not occur, horses are seldom sufficiently annoyed to require protection. The persistence of the common bot-fly and the repeated stamping of the animals are evidence that it is annoying, but when the throat bot-fly "strikes" the action of the horse becomes more violent.

The throat bot-fly is less persistent but more determined in depositing, and the horse usually responds with a violent nod or jerk, the violence depending upon the nervousness of the individual. In plowing it is sometimes necessary to place a strip of cloth or a small branch of a tree underneath the throat latch and extending to the bit rings.

In the nose-fly section the annoyance is produced by the two generally distributed species in addition to *G. haemorrhoidalis*. Upon the approach of this fly the horse moves the head backward and forward to prevent its darting on the lips, but this only seems to arouse its determination, for it quickly alights on the lips and within a second or two deposits a black egg. It apparently occasions a most annoying sensation, and a horse will most often snort and rub violently against the ground, a bowlder, a tree, barb-wire fence, or any convenient object.

The effects of ovipositions on pastured animals are worry, loss of flesh, and mechanical injuries. If the lips are examined barb-wire lesions will be found which resulted from the rubbing of the horse following an oviposition. (See Plate IV.)

With an unprotected work animal one may be suddenly confronted with a jerk or a similar violent action of the animal at each oviposition of the fly. When a few eggs have been deposited the animal proceeds from infuriated shaking of the head, sometimes accompanied by loud snorts, to complete loss of self-control, and will use any means for self-protection. Numerous runaways naturally occur and serious accidents have also occurred when horses were being used for mowing. The majority of farmers and breeders contend that "the fly stings the horse in the nose." The reactions of the animals are often so violent that at first it seemed that the horses really experienced pain. Dr. Parker, of the Montana State Board of Entomology, has published some notes[1] to the effect that the eggs were thrust into the skin, but he failed to recognize the minute hairs to which the eggs are attached. The pointed portion of the egg is merely a device by which it is attached to the hair. A horse does not experience any pain, as the ovipositions do not puncture the skin. Neither do the flies deposit in the nostrils. Careful search has failed to disclose a single egg in such locations, and it would appear that the snorting of the animal has given rise to this "popular opinion." It is believed, however, that annoyance is largely due at first to an instinctive fear and later to a tickling sensation when the eggs are attached to the minute hairs, as the lips are the most sensitive portions of the horse. Practically all horses in this section have sore lips from eating a "wild barley" or "foxtail grass" (*Hordeum jubatum*) and there is no doubt that this soreness contributes to the annoyance.

NATURAL PROTECTION OF HORSES.

The flies show no preference as to type, breed, color, or age, but naturally oviposit upon unprotected animals. Horses seek protection in pastures, the individuals gathering in a bunch and resting their lips upon one another. Colts and young animals not high enough to protect their lips in this way receive an abundance of eggs.

A horse will sometimes hold the lips upon the ground as if grazing, upon detecting the presence of the fly, and when held in such position the adult fly is rarely observed to oviposit. Often the annoyance of biting flies and other depositing Gastrophilus will cause a horse to walk, holding the lips near the ground. Frequently other horses will follow and protect themselves by placing their lips upon his back or the backs of other animals in the line. Usually they search for the highest elevation where the breeze is blowing, or for standing water, but if an open stall is convenient they will use it to good advantage. If protection is not found an unconfined animal will often wander a great distance from home.

Upon a bright still day ovipositions occur from 8 a. m. until about sunset, and the group of horses may be observed to shift from place

[1] See "Bibliography," page 50.

to place without eating, their lips resting upon one another, or they may congregate with cattle, which are not subject to attack. The horses spend such days in awaiting darkness, after which feeding takes place. Characteristic positions of the animals are shown in Plate III.

Wind with a velocity of 15 miles an hour or more greatly relieves the animals, and persons driving horses about thrashing machines often stop them so that they face the breeze.

Cloudiness is also a protection to horses, and if only a light cloud conceals the sun a bunch of horses may be observed to disperse and begin grazing. Often their feeding will have only begun when the sunlight returns, causing them again to seek protection in a group.

Horses in standing water are not annoyed by nose flies and frequently they seek this protection in order to eat, despite the fact that hundreds of mosquitoes feed upon each animal. This standing or feeding upon grass in water is excellent for a foundered horse, and the mud which adheres to his legs prevents *G. intestinalis* from ovipositing upon them.

While the wind and cloudiness are especially protective against *G. haemorrhoidalis*, the other two species of bot-flies are not much affected thereby. *G. intestinalis* may be observed to oviposit on windy and cloudy days. *G. nasalis* deposits under more adverse conditions than does *G. haemorrhoidalis*, but seems to be more sensitive to natural agencies than is *G. intestinalis*.

In barns the species of Gastrophilus never have been observed to oviposit. On numerous occasions ovipositing adults have been observed to pursue the animal only until it reaches the stall door. Post-mortem examinations of horses which had been confined in stalls failed to reveal a single larva. One of our correspondents reports that the annoyance of *G. haemorrhoidalis* was greatly reduced when he constructed a simple shed in the pasture where the horses could congregate.

SEASONAL HISTORY OF GASTROPHILUS.

At Aberdeen, S. Dak., the larvæ of *G. haemorrhoidalis* are observed attached to the margin of the anus of horses as early as May 5 to 10, and if suitable temperatures occur adults may be expected a little prior to June 15.

From June 21 to 27, 1915, *G. haemorrhoidalis* adults appeared at Lodge Grass, Hardin, Billings, Miles City, and Custer, Mont. At the same time they appeared at Aberdeen, S. Dak., and neighboring points. They have been observed at Aberdeen, S. Dak., as late as October 10, though they are seldom found after a killing frost, which is usually about September 15.

The other two species appear at Aberdeen, S. Dak., about the same time as *G. haemorrhoidalis*, but are most abundant just before a killing frost. The *G. haemorrhoidalis* are least abundant at this time, and are present in greater numbers during the early half of the season. After a killing frost one seldom finds a Gastrophilus except when warm temperatures prevail during a few days.

In the "nose-fly" district one must bear in mind that the period during which flies oviposit is that when farmers are most busy, and the most favorable time for fly ovipositions is when the weather is most favorable for working horses. The adults appear during the plowing of corn and sorghum, and the annoyance continues during the mowing of hay, the harvesting and thrashing of grain, and the marketing of farm products.

GASTROPHILUS HAEMORRHOIDALIS (Linnaeus).

SYNONYMY.

Oestrus haemorrhoidalis Linnaeus, 1761.
Gastrophilus haemorrhoidalis Leach, 1817.
Gastrus haemorrhoidalis Meigen, 1824.

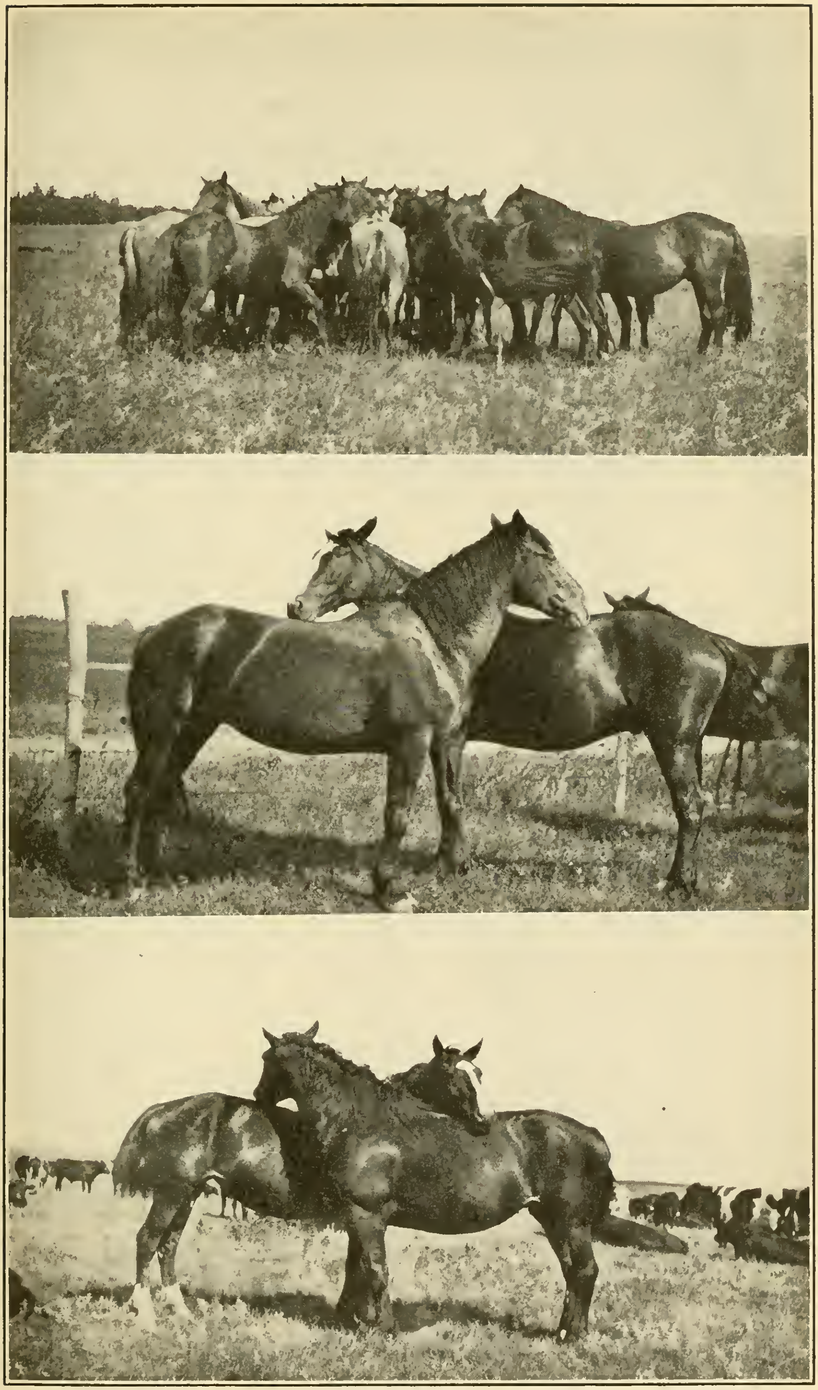
ATTACHMENT IN RECTUM AND DROPPING OF LARVÆ.

During the early spring and summer the fourth-stage larvæ are normally concealed within the rectum, where lesions have been noted in post-mortem examinations. Later they effect a temporary attachment to the margin of the anus, where they become accustomed to the air temperatures, assume a greenish color, and apparently increase their motility. Larvæ, normally exposed to the air at the rectum, after dropping seem to conceal themselves at grass roots so as to be protected from the heat of the sun much more easily than those unexposed at the margin of the anus. When a larva is attached so that only the posterior end is exposed at the rectum one will find the anterior end a pinkish color, while the posterior will be greenish.

Larvæ exposed at the rectum have been observed for the length of time they remain attached, and the shortest period was slightly more than 40 hours, while the longest was 71 hours. The heat of the sun for a few minutes was sufficient to cause larvæ to drop when an attempt was made to photograph a larval attachment at the anus. At various times during the day larvæ appear at the anus, as many as 13 sometimes being visible at one time. The larvæ are likely to drop under most any condition, but do not drop with manure, as is supposed. When manure is dropped during their attachment they seem to use more effort in clinging and are only pushed aside during its passage. (See Plate I, figure at upper right.)

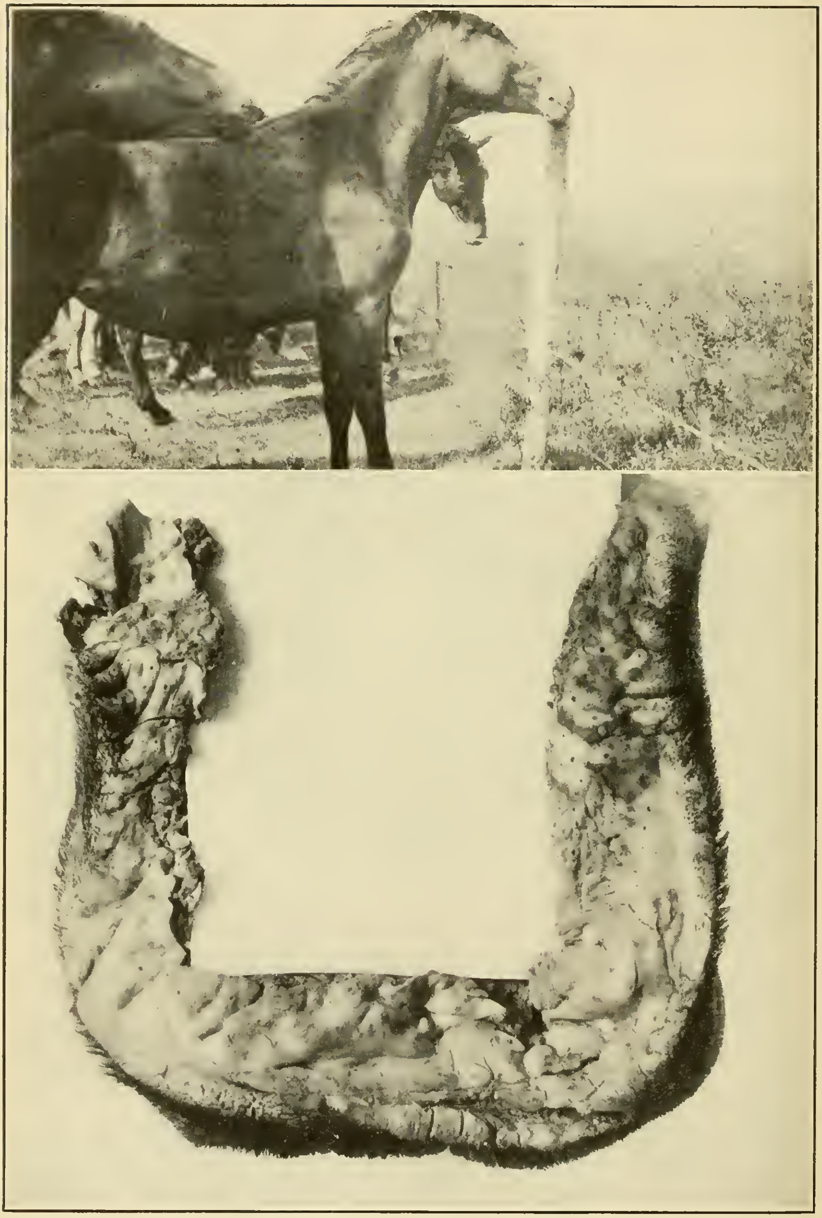
PREPUPATION AND PUPAL PERIODS.

In the normal pupation of a larva which has been exposed at the margin of the anus there is a gradual change from greenish to yel-



PROTECTION FROM BOT FLIES.

Upper.—Horses assembled for protection during ovipositions of *Gastrophilus haemorrhoidalis*. Center.—A method of protecting lips from ovipositing *G. haemorrhoidalis*. Lower.—Protecting under jaws from ovipositing *G. nasalis*. (Original.)



SECONDARY INJURY FROM BOT FLIES.

Upper.—Horses rubbing following ovipositions of *Gastrophilus haemorrhoidalis*. Lower.—Lower lip of horse showing barbed wire cut at the lower extremity which resulted from rubbing. The small holes are injury from the grass *Hordeum jubatum*. (Original.)

lowish, the larva contracting and assuming the form of a pupa. As the puparium becomes more hardened a reddish tinge appears, but after a few days it becomes black and retains this color until the adult emerges.

TABLE II.—*Some environmental effects on metamorphosis of Gastrophilus haemorrhoidalis at Aberdeen, S. Dak.*

Larvæ collected from rectum.	Environment.	Prepupal period.	Pupal period.	Temperature, collection to emergence.			Number larvæ.	Number pupæ.	Number adults emerged.	Longevity of larvæ not pupating.
				Max.	Min.	Mean.				
1915.		*Hours.*	*Days.*	° *F.*	° *F.*	° *F.*				*Days.*
June 4	Fresh horse manure in tin box	27–47	39–45	88	35	63.21	14	14	10	......
June 5	.....do	24–72	46–54	88	35	64.76	33	31	22	4
June 7	.....do	34–52	37–44	88	35	64.93	16	13	8	8
June 8	.....do	49	38–40	88	35	65.67	7	7	2	......
June 9	Clean tin box	35–55	36–48	88	35	65.02	12	11	9	......
June 12	Glass jar and fresh horse manure	53–146	33–36	88	40	65.73	14	14	5	......
June 15	Dry hard soil	75–122	28–30	85	40	62.40	10	10	5	......
Do...	Moist horse manure	122	29–31	85	40	62.56	10	8	7	15–22
Do...	Clean tin box	120	31–32	84	40	62.89	7	6	4	15
June 14	.....do	50–144	30–38	84	40	64.33	27	25	18	16
June 18	.....do	27	32–42	84	40	63.23	34	30	26	12
June 17	Moist manure in tin box	18–47	34–40	84	40	62.06	33	33	28	......
July 12	Black loam in tin can	23–39	34–35	85	40	64.23	8	5	2	......
Aug. 7	On grass sod	19–26	58–68	88	[1] 32	60.59	7	7	3	......
1916.										
May 22	Clean tin box	68	41	94	42	62.62	5	4	4	......
May 23	.....do	52–72	36–40	94	42	62.81	5	4	3	11
May 30	.....do	141–170	34–35	94	42	64.79	2	2	1	......
May 31	.....do	....	35	94	42	60.08	1	1	1	......
June 3	.....do	42–96	33–34	94	42	65.55	11	8	5	5
June 5	With moist sand	75–100	32–35	94	42	66.69	17	17	16	......
June 10	.....do	44	30–32	94	42	68.15	28	25	20	4
June 23	Clean tin box and moist loam	....	21–24	96	48	74.08	46	44	38	5

[1] Minimum, Sept. 21.

In rearing larvæ to adults a most convenient and efficient method was utilized by placing them in clean tin salve boxes upon moist sand in bread pans. Table II gives some results of rearing under such conditions, using various media within the tin boxes. The period of collections extends from June 4 to August 7, which includes practically the entire season during which larvæ appear at the anus of horses in Aberdeen, S. Dak. It will be observed that the prepupal stage, the period from removal of larvæ until pupation, varies from 18 to 170 hours. This is a much greater range of time than is normal and may be attributed to the fact that larvæ were removed before the critical period of dropping. In some instances under varying conditions they did not pupate, and, while some larvæ died within a few days, one is recorded as living for 22 days.

The removal of larvæ from the rectum prior to their normal exposure to the air at the margin of the anus has a pronounced effect upon rearing. A small percentage have been reared which were fully developed and concealed within the rectum, but larvæ less than normal size, which were not exposed at the margin of the anus, did not produce adults. Only larvæ possessing the greenish color indicating exposure at the margin of the anus were used in experiments recorded in the tables.

In Table II, of 347 larvæ collected, 319 pupated and produced 236 adults, the pupa period varying from 21 to 68 days. The greater portion emerged during the shorter periods indicated in the table.

FATE OF LARVÆ DROPPING UNDER VARYING CONDITIONS.

The variety of conditions under which larvæ are dropped naturally suggests the question of their ultimate fate. In an effort to determine this point by experiments, the most striking phenomenon observed was the larval "migration" which precedes pupation. In experiments recorded in Table III, larvæ placed upon the surface of the soil or media penetrated to a slight depth for protection of the pupæ. With larvæ buried in loose soil, as would ordinarily occur when they are dropped by plow horses, they moved upward to near the surface for pupation.

TABLE III.—*Natural pupation and artificial burials of Gastrophilus haemorrhoidalis at Aberdeen, S. Dak., 1915–16.*

Larvæ collected from rectum.	Environment.	Condition of soil.	Depth pupated.	Number larvæ.	Number pupated.	Adults emerged.		Period, collection to emergence.	Temperature, collection to emergence.		
						Male.	Female.		Max.	Min.	Mean.
1915.								*Days.*	° *F.*	° *F.*	° *F.*
June 10	On 2 inches fresh horse manure over 2 inches of loam.	Moist manure developed a mold.	Burrowed ½ to 1 inch in compact manure.	17	17	7	5	35–41	88	40	66.10
Do	On 2 inches dry horse manure over 2 inches of loam.	Very dry horse manure	Upon and near surface	17	16	8	4	35–40	88	40	66.06
June 15	On dry, hard soil	Kept dry	At surface	10	10	2	3	31–33	85	40	64.94
Do	On moist manure	Kept moist	½ to 3 inches deep	10	8	2	5	34–36	85	40	64.93
June 16	Buried under 4 inches black loam and fresh horse manure intermixed.	Pulverized by Lachnosterna larvæ.	3 pupated at surface	15	14	4	4	31–40	85	40	64.03
Do	Buried under 4 inches decaying straw and manure intermixed.	Fairly moist	Few near surface	15	15	6	1	33–40	85	40	64.56
June 19 [1]	Buried under 3½ inches black loam.	Fairly moist and compact	4 near surface	35	35	6	9	30–35	85	41	64.91
Do	On grass sod	Fairly moist	In crevices and near surface	35	35	19	13	34–41	85	40	63.81
July 9 [2]	On wet black loam	Kept wet	Near surface	17	8	1	1	35–36	85	40	63.95
1916.											
June 15 [3]	On grass sod	Kept moist	Near surface	21	19	1	2	32–34	96	42	70.74
June 17	Buried under 5 inches loam	Slightly moist	Pupæ placed 5 inches below surface.	38	32	14	15	24–31	96	42	71.34
July 10	On grass sod	Kept slightly moist	Near surface	43	42	20	18	23–24	98	53	71.66

[1] Pupæ decayed.

[2] 9 larvæ died; other pupæ decayed.

[3] Mouse ate contents of several puparia.

Questioning the fate of pupæ if buried, a lot consisting of larvæ that had moved near to the surface before pupating were replaced in moist loam to a depth of 5 inches. The adults had no difficulty in penetrating this soil, as 29 emerged normally from 32 pupæ. A lot of 15 larvæ buried 4 inches under black loam and fresh horse manure produced 14 pupæ, many of which were located near the surface. Lachnosterna larvæ were present and during their development kept the soil well pulverized. Of the 14 pupæ, 8 produced normal adults.

The experiments cited in Table III, with the exception of the lot of puparia eaten by a field mouse, show that the greater emergence percentage occurred when larvæ were placed upon grass sod. By this method sufficient moisture was supplied, and at the same time the movement of the larvæ to the roots of the grass protected the pupæ from excessive heat. In one lot 32 adults emerged from 35 pupæ, and in another, under similar conditions, 38 adults emerged from 42 pupæ.

It is also noted from other experiments that excessive moisture or dryness is less favorable for the metamorphosis.

EFFECT OF HEAT ON LARVÆ AND PUPÆ.

Doubtless numerous larvæ and pupæ are subjected to heat, in barren places, when dropping from work horses driven upon the roads. This may not be confined to the heat of the sun, for horses standing in stalls may drop larvæ which are placed with the manure in piles that generate heat. The results of some tests are given in Table IV.

TABLE IV.—*Effect of heat on larvæ and pupæ of Gastrophilus haemorrhoidalis at Aberdeen, S. Dak., 1915–16.*

Date subjected.	Stage.	Number.	Environment.	Period of time subjected.	Temperature experienced.			Number pupating.	Number adults emerged.	Per cent death.	Period, collection to emergence.	Temperature after heat test.		
					Max.	Min.	Mean.					Max.	Min.	Mean.
1915.					° F.	° F.	° F.				Days.	° F.	° F.	° F.
July 5	Larvæ	10	Glass jar with gauze cover, buried in manure pile.	6 hours			156.2			100				
Do	...do	5	Buried in manure pile	15 minutes	152.6	150.8	151.7			100				
July 13 [1]	...do	6	In sun, black loam	8 minutes	122.0	121.1	121.6	6	2		34–36	85	40	61.70
July 31	Pupæ	4	...do	30 minutes			116.6	4	0	100				
Do	...do	4	...do	62 minutes			116.6	4	0	100				
Do	...do	4	...do	98 minutes			116.6	4	0	100				
Do	...do	4	...do	137 minutes			116.6	4	0	100				
July Check								5	4		38–39	85	40	62.45
Do	Pupæ	8	In sun on black loam	137 minutes			116.6	8	0	100				
Do								6	4		38–39	85	40	62.48
1916.														
July 3	Larvæ	3	In sun on black loam	8 minutes	125.6	120.2	122.9	1	0	100				
Do	...do	3	...do	10 minutes	125.6	120.2	122.9	0		100				
Do [2]	...do	4	...do	12 minutes	125.6	120.2	122.9	1		100				
July 7 [2]	...do	3	...do	5 minutes	131.0	125.6	128.3	3	2		24–25	85	40	64.92
Do	...do	4	...do	7 minutes	132.8	125.6	129.2	2	0					
Do	...do	4	...do	9 minutes	132.8	125.6	129.2	1	1					
Do [1]	...do	4	...do	12 minutes	132.8	125.6	129.2	2	2					
Do	...do	4	...do	14 minutes	132.8	125.6	129.2	1	1		26	85	40	66–61
Do	...do	4	...do	17 minutes	133.7	125.6	129.7	2	1		26	85	40	66–61

[1] A fungus developed.
[2] Larvæ showed activity after subjection to heat.

Upon hard soil the larvæ are seldom observed to move more than a foot, and this sometimes requires 15 minutes. The tendency seems to be confined almost wholly to burrowing, and it is only when dropped on unsuitable places that they migrate. When exposed upon hard, barren soil to the heat of the sun during the summer it seems certain that only a few find protection and eventually produce adults. Certainly those not finding suitable protection from the sun's heat die within a short time. On black loam at a mean temperature of 122.9° F., 8 to 12 minute exposures caused 100 per cent mortality. Yet some larvæ seem to withstand even higher temperatures, for adults were produced after having been exposed from 5 to 17 minutes at a mean of 129° F. Pupæ, being unable to accommodate themselves by moving for protection, seem to be very susceptible to heat. Exposures of from 30 to 137 minutes at 116.6° F. were sufficient to render them inviable.

The heat generated in a manure pile produced greater mortality upon larvæ than ordinarily would be expected. Larvæ buried without protection at a mean temperature of 151.7° F. were dead within 15 minutes, having become soft and white.

EFFECT OF SUBMERGENCE ON LARVÆ AND PUPÆ.

Although, as shown in Table III, excess moisture seems to have had a destructive effect upon pupæ, the effect of submergence upon larvæ is not so great. Larvæ submerged 51 to 74 hours pupated and produced adults. (See Table V.) Larvæ submerged for 80 hours pupated, but failed to emerge when kept under favorable breeding conditions. While it is difficult to submerge pupæ, as they float and expose a portion of the posterior spiracles, three normal ones kept in water for 5 days failed to emerge. In view of the results in Table III, it is apparent that great mortality occurs among pupæ during wet seasons.

TABLE V.—*Effect of submergence on larvæ and pupæ of Gastrophilus haemorrhoidalis at Aberdeen, S. Dak., 1915–16.*

Date submerged.	Stage.	Number.	Period submerged.	Number pupated.	Adults emerged, (male.)	Larval longevity, including period of submergence.	Collection to emergence.	Temperature after period of submergence.		
								Max.	Min.	Mean.
1915.						*Days.*	*Days.*	*°F.*	*°F.*	*°F.*
July 5..	Larvæ...	6	51 hours............	4	3	5	36	85	41	63.93
July 14..	do....	3	74 hours............	2	1	....	38	85	41	64.21
Do...	do....	3	20 days............	0	....	17–20	....	85	41	62.95
July 21..	do....	5	14 days............	0	....	9-14	....	80	40	58.14
July 2..	Pupæ...	3	5 days............	0	....	....	....	82	40	59.40
1916.										
June 7..	Larvæ..	9	7 days............	0	....	12	....	76	43	64.83
Do...	do....	5	6 days............	1	....	8–12	....	76	43	64.83
July 12..	do....	15	7¼ days............	....	....	8	....	96	64	76.50
Do...	do....	5	80 hours............	5	....	4	....	96	64	75.90
Do...	do....	5	5¼ days............	....	....	7	....	96	64	76.50

Larvæ have been observed to remain alive during submergence for from 14 to 20 days; those submerged 6 and 7 days live for some few days after removal.

NATURAL CONTROL.

FUNGUS DEVELOPMENT.

Under conditions the same as those upon which adults were reared in Table II apparently two species of fungi developed upon living material. The first mentioned in Table VI occurred upon three larvæ, to one of which a particle of horse manure adhered. They were collected from the rectum of perspiring horses, and it appeared that the fungus developed from the manure and spread to the larvæ and pupæ. The larvæ giving promise of fungus development were placed in a clean tin pill box with three well-washed *G. haemorrhoidalis* larvæ, which had been exposed to the air at the anus of a horse for about 24 hours preceding the washing. The fungus developed upon all the larvæ and death ensued. This fungus was determined by Mrs. Flora W. Patterson, Mycologist of the Bureau of Plant Industry, as *Sporotrichum minutum*. This, with one exception, was the only lot in which fungi appeared on living larvæ. As this fungus had developed upon larvæ collected from perspiring horses, it seemed possible that such larvæ as were not washed might have developed a superficial growth. Later collections were made from work animals which were perspiring during the time of collection, and they were kept under similar conditions, but no fungus appeared. In collections of larvæ kept under normal rearing conditions, as given in Table VI, a fungus appeared on the pupa stages which apparently spread to other pupæ in the same lot. In some lots pupæ remained without becoming infected, but in others it even developed upon various parts of the tin boxes. The collections and rearing methods used in these experiments were not unlike those in which no fungus appeared, as new, clean, but unsterilized tin boxes were used in each breeding experiment, and sterilized forceps were used in handling. The soil or medium was different in the various boxes, but since these various conditions were also present in lots which developed no fungi, there appears to be no reason for attributing it to the type of soil or to the medium. Upon the pupæ it appeared within from 3 to 17 days after collection.

TABLE VI.—*Fungus development upon pupæ of Gastrophilus haemorrhoidalis in new tin boxes at Aberdeen, S. Dak., 1915–16.*

Larvæ from rectum.	Collection and environment.	Prepupal period.	Fungus appeared.	Pupal period.	Larvæ collected.	Larvæ pupated.	Number infected.		Adults emerged		Temperature collection to emergence.		
							Pupæ.	Larvæ.	Male.	Female.	Max.	Min.	Mean.
1915.		Hours.	1915.	Days.							°F.	°F.	°F.
June 11[1]	From perspiring horses....	79–220	June 15	34–36	13	10	10	3	2	2	88	40	65.54
June 15	....	75	June 30	35–38	10	10	10	....	5	1	88	40	64.66
June 21	....	20–219	June 25	30–32	34	29	29	5	7	6	85	41	63.88
July 6	With fresh horse manure..	6–25	July 13	34	5	3	3	....	1	....	85	41	63.85
Do...	From perspiring horse.....	23	....	....	1	1	0	....	....	....	....	....	......
July 7	....	6–43	July 13	33–36	3	3	3	....	1	1	85	41	62.12
July 10	With moist loam..........	5–18	...do.....	33–36	40	40	40	....	14	11	85	41	64.32
July 13	....	21–29	July 16	33–35	4	4	4	....	1	1	85	41	64.43
1916.			1916.										
May 17[2]	On blotting paper..........	22–32	May 29	....	7	7	7	....	....	....	....	....	......
June 2[2]	....	20–39	June 14	....	13	11	11	....	....	....	....	....	......
June 5	....	77–102	June 22	....	2	2	2	....	0	0	76	42	59.14
Do.[2]..	With moist sand...........	48–72	June 12	....	8	7	7	....	....	....	....	....	......
June 9[2]	.....do......................	22–70	June 17	....	10	10	10	....	....	....	....	....	......
June 24	.....do......................	4–122	June 29	21–25	62	59	59	....	24	15	96	48	74.67
June 26[2]	....	19–166	July 1	....	20	17	16	....	....	....	....	....	......
June 27	....	22–190	July 3	21–29	15	13	12	....	4	6	96	56	75.73
July 1	....	3–6½	July 6	20	4	4	4	....	....	1	96	58	77.07
July 18[2]	With moist sand...........	21–67	July 25	....	14	12	2	....	....	....	....	....	......
July 24	....	21–31	July 28	29	19	18	18	....	5	3	98	51	70.19

[1] Determined by Mrs. Flora W. Patterson as *Sporotrichum minutum.*
[2] Determined by Dr. A. T. Speare.

Except the collection on May 17, 1916, larvæ were not washed.

Several lots were sent to Dr. A. T. Speare, Mycoentomologist of the Bureau of Entomology, who made cultures and determined the characters showing that all the infestations were of one species and were not Sporotrichum.

According to Dr. Speare about 50 per cent of the pupæ sent to him produced adults. He reported that the fungus seemed to be restricted in its development to the chitinous wall of the puparium, and that death, if caused by the fungus, must have been brought about in some unusual way, as, for example, by closing the spiracles. However, the fungus seems to develop best at the rings of the segments and is seldom observed upon the posterior spiracles.

In Table IV it will be observed that a fungus appeared upon pupæ which had been subjected to heat tests, and this was apparently the same as has been observed in other experiments. A comparison of results and mortalities due to the fungi indicates that there is little hope of controlling the Gastrophilus by encouraging natural development of the fungus. Eighteen lots containing 283 larvæ produced 259 pupæ, of which 247 became infected with fungus in rearing experiments. Twelve of the lots, containing 194 pupæ, were retained for observations on mortality. Of these, 64 males and 47 females emerged as normal adults, giving 57 per cent emergence. The adults possessed a normal longevity as compared with others in rearing experiments.

The above percentage of mortality is based upon those experiments in which the fungus occurred. As there seems to be no reason for attributing the fungus to soil or media it is well to base this percentage upon all experiments in tin boxes and where pupæ were in close proximity. In Tables II and VI, 630 larvæ produced 578 pupæ. Of these 247, or approximately 43 per cent, developed a fungus. Of the ones kept under observation 57 per cent emerged, so that only 43 per cent of the infected pupæ were rendered inviable; 43 per cent of 43 per cent would approximate 18.5 per cent, or the percentage of loss in rearing experiments where numbers were kept in close proximity, which probably allowed the infection to spread over individual lots.

In Table III it is shown that no infected pupæ were found, and should a fungus develop in such conditions the single location of pupæ would prevent its spreading. This fungus has never been observed upon normal *G. intestinalis* or *G. nasalis*, though with dead larvæ of any Gastrophilus a long growth of fungus quite different from that met upon living *G. haemorrhoidalis* pupæ is frequently found.

PREDATORS AND PARASITES.

The dropping of larvæ under varying conditions and in locations where they do not pupate in close proximity renders the situation such that very little could be expected of predators and parasites in control. In rearing experiments some field mice devoured pupæ on grass sod, but even though they feed upon these in nature it is not likely that a great many are devoured. Chickens probably do not feed upon many larvæ when they drop, though a single hen has been known to devour about 40 dead *G. intestinalis* removed from a horse by a carbon disulphid treatment, and without any noticeable ill effects upon the chicken.

Desiring to know if the widely distributed *Nasonia brevicornis*, which parasitizes various species of dipterous pupæ, could be reared upon *G. haemorrhoidalis* pupæ, repeated efforts were made, but without success. The indications are that the flycatchers feed very little upon Gastrophilus adults. On account of the danger in shooting such birds in pastures very few examinations of stomachs have been made.

LIFE-HISTORY NOTES.

ADULT LONGEVITY.

The life of adults appeared so short at the beginning of experiments that it was attributed to abnormal conditions, but various cages and environments did not materially increase the periods. A total of

254 males and 184 females were used in the experiments. All of these emerged normally from reared material. While some adults died on the first and second days the maximum longevity was 7 days. The greater periods were always obtained when the cages were kept out of the bright sunlight and provided with more or less foliage to prevent adults from battering themselves against the sides of the cage. Twenty-seven males and 15 females liberated in the insectary (9 by 12 by 7 feet) died within 1 to 3 days and were found dead at a sunny exposure with the wings battered. Cages admitting a great amount of light and without foliage yielded similar periods of longevity.

Adults in screen cages 18 by 18 by 18 inches or in a parasite-rearing box (covered on two sides with glass and arm holes in the ends) usually died within 3 days. This longevity was slightly extended when green twigs were frequently replenished.

The longest periods were obtained in wooden boxes 4 by 4 by 6 inches half filled with moist soil and provided with a green twig and a glass cover. This lessened adult activity, and from the 51 longevity experiments it was observed that the greater periods were always accompanied with the least activity, while the converse was also true. These wooden boxes placed in the shade admitted enough light to permit of activity and flies were often observed to fly about with the head near the glass and would alight on the green twigs and rest. The usual longevity under such conditions ranged from 3 to 6 days. Some adults captured in nature were kept under similar conditions and lived from 3 to 5 days.

Various flowers were supplied as food for the adults, but in no case was feeding observed. Sweepings were also made from flowers blooming in pastures and from alfalfa in bloom, but adults were never captured under such conditions.

ADULT HABITS.

Adult flies in cages copulate most frequently about noon, the duration of the act ranging from 3 and 4 to 15 minutes. During the act the flies usually remain quiet, except for the distinct abdominal movements of the male. The male usually breaks from the female, leaving her at the place of copulation, but within a few minutes may be observed to return. One pair has been observed to copulate as many as four times within an hour. Males will mate with a freshly emerged female before her wings are dry, properly unfolded, or the body of a normal color. In nature the one object of the male seems to be copulation, and that of the female oviposition. Buzzing in midair about the horse the male may be easily caught with the hand. A female is only observed buzzing at a standstill in midair when a horse is grazing or otherwise protected from ovipositions. She usually comes from a distance and strikes at the lips. Her quick flight seems to be distinguished by the male, who attempts to mount her before she oviposits, but the momentum of the two usually carries the couple to some distant place so quickly that one can not tell whether copulation actually takes place upon the wing or whether they fall to the ground. At any rate, they fly for some distance. Apparently the sexes always meet at the horse, the males awaiting the approach of the females. At times the male encounters an adult female of *G. intestinalis* about the horse, and these two may be observed to fall upon the grass at the feet of the horse, usually separating within a few seconds.

PREOVIPOSITION PERIOD AND OVIPOSITIONS.

Just how soon after emergence copulation takes place is not definitely known, but it is certainly less than 18 hours. Adults emerging during the night copulate by noon of the following day and will oviposit during that afternoon. They will not oviposit in captivity. On five occasions in which flies emerged normally during the night, males and females were kept in a box with glass sides and with green foliage. By noon in each case some were observed to copulate and when liberated in the afternoon would oviposit. Their wings were colored with red ink, and when captured they could be identified easily. Under favorable conditions ovipositions took place as soon as adults were liberated, usually about 3 hours after copulation. After a lapse of a few minutes they were never to be collected about the same bunch of horses, which is probably due to the migration of adults and to the movements of the various horses upon which they oviposit.

A determination of the egg-laying period is important in that it shows the value of destroying adults at different times during this stage, but with such short preoviposition and longevity periods and the inability of flies to feed, the indication is that the flies oviposit throughout their existence. Dissections of females reared to adults indicate that they develop from 134 to 167 eggs, the usual number possibly being near 150.

Unlike *G. intestinalis*, which may stand in midair and consecutively deposit 15 or 20 eggs at one time, often placing two or more upon one hair, *G. haemorrhoidalis* deposits but one at a time and only one upon a hair. It leaves the animal for about one-half minute or longer after ovipositing, but not for so long a time as does *G. nasalis*. It never oviposits upon any other portion except the lips, preferably the portions moistened by saliva. The stalk portion of the egg is inserted in the pore of the skin at varying depths, but the stalk has never been observed to be inserted for its full length. Often it extends to such a slight depth that after a few days the egg may be found lying lengthwise upon the lips, yet firmly attached to the hair. The color, a jet black, so conceals the attachment to the transparent hair that it appears that the hair extends through the center of the stalk portion and through a portion of the side of the egg. The extreme point, however, shows a folding about the hair which may be attributed to the pressure when it is inserted in the pore of the skin. Above the stalk portion the hair is attached to the side of the chamber containing the larva in a similar manner to the attachment of other Gastrophilus eggs upon the hair.

INCUBATION AND INGRESS OF LARVÆ.

Having observed eggs upon both moist and dry portions of the lips of horses, large numbers in various stages of incubation were removed and placed in tubes for observation. About 100 were kept in a test tube, with a moist cotton stopper, at the air temperature of a living room. While a variation in color was at first observed, ranging from a black to a reddish color, after a few days the majority were of a reddish brown. Some were placed upon a slide and moistened, then by the use of two dissecting needles dead larvæ were removed. No larvæ had hatched of their own accord, but emerged when subjected to moisture and friction. In similar tubes which were kept dry three lots of eggs varying in color were observed and not a single larva hatched.

Examinations of the inside of horses' lips revealed numerous holes accompanied by much soreness which appeared as though the young larvæ hatched and had burrowed through the lips. Upon dissections in post-mortem examinations it was disclosed that the injury was caused by "wild barley" or "foxtail grass." This grass was determined by the Bureau of Plant Industry as *Hordeum jubatum*. Its injuries are more noticeable upon lips of livery horses when fed hay containing this grass, as pastured animals avoid eating it and the injury is less noticeable. It is worthy of note that this grass, in addition to its injury upon lips of horses, serves as a winter host of the black rust which is so destructive to wheat in the Dakotas.

On August 24, 1915, a suckling colt, its mother (a crippled horse) and another horse were carefully freed of eggs. Twenty-four hours later a diagram was made showing the exact location of each egg deposited during this time. Upon the following three days it was too cloudy for other adults to oviposit, so the horses were not kept in a barn to prevent further ovipositions, but were left to graze in the pasture. This allowed ample time for development of the embryo and of a distinguishing brownish-red color which greatly aided in keeping track of the eggs.

Upon the suckling colt the first egg disappeared upon the ninth day; the eleventh day, two; the thirteenth, five; and the fourteenth, six. Five other eggs about 1 inch from the mucous membrane and upon the dry portions yielded dead larvæ when examined.

Upon the lips of the cripple horse and within 1 inch of the mucous membrane 15 eggs were deposited. The first 6 eggs disappeared upon the seventh day from near the corners of the mouth. The last egg disappeared upon the eighteenth day.

The normal horse in grazing received 14 eggs within 1 inch from the mucous membrane. Upon the sixth day 10 eggs disappeared from near the corners of the mouth, which was probably five days from deposition. The other 4 disappeared during the following three days.

The striking feature of the above three cases is that those eggs deposited where they received most moisture and friction were the first to disappear. Prior to disappearance, the color changes, being first brownish, then a brownish red, finally with a whitish tip, thus clearly indicating embryonic development. It is also clearly seen that the amount of grazing affects the incubation, as the normal horse grazed practically the whole time, the cripple only at times, while the suckling colt was not observed to graze. There were no indications that the larvæ burrowed into the lips, and as well-incubated eggs have produced larvæ under moisture and friction when removed, it is certain that the method of ingress of larvæ into the host is not unlike that of *G. intestinalis.* It is true that eggshells were never found attached to the hairs after the larvæ had emerged, but it is believed the moisture and friction are sufficient to remove these after the larvæ leave the eggs and enter with the food.

Incubation records are not confined to the above three cases. Upon August 24, 1915, one other animal was freed of eggs and allowed to receive depositions during 24 hours. Upon the moist portions of the lips 17 eggs were found, while 6 were deposited upon the dry portions 1 inch from the mucous membranes. Separate notes give a comparative idea of the incubation. Upon the sixth day, probably 5 days from deposition, 4 eggs disappeared from the moist portions and others disappeared the following day. Upon the dry portions all were present upon the twelfth day. Three of these when removed contained dead forms and the other 3 disappeared from the eighteenth to the twenty-third day.

The day of oviposition in the above cases was favorably followed by three cloudy days, which prevented other ovipositions. The development of the embryo in eggs upon moist portions was quite in contrast to those upon the dry portions, showing clearly the necessity of moisture and friction. Such observations indicated that those eggs upon the moist portions incubated in from 5 days to a slightly longer period.

September 9 was preceded by two unfavorable days for oviposition and was itself very favorable, but was followed by rain and cloudy weather until September 15. At this time black eggs were found upon the dry portions of the lips, while upon the moist portions the eggs were reddish with whitish tips. Due to the scarcity of adults, the eggs were not plentiful at this time, and a few days later one only could be found, upon the dry portions of the lips.

Due to the comparatively long period during which the eggs remain attached upon the dry portions of the lips of horses, which is particularly due to the protection of the thick, coarse hairs surrounding them, it is believed that one could be misled easily as to the most favorable places of deposition of the adults.

GASTROPHILUS NASALIS (Linnaeus).

SYNONYMY.

Oestrus nasalis Linnaeus, 1761.
Oestrus veterinus Clark, 1797.
Oestrus salutiferus Clark, 1815.
Oestrus clarkii Leach, 1817.
Gastrus nasalis Meigen, 1824.
Oestrus duodenalis Schwab, 1840.
Gastrophilus nasalis Schiner, 1861.

OVIPOSITIONS AND LONGEVITY.

The female *Gastrophilus nasalis* often appears from the grass about the fore legs of a grazing animal, strikes under the jaws, remains a few seconds, and during that time deposits an egg about midway upon the hair. The adult then leaves, completely disappearing in the distance, but within a minute or two a similar oviposition may occur, except that the adult approaches from a distance. The presence of a person about the head of an animal does not interfere with egg deposition, and the fly may be caught with the hand when it alights upon the hairs underneath the jaws. It may also be observed to deposit upon the fore legs or the flanks. Dissections of the abdomen of reared females show that they are capable of depositing from 480 to 518 eggs. The attachment of these, as may be seen by referring to figure 3, *c*, extends to almost the entire length of the egg, and being attached about midway upon the hair, numbers are concealed unless the hair is brushed aside in making examinations. Often eggs may be observed near the end of the hairs, but this usually occurs after great numbers have been deposited. Then it is possible to find two or more eggs upon one hair. As yet the method of ingress of the larvæ has not been determined. Dr. C. H. T. Townsend thinks that the larvæ burrow through into the mouth and are swallowed. One author believes that a horse in eating will rub the jaws upon the manger, which hatches the eggs, and that they are taken into the mouth with the food. The fact that some eggs are deposited upon the fore legs and portions accessible to the mouth indicates that the ingress of larvæ may be similar to that of *G. intestinalis.*

Longevity in this species seems to be increased over that of *G. haemorrhoidalis*, as one reared adult kept under conditions similar to those of the nose fly lived for 12 days.

LARVA AND PUPA STAGES.

Coincidentally with the appearance of *G. haemorrhoidalis* at the anus of horses, the larvæ of *G. nasalis* occasionally may be observed to pass normally from horses and be found in their droppings. This normally occurs when larvæ become fully developed and is often attributed by farmers to "a destructive effect of grass upon the bots."

These larvæ seldom migrate a great distance, and apparently only burrow under the droppings for protection. Larvæ which dropped normally pupated in from 1½ to 2 days, though the prepupal periods in some cases in which larvæ were removed in autopsies and cited in Table VII extended for 7 days. It was observed that the short pupal periods were preceded by long prepupal ones, and that larvæ pupating within 2 days after dropping emerged in from 42 to 45 days. At Victoria, Tex., Mr. J. D. Mitchell collected a larva under manure, which pupated October 6, 1914, and emerged 20 days later. To rear larvæ collected in autopsies is a difficult task, even though they are well developed and appear normal, but during the late summer a small percentage may be reared if they are collected from horses immediately after death. The larvæ removed from dead animals are capable of remaining alive and active for some time, some having been kept as long as 25 days. Some larvæ have been observed to live submerged in water for 12 days.

TABLE VII.—*Pupal periods of Gastrophilus nasalis, Aberdeen, S. Dak., 1915–16.*

Larvæ collected.	Location.	Number larvæ.	Breeding environment.	Number pupated.	Range of pupal period.	Number emerged.		Longevity larvæ not pupating.	Temperatures.		
						Male.	Female.		Maximum.	Minimum.	Mean.
					Days.			Days.	°F.	°F.	°F.
1915. June 4	Fresh dropping........	1	With horse manure.	1	42	1	......	......	88	35	65.30
1916. May 29	.....do................	2	Clean tin box; moist sand.	2	44–45	1	1	......	94	42	67.93
June 12	Dropped from treatment.	4	.....do..............	1	31	1	......	7	94	42	[1]68.98
July 10	Duodenum............	19	Dry paper in tin box.	3	25–33	1	2	3–15	98	41	72.77
Aug. 11	Stomach..............	18	Moist sand..........	3	48	1	......	3–8	98	28	60.26
11	Duodenum............	18	.....do..............	3	56	1	1	11	95	28	59.97

[1] Horse treated with carbon disulphid.

GASTROPHILUS INTESTINALIS (DeGeer).

SYNONYMY.

Oestrus bovis Linnaeus, 1761.
Oestrus intestinalis De Geer, 1776.
Oestrus equi Clark, 1797.
Gastrophilus equi Leach, 1817.
Gastrus equi Meigen, 1824.
Oestrus gastricus major Schwab, 1840.

OVIPOSITIONS AND LONGEVITY.

The universal distribution of the common bot-fly, the familiarity of innumerable persons with its oviposition habits, and the numerous publications dealing more particularly with ovipositions and ingress of the larvæ into the host since Bracy Clark (1797), leave little to be desired. It is probable that there is no other insect whose eggs come so directly under the observation of farmers as does the common bot-fly. The common names of this Gastrophilus vary with the locality, but farmers are usually aware of the fact that this insect produces the bots in horses.

Some authors contend that the eggs are deposited upon those places most accessible to the horse's mouth, while others hold that the fly will deposit upon any portion where it is not disturbed. It has always been observed that these flies give preference to the forelegs, and, after these have become well covered with eggs, depositions occur at other points where the fly is not disturbed by the horse's tail. Very few eggs are deposited upon the hind legs or upon the backs of the animals, but when adult flies are in numbers the mane may become heavily infested, especially near the shoulder. Large numbers of eggs may be found upon the sides of the animals, and these are concentrated at points accessible to the mouth, as in cases of depositions upon the inside of the forelegs. It seems that the fly oviposits on the forelegs instinctively, and, after the legs become heavily infested, adults may be observed to deposit one or two eggs on them and then seek other portions of the body. At times two or more eggs may be found upon a single hair on the inside of the forelegs, but seldom has this been noted upon other portions. However, the length of the mane often permits adults to deposit large numbers upon a single hair. With the exception of the forelegs, the sides below and to the rear of the shoulder blades probably harbor most eggs.

The longevity of 14 reared adults in 9 tests, in which the flies were kept under conditions similar to those employed in rearing *G. haemorrhoidalis* varied from 7 to 21 days. The longer periods occurred during early fall, when lower temperatures were experienced. These adults, like those of other species of Gastrophilus, were never observed feeding upon flowers, but green twigs were favorable resting places in rearing cages.

A female taken while ovipositing was placed within a tube containing a male, and they were observed to copulate for 5 minutes.

Dissections of 5 females showed the following egg capacity: Maximum, 770; minimum, 397; average, 541.

INCUBATION AND INGRESS OF LARVÆ.

While making observations in pastures, on four occasions large numbers of eggs were collected which had been deposited upon the author's horse. The eggs were kept in tubes at air temperatures of a living room and none hatched without friction and moisture. By placing the infested hair upon a microscope slide and moistening it the larvæ were most easily removed by rubbing the lot with a dissecting needle. In such tests the eggs remained attached to the hair, while the operculum was removed, allowing the larva to emerge. Very good results were also obtained by rubbing a moistened finger over the lot. When eggs were less than 7 days old it was found difficult to obtain living larvæ, though at 9 and 11 days active larvæ were removed. When they were slightly older than 11 days they emerged without difficulty when attended by moisture and friction, and one living larva was found as late as the forty-eighth day. This seemed to be an exception, as in the other lots all were dead after 40 days. In general, all experiments tended to confirm those of Osborn. According to Guyot, with various lots placed in paper bags and kept in a pasteboard box at room temperatures, some emerged without moisture and friction. On December 28, 1900, Guyot obtained quite agile larvæ as late as 96 days after collection of the eggs. In another case, with eggs collected on October 6, he succeeded in obtaining larvæ from January 7 to 13 following, a period of 92 to 98 days. Due to this fact, Guyot concludes that the larvæ are capable of withstanding comparatively low temperatures after the eggs have been removed from the host. From eggs collected on horses in the open, active larvæ were removed as late as December 1.

LARVA STAGES.

The attachment of young larvæ frequently occurs in almost any part of the stomach, but, as has been previously stated, they are found as fourth-stage larvæ upon the mucosa of the stomach, more especially on the left sac. If living larvæ are removed from an animal during a post-mortem examination a great tendency for reattachment will be observed. During such examinations they have been frequently separated into lots according to species, and in a short time they would attach to a piece of paper or stomach section or even to one another. This is only a temporary attachment, however, and apparently no attempt at feeding takes place.

The studies of Brauer, Numan, and Guyot indicate that the larvæ molt during their development and that there are at least three stages. No experiments have been reported as to the exact time that larvæ remain within the body of the horse, although apparently they spend about 10 months in this parasitic stage. On some occasions, as will be observed in Table I, well-developed larvæ were disclosed on post-mortem examinations in early fall. The indications are that some larvæ are not sufficiently developed to pass out in time to produce adults and that they succumb to low temperatures. There are various factors that apparently tend to influence the extension of larval periods. When gross infestations occur the development is markedly slower than in those horses containing only a few larvæ. Laxative foods have a greater tendency to discharge well-developed larvæ than foods of a non-laxative nature, as is observed in comparing autopsies of livery and pastured animals. Since there is such a wide range of variation in the ages of larvæ within the eggs at which they are capable of being ingested it is possible that this may tend to prolong the period during which the last-stage larvæ drop.

SUBMERGENCE OF LARVÆ.

Last-stage larvæ removed from horses immediately after death remained alive and active from 21 to 33 days when submerged in water, but when submerged for only 6 days they would not attempt pupation. These periods are considerably decreased if larvæ are not removed shortly after the death of the animal.

PUPA PERIODS.

The larvæ drop naturally with manure, burrow only enough for protection, and normally pupate within a day or two. The periods of dropping extend over a long time and very few larvæ are found in droppings. It is a difficult matter to rear larvæ taken in post-mortem examinations, and this is best undertaken in the late summer or early autumn, when the greatest number of larvæ are fully developed. With such larvæ, used in the experiments, the pupa periods have been observed to vary from 27 to 43 days, with an average of 38 days.

EFFECT OF DEATH OF HOST UPON GASTROPHILUS LARVÆ.

The resistance of larvæ and the death of horses from infectious diseases naturally suggest the fate of larvæ during the period when they normally drop. In experiments larvæ were not kept with the animals during the decay, but were removed in autopsies, separated according to species, and placed under favorable rearing conditions. It is evident that larvæ within the stomach and duodenum are not capable of withstanding the internal processes which accompany the decomposition of animal tissues, especially during warm periods. There is excessive gas formation with the breaking down of the tissues, and the larvæ apparently become asphyxiated, since they are found bloated and when crushed become flat. During cool periods larvæ are affected very little for a number of hours, and in stated cases as long as 30 and 48 hours after death of the host larvæ have been reared to adults. Low temperatures hold back that period of decay in the carcass which normally would cause the death of larvæ.

From post-mortem examinations, as will be seen in Table I, *G. haemorrhoidalis* larvæ are seldom found in the rectum. In all probability they drop shortly after death, and during the normal period of dropping are capable of producing adults.

CONTROL STUDIES.

REMOVAL OF G. HAEMORRHOIDALIS LARVÆ FROM RECTUM.

The effectiveness of the extraction of Hypoderma larvæ as advocated by various authors suggests a mechanical removal of *G. haemorrhoidalis* larvæ. While they appear at the margin of the anus daily, studies show that they remain visibly attached from 40 to 71 hours. This would necessitate much work during a busy season with farmers, but extractions at feeding time would greatly reduce the number in work animals. In practice this periodical detaching caused much discomfort and soreness about the anus.

The attachment of clusters of larvæ within the rectum and the recommendation of tobacco decoctions, by the Bureau of Animal Industry (1911), for larvæ lodged in the rectums of horses, indicated the need of information as to the effect, on this species of Gastrophilus, of substances used as enemas. This necessarily required a detailed study of the effects of various substances upon larvæ, and these are reported in Table VIII.

TABLE VIII.—*Treatment of Gastrophilus haemorrhoidalis larvæ from rectums of horses, with contact insecticides, Aberdeen, S. Dak., 1915–16.*

Number of larvæ.	Contact insecticides.	Exposure.	Immediate effects on larvæ.	Larvæ died.	Larval longevity after treatment.	Number pupating.	Prepupa period.	Pupa period.	Emergence.	
									Male.	Female.
					Days.		*Days.*	*Days.*		
5	Tincture quassia	1 hour 10 minutes	Apparently none	0		5	1–5	35–36	1	2
5	Essence ginger	10 minutes	Hooks concealed	0		5	1–2	33–36	2	2
5	Saturated solution borax [1]	5 hours	do	All.						
5	10 per cent carbolic acid	5 hours 15 minutes	Contracted	All.						
5	Tar soap, soft	4 minutes	Activity increased	All.						
5	Tar soap, soft, and resin	do	do	All.						
5	Saturated solution boric acid	26 minutes	Contracted	All.						
5	do	10 minutes	None	0		5	1–2	33–34	2	2
5	Beta naphthol, chloroform, soap, and water	40 minutes	Inactive	All.						
2	Hellebore and water	2 days		1	12	1	6	44		1
2	Soft tar soap, water, and resin	2¾ days		All.						
4	3 per cent carbolic acid	5 minutes	Contracted	All.	7					
5	10 per cent carbolic acid	Posterior end dipped	Inactive	All.						
5	do	2 minutes	do	All.						
10	Nicotine sulphate	do	do	All.						
6	Nitrobenzine gas	21 hours	None	0		6	2–4	28–29	2	
5	do	1 minute	do	All.	1–6					
6	Cresol, 2.7 per cent phenols [2]	do	do	All.						
5	Cresol, 1.35 per cent phenols [2]	do		All.	6					
5	Nitrobenzine	2 minutes				5	1–3	26–28	2	1
4	Cresol, 1.35 per cent phenols [2]	Posterior end dipped	None			4	2–3	27–29	2	1
6	Cresol, 0.45 per cent phenols [2]	5 minutes	do			6	3–5		0	0
3	do	10 minutes	do			3	1–3	26–28	1	2
3	do	15 minutes	do			3	1–3	26–28	1	2
5	do	20 minutes			6	4	1–3	26		1
6	Nitrobenzine	4 hours	Inactive	All.	4					
5	do	1 minute	None	All.	7					
5	do	2 minutes	do	All.	7					
5	do	3 minutes	do	All.	7					
3	16⅔ per cent carbolic acid	do	Contracted	All.						
4	do	4 minutes	do	All.						
3	8⅓ per cent carbolic acid	2 minutes	do	All.	2					
4	do	4 minutes	do	All.	2					
3	4⅙ per cent carbolic acid	2 minutes	Soft	All.	4					
4	do	4 minutes	do	All.	4					
5	6⅔ per cent nicotine sulphate	1 minute	None	All.	2–4					
5	do	2 minutes	do	All.	2–4					
5	do	3 minutes	do	All.	2–4					
5	3⅓ per cent nicotine sulphate	1 minute	do	All.	2–9					
5	do	2 minutes	do	All.	2–4					

5	$3\frac{1}{3}$ per cent nicotine sulphate	3 minutes	do	All.	2–9					
5	$1\frac{2}{3}$ per cent nicotine sulphate	1 minute	do	All.	2–9					
5	do	2 minutes	do	All.	4–13					
5	do	3 minutes	do	All.	2–9					
4	do	5 minutes	do	All.	2–7					
4	do	12 minutes	do	All.	4–9					
5	do	20 minutes		All.	4–9					

[1] No effect from 10-minute submergence.

[2] Cresol suspended in resin soap.

Some of the tænicides and larvicides which have been successfully used upon insects, as well as soapy enemas, were tested upon detached larvæ in tin boxes. As with other Gastrophilus larvæ, remarkable resistance was noted. It will be observed that negative results were obtained by using the common tænicides, that soap solutions seemed more effective, and that nicotine sulphate gave good results.

LARVAL TREATMENTS.

Experimenters have been impressed with the resistance of Gastrophilus larvæ to various contact substances, and it is practically agreed that any contact substance capable of killing the larva would seriously injure the stomach membranes of the horse. The internal method for use must necessarily be in the form of a fumigant. The use of carbon disulphid internally, as brought out by Perroncito and Bosso, has been tried and indorsed by many veterinarians. A list of indorsements from many countries can be found in articles dealing with this subject. Originally the disulphid was administered in 12-gram capsules surrounded by aloes, the whole contained in 48-gram gelatine capsules. In the hands of various workers it has been subjected to modifications, but each reports that large numbers of larvæ pass as a result of the treatment, and some remark upon the beneficial effects of the removal of larvæ upon the animal.

The Bureau of Animal Industry, after employing this treatment upon a number of horses, recommends the following procedure:

> The day preceding the treatment a small amount of hay and a moderate amount of oats is given in the morning; in the evening food is withheld and a purgative given—Barbados aloes 1 ounce, or raw linseed oil 1 pint. The day of the treatment, at 6 o'clock in the morning, give 3 drams of carbon disulphid in a gelatin capsule; at 7 o'clock repeat the dose in the same manner; and at 8 o'clock give the third and last dose, making in all 9 drams of carbon disulphid in three gelatin capsules.
>
> The above treatment is for the adult horse. For a yearling colt half the quantity of carbon disulphid used for a mature horse will give the desired results. If properly administered the gelatin capsule reaches the stomach intact, but soon dissolves and the carbon disulphid rapidly evaporates, suffocating all bot larvæ and other parasites with which it comes in contact, but not injuring the horse. Worms are quite often expelled as well.

The Bureau of Animal Industry calls attention to the fact that the so-called 4-dram capsules hold about 3 drams of carbon disulphid.

Desiring to know the periods of time required to kill the larvæ in the treatments, a number of experiments have been conducted in fumigating stomach sections to which larvæ were attached. Only larvæ from those animals that could be secured shortly after the death of the hosts were used, and the sections with larvæ in situ were placed in wooden boxes tightly covered with glass after the box was well moistened. The sections came from both the stomach and duodenum, and the tests include all three species of Gastrophilus. After the short periods of fumigation, which were ineffective with last-stage larvæ, it was observed that the larvæ lived for some days. At the end of fumigation tests it was impossible to determine the viability of larvæ except by observing them for a number of days. As will be seen in Table IX, chloroform was not wholly effective at 4 hours, but at a later date larvæ were killed with carbon disulphid within 3 hours. In no case did larvæ live after subjection to 3½ hours of carbon disulphid. These gases were liberated from absorbent cotton in the corner of the box, and no larvæ came in direct contact with the liquid, as would probably be the case within the stomach. The carbon disulphid, being soluble in water, evidently reaches all portions of the stomach, either as a gas or in solution.

TABLE IX.—*Fumigations of horse stomach and duodenum sections with Gastrophilus larvæ in situ, Aberdeen, S. Dak., 1916.*

Post mortem and fumigation.	Species and number attached.	Exposure.	Fumigant.	Status at end of fumigation.	Mortality.	Longevity after fumigation.	Temperature since autopsy.			Remarks.
							Maximum.	Minimum.	Mean.	
1916.						*Days.*	° *F.*	° *F.*	° *F.*	
May 20	5 G. intestinalis	1 hour	Carbon disulphid	Attached and active	All alive	19–44	94	42	61.34	Reattached to one another.
Do	10 G. intestinalis	1½ hours	do	do	do	4–33	82	42	59.39	Detached after fumigation.
Do	17 G. intestinalis	do	do	do	do	9–28	82	42	59.28	Attached 40 hours.
Do	5 G. intestinalis	1 hour	Chloroform	do	do	10–35	82	42	59.39	
Do	7 G. intestinalis	1½ hours	do	do	do	4–42	94	42	60.54	Detached themselves after fumigation.
Do	21 G. intestinalis	do	do	do	do	16–44	94	42	61.34	Attached 40 hours after fumigation.
Do	2 G. nasalis	do	do	do	1 dead	0–9	79	42	58.50	One reattached to paper in breeding box.
Do	5 G. intestinalis	1 hour	Benzine	do	All alive	16–33	82	42	59.39	
Do	9 G. intestinalis	1½ hours	do	do	do	19–33	82	42	59.39	Detached themselves after fumigation.
Do.[1]	7 G. intestinalis	do	do	do	do	17–30	82	42	59.03	Attached 40 hours after fumigation.
Do	1 G. haemorrhoidalis	do	do	do	Alive	16	82	42	59.53	Detached after fumigation.
May 29	6 G. intestinalis	4 hours	Carbon disulphid	do	All dead					Attached 26 hours after fumigation, bloated.
Do	19 G. intestinalis	do	do	Detached and inactive	do					Bloated less than larvæ remaining attached.
Do	5 G. haemorrhoidalis	do	do	do	do					Did not bloat.
Do	3 G. haemorrhoidalis	do	Chloroform	do	All alive	16–21	82	43	59.48	
Do	3 G. intestinalis	do	do	do	do	16–21	82	43	59.48	
Do	20 G. intestinalis	do	do	Attached and inactive	do	19–24	82	43	59.65	Attached to string in breeding box.
Do	1 G. haemorrhoidalis	do	do	do	Alive	21	82	43	59.48	
June 8	do	3 hours	Carbon disulphid	Detached and inactive	Dead					Section of duodenum.
Do	11 G. nasalis	do	do	2 attached, all inactive	do					Do.
Do	15 G. intestinalis	do	do	do	do					Bloated few days after fumigation.
Do	4 G. haemorrhoidalis	do	do	All inactive, 1 attached	do					
July 11	19 G. intestinalis	1 hour	do	Detached and inactive	Some alive	3–13	96	58	74.90	Fungus developed on dead larvæ.
Do	1 G. nasalis	do	do	do	Alive	8	96	60	76.87	Do.
Do	20 G. intestinalis	2 hours	do	do	Some alive	3–13	96	58	74.90	Do.
Do	do	3 hours	do	do	Dead (?)					Kept 13 days; 1 appeared alive tenth day.
Do	40 G. intestinalis	3½ hours	do	do	All dead					No life whatever.
July 24	406 G. intestinalis	do	do	do	do					12 detached first 12 minutes.
Do	111 G. nasalis	do	do	do	do					In duodenum, 20 detached first 12 minutes.
Sept. 16	37 small Gastrophilus	2 hours	do	All inactive and some detached.	do					Appeared dead at 40 minutes' exposure.

Do....	2 Gastrophilus	....do	....do	Active when handled.	Alive	11	80	28	53.23	Larvæ detached at 40 minutes' exposure.
Do....	31 small Gastrophilus.	....do	....do	All inactive and some detached.	All dead					In duodenum, appeared dead in 40 minutes.
Sept. 18	19 small Gastrophilus.	1 hour	....do	All inactive and 7 attached.	....do					
Do....	3 G. intestinalis	....do	....do	Inactive and detached.	Alive	9	80	32	55.83	
Do....	46 small Gastrophilus.	....do	....do	All inactive and 21 attached.	All dead					Section of duodenum.
Dec. 9	50 small Gastrophilus.	45 minutes	....do	Inactive and attached.	....do					Fumigation at Dallas, Tex.

[1] Two larvæ pupated 13 and 18 days after fumigation but did not emerge.

Except as otherwise indicated in "Remarks," larvæ were taken with stomach section.

The *G. intestinalis* are the most resistant of the Gastrophilus to treatments, but these, being found in the stomach, are in the most favorable place for treatment. No immediate effects of the gas upon last-stage Gastrophilus larvæ are observed, as they remain motionless for some time. Finally they contract so as to conceal the hooks of attachment and then drop from the stomach section. This sometimes occurs within 30 minutes after the fumigation begins, but most often it is after 1 or 2 hours. Occasionally the contraction is not so great and larvæ remain attached but drop at the slightest touch. A number of observations were made upon animals treated by local veterinarians. During the spring and early summer records were kept on 23 of these horses, which were treated when they contained only last-stage larvæ. The treatment was given as recommended by the Bureau of Animal Industry. Within 36 to 48 hours the first bots appear in the fæces, though if the physic acts well they may be found after 24 hours. The writer observed bots to pass for a period of 5 days, beginning about 36 hours after the treatment. With the first droppings a few living larvæ may be found which detached from the stomach before the treatment, and in one case *G. nasalis* was reared from such larvæ. *G. haemorrhoidalis* may appear at the anus as usual if this treatment is given in the spring, as by this time numbers have previously migrated to the rectum.

While Table IX shows that carbon disulphid gas is capable of killing last-stage larvæ within 3½ hours, the ideal time for treatment of horses would be in the autumn when all larvæ are young and the *G. haemorrhoidalis* are still within the stomach and duodenum. The last-mentioned experiments in Table IX show some fumigation results with small Gastrophilus. It will be observed that 1 hour was an amply sufficient time, though a few last-stage larvæ were present as late as September 18. If not caused to detach these would possibly drop during the winter and succumb to low temperatures. In Dallas, Tex., 45 minutes was sufficient to kill young larvæ on December 9, 1916.

The fact that *G. nasalis* attaches in the throat, where the larvæ are not in a position to be affected by the carbon disulphid treatment, emphasizes the fact that " an ounce of prevention is worth a pound of cure."

REPELLENTS.

The rubbing of horses upon posts, bowlders, and other convenient objects suggested a device for use in pasture whereby horses could rub their lips upon a repellent. The short period of effectiveness of repellent substances and the inability to obtain one that will remain on the lips during grazing are difficulties which would seem to be overcome by such a device. A keg reservoir was devised whereby a flow of repellent, which was regulated by a stopcock, moistened a padded plank by means of a small pipe perforated with holes. This was placed at a salting and resting place of the horses and the amount of rubbing noted was very encouraging. Unfortunately, the horses did not rub the corners of the mouth, which are favorable places of egg deposition, and the scheme was abandoned.

Dr. Van Es suggested the use of a repellent upon the forelegs of horses and other portions of the body accessible to the mouth, so as to cause the common bot fly to deposit eggs upon places where they could not be reached by the horse's mouth. A marked repellent quality was observed in equal parts of pine tar and lard, no adults having been observed to oviposit during the following 4 days. There was apparently no injury to the animal, and 1 part of tar to 2 parts of lard was effective during 3 days. The disadvantage in some of the treatments was the fact that animals would walk through mud and water and cause a decrease in the repellent qualities of the mixture applied. Very good results were obtained with pine tar $3\frac{3}{4}$ ounces, kerosene $1\frac{1}{4}$ ounces, laundry soap 1 ounce, powdered resin 1 ounce, and hot water to make 14 ounces. The pine tar was thinned with kerosene, the soap and resin dissolved in hot water, and the two mixtures poured together. There was not only great repellent action observed, but the resin caused the hair to stick together in small bunches and prevented the adult flies from ovipositing. There was apparently no injury to the skin of the animal, and these same repellents prevented *G. nasalis* from ovipositing under the jaws. A successful repellent that would not require renewal over a reasonable period is desirable, since the loss of time due to the renewal of repellents is a great loss.

MECHANICAL PROTECTIVE DEVICES FOR WORK HORSES.

The protective devices found upon work animals vary, but there are none used in the Dakotas on pastured animals. (See Plate V.) Various forms of fringes are most frequently found and may consist of leather, burlap, or a portion of the leg of trousers. These are probably the least effective of the devices, as examination of teams wearing such fringes developed the fact that they are often found infested with eggs. Leather seems to be the most efficient of the fringes, as it is not so easily blown aside by the wind and does not hinder the horses in breathing. Those extending completely around the head retail for 50 cents each, while those covering only the face sell for 25 cents.

Baskets which are used extensively in nose-fly districts serve as muzzles during the last plowing of corn, but are not very effective nose-fly protectors. The mesh is of sufficient coarseness to permit flies to oviposit if the lips can be touched. They do not always fit well at the top and occasionally a nose fly will get on the inside, producing great annoyance by its buzzing. During thrashing moisture collects within the basket and, when the dust settles upon this, creates a condition which greatly handicaps the animal's breathing. These baskets retail for 35 cents each when fitted with two snaps.

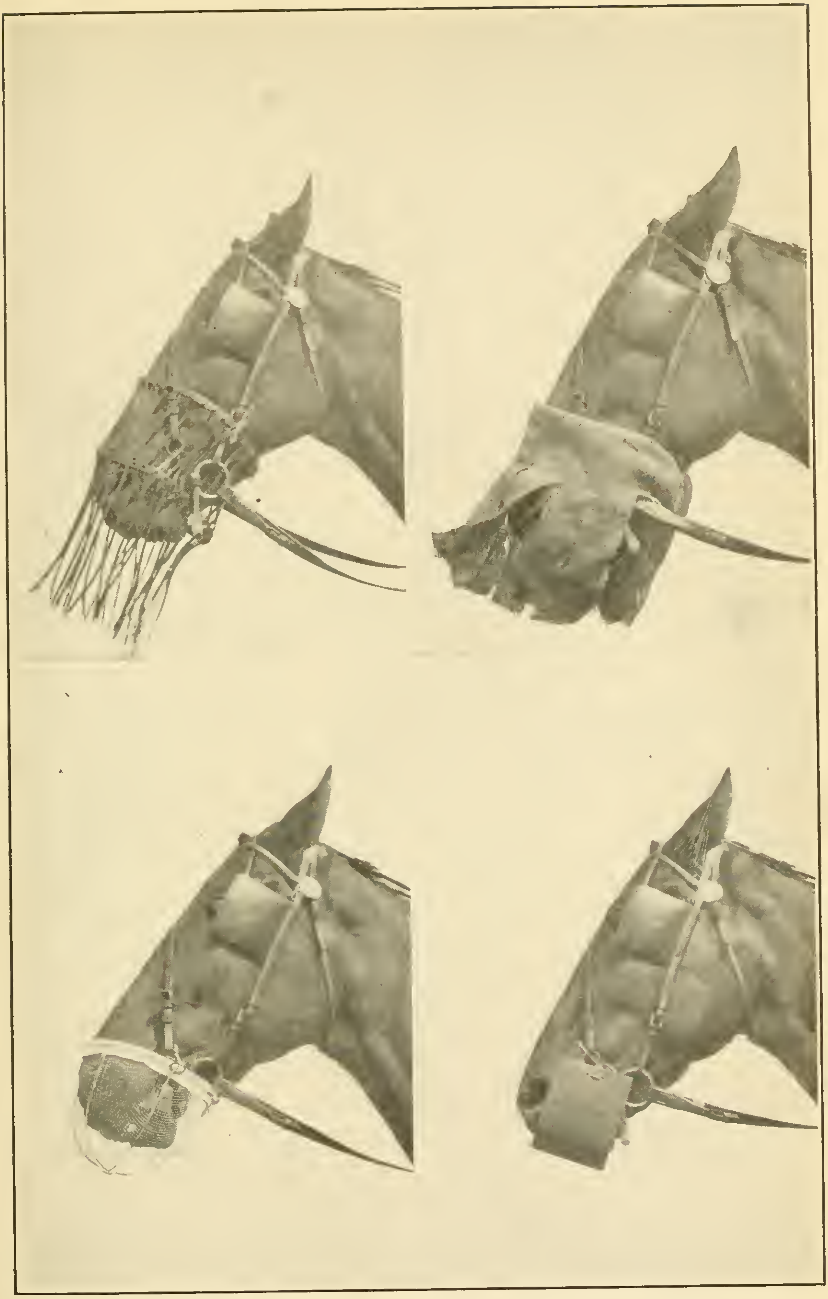
While protection of any description about the lips will prevent many ovipositions and annoyance by flies, by far the most effective device consists of a simple strip of leather extending over the lips and fastened at the bit rings. This actually covers the portions of the lips upon which the flies lay their eggs and upon horses thus protected an absence of eggs and annoyance has been noted. During the movement of the horse's head in walking, especially when working, this protection not only covers the lips, but swings to and fro and tends to repel the flies. The nostrils being exposed, it does not hinder breathing. Due to the cost of leather, very few of these are in use, but if one obtains an old belt from a thrashing machine great numbers can be made. It requires only a strip which will extend from one bit ring to the other and be from 4 to 6 inches in width. The size of the strip will depend upon the size of the horse's head. A snap placed at each end near the center facilitates handling, and the protector can be snapped onto the harness when not in use.

PROTECTORS FOR PASTURED ANIMALS.

Studies of efficiency of halter appliances for pastured horses have been made, and while conclusive results have not been obtained, a type has been designed which promises to meet the demand. At first halters were used with a piece of leather covering the jaws and hanging so as to flap against the lips when the animal walked. The front of the halter was provided with a face net which swung over the nostrils and lips. This proved unsatisfactory, as the flap, if long enough to protect the animals during depositions, was too long during grazing. The horses would step upon them with the fore feet, causing them to break.

A variation from the most efficient work-horse protector was devised by using a piece of duck on the rear, so as to cover the jaws and prevent *G. nasalis* from depositing in this location (see fig. 4). A block of wood under the center and below the lips enables a horse to graze with ease and at the same time be protected from flies when the head is held above the ground. The cloth on the rear also prevents ingress of *G. intestinalis* larvæ by preventing the horse from scratching portions infested with eggs. When the head is placed upon other animals the device occasions such discomfort that almost immediately the horses move and prevent the protected animal from becoming infested from their bodies.

For pasture uses the leather becomes soft and at times exposes the corners of the mouth, but excellent results have been obtained by sub-



DEVICES IN USE TO PROTECT WORK HORSES FROM OVIPOSITING G. HAEMORRHOIDALIS.

Upper left.—A leather fringe is fairly effective. Upper right.—A burlap fringe hinders breathing. Lower left.—A wire basket often permits ovipositions on account of coarse mesh and ill fitting. Moisture and dust collect and hinder breathing. Lower right.—A strip of leather actually covers oviposition places and allows the horse to breathe easily. (Original.)

stituting a hard wood. The weight in either case will compare with the weight of blind bridles. Horses using these in experiments became free of *G. haemorrhoidalis* eggs during the summer of 1916, whereas unprotected animals were heavily infested. There was also a marked difference in the feeding, as protected animals grazed normally in bunches. While the device indicates a favorable preventive measure, before its adoption tests of durability should be made and minor points in the construction determined. It seems possible that the construction could be made so simple that farmers could make the protectors at a nominal price.

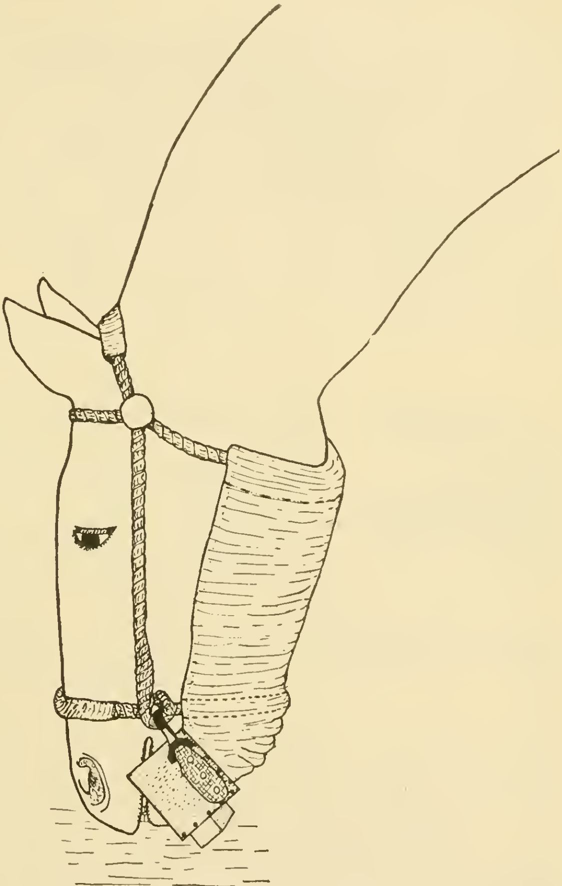


FIG. 4.—A bot preventive. The box prevents "nose flies" from ovipositing when the head is held upright, while the block of wood underneath the box allows the horse to graze easily. The canvas prevents normal ovipositions of the "throat bot-fly," and does not permit the horse to bite the portions infested with eggs of the "common bot-fly." (Original.)

A halter attachment would permit horses to graze during times that are favorable for depositions of flies, and would prevent eventual infestations by all three species of Gastrophilus. A shed constructed in the pasture would protect animals from nose flies, although it would not prevent infestations by the other species of Gastrophilus. Such a shed would keep the animals from grazing during times that were favorable for depositions, and could be used for storage of feed during the winter.

EFFECTIVENESS OF WASHES UPON EGGS.

Regardless of whether horses are treated internally for bots, which is best during the autumn, when larvæ are small, or whether they wear halter appliances during the summer, it is necessary to treat the eggs during the autumn to prevent a late infestation from the well-incubated eggs after the protectors have been removed. Then, too, the ease with which places so accessible to the horse's mouth can be washed makes the use of washes a practical prevention in regions where bots are not so numerous.

LARVÆ REMOVED FROM EGGS PRIOR TO TREATMENT.

Active larvæ were removed from well-incubated eggs and subjected to substances reported in Table X. Only larvæ in excellent condition were used, and these were observed in watch glasses, small tin boxes, and test tubes at short intervals until dead. When in doubt they were removed with a drop of the liquid to a microscope slide, and the warmth of one's breath was sufficient to cause living ones to move. Larvæ were killed instantly when placed in volatile liquids or gases of carbon disulphid and in absolute alcohol.

TABLE X.—*Resistance of first-stage larvæ of Gastrophilus intestinalis, Aberdeen, S. Dak., 1916.*

Larvæ placed in—	Longevity.	Larvæ placed in—	Longevity.
Dry tin box	72 to 126 hours.	Borax, saturated solution	40 minutes.
Water	76 to 99 hours.	50 per cent alcohol	30 minutes.
Tincture quassia	24 to 36 hours.	Petroleum, refined	30 minutes.
Beta-naphthol in alcohol	20 to 28 hours.	Do	30 minutes.
10 per cent oil of tar emulsion	41 to 48 hours.	Boric acid	13 minutes.
Borax, saturated solution	28 to 41 hours.	33⅓ per cent pine tar and 66⅔ per cent kerosene.	1 minute.
Do	24 to 43 hours.		

Dr. Guyot's results compare favorably with those herein reported. His larvæ remained alive in water for 4 days, nearly a day in olive oil, and more than 14 hours in bichlorid of mercury solution 1 to 1,000.

The movement of freshly emerged larvæ is very rapid upon moist surfaces, but upon a dry surface they seldom move from the original location, although they have been observed to live for 72 to 125 hours. When placed in water the larvæ became submerged with the exception of the posterior spiracles, which remained exposed at the surface. They are capable of living in this manner for 76 to 99 hours.

LARVÆ REMOVED AFTER TREATMENT OF EGGS.

Hundreds of eggs were collected from horses in pastures during the latter part of August and the early half of September. At this time the activities of adults of *G. intestinalis* were being directed to the manes of horses for oviposition, as in most cases the inside of the forelegs and sides immediately behind the forelegs were very grossly infested. These hairs were of sufficient length to render handling easy, and the eggs were about the same age. Except as otherwise indicated in Table XI, infested hair was placed in tubes at air temperatures of a living room and allowed to remain until larvæ were well formed and ready for emergence. Some of the eggs were then tested and the viability determined. A check was not kept, as the brownish color of the dead larvæ easily distinguished them from the transparency of the active larvæ.

TABLE XI.—*Effectiveness of washes upon eggs of Gastrophilus intestinalis, Aberdeen, S. Dak., 1915–16.*

Date eggs treated.	Insecticide.	Exposure.	Number larvæ examined.	Mortality of larvæ.			Remarks.
				Dead.	Living.	Doubtful.	
1915.		*Minutes*					
Sept. 6	Refined petroleum	6–18	7	0	7	0	Engine oil, No. 1.
Do.	do	18–31	8	4	4	0	Do.
1916.		*Hours.*					
Sept. 7	Kerosene	24	20	19	....	1	
Do.	1.35 per cent phenols [1]	24	38	38	0	0	Reddish brown in color.
Do.	2 per cent nicotine sulphate.	24	17	12	5	0	
Do.	Carbolic acid 2 per cent phenol.	24	20	19	1	0	
Do.	Lard	24	20	0	20	0	
Do.	Nitrobenzine gas	25	38	38	0	0	
Sept. 9	Carbolic acid 2 per cent phenol.	5	28	23	0	0	2 larvæ yellow in color.
Do.	Kerosene	29	22	5	17	....	5 dead larvæ yellow in color.
Do.	0.135 per cent phenols [1]	29	23	23	0	0	3 dead larvæ yellow in color.
Sept. 11	Nitrobenzine gas	4	34	7	22	5	
Do.	do	10	40	37	....	3	
Do.	do	25	42	42	0	0	
Do.	0.054 per cent phenols [1]	26	40	40	0	0	
Do.	Kerosene	25	28	5	23	....	18 larvæ very active.
Do.	2 per cent nicotine sulphate.	26	26	9	14	3	
Do.	2 per cent carbolic acid	26	38	38	0	0	
Sept 15 [2]	Kerosene	24	55	11	38	6	38 larvæ very active.
Do.[1]	Carbolic acid 2 per cent phenol.	24	48	47	0	1	
Do.[1]	0.054 per cent phenols [1]	25	49	49	0	0	
Do.[1]	Kerosene	147	24	3	19	2	
Do.[1]	Carbolic acid 2 per cent phenol.	146	27	27	0	0	
Do.[1]	0.054 per cent phenols [1]	147	21	21	0	0	

[1] A proprietary compound of cresol in combination with resin soap.
[2] Eggs not well incubated were treated and larvæ removed Sept. 21.

In the tests with larvæ removed from the eggs it was observed that the minimum period causing death by contact was 1 minute with pine tar 1 part and kerosene 2 parts. The ease with which either of these can be obtained suggested a study of these and similar substances.

It will be observed that kerosene, which is commonly reported to be in use by farmers, even at an exposure of 147 hours, had practically no effect upon larvæ. When eggs upon hair were rubbed they more readily yielded to hatching and apparently the larvæ were more active than from any similar treatment. The kerosene seemed to facilitate the emergence of the larvæ. While it was ineffective against well-developed larvæ, it was thought that upon freshly deposited eggs it would probably prevent development of the embryo, as is the case with hens' eggs during incubation; but even a test of this kind was only slightly effective.

A 2 per cent nicotine-sulphate solution was only partially effective. Nitrobenzine gas, which has recently been brought to our attention as a fumigant for external parasites of animals by Prof. William Moore, of the University of Minnesota, yielded good results at 25, 24, and 10 hours' exposure, but only a small percentage was killed at 4 hours. The fumigation was conducted in a common glass fruit jar into which a strip of cloth, impregnated with a few drops of nitrobenzine, was suspended.

The phenol compounds, by a contact application, seem to be most effective in destroying young larvæ and preventing the further development of embryos. It will be observed that carbolic acid containing 2 per cent phenol yielded as good results as higher percentages, and that this substance was most effectively used.

With carbolic acid as a wash it will be well to be cautious of its effects upon the hands. If used at too great strength, the exposed skin of the hand will become white and peel off, although it does not affect the skin of the horse, which is protected by the hair.

SUMMARY.

Three species of horse bots—the common bot-fly (*Gastrophilus intestinalis*), the throat bot-fly (*G. nasalis*), and the nose fly (*G. haemorrhoidalis*)—occur in the United States, and each is a source of considerable injury to horses. This injury is produced through worriment caused by the flies at the time the eggs are laid and by the attachment of the larvæ, or bots, in the alimentary tract.

Gastrophilus intestinalis and *G. nasalis* are widely distributed in the United States but *G. haemorrhoidalis* is confined to the North-Central and northern Rocky Mountain States.

The nose fly (*G. haemorrhoidalis*) is by far the most annoying to horses at the time its eggs are laid. The adults appear early in June and reach the maximum of abundance during the first half of the season, disappearing with killing frosts. The eggs are deposited on the minute hairs on the lips, and those near the edges which are kept moist and receive friction hatch in from 5 to 10 days. The larvæ are taken in with food or water and attach themselves to the walls of the stomach. Here they remain until the following winter or spring and then migrate to the rectum, where they reattach. Before leaving the host they usually attach close to the anus and protrude from it. They remain in this position from 40 to 71 hours. After dropping to the ground the bots seek protection and pupate in from 18 to 170 hours later. The pupa stage lasts from 21 to 68 days. The adults are

very active, and as they deposit only one egg at a time they are not so frequently seen about horses as are the adults of the common bot-fly. They take no food in the adult stage. Their length of life is from 1 to 7 days.

The throat bot-fly (*G. nasalis*) deposits its eggs on the hairs under the jaws and to some extent on the shoulders and other parts of the host. The larvæ of this species attach themselves to the walls of the pharynx and also to those of the stomach and duodenum. They do not reattach in the rectum or at the anus as do the bots of the nose fly. Pupation occurs in from 1½ to 2 days after the larvæ have passed from the host, and adults emerge in from 20 to 56 days later. The adults are somewhat longer lived than those of the nose fly. The flies cause considerable annoyance to horses during oviposition but not as serious as in the case of the nose fly.

The common bot-fly (*G. intestinalis*) usually appears later in the season than the nose fly and becomes most abundant just before killing frosts. The eggs are deposited on all parts of the body, but preferably on the fore legs. They hatch upon the application of moisture and friction. From 9 to 11 days after oviposition appears to be the most favorable period for hatching, although some may hatch as early as 7 days and others as late as 96 days after oviposition. The larvæ attach in any part of the stomach, but the last-stage bots are found mostly in the left sac. They continue to drop from the host for a long period of time. Pupation takes place in protected places on the surface of the soil and the pupa stage lasts from 40 to 60 days.

All Gastrophilus larvæ are surprisingly resistant to chemicals. The treatment of horses with carbon disulphid in three doses followed by a physic is satisfactory if administered in the late fall. Spring treatment is less effective, as the full-grown larvæ are more resistant, and many of the nose-fly bots have left the stomach and passed back to the rectum at that time.

Larvæ of *G. haemorrhoidalis* may be removed from the rectum mechanically, but this is laborious. The use of enemas containing insecticides is ineffective.

As a repellent, pine tar mixed with other material gave good results against the common bot-fly and the throat bot-fly. Such mixtures may be utilized to cause the flies to lay eggs on parts of the body less accessible to the horse's mouth.

Various nose protectors are in use against *G. haemorrhoidalis*, but there are objections to many of them. A piece of leather suspended below the lips from the bit rings is simplest and best. For animals on pasture a halter with a box-like arrangement and throat cover has been devised to protect horses against infestation by all three species.

Kerosene oil used as a wash is ineffective in destroying the eggs of Gastrophilus, but certain other substances have given good results. Carbolic acid containing 2 per cent phenols is satisfactory for destroying eggs when applied to the infested parts of the host.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 598

Contribution from the Bureau of Entomology
L. O. HOWARD Chief

Washington, D. C. PROFESSIONAL PAPER. February 4, 1918

ORCHARD INJURY BY THE HICKORY TIGER-MOTH.

By Dwight Isely, *Scientific Assistant, Deciduous Fruit Insect Investigations.*

CONTENTS.

INTRODUCTION.

The injurious stage of the hickory tiger-moth, *Halisidota caryae* Harris,[1] is a gregarious summer caterpillar (Pls. I, II) which, although a general feeder on deciduous trees and shrubs, causes occasional injury in orchards of pomaceous fruits and cultivated walnuts. While in this respect it is a minor pest, its injury, where it occurs, is severe and conspicuous and is the source of frequent inquiries to the Bureau of Entomology and to entomologists in the field. The writer's attention was frequently called to the work of this caterpillar while stationed at North East, Pa., during the seasons of 1914, 1915, and 1916, and there, incidental to the major projects then under investigation, the seasonal history and habits of this insect have been studied and the necessary remedial measures determined.[2]

HISTORY.

Injury by the hickory tiger-moth was first described by Harris in 1841 (1) in the earliest important work on economic entomology pub-

[1] Order Lepidoptera, family Arctiidae.

[2] The writer was assisted in 1915 by E. R. Selkregg and in 1916 by James K. Primm.

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lished in America. Since then frequent reports of local outbreaks have been recorded in entomological literature. Complaints have been made to the Bureau of Entomology regularly since 1870, and specimens and records of injury have been received annually since 1904. Yet in spite of this constant occurrence there appear to be no records of very great destructiveness. The nearest approach to a general outbreak recorded occurred in 1907, when the bureau received numerous complaints from New England as well as scattered reports from other parts of the United States and from Canada. When Harris (1)[1] first described the adult, larva, and pupa as *Lophocampa caryae*, he gave in addition a brief account of the larval feeding and cocoon-making habits, and listed hickory, elm, and ash as food plants. Fitch (2) in 1855 gave a further account of larval habits and added butternut, sumach, and slippery elm to Harris's list of food plants; and during this same year the species was listed by Walker (3) and figured by Herrich-Schäffer (4). In 1882 it was listed by Grote (5). Few biological data were added until Beutenmüller (6) in 1890 listed 32 food plants of the hickory tiger-moth. The same year Dyar (7), in discussing head measurements of lepidopterous larvæ, recorded nine larva stages of *H. caryae*. Soule (8) in 1891 first described the egg and gave life-history records from egg to pupa, but recorded only seven larva stages. Packard (9) in 1893 also described the egg and larva stages and of the latter recorded only five. Eliot and Soule (11) in 1902 gave a popular account of the life history similar to the previous one by the junior author, and this later account is the most nearly complete record of its biology.

From 1905 to 1908, inclusive, the period when inquiries made to the Bureau of Entomology regarding this insect were most frequent, there were a number of brief references to it by economic entomologists in the northeastern United States. These references were brief and added little to the published records except to note its economic importance. Patch (12) mentions it as a late summer feeder, Felt (13 and 15) records it as of economic importance in New York, Sanderson (14 and 19) records it among apple insects of New Hampshire, Britton (16) refers to it as abundant in Connecticut, and Gibson (17) records an unusual outbreak for two years in several Canadian Provinces. Dr. L. O. Howard states that this species was unusually abundant in Greene County, N. Y., in September, 1917.

COMMON NAME.

This insect was called the hickory tussock moth by Harris (1), and until a comparatively recent time this name has been used. Comstock (10) called it the hickory tiger-moth. The latter name would

[1] Reference is made by number to "Literature cited," p. 13.

seem preferable, since the insect belongs to the family of tiger-moths (Arctiidae) and not to the family of tussock moths (Lymantriidae).

SYNONYMY.

Lophocampa caryae Harris, 1841.
Halesidota annulifacia Walker, 1855.
Phegoptera porphyrea Herrich-Schäffer, 1855.
Halisidota caryae (Harris) Grote, 1882.
Halisidota caryae (Harris) *Packard*, 1890.

DISTRIBUTION.

The hickory tiger-moth is distributed over the northeastern United States and the adjacent Canadian Provinces. According to records of the Bureau of Entomology and literature, its range extends from the Atlantic Ocean west to Missouri, Minnesota, and Saskatchewan, and from the Canadian Provinces bordering the United States south to North Carolina and southern Ohio. Records have been taken from the following States and Canadian Provinces: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, New York, Pennsylvania, New Jersey, North Carolina, Ohio, Michigan, Illinois, Wisconsin, Missouri, Quebec, Ontario, Manitoba, and Saskatchewan. It is probably much more frequent in New England and the Middle States, however, since more than 75 per cent of the reports of destructiveness have come from this region.

DESCRIPTION OF STAGES.

EGG.

(Pl. II, fig. 4.)

The egg is nearly globular, flattened on the side of attachment, 0.75 mm. in diameter. The surface is glassy and in color it is a robin's-egg blue when first deposited. A brown ring appears on the upper surface about the second day, and in a few days the egg appears olive brown when viewed from above, although when viewed from the side it is greenish. In about two weeks, just before hatching, it becomes leaden blue. Infertile eggs do not change in color, but dry up in a few weeks. Eggs are deposited in a broad patch of 50 to 400 on the underside of the leaf. The writer has found one patch of 625 eggs.

LARVA.

(Pl. I, Pl. II, figs. 1, 2, 3.)

Full-grown larva.—Length, 32 to 38 mm. A striking grayish-white and black hairy caterpillar. It is covered with short spreading tufts of grayish white hairs, with a dorsal row of contiguous black tufts which appear like a velvety crest. These tufts occur on the first eight abdominal segments and a small one may be seen on the ninth. There also may be a pair of slender black pencils arising from the first abdominal segment, and another pair arising from the seventh. These pencils may be very long, may be inconspicuous, or absent altogether. The head and feet are black. The hair arising from the thoracic segments is longer than that of the rest of the body and when the larva is at rest covers the head. The spreading side tufts give the larva a depressed appearance.

First instar (Pl. II, fig. 1).—Width of head, 0.46 to 0.50 mm; total length. 1.5 mm.; when full fed, 3 mm. The head is shining black and is much wider than the thorax of a newly hatched larva. The body is cylindrical, pale greenish white, and marked with black setiferous tubercles. Dorsally the tubercles appear as follows: On the first thoracic segment, a large dorsal plate and two very small tubercles on either side; second thoracic segment, one large compound tubercle on either side near the cephalic margin and a very small median tubercle near the caudal margin; third thoracic segment, 2 conspicuous tubercles on either side; first to eighth abdominal segments, 3 conspicuous tubercles on either side arranged in a triangle, two of them being near the cephalic and one near the caudal margin; ninth abdominal segment, 1 large compound tubercle on each side; tenth abdominal segment, 1 large plate covering most of the dorsal aspect of the segment. On all the thoracic segments and on third to ninth abdominal segments there are 3 small tubercles on each side; on abdominal segments 1 and 2 there are 4 on each side; and on abdominal segment 10 there is 1 one each side. All the lateral tubercles and lateral-dorsal tubercles bear 1 white seta. Black setæ are all dorsal, 4 arising from each thoracic segment, 1 from each of the 4 median abdominal tubercles, and 6 from the anal plate.

Second instar.—Width of head, 0.65 mm.; total length, 5 to 6 mm. when full fed. This instar differs chiefly from the preceding in the abundance of long whitish hairs which arise in considerable numbers from all the tubercles. The tubercles are larger and contrast strikingly with the color of the body.

Third instar.—Width of head from 1.12 to 1.16 mm.; total length, 10 mm. when full fed. More hairy than the preceding instar.

Fourth instar (Pl. II, fig. 2).—Width of head, 1.7 mm.; total length, 13 to 14 mm. The dorsal tubercles are nearly obscured by the hair arising from them.

Fifth instar.—Width of head, from 1.88 to 2.19 mm., average 2.1 mm.; total length, 18 to 19 mm. Tufts at sides of each body segment becoming conspicuous, and the black pencils may appear in this instar.

Sixth instar.—Width of head, from 2.91 to 3.09 mm., average 3.0 mm.; total length when full fed, 22 to 25 mm. The side tufts have become so conspicuous that they give the larva an almost flattened appearance. The black dorsal tufts are not yet touching and do not yet form a conspicuous crest.

Seventh instar (Pl. II, fig. 3).—Width of head, from 3.43 to 3.52 mm., average 3.46 mm.; total length, 27 to 32 mm. Practically the same as the preceding.

Eighth instar.—Width of head, from 4.10 to 4.30 mm., average 4.2 mm.; total length, 32 to 40 mm. This larva is very much like the preceding if it has yet to pass through another instar, or if this instar is the last it is like the mature larva previously described.

Ninth instar (Pl. I).—Width of head, from 4.7 to 4.9 mm., average 4.8 mm.; total length, 35 to 42 mm. This instar differs conspicuonsly from the immature forms because of the striking black crest.

COCOON.

(Pl. III, fig. 3.)

The cocoon is usually ellipsoidal, sometimes slightly flattened on one side, depending on the material which surrounds it. In length it averages 23 mm. and in width 15 mm. The larva mixes most of its gray hairs into the silk, making the cocoon very hairy. In color it is dirty gray.

PUPA.

(Pl. III, fig. 2.)

Length, 10 to 13 mm; width of thorax, 6 mm; width of abdomen, 7.5 mm. The abdomen is much stouter than the thorax and there is a slight constriction between them; the wingpads extend to the fifth abdominal segment; on the caudal end is a transverse row of spines recurved at the end. Color when newly transformed, yellowish, but soon becoming reddish brown; margins of segments and spiracles darker.

IMAGO.

(Pl. III, fig. 1.)

The following is Harris's original description of the moth (1):

* * * very light ochre-yellow in color; the fore-wings are long, rather narrow, and almost pointed, are thickly and finely sprinkled with little brown dots, and have two oblique brownish streaks passing backwards from the front edge, with three rows of white semitransparent spots parallel to the outer hind margin; the hind-wings are very thin, semitransparent, and without spots; and the shoulder covers are edged within with light brown. They expand from one inch and seven-eighths to two inches and a quarter or more. The wings are roofed when at rest, the antennæ are long, with a double narrow, feathery edging, in the males and a double row of short, slender teeth on the under-side, in the females; the feelers are longer than in the other Arctians, and not at all hairy; and the tongue is short but spirally curled.

FOOD PLANTS.

The hickory tiger-moth is usually recorded as a general feeder on the foliage of deciduous trees and shrubs. No less than 49 host plants from widely separated families have been listed by various observers. However, this wide range of food plants is confined to the nearly mature larva. The number of food plants upon which larvæ can develop from egg to pupa is much smaller and, as far as the writer has observed, is restricted to trees of the walnut and hickory family and to pomaceous fruits.

The writer has reared larvæ from egg to pupa on Japanese walnut, English walnut, black walnut, apple, and pear. In the field, colonies have been found frequently on all of the above and also on butternut, quince, and once on white hickory. In spite of its name walnut and not hickory seems to be its favorite food plant. An egg mass was found on a sour-cherry leaf, but a colony of larvæ were never found feeding on cherry in the field. Miss Soule (8) records finding an egg mass on a thorn leaf (*Crataegus* sp.).

The lots of larvæ which were fed on black walnut, Japanese walnut, English walnut, pear, and apple all reached the pupa stage and appeared normal. In the early larva instars the development was about the same. The later instars on Japanese walnut developed somewhat faster than any of the others, and nearly all of them attained the ninth instar before pupation, although those hatching very late passed through only eight instars. Those reared on apple developed more slowly and passed through only eight stages, while the larvæ on pear passed through either eight or nine. The length of stages of larvæ feeding upon these plants will be given in detail in the discussion of seasonal history.

In confinement larvæ would feed on the foliage of many trees upon which they could not mature. Attempts to rear larvæ from hatching to pupation on sour cherry (Early Richmond variety), red oak, and slippery elm were unsuccessful. Those fed on oak and cherry passed through the early molts with regularity, but growth was slower than that of those reared on walnut and apple, and finally stopped altogether. A few larvæ that were started on oak and cherry at the beginning of the second stage reached the seventh, but were undersized and unhealthy in appearance. Elm was more distinctly unfavorable than either oak or cherry. Larvæ placed upon elm immediately after hatching failed to pass even the first molt, and those transferred from walnut as late as the fourth stage failed to pass the seventh.

Table I gives a list of the food plants recorded in entomological literature and in the records of the Bureau of Entomology with the authority for the previously published records. In this list nomenclature of the native species is according to Gray's Manual of Botany, seventh edition (1907), and the nomenclature for imported species is that of Bailey's Standard Cyclopedia of Horticulture.

TABLE I.—*A list of native and imported food plants of the hickory tiger-moth (Halisidota caryae).*

Acer saccharinum L. Silver maple. (Beutenmüller 1890.)
Acer pseudoplatanus L. Sycamore maple. (Beutenmüller 1890.)
Acer rubrum L. Red maple. (Beutenmüller 1890.)
Acer negundo L. Boxelder. (Beutenmüller 1890.)
Acer saccharum Marsh. Sugar maple. (Beutenmüller 1890.)
Aesculus glabra. Welld. Buckeye. (Beutenmüller 1890.)
Alnus rugosa (Du Roi). Alder. (Beutenmüller 1890.)
Betula a. var. *papyrifera* Marsh. Paper birch. (Beutenmüller 1890.)
Betula populifolia Marsh. Gray birch. (Beutenmüller 1890.)
Carpinus caroliniana Wall. Hornbeam. (Beutenmüller 1890.)
Carya sp. Hickory. (Harris 1841.)
Carya alba (L.) White hickory. (Beutenmüller 1890.)
Carya glabra (Mill.). (Beutenmüller 1890.)
Castanea dentata (Marsh). Chestnut. (Beutenmüller 1890.)
Celtis occidentalis L. Hackberry. (Beutenmüller 1890.)
Crataegus sp. Thorn. (Soule 1891.)
Cydonia oblonga Mill. Quince.[1]

[1] Confirmed by writer.

Fagus grandifolia Ehrh. Beech. (Beutenmüller 1890.)
Fraxinus sp. Ash. (Harris 1841.)
Hamamelis virginica L. Witch-hazel. (Beutenmüller 1890.)
Juglans cinerea L. Butternut.[1] (Fitch 1855.)
Juglans nigra L. Black walnut.[1] (Fitch 1855.)
Juglans regia L. English walnut.[1]
Juglans sieboldiana Maxim. Japanese walnut.[1]
Larix decidua Mill. Tamarack. (Fitch, according to Felt, 1905.)
Larix laricina (Du Roi). Larch. (Fitch, according to Felt, 1905.)
Ostrya virginiana (Mill.). Hop hornbeam.[1]
Prunus serotina Ehrh. Black cherry.[1] (Beutenmüller 1890.)
Prunus virginica L. Chokecherry. (Beutenmüller 1890.)
Prunus cerasus. Sour cherry. (Lintner 1891.)
Platanus occidentalis L. Sycamore. (Beutenmüller 1890.)
Platanus orientalis L. Sycamore. (Beutenmüller 1890.)
Pyrus communis L. Pear.[1] (Lintner 1891.)
Pyrus malus L. Apple.[1] (Beutenmüller 1890.)
Quercus alba L. White oak. (Beutenmüller 1890.)
Quercus palustris Muench. Pin oak. (Beutenmüller 1890.)
Quercus rubra L. Red oak. (Beutenmüller 1890.)
Rhus sp. Sumach. (Fitch 1855.)
Rosa sp.[1]
Rubus sp. Raspberry. (Eliot and Soule 1902.)
Tilia americana L. Basswood. Beutenmüller 1890.)
Tilia alba. White linden. (Beutenmüller 1890.)
Tilia europea. European linden. (Beutenmüller 1890.)
Salix sp. Willow. (Eliot and Soule 1902.)
Ulmus sp. Elm. (Harris 1841.)
Ulmus americana L. American elm. (Beutenmüller 1890.)
Ulmus campestris L. English elm. (Beutenmüller 1890.)
Ulmus fulva Michx. Slippery elm. (Fitch 1855.)

SEASONAL HISTORY.

EMERGENCE OF MOTHS.

There is one generation annually. The insect pupates in the fall, hibernates in the pupa stage, and the moths emerge in early summer. During the season of 1916 the earliest emergence from a lot of 36 cocoons was June 9 and the latest June 24, the majority emerging from June 12 to 15, inclusive. No adults were reared in either of the two previous seasons, but in 1914 larvæ were found in the field as early as June 18, indicating that moths must have emerged as early as June 1. In 1915 the larvæ appeared in the field about the same time as in 1916. The data relating to emergence of moths in 1916 are given in Table II.

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[1] Confirmed by writer.

TABLE II.—*Time of emergence of adults of the hickory tiger-moth at North East, Pa., 1916.*

Date of emergence.	Total number of moths.	Number of males.	Number of females.	Date of emergence.	Total number of moths.	Number of males.	Number of females.
June 9	1	1	....	June 16	1	....	1
10	1	1	....	19	1	....	1
12	4	3	1	22	1	....	1
13	8	7	1	24	1	....	1
14	4	3	1				
15	3	2	1	Total	25	17	8

LENGTH OF EGG STAGE.

The length of the egg stage, based on records from 4 egg masses deposited in 1916, was 15 to 16 days. Two masses of eggs deposited June 15 hatched July 1; one mass deposited the same day hatched July 2; the fourth mass, deposited June 16, hatched July 3.

DURATION OF LARVAL FEEDING PERIOD.

The duration of the larval feeding period varies greatly. Miss Soule (8) records rearing one colony from egg to cocoon in 47 days, which passed through only 7 instars. During the season of 1915 larvæ reared by the writer on Japanese walnut required from 62 to 85 days from egg to cocoon, averaging 74.73 days. (See Table III.)

TABLE III.—*Duration of the larval feeding period, North East, Pa., 1915.*

Number of individuals.	Duration of larval feeding period.	Number of individuals.	Duration of larval feeding period.	Number of individuals.	Duration of larval feeding period.
	Days.		*Days.*		*Days.*
1	62	1	72	2	79
1	64	2	74	2	80
1	66	1	75	1	82
1	68	2	76	1	85
1	70	1	77		
1	71	3	78	22	[1] 74.73

[1] Average.

During the season of 1916 larvæ reared on the same food plant required 80 to 100 days, averaging 89.04 days. (See Table IV.)

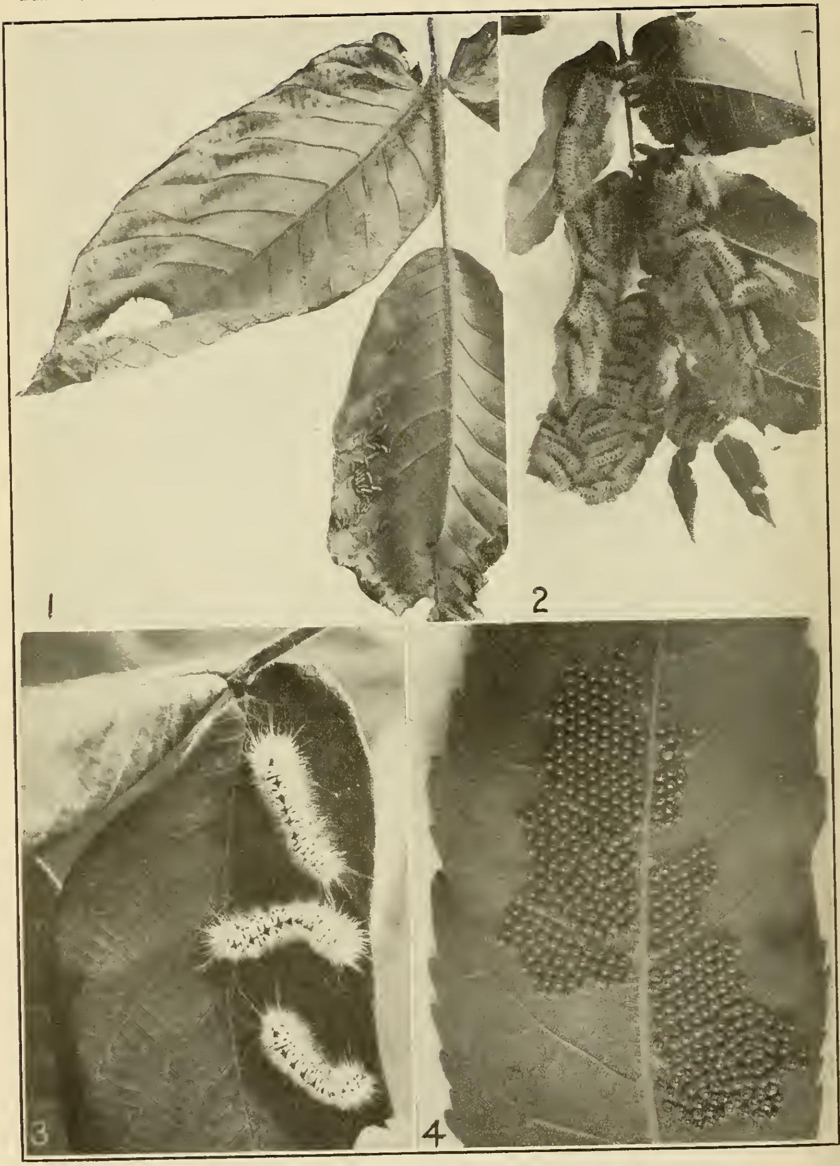
TABLE IV.—*Duration of the larval feeding period, North East, Pa., 1916.*

Number of larvæ.	Duration of larval feeding period.	Number of larvæ.	Duration of larval feeding period.	Number of larvæ.	Duration of larval feeding period.
	Days.		*Days.*		*Days.*
3	80	15	88	2	94
2	82	31	89	2	95
4	83	26	90	1	96
9	84	4	91	1	100
6	85	6	92		
21	86	8	93	145	[1] 89.04
4	87				

[1] Average.

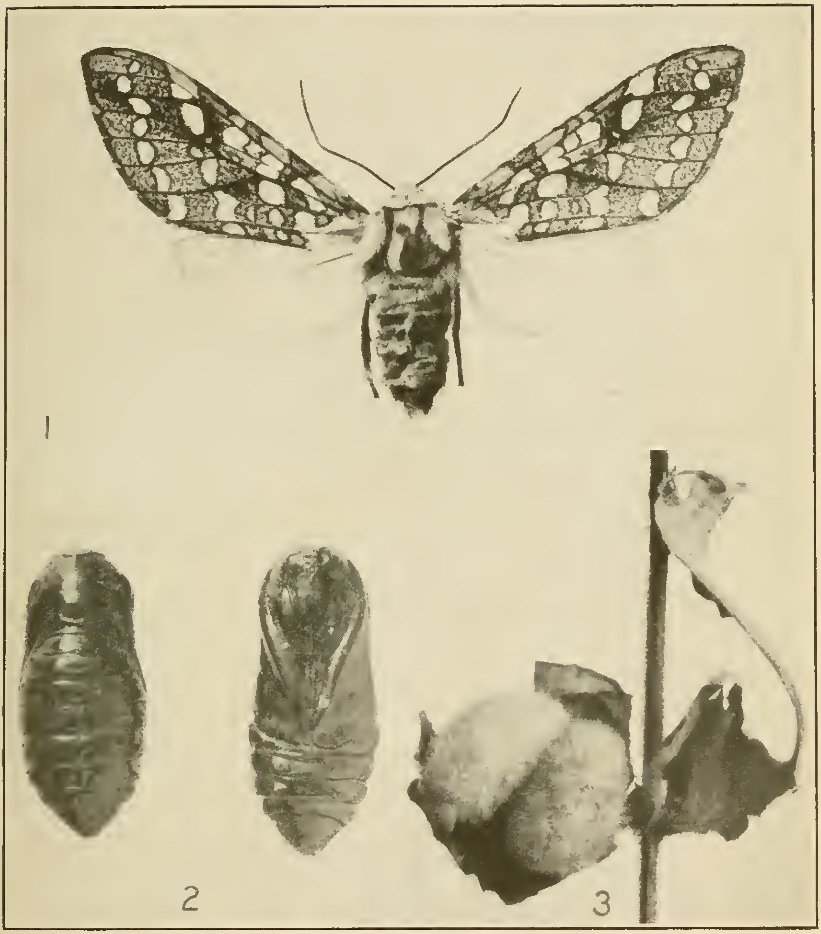
THE HICKORY TIGER-MOTH.

Larvæ on apple leaves, ninth instar. (Original.)



STAGES OF THE HICKORY TIGER-MOTH.

FIG. 1.—Larvæ, first instar. FIG. 2.—Fourth instar. FIG. 3.—Seventh instar. FIG. 4.—Eggs. (Original.)



THE HICKORY TIGER-MOTH AND STAGES.

FIG. 1.—Adult. FIG. 2.—Pupæ. FIG. 3.—Cocoons. (Original.)

The larvæ reared in 1915 passed through only 8 instars, but the majority of those reared in 1916 passed through 9 instars. This could not have affected greatly the time required for development, however, as the few larvæ which passed through only 8 stages in 1916 required an average of 88.71 days. In 1915 the larvæ were reared under natural conditions in bags on a tree, whereas in 1916 all lots but one were reared in battery jars. The one lot of 22 larvæ reared on the tree in 1916 required from 85 to 92 days from egg to cocoon, with an average of 87.18 days, very nearly the same as that of those reared in confinement.

No explanation is offered for the difference in time required for development of larvæ in the two seasons, but it should be stated that the season of 1915 was excessively rainy, whereas the 1916 season was excessively dry. It is probable that humidity affected the rate of development either directly or by its effect upon the food plant.

The duration of the larval feeding period varies somewhat when different food plants are used. The development of those reared on apple was similar to that on walnut, but a little slower, and the larvæ passed through only 8 stages. The shortest period required for development from egg to cocoon was 89 days and the longest was 96 days, with an average of 92.87 days.

Pear seemed a slightly more favorable food plant than apple. The development of the larvæ was more rapid, and although the majority passed through only 8 stages a few passed through 9 stages. Eighteen larvæ which passed through 8 stages required from 87 to 91 days, with an average of 88.77 days; 5 larvæ which passed through 9 stages required from 98 to 100 days, averaging 98.40 days.

The duration of the stages of larvæ reared on Japanese walnut during the season of 1916 was as follows:

First stage: Minimum 6 days, maximum 7 days, average 6.12 days; 232 larvæ reared.

Second stage: Minimum 4 days, maximum 7 days, average 4.78 days; 232 larvæ reared.

Third stage: Minimum 5 days, maximum 7 days, average 5.62 days; 232 larvæ reared.

Fourth stage: Minimum 6 days, maximum 7 days, average 6.02 days; 232 larvæ reared.

Fifth stage: Minimum 6 days, maximum 8 days, average 6.25 days; 232 larvæ reared.

Sixth stage: Minimum 6 days, maximum 13 days, average 8.52 days; 145 larvæ reared.

Seventh stage: Minimum 8 days, maximum 20 days, average 12.33 days; 145 larvæ reared.

Eighth stage (excluding larvæ that completed their feeding period in this stage): Minimum 13 days, maximum 25 days, average 18.03 days; 138 larvæ reared.

Eighth feeding stage (including only larvæ that spun cocoons at end of this instar): Minimum 19 days, maximum 29 days, average 23.29 days; 7 larvæ reared.

Ninth feeding stage (until spinning of cocoons): Minimum 13 days, maximum 26 days, average 20.95 days; 138 larvæ reared.

The period covered by the rearing records in 1915 began when the larvæ under observation hatched, on July 17, and continued until time of spinning cocoons, which extended from September 17 to October 10. In 1916 the earliest larvæ hatched June 30, and the first cocoon under observation was spun September 24 and the latest October 10.

DURATION OF PREPUPA PERIOD.

The larva period in the cocoon at North East, Pa., in 1916 averaged between 7 and 8 days. Of 19 larvæ which spun cocoons on September 24, 25, and 26, 10 pupated in 7 days and 9 in 8 days.

HABITS.

THE LARVA.

Larvæ from the same egg mass hatch almost simultaneously and upon hatching eat the greater part of the eggshells. They are gregarious in the early stages, and even in the later stages molt together. During the first four stages they feed gregariously, beginning to scatter in the latter part of the fourth. If during the first three stages a larva is separated from its fellows and is placed on a separate leaf or shoot, it will invariably find its way back to the others within a few hours. When one leaf or shoot is stripped the larvæ move in mass to another, often to another part of the tree.

After the fifth stage the larvæ scatter more or less and are solitary except about molting time. Often they migrate to trees quite a distance from the one on which the colony started. After the last molt the larvæ scatter widely.

The molting of the majority of larvæ from a given egg mass is almost simultaneous, and at this time the gregarious habit is most pronounced. Even after larvæ have scattered over a tree they come together to molt. A short time before molting a silken mat is spun upon which the larvæ rest for about a day before the early molts and sometimes for several days before later ones. This molting mat is spun upon a leaf or bunch of leaves, and sometimes before the later molts on the side of a branch or tree trunk. At each molting period there are often a few larvæ which fall behind and fail to molt with the rest. These invariably develop very slowly and usually do not mature.

Feeding injury is seldom conspicuous and usually unnoticed until the third or fourth instar is reached when the larvæ become very voracious. Larvæ in the first stage are surface feeders. Those on walnut and pear feed on the underside, eating nearly to the upper epidermis. Those on apple and quince feed on the surface. On these food plants the larvæ eat the leaf tissue as they go, while larvæ on cherry and oak leave patches of surface uneaten and also may feed on either upper or lower surface of the leaf. Larvæ in the second stage feeding on walnut and in the third stage on pomaceous fruits feed at the edge of the leaf, eating everything except the thicker leaf veins.

The cocoon is spun among leaves or in protected situations on the ground. If the infested trees are in the neighborhood of buildings cocoons may be found under boards, behind doors, or in similar situations.

THE PUPA.

The pupa hibernates on the ground. Moisture is probably necessary for successful hibernation, for from 36 cocoons wintered out of doors in a screen basket 25 moths emerged, whereas from 21 cocoons wintered in the insectary in a battery jar and protected from snow and rain, but exposed to the same temperature conditions, none emerged.

THE MOTH.

In emerging the moth usually breaks the pupal skin and then forces its way out of the end of the cocoon. If the cocoon is very loosely constructed the pupa may break out of it before eclosion, but this is not usual.

Copulation has been noted as early as the day of emergence and oviposition as early as 3 days thereafter. One moth continued ovipositing for 2 days, day and night, apparently without interruption, adding eggs to the same egg mass. Oviposition is performed deliberately. The moth's wings are folded back at rest at this time.

Moths oviposit readily in cages without being fed. They seem to prefer to oviposit on Japanese walnut leaves but will place eggs on cheesecloth or on the sides of the cage. The moths are very sluggish and can be handled easily in cages.

PARASITES.

This insect is remarkably free from parasitic enemies. None has been reared by the writer, and as far as he is aware only one species, *Pimpla pedalis* Cress (18), has been recorded.

ECONOMIC IMPORTANCE.

Injury by this insect is intensive and not extensive. It is due to the gregarious larvæ of the early stages which strip branches and sometimes small trees of their foliage. The injury to young trees in particular may be severe. After the gregarious habit is lost the larvæ scatter so widely that the injury done by them is inconspicuous.

Infestation by this insect so far as the writer has observed is not general even within an orchard. Several colonies of larvæ may be on one tree, but the writer has never seen a large tree completely stripped. Usually damage occurs in young orchards on which the codling-moth sprays have not been applied. The increasing importance of the cultivated walnut trees in the northeastern United States probably will cause this pest to become correspondingly more important.

CONTROL.

Spraying with arsenicals is the usual recommendation for the control of this pest. In orchards which have been thoroughly sprayed for the codling moth the writer has never noted an infestation. Nevertheless, the caterpillar soon becomes very hard to poison, and very large amounts are required to kill it in the later stages.

If control measures are not adopted until the larvæ are in evidence, they probably will not be applied until some of the larvæ are in the third or fourth instar. Spraying at this time is likely to produce discouraging results. Two trees infested with colonies of fourth-stage larvæ were sprayed with arsenate of lead July 31, 1915; on one the poison was applied at the rate of 3 pounds (paste) to 50 gallons and on the other 5 pounds (paste) to 50 gallons. None of the larvæ died until two days later on the tree sprayed with the larger amount of poison, and not until three days later on the tree sprayed with the smaller amount. On the tree sprayed with the smaller amount about 10 per cent of the larvæ survived. It was evident that unless they fed on poisoned leaves continuously for some time they were not affected at all. Unless the larvæ are confined on a sprayed tree they are very likely to migrate to another before eating enough to kill them.

In the gregarious stages colonies of these larvæ are easily collected and destroyed. When the infestation is scattered throughout an orchard this method is much the cheapest that can be employed and is entirely effective.

On young orchards which would not receive the spring spray applications for the codling moth, an application about the last of June of arsenate of lead (paste), 3 pounds to 50 gallons of liquid, would be of value in preventing injury by this pest.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 599

Contribution from Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER March 16, 1918

THE STRIPED PEACH WORM.[1]

By H. G. INGERSON, *Scientific Assistant, Deciduous Fruit Insect Investigations.*

CONTENTS.

INTRODUCTION.

The striped peach worm (*Gelechia confusella* Cham.), although described in 1875, has received little notice as an economic species. The larvæ feed in conspicuous webs on the foliage of the peach and on sand cherry (*Prunus pumila*) in smaller but more compact webs. While at present this insect is not a major pest on peach, the larvæ have been observed feeding on sand cherry in such numbers as to web nearly every terminal, partially defoliating the host plant, and this shows the latent possibility of extensive injury to peach orchards.

Under the direction of Dr. A. L. Quaintance, Entomologist in Charge of Deciduous Fruit Insect Investigations, the writer studied the biology and habits of the insect during the seasons of 1915 and 1916. The biological data secured, together with descriptions of all the stages and suggestions for control, are recorded in this paper.

[1] The writer is indebted to the following members of the Bureau of Entomology staff: To E. H. Siegler for the photograph used in Plate I, figure 1; to H. K. Plank for Plate II, figure 1, and Plate III, figures 1, 2, and 3; to J. H. Paine for Plate II, figures 2 and 3, and to F. L. Simanton for determining the place of oviposition on sand cherry and for conducting the spraying work in connection with the remedial measures.

The life-history studies were started at Benton Harbor, Mich., in 1915 and completed in 1916.

Adults were reared separately from larvæ collected on the two host plants and were identified as *Gelechia confusella*, by Mr. August Busck, of the Bureau of Entomology.

HISTORY.

The adult of *Gelechia confusella* was first described by Chambers (1)[1] in 1875, but with no mention of the source of his material. Pettit (4), under the heading "A new peach worm," writes as follows:

> A number of worms working in peach leaves were received from Mr. T. D. Atkinson, of Holland, Mich., on September 17. They were lepidopterous larvæ and were said to be very troublesome. The same species was received on July 3, 1899, from Monroe, Mich. One or two complaints were made from other places, though no specimens were sent.

These are apparently the only published accounts of the occurrence of this insect.

SYNONYMY.

In 1899 Pettit (4) described the larva of this insect and figured the larva and pupa, designating them "Peach leaf-binder, *Depressaria persicaeella* Murt." In the same publication (5) the adult is described as *Depressaria persicaeella* by Miss Mary E. Murtfeldt, of Kirkwood, Mo., from material sent her by Mr. Pettit. Miss Murtfeldt (6) changes *Depressaria persicaeella* Murt., to Gelechia.

Dyar (7) lists *Gelechia confusella* Cham., with *persicaeella* Murt. as a synonym. Busck (8) lists *Gelechia confusella* Cham. with synonyms *Depressaria persicacella* Murt. and *Gelechia persicaeella* Murt., and makes the following note:

> Cotypes of Miss Murtfeldt's species are in the United States National Museum under type No. 4697. The species is very close to the foregoing, and I have no doubt is the same as Chambers's *Gelechia confusella*, the type of which is lost but the description of which tallies in every detail with the peach feeder.

In 1904 Pettit (9), under the name "The striped peach-worm (*Gelechia confusella*)," copied part of his former description and reproduced the figures of the larva and pupa of 1899, designating them as the "striped peach-worm." The synonymy stands:

Gelechia confusella Cham., 1875.
  Depressaria persicacella Murt., 1899.
  Gelechia persicaeella Murt., 1900.

The writer has accepted the name "striped peach worm," as it seems to distinguish this insect from all other peach feeders and briefly describes the larva, which is the only stage commonly seen.

[1] Reference is made by number to "Literature cited," p. 14.

FOOD PLANTS.

Previously published notes have recorded *G. confusella* as feeding only on peach foliage. During July, 1915, the writer observed a webbed condition on sand cherry (*Prunus pumila*) (Pl. IV) which resembled somewhat the injury already noted on peach (Pl. I), though the webs were more tightly bound and less silk was observable. The injury was so extensive and uniform over a sand-cherry thicket of about 15 acres in extent at this place near St. Joseph, Mich., that it seems probable that this is the native host plant of the insect.

FEEDING HABITS OF THE LARVA.

The larva feed either singly or gregariously on both host plants, and, though not voracious feeders, by their well-developed webbing habit include in their webs much foliage that is not used as food. The larvæ begin webbing directly after hatching, even before they feed, and usually spin the first thin white web on the underside of the leaves next to the midrib. They begin feeding next to the midribs of the leaves, first eating small irregular holes through the parenchyma and later skeletonizing either or both leaf surfaces.

CHARACTER OF INJURY ON PEACH.

The injury to the peach is caused by the feeding of the larvæ on the foliage. The webs spun by the larvæ are loose, with considerable silk showing, and are often very conspicuous. The leaves soon become dry and cease to function, when included in the webs.

CHARACTER OF INJURY ON SAND CHERRY.

The webs on the sand cherry are small and compact, with only a little silk showing, but in the fall the infested terminals and branches become prematurely brown and conspicuous. Feeding is confined to the foliage, and, although in rare instances the webs are constructed about fruit, in no cases have larvæ been observed to feed on the fruit. Larvæ of varying sizes are found in the same webs, indicating the probability of repeated oviposition in the same terminal. From 2 to 12 larvæ are usually found in the webs on the separate terminals, although the number is sometimes as high as 30. In most cases observed when there was only one web on a branch it was located at the terminal, but when more than one was present the webs started from the base as well as from the terminal. As the larvæ enlarge the webs, they extend them along the branches, gradually including more and more foliage.

DESCRIPTION.

THE ADULT.

(Pl. III, fig. 3.)

Because of its completeness the description of the adult is copied from Murtfeldt:

Antennæ dark fuscous, indistinctly pectinate and banded on the under side with pale buff. Palpi long, exceeding the vertex. Basal joint short, pale; second joint one-third longer than apical. Brush quite dense, distinctly divided, dark fuscous overlaid with cream-coloured scales, palest on inner side. Apical joint dark, very slender, with extreme tip cream white, most conspicuously so in ♂. Tongue long, sparsely scaled. Vertex dark brown. Face cream white. Thorax and tegulæ purplish-brown. Fore wings almost black, with rich purplish gloss, and sparsely sprinkled with white scales. On the costa back of the apex is a small, irregularly triangular, cream white spot, and a few scattered scales of the same colour form an obscure outer border. In the cell near its upper margin are two somewhat indefinite, cream-coloured dots in line, with a third one below and slightly back of the one nearest the base. Cilia fuscous, shading outward to gray. Lower wings shining silky, cinereous, almost silvery. Abdomen pale brown, terminal segment banded with buff at posterior margin. Lateral tufts buff, inconspicuous; anal tuft reddish-brown. Under surface speckled with brown and cream. Legs brown, annulate with cream white at the joints and middle of the tibiæ. Alar expanse from 16 to 17 mm.

THE EGG.

(Pl. II, fig. 3.)

The egg is bluntly elliptical, somewhat flattened at the smaller attached end; length, 0.57 mm.; greatest width, 0.42 mm. The color is clear white when newly deposited, changing within 24 hours to a creamy yellow, the surface smooth and shiny without markings. About 24 hours before hatching the eggs change to a pearl gray color.

THE LARVA.

(Pl. II, fig. 1.)

The newly hatched larva is about 1.5 mm. in length and is yellowish white in color, with head and thoracic shield fuscous. The reddish brown stripes are discernible after about 9 days and as they develop they give color to the larva. A detailed description of the full-grown larva is copied from Pettit:

The larva, when full grown, is three-eighths of an inch in length and quite slender. Its color is dirty yellowish-white with back and sides marked by six reddish-brown longitudinal stripes all of which extend the entire length from the thoracic shield to the caudal extremity except the pair on the dorsum which unite on the last segment and terminate there. Last segment bordered caudally with fuscous and base of anal pro-legs colored the same. Venter marked along the middle with a stripe like those on dorsum and sides, which are about equidistant from each other and of about the same width as the spaces between them, color reddish-brown. Some of the spaces (yellowish-white) have dark points in them. Head and thoracic shield yellowish-brown, feet fuscous and dirty yellow. Four pairs of pro-legs beside anal pair which are of the same color as the ground color of the body. Base of anal pair black.

Mature larvæ (Pl. II, fig. 1) were found to vary from three-eighths to five-eighths inch in length, and in color to vary from yellowish white with poorly defined stripes to a clear white with vivid venetian-red stripes. There is an anteriorly directed semicircular black patch over each ocellar area.

THE PUPA.

(Pl. III, fig. 1.)

The pupa is unusually broad across the thoracic region, slightly flattened dorso-ventrally and quite variable in size. The average dimensions of 10 were found to be 6.3 mm. by 2.6 mm. When newly formed, the pupa is a light brown, changing later to a dark brown, the head, thorax, and ventral region obtaining a much darker color than the other regions. The wing pads are long, extending to cover all but the 3 posterior segments of the abdomen.

THE COCOON.

(Pl. III, fig. 2.)

This species differs from many of the genus in that it pupates normally in the soil. The larva enters the soil to a depth of about one-half inch and spins a white silken cocoon, which it incloses in fine soil particles and to the outside attaches coarser particles. Within this cocoon the larva pupates. The average size of 38 cocoons measured was 9.3 mm. in length by 4.4 mm. at the greatest width, slightly flattened to conform to the pupæ and usually distinctly curved.

SEASONAL HISTORY AND HABITS.

The following seasonal-history records were started at Benton Harbor, Mich., during the season of 1915 and were completed in 1916, in open-air insectaries in which glass battery jars were used as rearing cages. In all cases peach foliage was used as food for the larvæ. There is one full brood and a partial second brood.

The rearing studies began with the collection of a quantity of larvæ September 3, 1914. These overwintered, and the moths which emerged were used for part of the 1915 records. The rearing material for 1916 was that kept from the season of 1915, together with moths emerging from pupæ collected in May, 1916.

EMERGENCE OF SPRING BROOD OF MOTHS, 1916.

The earliest emergence of moths took place on May 22 and beginning on June 5 was quite regular until July 14, with the maximum emergence on June 29.

TABLE I.—*Emergence of spring brood of moths of the striped peach worm in 1916.*

Date of observation.	Number of moths.	Date of observation.	Number of moths.	Date of observation.	Number of moths.	Date of observation.	Number of moths.
May 22	1	June 13	12	June 29	60	July 13	3
May 30	2	June 15	30	July 2	32	July 14	3
June 5	1	June 17	24	July 4	14		
June 6	4	June 18	21	July 5	3	Total	364
June 8	5	June 21	56	July 7	18		
June 10	6	June 23	43	July 10	4		
June 11	3	June 25	17	July 12	2		

OVIPOSITION OF SPRING BROOD OF MOTHS.

As the moths emerged they were placed in jars with peach foliage and fruit. The moths oviposited freely in confinement whenever fruit was supplied in the oviposition jars. The eggs were deposited both on the fruit (Pl. II, fig. 2) and under the scales surrounding the attachment of the peach to the stem. In a single instance one egg was found in the axil of a peach leaf. On the sand cherry the eggs were found under the bud scales at the base of the current season's growth and in the axils of the leaves as indicated by the circles shown in Plate IV, figure 1, *a*. The occurrence of the eggs on the peach under orchard conditions was not noted. From Table III it will be seen that in 1915 eggs were being deposited in the jars from June 2 until June 26.

LENGTH OF LIFE OF MOTHS OF SPRING BROOD.

The length of life of 20 adults which were provided with a weak solution of clarified honey for food is shown in Table II.

TABLE II.—*Length of life of 20 moths of the spring brood of the striped peach worm, 1916.*

Number of moths.	Days of life.	Number of moths.	Days of life.
1	4	3	14
5	6	1	16
5	9	1	28
4	12		
		20	

Maximum length of life .... days .. 28
Minimum length of life .... do 4
Average length of life .... do 10.6

The average length of life of the adults is seen to be 10.6 days. From observations made in 1915, however, one adult was found to live 31 days, and eight moths emerging previous to May 24 were alive a month later. These moths were not supplied with food.

HABITS OF THE MOTHS.

The adults are not often seen in the field because of their small size and inconspicuous coloring. They are difficult to follow when seen because of their habit of short irregular flights and their resemblance when at rest to the color of the twigs of the host plant. The characteristic resting position is shown in Plate III, figure 3, from a photograph of a live specimen. One pair of adults was observed in copulation in a rearing cage on June 21, 1916, at 10.30 a. m. The heads of the male and female were in opposite directions and no parts were in contact except the genital organs. Both moths remained quiet during copulation.

FIRST BROOD.

Incubation.

In Table III the incubation period for the eggs deposited each day is shown. It will be seen that there was a variation of from 10 to 19 days in the incubation period, and even with eggs deposited the same day on the same fruit and thus subjected to the same external conditions there was a variation of five days. The average length of the incubation period was 13.18 days.

Table III.—*Incubation period of first-brood eggs of the striped peach worm at Benton Harbor, Mich., 1915.*

Date of oviposition.	Number of eggs deposited.	Date of hatching.	Number of larvæ.	Egg stage.	Date of oviposition.	Number of eggs deposited.	Date of hatching.	Number of larvæ.	Egg stage.
				Days.					*Days.*
June 2...	11	June 15.	11	13	June 16..	6	June 26..	2	10
June 3...	6	June 16..	1	13			June 27..	2	11
		June 19..	2	14			June 28..	1	12
		June 20..	1	15	June 18..	29	June 28..	10	10
June 5...	4	June 21..	3	16			June 29..	13	11
June 6...	28	June 20..	23	14			June 30..	5	12
		June 23..	1	17			July 1...	1	13
		June 24..	3	18	June 20..	4	June 30..	2	10
		June 25..	1	19	June 26..	5	July 7...	1	11
June 10..	2	June 23..	2	13					
June 12..	20	June 26..	20	14	Total..	118	....	107	....
June 12..	3	June 27..	2	15					

Maximum egg stage....................days.. 19
Minimum egg stage....................do.... 10
Average egg stage....................do.... 13.18

FEEDING PERIOD OF FIRST-BROOD LARVÆ.

The feeding period of the larvæ in the rearing cages in 1915 extended from June 15 to August 5. In 1916, larvæ were feeding from June 22 until August 1 as shown in Tables IV and V. The longest feeding period recorded was 48 days, the shortest 22 days, and the average 29.6 days for transforming larvæ, and 34.2 days for overwintering larvæ. On July 28, 1915, the writer came upon the injury on sand cherry. The infestation was at its height and practically all the insects in the larva stage. By August 11 about one-half the larvæ had left the webs and newly formed pupæ were to be found in the soil. Observations made on September 14 showed that from 95 to 98 per cent of the larvæ had left the webs.

TABLE IV.—*Length of feeding period of transforming first-brood larvæ of the striped peach worm, 1916.*

Date of hatching.	Date of of cocooning.	Number of cocoons.	Days of feeding.	Date of hatching.	Date of cocooning.	Number of cocoons.	Days of feeding.
June 22	July 20	1	28	June 25	July 17	2	22
Do	July 22	3	30	Do	July 20	2	25
Do	July 24	1	32	Do	July 26	1	31
Do	July 26	1	34				
Do	July 27	2	35	Total	....	14	....
Do	July 28	1	36				

Maximum length of feeding period ....days.. 36
Minimum length of feeding period ....do.. 22
Average length of feeding period ....do.. 29.6

TABLE V.—*Length of feeding period of wintering first-brood larvæ of the striped peach worm, 1916.*

Date of hatching.	Date of cocooning.	Number of cocoons.	Days of feeding.	Date of hatching.	Date of cocooning.	Number of cocoons.	Days of feeding.
June 22	July 20	2	28	June 22	Aug. 9	1	48
Do	July 23	1	31	June 25	July 17	1	22
Do	July 24	2	32	Do	July 26	3	31
Do	July 27	1	35	July 5	July 31	1	26
Do	July 28	4	36	Do	Aug. 1	1	27
Do	July 31	3	39				
Do	July 30	2	38	Total	....	23	....
Do	Aug. 8	1	47				

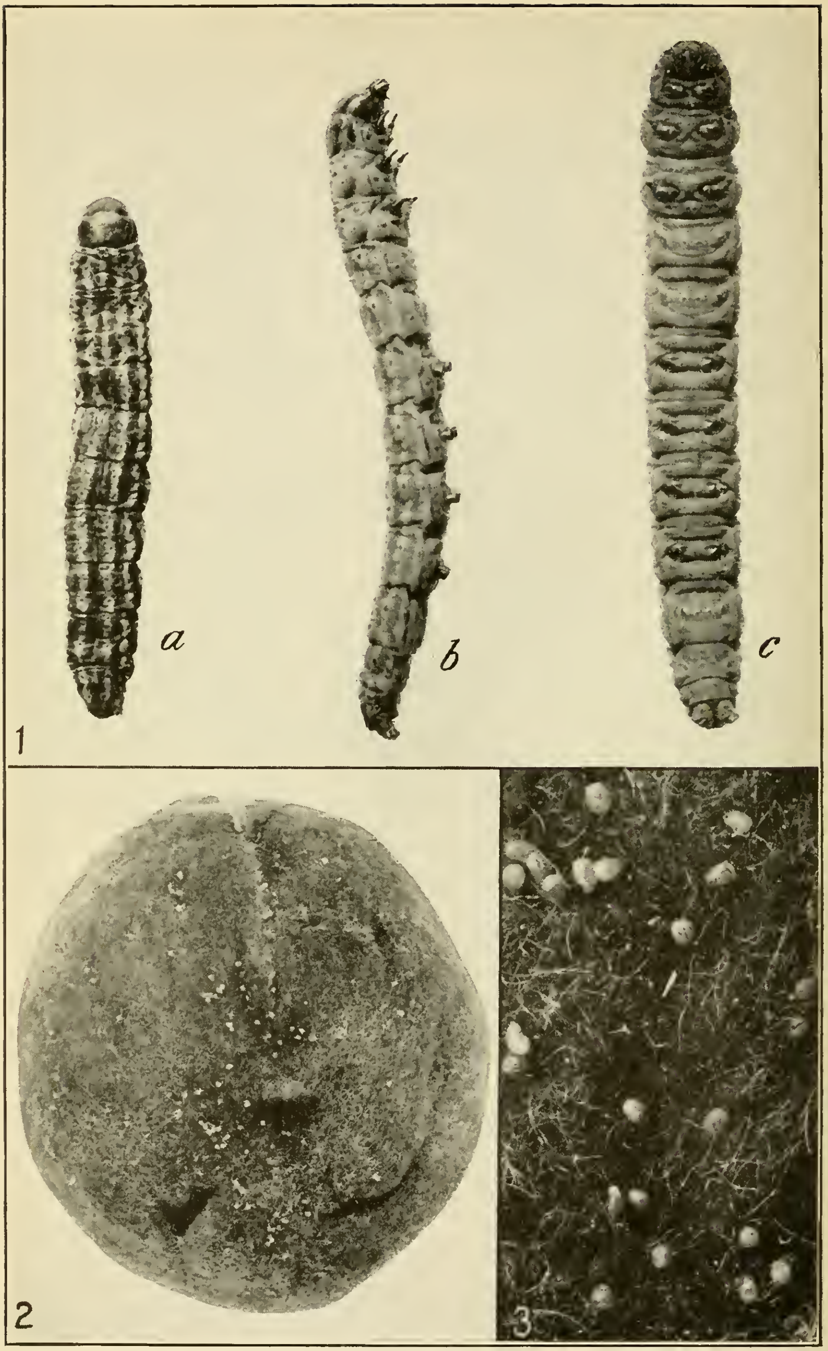
Maximum length of feeding period ....days.. 48
Minimum length of feeding period ....do.. 22
Average length of feeding period ....do.. 34.2

COCOONING OF FIRST BROOD.

Cocooning takes places in the soil at an average depth of one-half inch, in fine sandy loam in the rearing cages, and this was found to be the usual depth in the soil in the field where the pupæ were found. Of a total of 203 individuals recorded, 31 pupated on the surface of the soil, 154 in the upper half inch, 18 in the second half inch,

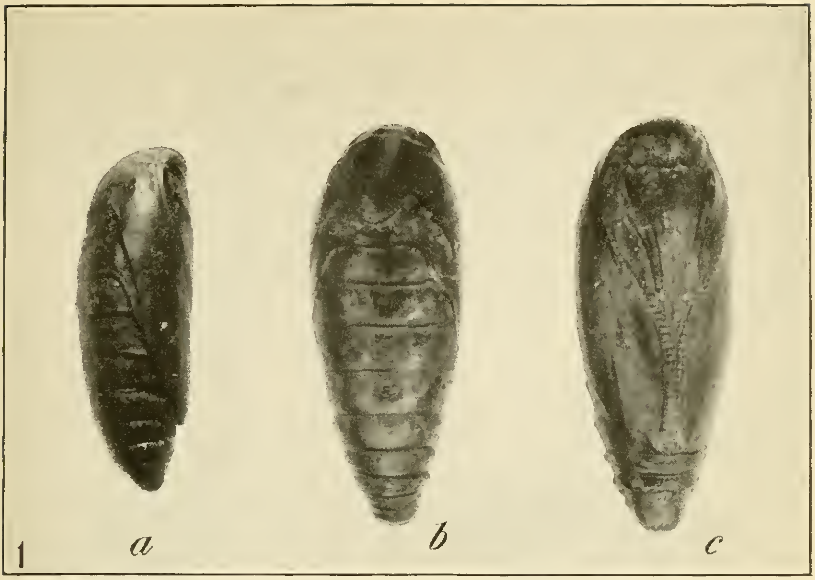
WORK OF THE STRIPED PEACH WORM (GELECHIA CONFUSELLA).

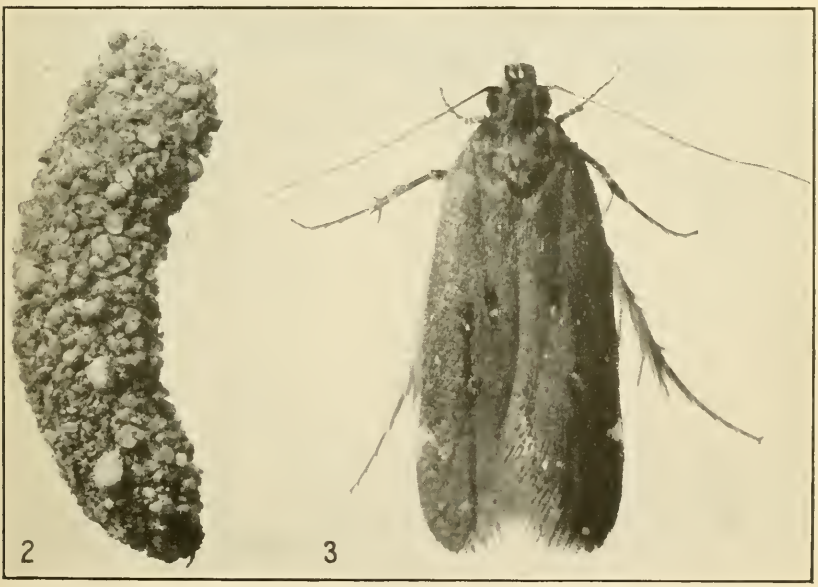
Injury to peach foliage and characteristic webbing. From photograph of limb taken from orchard. About one-half natural size. (Original.)



THE STRIPED PEACH WORM (GELECHIA CONFUSELLA).

FIG. 1.—Views of larvæ: *a*, Dorsal; *b*, lateral; *c*, ventral. All enlarged about 6 times. FIG. 2.—Eggs on peach, about natural size. FIG. 3.—Eggs enlarged about 11 times. (Original.)





THE STRIPED PEACH WORM (GELECHIA CONFUSELLA).

FIG. 1.—Views of pupæ: *a*, Lateral; *b*, dorsal; *c*, ventral. Enlarged about 9 times. FIG. 2.—Pupal case, enlarged about 10 times. FIG. 3.—Adult, enlarged about 11 times. From photograph of living specimen showing natural position when at rest. (Original.)

WORK OF THE STRIPED PEACH WORM (GELECHIA CONFUSELLA).

FIG. 1.—*a*, Sand cherry terminal uninjured. Circles indicate place of egg deposition. *b*, Sand cherry terminal in early stage of injury by larvæ, lowest leaf showing skeletonizing. FIG. 2.—Sand cherry terminal completely webbed by larvæ. All reduced about one-third. (Original.)

and none deeper. The larvæ in the rearing cages cocooned from July 17 to August 9, but nearly full-grown larvæ collected on sand cherry August 11 were cocooning from August 12 until September 14. The dates of cocooning for the season of 1916 are shown in Tables IV and V, and the length of the period in the cocoon for 17 individuals is shown in Table VI. The average length of the period in the cocoon was determined to be 12.4 days; the longest period, 21 days; and the shortest period, 9 days.

TABLE VI.—*Length of time spent in the cocoon by the first brood of the striped peach worm, 1916.*

Date of cocooning.	Number of cocoons.	Date of moth emergence.	Days in cocoon.	Date of cocooning.	Number of cocoons.	Date of moth emergence.	Days in cocoon.
July 17	2	July 28	11	July 27	1	Aug. 7	11
July 20	3	Aug. 1	12	Do	1	Aug. 9	13
July 22	2	Aug. 2	11	July 28	1	Aug. 18	21
Do	1	Aug. 4	13	Aug. 1	1	...do....	17
July 24	1	Aug. 6	13	Aug. 3	1	...do....	15
July 25	1	Aug. 4	10				
July 26	2	...do....	9	Total	17	....	....

Maximum length of time in the cocoon....days.. 21
Minimum length of time in the cocoon....do.. 9
Average length of time in the cocoon....do.. 12.4

EMERGENCE OF FIRST-BROOD MOTHS.

TABLE VII.—*Emergence of first-brood moths of the striped peach worm at Benton Harbor, Mich., 1915.*

Date of emergence.	Number of moths.		Date of emergence.	Number of moths.	
	Male.	*Female.*		*Male.*	*Female.*
Aug. 4	0	4	Aug. 16	0	3
Aug. 5	0	1	Aug. 20	1	0
Aug. 6	0	3	Aug. 21	1	0
Aug. 7	0	4	Aug. 27	0	2
Aug. 9	0	3	Aug. 28	1	1
Aug. 10	0	9	Aug. 29	1	0
Aug. 11	3	1	Sept. 1	0	2
Aug. 12	0	2	Sept. 11	0	1
Aug. 14	0	1	Sept. 12	2	3
			Total	9	40

Table VII shows that first-brood moths were emerging from August 4 until September 12 in 1915, with the largest number on August 10. From 683 larvæ collected on sand cherry July 28 only two moths subsequently emerged that season—one on August 28 and the other on September 9. The dates of emergence of first-brood moths in 1916 are shown in Table VI.

Oviposition of First-Brood Moths.

Table VIII.—*Oviposition of first-brood moths of the striped peach worm at Benton Harbor, Mich., 1915.*

Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.
Aug. 15	178	Aug. 18	13
Aug. 16	26	Aug. 19	10
Aug. 17	10	Total	237

It will be seen from Table VIII that eggs were being deposited from August 15 until August 19, with the greatest number on August 15. The oviposition records are from the moths recorded in Table VII; the late emerging moths failed to oviposit. On the morning of August 19, in transferring a peach on which eggs had been deposited, by mistake one moth was transferred. When the condition of the eggs was observed on the morning of August 23 the moth had deposited 42 eggs in addition to those previously recorded.

SECOND BROOD.

Incubation Period of Second-Brood Eggs.

Table IX.—*Incubation period of second-brood eggs of the striped peach worm at Benton Harbor, Mich., 1915.*

Date of oviposition.	Number of eggs.	Date of hatching.	Number of larvæ.	Egg stage.
				Days.
Aug. 16	26	Aug. 31	14	15
	....	Sept. 1	2	16
	....	Sept. 2	3	17
	....	Sept. 3	1	18
	....	Sept. 5	4	21
Aug. 17	11	Sept. 1	5	15
Aug. 18	13	Sept. 2	8	15
	....	Sept. 3	1	16
Aug. 19	17	Sept. 3	17	15
Total	67	....	55	....

Maximum length of incubation period........days.. 21
Minimum length of incubation period........do.... 15
Average length of incubation period........do.... 15.6

In Table IX it will be seen that eggs began to hatch on August 31 and continued to hatch until September 3; the average incubation period being 15.6 days.

The Emergence of the Larva From the Egg.

The larva cuts the top of the eggshell with its mandibles and eats the part cut away. By a wriggling movement it forces its head and thoracic legs out of the shell and with these legs on the edge of the shell pushes the rest of the body out by the use of the caudal part of the abdomen. Of four individuals observed, 13 minutes was consumed by each from the first cutting of the eggshell until the larva was entirely free.

Feeding Period of Second-Brood Larvæ.

Table X.—*Length of feeding period of second-brood larvæ of the striped peach worm at Benton Harbor, Mich., 1915.*

Date of hatching.	Date of cocooning.	Number of cocoons.	Days of feeding.	Date of hatching.	Date of cocooning.	Number of cocoons.	Days of feeding.
Aug. 23	Oct. 7	10	45	Sept. 1	Oct. 24	2	53
Do	Oct. 9	14	47	Do	Oct. 27	2	56
Do	Oct. 12	1	50	Do	Oct. 30	1	59
Do	Oct. 15	1	53	Do	Nov. 2	3	62
Do	Oct. 24	1	62	Do	Nov. 10	8	70
Do	Oct. 30	1	68	Do	Nov. 14	2	74
Aug. 31	Oct. 9	4	39	Sept. 2	Oct. 22	4	50
Do	Oct. 12	2	42	Do	Oct. 24	1	52
Do	Oct. 24	11	54	Sept. 3	Oct. 12	1	39
Sept. 1	Oct. 12	2	41	Do	Oct. 24	1	51
Do	Oct. 22	8	51				
Do	Oct. 15	1	44	Total		81	

Maximum length of feeding period .... days.. 74
Minimum length of feeding period .... do.... 39
Average length of feeding period .... do.... 52.1

Larvæ were feeding from August 23 until November 14, the average length of feeding period being 52.10 days. This late date of feeding is undoubtedly later than would have been possible in the field, for defoliation of peaches occurs previous to this date, although in the rearing jars the larvæ secured the foliage to the twigs by the silken webs in such a way that it could not drop.

Cocooning of Second-Brood Larvæ.

Although cocooning normally takes place in the soil, 13 of 361 individuals recorded pupated in the webbed foliage in which they had lived as larvæ. These pupæ were closely rolled in the individual leaves but not attached to them, and no cocoons were formed. The dates of cocooning are shown in Table X.

SUMMARY OF SEASONAL-HISTORY STUDIES.

Table XI shows a summary of the seasonal-history studies made on material in rearing cages during the seasons of 1915 and 1916.

Table XI.—*Summary of seasonal-history studies of the striped peach worm as observed by rearing during the seasons of 1915 and 1916.*

Observation.	Season.	Number of individuals.	Number of days.		
			Average.	Maximum.	Minimum.
Length of life of moths of spring brood	1916	20	10.6	28	4
Incubation of eggs of first brood	1915	118	13.18	19	10
Feeding period of transforming larvæ of the first brood.	1916	14	29.6	36	22
Feeding period of wintering larvæ of the first brood	1916	23	34.2	48	22
Length of period in cocoon of first brood	1916	17	12.4	21	9
Incubation of eggs of second brood	1915	55	15.6	21	15
Feeding period of second-brood larvæ	1915	81	52.1	74	39

PARASITES.

While conducting the seasonal-history studies, it was found that the striped peach worm was parasitized by a number of insects. Table XII records the emergence of the Hymenoptera and Diptera which parasitized the 683 larvæ collected on sand cherry July 28, 1915, and 60 pupæ collected in May, 1916.

TABLE XII.—*Emergence of parasites of the striped peach worm (Gelechia confusella), Benton Harbor, Mich., 1915 and 1916.*

Date of emergence.	Number of parasites.		Date of emergence.	Number of parasites.		Date of emergence.	Number of parasites.	
	Diptera.	Hymenoptera.		Diptera.	Hymenoptera.		Diptera.	Hymenoptera.
1915.			1915.			1916.		
Aug. 12...	0	3	Sept. 2...	0	1	June 18...	3	....
Aug. 13...	0	3	Sept. 3...	1	0	June 23...	3	....
Aug. 14...	0	1	Sept. 4...	0	1	June 25...	1	....
Aug. 15...	0	4	Sept. 10..	1	1	June 29...	9	....
Aug. 17...	1	1	Sept. 11..	0	2	July 2....	12	....
Aug. 18...	0	1	Sept. 12..	0	4	July 4....	9	....
Aug. 19...	0	2	Sept. 14..	2	0	July 7....	10	....
Aug. 21...	0	2	Sept. 15..	0	1	July 10...	14	....
Aug. 22...	1	4	Sept. 26..	1	0	July 12...	2	....
Aug. 23...	0	1	[1]	0	2	July 13...	6	....
Aug. 25...	0	1				July 14...	9	....
Aug. 27...	0	1	1916.			[1]	17	....
Aug. 28...	0	2	June 11...	1	....			
Aug. 29...	0	1	June 13...	5	....	Total..	108	40
Sept 1...	0	1	June 15...	2	....			

[1] No record.

The hymenopterous parasites were identified by Mr. R. A. Cushman, of the Bureau of Entomology. Of 40 specimens submited, the different genera and species were represented as shown in Table XIII.

TABLE XIII.—*Parasites reared from the striped peach worm (Gelechia confusella), Benton Harbor, Mich., 1915 and 1916.*

Parasite, order and family.	Number of individuals.	Stage of host collected.	Parasite emerged from—
HYMENOPTERA.			
ICHNEUMONIDAE.			
Angitia discoocellellae Vier	20	Larva	Pupa.
Cremastus forbesii Weed	1	....do	No record.
Cremastus sp	1	....do	Do.
Epiurus indagator Walsh	1	....do	Do.
BRACONIDAE.			
Apanteles gelechiae Vier	8	....do	Pupa.
Ascogaster carpocapsae Vier	2	....do	No record.
Epirhyssalus atriceps Ashm. 3 ♂, 4 ♀	7	....do	Do.
DIPTERA.			
TACHINIDAE—			
Exorista pyste Walk	2	....do	Pupa.
Frontina ancilla Walk	61	Larva and pupa	Do.
BOMBYLIIDAE—			
Anthrax lateralis Say	2	Pupa	Do.

The dipterous parasites which emerged in 1915 were identified by Mr. Harrison E. Smith, of the Bureau of Entomology, and those emerging in 1916 were identified by Mr. W. R. Walton, Entomologist in Charge of Cereal and Forage Insect Investigations.

REMEDIAL MEASURES.

Experiments were conducted in 1916 to determine the efficacy of arsenical sprays in the control of the striped peach worm. Plats were laid out in a sand-cherry thicket and sprayed with arsenicals according to the formulas in Table XIV, all of the adjoining sand cherry serving as checks for comparison.

TABLE XIV.—*Experiments for control of the striped peach worm, Benton Harbor, Mich., 1916.*

Plat No.	Formula used.	Date of spraying.	Result of spraying.
1	Arsenate of lead powder, 1 pound to 50 gallons water.	June 29	5 per cent of terminals webbed.
2	Arsenate of lead powder, 1½ pounds to 50 gallons water.	...do.....	3 per cent of terminals webbed.
3	Check; unsprayed		90 per cent of terminals webbed.

At the time of spraying, a few of the larvæ had hatched and webbed a few terminals. The spray material was applied with a small compressed-air sprayer at a pressure of 70 pounds and sprayed just to the drip. The results of the spraying were very conclusive and both sprayed plats were almost entirely free from infestation when observed on September 19.

RECOMMENDATIONS.

The occurrence of the striped peach worm may be so local as to permit of the cutting out of the infested terminals or branches, and it will probably not occur in damaging numbers in orchards that are sprayed regularly with arsenicals for control of the plum curculio. Should the infestation be such as to warrant spraying, it is probable that a single application of arsenate of lead paste 2 pounds, or powder 1 pound, to 50 gallons of water to which 2 pounds of freshly slaked lime is added, applied when the first webbing of the leaves appears, will satisfactorily control this insect.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 609

Contribution from Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER November 22, 1917

THE SWEET-POTATO LEAF-FOLDER.

By THOS. H. JONES,[1] *Entomological Assistant, Truck-Crop Insect Investigations.*

[With a complementary report regarding spraying experiments for its control, conducted in southern Texas by M. M. High.]

CONTENTS.

INTRODUCTION.

The larva of *Pilocrocis tripunctata* Fab. (fig. 1 *c*, *d*), a member of the lepidopterous family Pyralidæ, was noted first as an enemy of sweet potatoes in Louisiana by the writer while cooperating with the Louisiana Experiment Stations in the fall of 1914. Since that time the species has been kept under observation at Baton Rouge, La., and has been noted also in Plaquemines and Tangipahoa Parishes.

The species, which may be called the "sweet-potato leaf folder" because of the habits of the larva, has not been observed as yet in destructive numbers in Louisiana; but it has been reported by Mr. M. M. High, of the Bureau of Entomology, as very injurious to the sweet potato near Brownsville, Tex., where he conducted control experiments with poisons during the fall of 1916. As it is possible that this pest may become an important enemy of sweet potatoes in the Southern States, it seems advisable to publish the results concerning its biology and the results of Mr. High's control experiments.[2]

[1] The author wishes to acknowledge the assistance of C. E. Smith and J. L. E. Lauderdale in the studies on the history and habits.

[2] Besides the complementary report by Mr. High, this bulletin includes notes made by him regarding the life history, habits, and enemies of the species in southern Texas. Especially because development under conditions existing in southern Texas may differ from that under conditions at Baton Rouge, statements taken from Mt. High's notes are credited to him. All other observations were made at Baton Rogue.

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HISTORY, DISTRIBUTION, AND SYNONYMY.

The only published record regarding injury by this species appeared in 1915, when the writer mentioned the occurrence of the larva on sweet potato in Porto Rico (6).[1] It was described first as

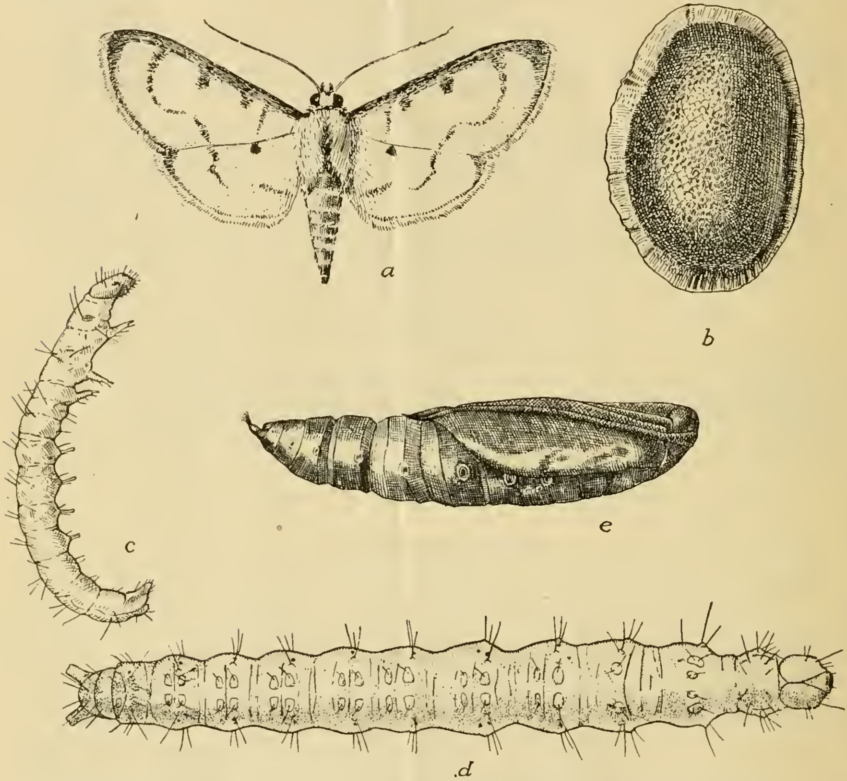

FIG. 1.—The sweet-potato leaf-folder (*Pilocrocis tripunctata*): *a*, Moth; *b*, egg; *c*, early stage of larva, from side; *d*, ventral view of larva; *e*, side view of pupa. All enlarged; *b*, highly magnified. (Original.)

Phalaena tripunctata by Fabricius in 1794 from material from the Central American Islands (1). Guénée recorded it (as *Botys cubanalis* Gn.) from Cuba (2), and Dyar listed it from Florida, Texas, and the West Indies (5).

Specimens from the following-named localities and now in the National Museum have been identified by Mr. August Busck: Kerville, Victoria, and San Antonio, Tex.; Mexico; Costa Rica; Jamaica, Cuba, and Grenada, West Indies. The addition of Baton Rouge, La., and Brownsville, Tex., completes the list of known localities where the species occurs.

[1] Figures in parentheses refer to "Literature cited," p. 12.

The following synonymy is recorded:

Phalaena tripunctata Fabr. 1794.
Botys cubanalis Guén. 1854.
Botys memmialis (F.) Walker. 1859.
Pilocrocis tripunctata Fabr. (Hampson). 1898.

DESCRIPTION OF STAGES.

THE EGG.

(Fig. 1, *b*.)

Thin, scalelike, with delicate walls, reticulated on upper surface; more or less regularly elliptical in outline, especially when laid singly. Being very plastic, the eggs vary considerably in shape. When laid the egg is at first colorless, practically transparent, and later the developing embryo can be seen plainly within. Measurements of 10 eggs that had been deposited singly: Average length, 1.06 mm., average width, 0.79 mm.

THE FIRST LARVA STAGE.

Of a number of larvæ examined, none of which was more than 24 hours old, the smallest measured about 1.5 mm. in length. The width of the head shield of all these individuals was very constant, about 0.25 mm.

Newly hatched larvæ are opaque, colorless, except for the dark, reddish-brown ocelli and the mouth parts, which are tinged faintly with brown. The body is cylindrical in shape, the surface smooth, glistening, with the setæ arising from colorless tubercles. In these newly hatched larvæ the head and legs are comparatively large, noticeably out of proportion to the rest of the body. After emergence from the eggs, however, the larvæ begin to increase rapidly in size, and this lack of proportion is soon lost. When the larvæ begin to feed the chlorophyll taken into their bodies imparts to them a greenish tinge.

LATER LARVA STAGES.

(Fig. 1, *c*, *d*; fig. 2, *a*, *b*.)

During the succeeding instars the shape of the larva remains cylindrical, the surface smooth and glistening. *In the third and subsequent instars tubercle ii of segments 3 and 4*[1] *is usually conspicuous because of its brownish or blackish color.* Sometimes, however, especially on segment 4, the tubercle is not dark.

When at rest the full-grown larva measures, immediately after feeding, about 27 mm. in length and 5 mm. in width. Measurements of the width of the head shields of 10 individuals gave an average of 1.81 mm., ranging from 1.75 mm. to 1.88 mm. The general color of the larva is bluish green. The head (fig. 4) is pale yellow, and the ocelli, tips of the antennæ, mouth parts, and claws of the true legs are brown.

THE PUPA.

(Fig. 1, *e*; fig. 2, *c*.)

The pupa is dark brown in color, somewhat lighter toward the posterior end. The surface is smooth, that of the abdominal segments dull and the remainder glistening. Eight bristles, curled at their tips, occur at the end of the cremaster.

Five pupæ averaged 15 mm. in length and 4 mm. in width at the widest point.

[1] The head is considered as segment 1, the prothorax as segment 2, and the others in succession.

THE ADULT.

(Fig. 1, *a*; fig. 3.)

The general color of the upper surface of the body and wings of the moth is light yellow, the wings iridescent. A dark grayish-brown band begins at the humeral angle of the forewing, from which it extends to the eye, and continues along the costal and outer margins of this wing and the outer margin of the hind wing. On either wing this band is widest at the apex. Inside the band and about one-sixteenth of an inch from it a wavy line of the same color crosses both wings. Two black spots occur on the forewing, near the costal margin. The outer and larger one is near the middle of the margin and the smaller one about halfway between this and the base of the wing. A short, wavy, dark grayish-brown line occurs just inside this small black spot, extending backward from the band on the costal margin to a point about halfway across the wing. There is also a small black spot on the hind wing, near the costal margin and about halfway between the base of the wing and the wavy line previously noted. The markings are shown in figure 1, *a*.

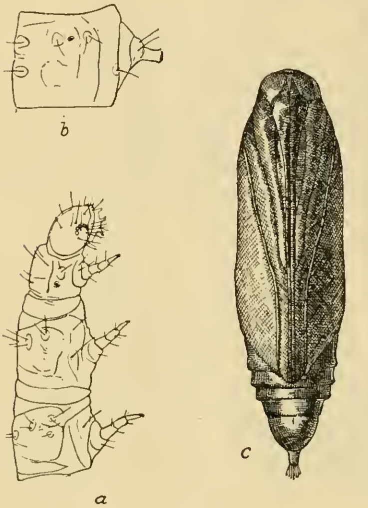

FIG. 2.—The sweet-potato leaf-folder: *a*, First three joints of larva, showing legs and arrangement of spiracles and spiracular tubercles; *b*, lateral view of a ventral segment; *c*, pupa, ventral view. All greatly enlarged. (Original.)

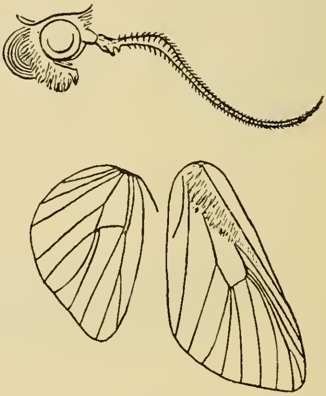

FIG. 3.—Wing venation and lateral view of head and antenna of a related species, *Pilocrocis ramentalis*, to show characters of genus. (Hampson.)

The underside of the wings is lighter in color than are above, but have the same iridescent reflection with indications of the markings of the upper surface.

The ventral surface of the thorax and abdomen is white. The antennæ are light yellowish brown, and the legs white, except that the anterior surfaces of the first pair are for the most part of a dark grayish brown.

In the male the abdomen tapers more gradually to the posterior end than is the case in the female. The upper surface of the thorax also presents a more hairy appearance in the male, owing to the longer hairs of the tegulæ or lappets. With a lens a third point of difference is seen in the short bristles present on the underside of the basal portion of the antennæ of the male. These do not occur on the antennæ of the female.

Measurements of the wing expanse of 11 reared females gave an average of 27 mm., ranging from 25 mm. to 29 mm. The wing expanse of 7 reared males ranged from 25 mm. to 27 mm.

FOOD PLANTS.

In addition to the sweet potato as a food plant, moths have been reared from larvæ found feeding on uncultivated plants of the genus Ipomoea, to which the sweet potato belongs. It seems probable that some species of this genus, known under the common names of "bindweed," "wild sweet potato," and "wild morning-glory," are the natural larval food plants, and that the larvæ will feed on any of the numerous species of Ipomoea, in which genus are included a number of ornamental vines.

SEASONAL HISTORY AND HABITS.

OVIPOSITION.

Eggs have not been observed in the field at Baton Rouge, but the females, after feeding from pieces of sponge moistened in sweetened water, oviposited freely on sweet-potato plants in cages.

The eggs, which are securely fastened to the leaf, were placed on the underside, the areas alongside the leaf veins being a favorite location; Mr. High, however, from observations made in Texas, noted that apparently the eggs are deposited indiscriminately on either side of the leaf. Eggs are sometimes placed singly but as many as five have been noted in a group, their edges overlapping, although in no regular arrangement.

INCUBATION.

Eggs laid in the insectary at Baton Rouge on July 29 and 30 hatched on August 2 and 3, respectively. The period of incubation was, therefore, under these conditions, four days. The averages of the daily maximum and minimum temperatures for the insectary from July 29 to August 3, inclusive, were 92.5° and 74.0° F.

HABITS OF THE LARVA.

In the field the larvæ are found between separate leaves or portions of the same leaf which have been fastened together to form "shelters," each of which usually protects one larva. The larva constructs its shelter by spinning threads of silk from side to side across a portion of a leaf near the edge, each strand being shortened as the preceding strands contract in drying, until finally the edge of the leaf is drawn completely over and fastened down with the shorter bands of silk. The precise process of this species has not been noted in detail. Mr. High has found that the larva when young eats small irregular holes in the leaf, but later consumes more of the leaf as the larva increases in size, in extreme cases devouring all of the leaf except the larger veins and midrib. The shelters and the injury to the leaves, due to the feeding of the larvæ, are shown in figure 4.

FIG. 4.—Sweet-potato vine showing work of sweet-potato leaf-folder. (Original.)

When the shelters are broken open and the larvæ disturbed they throw themselves rapidly about, much as a fish does when removed from water, and this violent action soon results in their reaching the surface of the soil, where, if there is a heavy growth of vines, they are difficult to find.

LENGTH OF LARVA STAGES.

The number of molts the larvæ undergo may vary, but the usual number apparently is 6. In the insectary at Baton Rouge during 1916 2 lots of adults were reared from eggs that had been laid by moths kept in confinement. The first lot were from larvæ that issued on June 21. Eight of these spent 13 days in the larva stages, and 2 pupated 14 days after issuing from the egg. The averages of the daily maximum and minimum temperatures for this period, taken from a self-registering thermograph, were 95.3° and 72.6° F., respectively.

The second lot of larvæ were reared during August. They issued on August 3. Two pupated 13 days after issuing from the egg, while two required 14 days, one 15 days, and six 16 days for the larva stages. For this period the average of the daily maximum temperatures was 90° F. and the average of the daily minimum temperatures 72.8° F.

In the case of the larvæ reared during August observations were made to determine the length of time required for the various instars. Because of the fact that after the first five molts the larva usually devours all of the cast skins, with the exception of the tougher portion from the head, it is rather difficult to determine the exact time of molting, especially in the early stages. The time spent in each of the 6 instars was, however, ascertained from 7 larvæ. With two exceptions the periods were as follows: First instar, 3 days; 2d, 3d, 4th, and 5th instars, 2 days each; 6th instar, 5 days. One larva spent 3 days in the second instar and another only 4 days in the sixth instar.

PREPARATION FOR PUPATION.

After completing its growth the larva ceases feeding and constructs a cocoon, within which it transforms later to the pupa. During the period intervening between the time when the last food is taken and the time of pupation the larva undergoes a gradual change; it becomes shorter, the bluish-green color disappears, and the larva becomes sluggish.

In the insectary during July and August the time required in preparation for pupation was, with few exceptions, two days. In a few cases three days were required. Under the heading "Hibernation." the length of time passed in preparation for pupation by individuals that complete their larval growth later in the season is given.

PUPATION.

In the field and in the insectary pupæ normally are found in loose cocoons within the shelters made by the larvae. Larvae developing after the latter part of August sometimes construct in confinement a somewhat different type of cocoon, which will be discussed later.

The pupa period occupied from 6 to 9 days in the insectary during July and August. During September, 1915, two individuals kept outdoors in glass jars transformed to moths 7 days after becoming pupæ.

HIBERNATION.

This species, judging by analogy, passes the winter months as a larva. The behavior of individuals kept in the insectary, however, should be mentioned in this connection. Larvæ collected in the field August 23, October 16, and November 1, 1915, the last date being the latest when larvæ were taken outdoors in 1915, were placed in the insectary. Here they constructed above the surface of the soil rather tough, brownish, silken cocoons of a more substantial nature than those from which moths issued during the summer months. Examination of some of these cocoons, made as late as December 11, showed that they contained inactive larvæ. The exact date when pupæ were formed was not ascertained, but moths began to issue as early as May 10. From observation it would appear that eggs are first deposited outdoors about this time.

On October 10, 1916, larvæ were found, in cocoons similar to those mentioned above, in a field of sweet potatoes at Baton Rouge. These cocoons were found at the surface of the soil, in portions of old, dead, sweet-potato leaves.

In southern Texas, according to Mr. High, the last generation doubtless passes the winter in the last larva instar and pupates in the spring or late in the winter. He has observed that the mature larva of this generation spins a cocoon of strong silk during the first half of November and remains in a quiescent state until ready to pupate. The cocoons usually are covered with soil or leaves, although any material the larva is able to draw together may be utilized. Where no such material is available it will make the cocoon entirely of silk.

THE LIFE CYCLE.

The minimum time required for the various stages in the insectary at Baton Rouge was as follows:

	Days.
Egg stage	4
Larva stages	13
Prepupa stage	2
Pupa stage	6
Total life cycle	25

In June larvæ were found in a cage 7 days after newly emerged moths had been placed therein, so that it appears that moths may begin egg-laying within at least 3 days after they have issued. This would give a minimum total of 26 days for the life cycle.

Under normal outdoor conditions the time necessary for the life cycle probably would be somewhat longer than that required in the insectary, since the temperature of the insectary is higher than the outdoor temperature. In outdoor cages moths began to issue on August 24 and August 26, 28 and 29 days after the eggs had been deposited.

It appears that during the summer months the life cycle requires about five weeks in the field at Baton Rouge. Early in September, moths, pupæ, and larvæ in all stages of development were found on sweet-potato vines. There are probably four, and possibly five, generations during the season in the latitude of Baton Rouge.

NATURAL ENEMIES.

A tachina fly (*Exorista pyste* Walk.) and an ichneumon fly which Mr. A. B. Gahan, of the Bureau of Entomology, has pronounced to be a new species of the genus Bassus, have been reared from collections of larvæ made in the field at Baton Rouge, indicating that they are parasites of the sweet-potato leaf-folder. Adults of the spined soldier bug (*Podisus maculiventris* Say) have been observed with larvæ impaled on their beaks.

Mr. High observed a predacious enemy of the larva in the "jackdaw," or boat-tailed grackle (*Megaquiscalus major macrourus* Swainson). The following notes are from his records.

"This bird winters in southern Texas by millions and feeds on a number of insects that attack truck crops and particularly on larvæ. * * * observed it first feeding on the cabbage looper (*Autographa brassicæ* Riley) in 1913, two days after cabbage had been sprayed with an arsenical.

"Some species of larvæ after being poisoned have a habit of crawling to the top leaves of the plant upon which they are feeding before dying, and here they fall easy prey to the grackle. The poison apparently does not seriously affect the birds, since none have been found dead in the vicinity of sprayed crops."

THE SWEET-POTATO LEAF-FOLDER IN SOUTHERN TEXAS.[1]

The sweet-potato leaf-folder (*Pilocrocis tripunctata* Fab.) was first observed by the writer in southern Texas September 17, 1916, when larvæ were found sparingly on a plat of sweet potato at Brownsville, Tex. On September 29 the larvæ were observed at work in another field near Brownsville, and by this time were more numerous in the plat where first they were found. At this time a sudden change in the weather accompanied by hard showers somewhat reduced their numbers.

By the middle of October the caterpillars had become so abundant that it was found advisable to spray immediately. Later a

[1] Reported by M. M. High, Entomological Assistant, Bureau of Entomology, United States Department of Agriculture.

second application was made. The results of these treatments are recorded in this report.

SPRAYING EXPERIMENTS.

On October 19 some sweet potatoes at Brownsville were sprayed for the sweet-potato leaf-folder with arsenate of lead at the rate of 1 pound (powder) to 50 gallons of water. At the time the spray was applied the infestation was localized in spots, mainly on one side of the plat. On the following night a shower washed a considerable amount of the poison from the vines. An examination October 22 showed that somewhat more than one-half of the larvæ were still feeding actively and did not appear to be poisoned. By October 25 the living larvæ had decreased to about 25 per cent of the original number, though it appeared that birds were partially responsible for the decrease.

Afterwards few larvæ were found up to the first few days of November, when they reappeared in large numbers and dozens could be collected in a very small space.

November 9 the sweet-potato patch was divided into three plats and sprayed with lead arsenate and zinc arsenite at different strengths. On account of the matting of the vines it was impossible to ascertain the number of larvæ by count on any one plant, so that the number was estimated over a given space both before and after spraying.

Plat No. 1 was sprayed with lead arsenate: 2 pounds (powder) to 50 gallons of water. The powder was first converted to paste and the remainder of the water was added. The spray was applied early in the afternoon, when the foliage was perfectly dry and a fairly uniform coating was secured. Particular care was taken to coat at least one side of the foliage thoroughly.

Plat No. 2 was sprayed immediately with lead arsenate at the rate of 1 pound (powder) to 50 gallons of water. This was applied in the same manner as in plat No. 1, but the spray seemed to spread more uniformly over the leaves than did the heavier dosage.

Plat No. 3 was sprayed with zinc arsenite: 1 pound (powder) to 40 gallons of water in which 12 pounds of cactus, to increase adhesiveness, had been placed 20 hours before. The solid cactus detritus was thrown out and the zinc arsenite added. This spray adhered better to the foliage than did either of the other sprays, though the whitening of the foliage was less definite than in plat No. 1, and hardly as much so as in plat No. 2.

On November 11 an examination showed that in plat No. 1 the leaves of the potato were scorched slightly, although not enough to cause serious damage. It was estimated that about 94 per cent of the larvæ had been destroyed or were past feeding. In plat No. 2

the mortality ranged from 93 to 95 per cent; in plat No. 3 mortality was a fraction higher, about 95 to 96 per cent.

All the plats were sprayed with a hand sprayer holding about 5 gallons of spray mixture, and probably a little more thoroughly than would be done on a large scale by inexperienced help. When potatoes are planted on soils with high nitrogen content, the foliage is usually heavy, requiring careful manipulation to secure thorough distribution of the spray mixture.

SUMMARY OF SPRAYING EXPERIMENTS.

The foregoing experiments demonstrate that the larvæ of the sweet-potato leaf-folder (*Pilocrocis tripunctata* Fab.) can be killed readily by timely applications of arsenical sprays. Either arsenate of lead or zinc arsenite at the rate of 1 or 2 pounds (powder) to 50 gallons of water will give favorable results. If the spraying is done early, one application may be sufficient, whereas if treatment is delayed until a large number of larvæ have spun cocoons, two or more applications may be necessary in order to effect complete control.

SUMMARY.

The caterpillar of a pyralid moth (*Pilocrocis tripunctata* Fab.) was very injurious to the foliage of sweet potato in southern Texas during the fall of 1916. No previous instance of injury appears to be recorded although the insect has long been known to inhabit the Gulf region. It occurs also in the West Indies and has been mentioned as feeding on the sweet potato in Porto Rico.

The various stages of this insect, which, because of the habits of the larva, has been given the name of "the sweet-potato leaf-folder," have been described from life-history studies carried on at Baton Rouge, La.

The minimum length of time required for the life cycle in the insectary at Baton Rouge, La., was found to be about 26 days. In the field there are probably 4, and possibly 5, generations a year in the latitude of Baton Rouge. The winter months apparently are spent in the last larva stage within a cocoon at or near the surface of the soil.

Two parasitic flies have been reared from the larvæ, and the spined soldier-bug has been found to be predacious upon the larvæ. In Texas the "jackdaw" or boat-tailed grackle feeds upon them.

Experiments conducted by the Bureau of Entomology indicate that the larvæ can be killed readily by spraying the foliage with either arsenate of lead or arsenite of zinc at the rate of 1 or 2 pounds (powder) to 50 gallons of water.

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Mention of injury to sweet-potato leaves by larvæ. Original figure of adult.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 616

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER February 14, 1918

THE CITRUS THRIPS

By

J. R. HORTON, Scientific Assistant

CONTENTS

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THE CITRUS THRIPS.

By J. R. Horton,

Tropical and Subtropical Fruit Insect Investigations.[1]

CONTENTS.

INTRODUCTION.

The citrus thrips [*Scirtothrips*[2] (*Euthrips*) *citri* Moul.] has caused more or less injury to oranges, grapefruit, and lemons in California for the last 20 or 25 years. Owing to its minute size the insect remained undiscovered for many years, and its injury to the fruit was attributed to other causes, such as wind whipping, freezing, etc. About the year 1908 the injury became so severe in Tulare County that the old theories began to be doubted and the need of expert investigation was realized. The preliminary examination in behalf of the Bureau of Entomology was made by Dudley Moulton (2)[3] and resulted in a description of the insect and its injury. Subsequently the bureau undertook a thorough investigation of the life history and control of the insect, this project being started at Lindsay, Tulare County, Cal., in 1909. A report of progress by Jones and Horton (5) and a Farmers' Bulletin on the control of the thrips by the writer (15) have appeared since.

[1] Transferred to Cereal and Forage Insect Investigations, October 1, 1917.

[2] Hood (14) places this insect in the genus Scirtothrips on the apparently adequate grounds that the thorax is finely, transversely striate and the abdomen clothed with minute hairlike processes.

[3] See Bibliography, p. 41.

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HISTORY AND DISTRIBUTION.

Although the citrus thrips has been recognized so recently as the cause of the scabbing and scarring of citrus fruits in California, there is unmistakable evidence that it is native to the orange-growing sections of that State and Arizona. Its present known distribution lies within the arid portion of the Lower Austral life zone in central and southern California and south-central Arizona. It is most abundant and injurious in those sections of this area where the minimum rainfall occurs and where the average summer temperatures are highest, such, for example, as in the San Joaquin Valley, where a climate favorable to the development of the pest and extensive recent plantings of citrus offer an ideal environment. In southern California it becomes seriously injurious only in certain seasons and only in the local sections about Riverside, Redlands, Highland, and Rialto, injury decreasing as the coast is approached. The natural habitat of the citrus thrips, therefore, appears to be the arid Lower Sonoran life zone of North America. This belief is substantiated further by its occurrence on plants native to this region and distant from citrus trees. The citrus thrips is known to occur in eight counties in California (see fig. 1), viz., Sacramento, Fresno, Tulare, Kern, Los Angeles, San Bernardino, Riverside, and Orange. The infestation is most serious in Tulare, Fresno, Riverside, and San Bernardino Counties. In Kern County the insect is increasing rapidly and with increased plantings of citrus doubtless will become quite as injurious as in Tulare County.

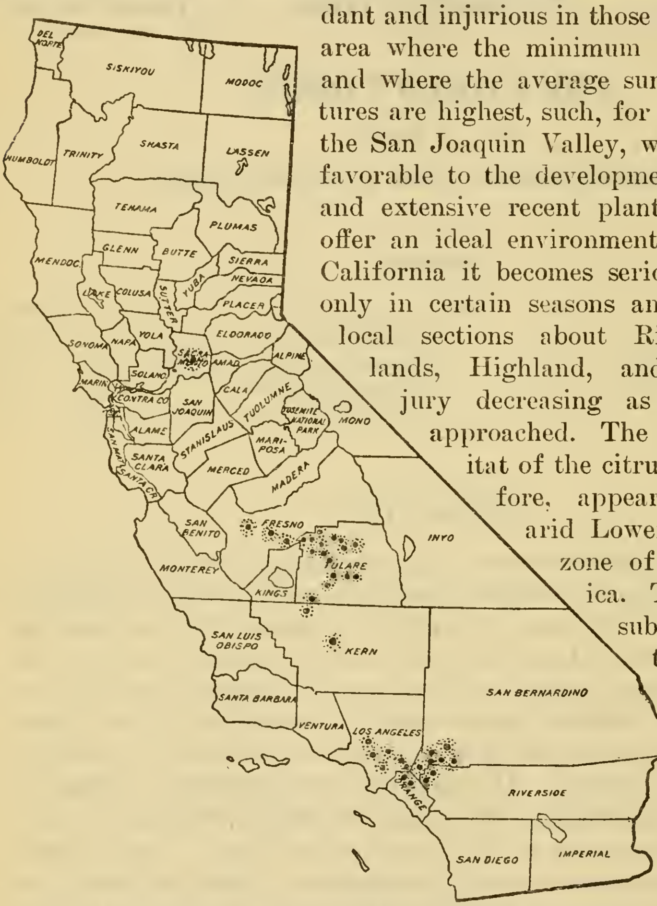


FIG. 1.—Map showing present known distribution of the citrus thrips (*Scirtothrips citri*) in California. (Original.)

Although the insect occurs in injurious numbers in Arizona, thus far it has been taken only in the Salt River Valley near Phoenix and Mesa (fig. 2). Dr. A. W. Morrill informed the writer by letter that he thought he detected traces of thrips injury in an orange grove near Yuma, but specimens have not been taken there.

POSSIBILITY OF ITS OCCURRENCE ELSEWHERE.

No verified reports of the occurrence of the citrus thrips in States or countries other than the foregoing have been made, although it is said to occur at Hermosillo, Sonora, Mexico. There are various reports of thrips injuring citrus fruits, the species concerned being often in doubt. Thus, Tower[1] states that certain scars found on oranges in Porto Rico probably are caused by thrips which were present in the trees in great numbers, but the identity of the thrips is not given. Rolfs, Fawcett, and Floyd[2] describe injury to oranges in Florida by a thrips which appears to be *Frankliniella* (*Euthrips*) *tritici* Fitch, if indeed the injury illustrated by them is caused by thrips. The citrus thrips does not occur in southern Louisiana, and doubtless could not thrive there because of the high humidity and heavy rainfall, and for the same reason probably does not occur in Florida.

FIG. 2.—Map showing present-known distribution of the citrus thrips in Arizona. (Original.)

NATURE AND EXTENT OF INJURY.

The citrus thrips obtains its food by puncturing the tissues and draining the contents of the cells, causing the cell walls to collapse. Growth expansion of the surrounding living cells leaves the punctured and dead areas sunken and distorted. The very characteristic scabbing of the fruit is caused by the dead and dry cell walls being forced outward by the growing cells beneath, the resultant scabs often covering a large portion of the rind. The various rings, streaks, splashes, and other patterns in the tissues result from the almost incessant movement of the thrips as they feed (Pl. I). The

[1] Tower, W. V. Insects injurious to citrus fruits and methods for combating them. Porto Rico Agr. Exp. Sta. Bul. No. 10, p. 20. 1911.

[2] Rolfs, P. H., Fawcett, H. S., and Floyd, B. F. Diseases of citrus fruits. Fla. Agr. Exp. Sta. Bul. 108, p. 32–33. 1911.

"stem-end ring" is the most characteristic form of fruit injury, and is caused by the thrips feeding and ovipositing in a circle under the protection of the sepals when the fruit is small, the injury expanding as the fruit grows. Injury resulting from feeding punctures in mature fruits appears as brownish, glossy discolorations due to cell sap drying on the surface. A large proportion of the badly marked fruit is undersized owing to failure to mature normally, and much of it is at times distorted by failure of the injured tissues to grow.

The more characteristic injury to the leaves is the grayish streaks and areas (Pl. II, fig. 2) and curling. At times cuplike depressions or pockets resembling aphid galls are formed, but oftener the leaves are crinkled or even tightly curled (Pl. II, figs. 1 and 3).

The unfolding leaf buds and especially the terminal buds are often attacked with such severity as to cause them to wither and die, these turning brown or black and finally dropping off.

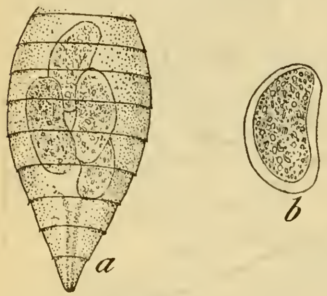


FIG. 3.—*a*, Eggs of the citrus thrips in situ; seen through the abdominal wall. *b*, Single egg of the citrus thrips. Highly magnified. (Original.)

DAMAGE TO FRUIT.

DROPPING.

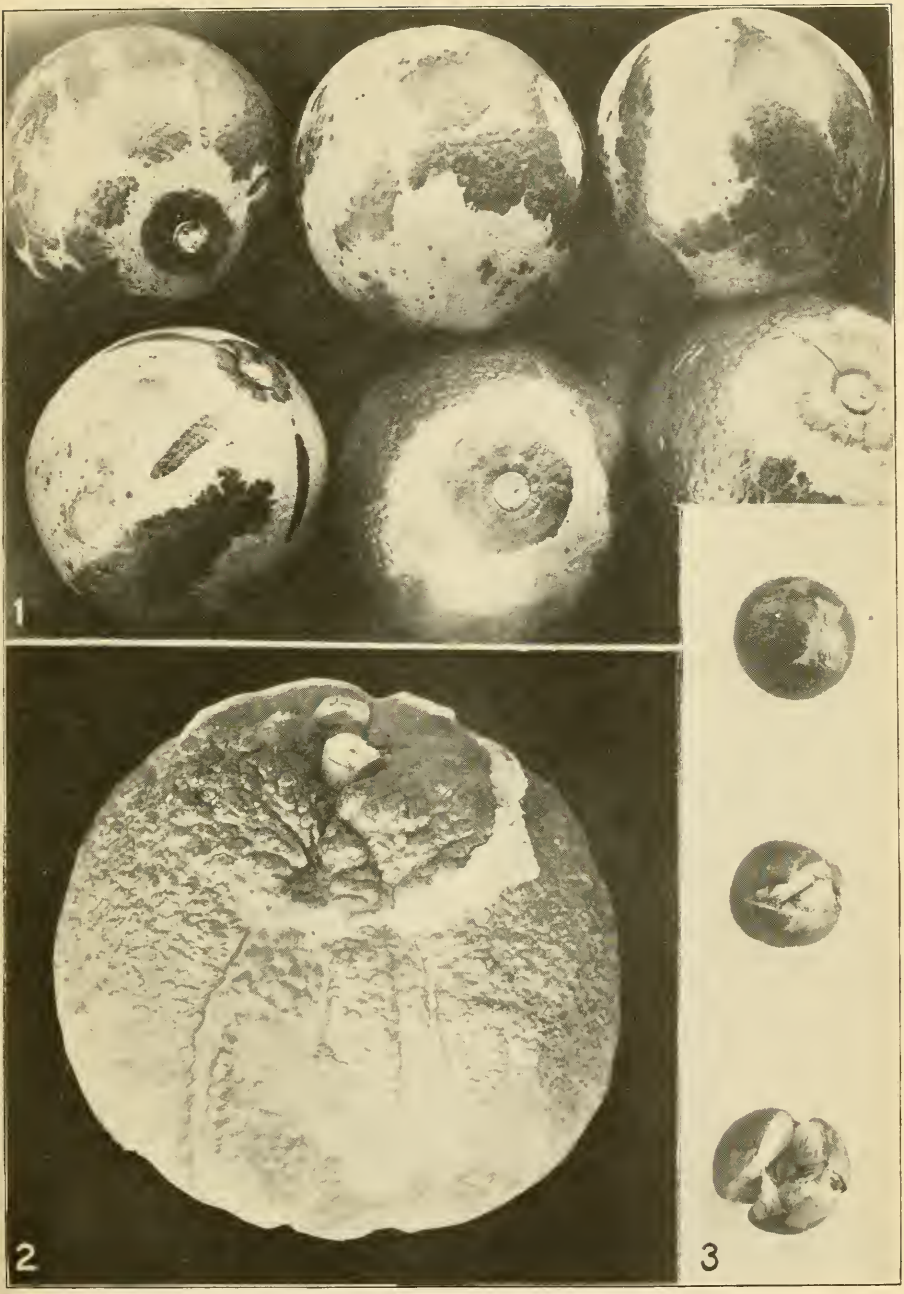
In exceptionally severe infestations, much of the young fruit is punctured over its entire surface during the first three weeks following the blossoming period and thus is prevented from acquiring normal growth, the little fruits eventually dropping to the ground. An appreciable percentage of the crop is lost in this way in certain orchards of Tulare County, Cal., in certain years.

SPLITTING.

While only a small proportion of the usual fruit splitting is caused primarily by thrips, a certain amount of splitting of young oranges does occur every season as a result of the long-continued feeding of thrips over an area usually near the navel end of the fruit. The affected tissues die and dry out and the scabbed area, unable to expand with the growing fruit, cracks (Pl. I).

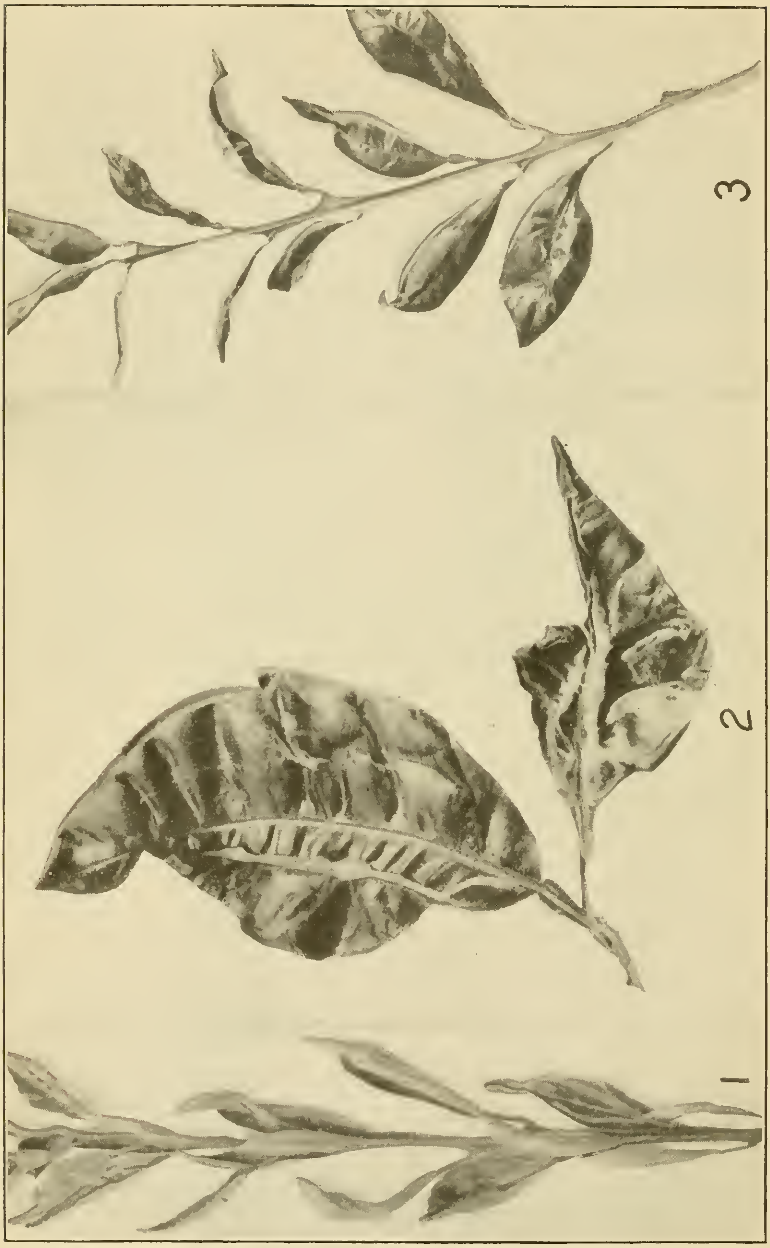
MALFORMATION.

From less than 1 to as much as 6 per cent of the orange crop, depending upon the orchard and the season, is so badly deformed by the citrus thrips that it must be culled out and sold at the packing house for whatever it will bring. The better culls usually command



CHARACTERISTIC DAMAGE BY THE CITRUS THRIPS (SCIRTOTHRIPS CITRI).

FIG. 1.—Typical citrus thrips scabbing on young oranges. (Natural size.) FIG. 2.—Unusual form of thrips injury on rough orange. FIG. 3.—Splitting of young oranges due to thrips injury. (Original.)



DAMAGE TO THE FOLIAGE OF CITRUS BY THE CITRUS THRIPS.

FIG. 1.—Orange leaves distorted and tightly curled by the citrus thrips. FIGS. 2 and 3.—Orange leaves "cupped" by the citrus thrips, showing streaks of dead and discolored tissue. (Original.)

25 cents per box. Although in seasons such as 1911 only a small percentage of the fruit is culled from this cause, in one instance an entire shipment of navel oranges from a 5-year-old, untreated orchard was refused at the eastern market, with the statement that the oranges were too badly scabbed to be salable. In several other orchards inspected that year from 1 to 2 per cent of the fruit was malformed as the result of thrips feeding.

GRADE REDUCTION.

The most important damage resulting from the feeding of thrips upon trees that have passed the period of rapid growth is the lowering of the market value of the fruit by unsightly scabbing and scarring. Although the eating quality of the orange is not affected thereby, its commercial grading is lowered considerably and the selling price correspondingly reduced.

EXTENT OF DAMAGE TO ORANGES IN TULARE COUNTY.

In 1909 more than 80 per cent of the oranges of Tulare County, Cal., were so damaged by the citrus thrips as to lower the grade; in 1910 the grading affected about 63 per cent of the crop, and in 1911 about 65 per cent was affected.

To calculate the loss due to grade reduction because of damage by thrips it is necessary to know the method of grading and relative value of the grades. In California oranges usually are packed in either three or two grades. In the 2-grade pack the quality of the fruit of the first grade is about the same as would be obtained by placing together the first and second grades of the 3-grade pack, the quality being sufficiently lowered to include fruit which would be of second grade in a 3-grade pack.

Taking the season of 1911 as fairly representative of recent years, returns received by different packing houses on a total of about 358,000 boxes of oranges of all grades indicate the following price range between the different grades. First-grade fruit average 37 cents more per box than second grade; the latter 28 cents more than third grade. Receipts from several carloads of fruit shipped in two grades gave an average difference of 51 cents per box in favor of the first grade. Examination of thousands of boxes of oranges throughout the district from Mount Campbell to Porterville showed 34 per cent of the fruit to run first grade, 43 per cent second grade, and 23 per cent third grade, so far as thrips marking was concerned.

Statistics on the amount and value of the total orange crop shipped from the entire San Joaquin Valley in 1911 are not available, but from Lindsay and its tributaries, constituting much the largest single citrus section of the valley, 1,525 carloads, or about 594,750 boxes, of navel oranges were shipped. The loss suffered from grade reduction due to thrips by the Lindsay district alone, and in a season of comparatively light infestation, was therefore about as follows: Forty-three per cent, or 255,742 boxes, reduced to second grade at a loss of 37 cents per box, making $94,624.54; and 23 per cent reduced to third grade at a loss of 65 cents per box, making an additional $88,914.80, or a total loss of $183,539.34.

EXTENT OF DAMAGE IN SOUTHERN CALIFORNIA.

It is calculated that from 20 to 40 per cent of the 1910 orange crop of Riverside County was sufficiently marked to keep it out of first grade. The injury was most severe in groves in the hills to the south and east of Riverside and in the vicinity of Highgrove, where conditions are similar to those along the foothills in the San Joaquin Valley. In this section about 55 per cent of the crop was lowered in grade because of thrips marking. Of the 1911 crop in the same groves, however, only 16.9 per cent was marked sufficiently to throw it out of the first grade.

At Redlands the injury was somewhat less severe than at Riverside. Only from 2 to 5 per cent of the first-grade fruit running in the packing houses was marked, and that slightly, while from 50 to 60 per cent of the second-grade fruit was more seriously damaged. The writer was informed that fruit from some of the groves was injured more severely than that then passing, and when such fruit was being packed an additional or third grade was added to accommodate the thrips-marked oranges.

In the Pomona-Claremont-Upland section damage by the citrus thrips was much less severe than at Riverside and Redlands. The grades of fruit then running were "fancy" and "choice," and it was estimated that about 10 per cent of the first-grade oranges had traces of marking and about an equal percentage of the second, or choice, fruit was more conspicuously marked. The most severe marking occurred at Claremont, which is nearer the hills, a little warmer, and produces very vigorous trees. First-grade fruit was scarred about equal to that at Pomona, but a third grade was run at Claremont, about 25 per cent of which had been reduced because of thrips scabbing.

The injury decreases toward the coast, so that at Whittier only about 10 per cent of the entire crop was scabbed. About 2 per cent of the first and 5 per cent of the second-grade fruit had been slightly marked. Less than 1 per cent of the marked fruit of second grade would be placed in that grade because of thrips injury alone. Lemons were blemished about as much as oranges. At Pasadena 90 per cent of the 2,000 oranges examined in the field was entirely free from thrips marking; 9.5 per cent had received a few scratches which would in no way affect their value, and only a few oranges were characteristically and severely marked.

INJURY IN ARIZONA.

The amount of thrips injury to citrus in Arizona varies greatly in different groves, depending upon the health and vigor of the trees. It has never been as serious in Arizona as in the San Joaquin Valley, Cal. In the poorer conditioned groves the fruit injury varies from none to 25 per cent scarred sufficiently to reduce the grade. In some seasons the injury has run much higher than this in certain groves. Thus Morrill (9) in 1912 stated that in the various groves injury to the 1911 orange crop ranged from none to about 60 per cent scarred sufficiently to affect the market value, and calculated that there was a 28 per cent reduction of oranges to second grade and a 25 per cent to third grade, and that about 1 per cent were culled partly or entirely because of thrips marking.

INJURY TO TREES.

In many orchards in the San Joaquin Valley the foliage was subjected to prolonged attack from thrips until the functions of the leaves became so disturbed that the trees were prevented from reaching their normal size and fruiting capacity. Stunting due to thrips feeding begins in the nursery. In seasons of severe infestation the leaves and stems of nursery trees are so badly scarred and twisted as to appear blighted, preventing sale at a fair price, and often the growth of the trunk is so retarded that the trees must be held a year or more beyond the proper time for sale in order to meet the size requirements. It sometimes happens that this class of stock is sold along with better trees and, thrips attacks continuing for several years in the orchard, the trees remain undersized and relatively unproductive.

DISSEMINATION.

The spread of the citrus thrips from one citrus-growing section to another is accomplished mainly in the egg stage. The shipping and planting of nursery trees occurs principally from February to May, the transfer of trees being well under way before first-generation larvæ begin to issue from the eggs deposited the preceding fall. Quarantine inspection is entirely inadequate to prevent the introduction of the insect into new districts, since it is practically impossible to detect the eggs of the species. Complete defoliation of the trees prior to shipment accomplishes the destruction of many of the overwintering eggs, but a proportion of them escape because of insertion into the bark of the smaller branches.

A few eggs also pass the winter in the ripening fruit and are thus distributed to practically every part of the United States. Some of these eggs may hatch and survive from fruit marketed in tropical and subtropical climates, but there is very little danger of the insects becoming established in any of the localities where oranges are marketed generally.

Thrips larvæ are to some extent distributed on nursery stock and, though not so difficult to detect as eggs, would be overlooked very largely in commercial inspection because of their minute size and habit of hiding in crevices in the bark. It is probable that occasionally the larvæ are shipped on fruit, especially on the Valencia orange, but nearly mature fruit has little attraction for them, and it is further probable that few survive the handling incidental to picking and packing.

Local spread is accomplished largely by flight. The citrus thrips is a very ready flier when disturbed or when it desires better food. An observer standing in a favorable position with regard to the light may see numbers of these minute insects leave one tree and make for another, usually disappearing at a distance of 4 or 5 feet because of the light not striking just right. The insect will leave either tree or orchard as soon as leaves, stems, and fruit become somewhat tough. Thus in a grove of young Valencia trees where thrips were present to the number of 80 to 150 per leaf at one examination, not a single adult thrips could be found two weeks later. The explanation was that the leaves had hardened and were no longer suitable as food, while on some older navel trees near by a luxuriant growth of leaves had just reached prime condition for food, and here the insects were found in as large numbers as they had been found on the trees they had deserted.

The citrus thrips usually takes a rapid spiral or zigzag course in short-distance flights, but in extended flights the course is more direct. The flight somewhat resembles that of katydids and grasshoppers. By mounting in a strong wind the thrips undoubtedly would fly a mile or possibly more.

FOOD PLANTS.

Although the citrus thrips thrives best and reaches its maximum abundance on plants of the citrus group, it feeds continuously or occasionally on plants widely separated botanically from the citrus group. In Table I the food plants are arranged according to the extent of infestation as nearly as possible in the order of their importance as food for thrips. There is very little difference, however, in the extent to which the different plants in Group III are infested, and certain plants in Group II are infested almost as badly as any of the citrus fruits of Group I. It will be noted in Table I that the

DAMAGE TO CITRUS AND GRAPES BY THE CITRUS THRIPS.

FIG. 1.—Lemons injured by the citrus thrips. FIG. 2.—Pomegranates injured by the citrus thrips. FIG. 3.—Grapes scarred by the citrus thrips. (Original.)

range of food plants is wide and includes practically all the citrus fruits grown in California, certain deciduous fruits and nuts, a few ornamentals, and several noncultivated plants.

TABLE I.—*Food plants of the citrus thrips in order of importance.*

Group I, generally infested.	Group II, occasionally infested.	Group III, rarely infested.
1. Sweet oranges. 2. Mandarin orange (*Citrus nobilis*). 3. Pomelo, or grapefruit. 4. Lime and lemon. 5. Kumquat (*Citrus japonica*).	6. Pomegranate (*Punica granatum*). 7. Grape. 8. California pepper tree (*Schinus molle*). 9. Chinese umbrella tree (*Melia azedarach umbraculifera*). 10. Apricot.	11. Peach. 12. Plum. 13. Pear. 14. Raspberry. 15. Pecan. 16. Walnut. 17. Olive. 18. Rhubarb. 19. Dock (*Rumex* sp.). 20. Purslane (*Portulaca oleracea*). 21. Willow. 22. Wild morning-glory (*Convolvulus* sp.). 23. Nightshades (*Solanum* spp.). 24. Almond. 25. Tumbleweed (*Amaranthus* sp.).

The sweet oranges suffer greatest damage from the citrus thrips, especially the varieties known as Washington, Thompson's Improved, and Australian navels, and the Parson Brown and Homosassa. Valencias are damaged considerably when the trees are young, and the fruit is attacked at all times, but not severely. Blood oranges generally escape with very little injury. The Washington navel orange covers a greater acreage in Tulare County than all other varieties together. This fact probably accounts for this variety holding first rank as a food plant of the thrips. As a rule not more than 25 per cent of the Valencia crop is injured sufficiently to depreciate its market value; and it is rarely that more than 10 per cent of blood oranges show any marking whatsoever. Oranges of the Mandarin group, especially the tangerines, are subject to very severe marking, for the reason that they remain attractive to thrips until nearly mature. The Satsuma often becomes much distorted because of thrips marking, but this fruit is an unimportant crop in California. Pomelos, limes, and lemons (Pl. III, fig. 1) share nearly equally in severity of thrips marking, but the trees are not often severely injured, as the foliage is not particularly attractive to the insect. Limes often become severely scarred, the rind remaining tender throughout the growth of the fruit. Of all the citrus fruits the kumquat is the least attractive to thrips, rarely more than from 2 to 5 per cent of the fruit becoming slightly scarred by them.

The pomegranate (Pl. III, fig. 2) is the most preferred fruit other than citrus. Pomegranate trees mostly are planted as ornamentals bordering citrus groves, but in 1910 in a 20-acre pomegranate orchard at Lindsay, Cal., 75 per cent of the fruit showed the characteristic scabbing of the citrus thrips. Pomegranates of clear, red color natural to the ripe fruit are rare in that section, a blending or streaking of the natural red and the gray thrips injury being characteristic. The grape (Pl. III, fig. 3) ranks next to the pomegranate in degree of infestation. It is attacked mostly during the period between growths of the orange. Both leaves and fruit suffer, but chiefly the fruit. In 1911, when citrus trees made but slow and scant growth, a case of severe injury to a small vineyard of Malaga grapes was reported to the writer. This vineyard was located among orange trees which had grown very little during the summer, and the thrips had concentrated there, scarring a large percentage of the berries and distorting many leaves.

Apricots, peaches, plums, and pears are attacked more rarely; raspberry, very rarely. A part of the scabbing found on the pear is probably due to other species of thrips, although new pear leaves occasionally have been found so badly curled by *Scirtothrips citri* that they looked diseased.

The California pepper tree and the Chinese umbrella tree are both very attractive to the citrus thrips, which become abundant on them at certain times of the year. Neither of these trees show the effect of thrips injury from a distance, as do orange trees, and though oviposition takes place in both varieties eggs are not deposited in umbrella-tree leaves in the fall. The insects do not attack the small, berry-like fruit of the pepper tree.

The remaining food plants listed in Table I are attacked but rarely and some of them (almond, walnut, and tumbleweed) are probably only accidental food plants. More thrips have been found occasionally on the common dock than on any other of the noncultivated plants.

LIFE HISTORY AND HABITS.

THE EGG.

DESCRIPTIVE.

The egg (fig. 3), as seen in position through the translucent body wall of the parent thrips, is a bluish-white, bean-shaped object measuring on an average about 0.185 mm. in length by 0.085 mm. in width. It is comparatively very large, so that five eggs in an advanced stage of development occupying the ovaries at the same time cause considerable distention of the abdomen.

When freed from the ovaries, immediately after deposition, the egg is thick at the base, with the upper two-thirds gradually drawn out into a narrower, necklike portion. The color is then clear ultramarine and the surface is smooth and glistening. The membrane is flexible, so that the egg may assume other shapes within certain limits. As the embryo develops the bright-red eyes become visible through the transparent shell.

INCUBATION PERIOD.

The time required for the development of the egg after deposition varies considerably at different times of the year and is influenced largely by the prevailing temperature. There is also some variation among eggs deposited the same day, in the same plant, and kept under precisely the same conditions of temperature. The incubation period ranged from a minimum of 6 days to a maximum of 24 days, the average for the entire season being 16 days. The records on incubation in 1911 are given in Table II. The principal average seasonal variations, together with the prevailing mean temperatures for the periods covered, are shown in Table III. It will be seen that in the cool weather of spring and early summer and again in the fall the incubation period is about two and one-half times as long as in the hottest period of summer. In like manner the egg stage and other immature stages as well are short in exceptionally hot, dry summers, such as those of 1908 and 1909, and considerably prolonged in cooler years, such as 1911.

TABLE II.—*Incubation period of the citrus thrips, Lindsay, Cal., 1911.*

Record No.	Number of eggs.	Deposited.	Hatched.	Duration of stage.	Record No.	Number of eggs.	Deposited.	Hatched.	Duration of stage.
				Days.					*Days.*
1	11	May 4	May 21	17	18	1	May 9	May 26	17
2	61	do	May 22	18	19	1	do	May 27	18
3	15	do	May 23	19	20	1	do	May 28	19
4	6	do	May 24	20	21	1	July 17	July 23	6
5	2	do	May 25	21	22	1	do	July 24	7
6	1	do	May 26	22	23	2	July 22	July 28	6
7	1	do	May 27	23	24	1	do	July 29	7
8	1	do	May 28	24	25	1	do	July 30	8
9	8	May 5	May 21	16	26	1	Aug. 1	Aug. 9	8
10	31	do	May 22	17	27	1	do	Aug. 10	9
11	2	do	May 24	19	28	1	Sept. 6	Sept. 23	17
12	11	May 6	May 22	16	29	3	Sept. 8	Sept. 21	13
13	7	do	May 23	17	30	2	do	Sept. 22	14
14	5	do	May 24	18	31	2	do	Sept. 24	16
15	3	do	May 25	19	32	1	Sept. 18	Oct. 8	20
16	1	do	May 27	21	33	1	do	Oct. 10	22
17	1	May 9	May 25	16					

	Days.
Maximum	24
Minimum	6
Average	16

TABLE III.—*Principal seasonal variations in incubation of eggs of the citrus thrips, Lindsay, Cal., 1911.*

Period of season.	Range.	Average.	Mean temperature.
	Days.	*Days.*	*° F.*
May 4 to May 28	16–24	18.8	64.06
July 17 to Aug. 10	6–9	7.3	81.52
Sept. 6 to Oct. 10	13–22	17.0	62.18

HATCHING.

When ready to hatch, the upper end of the eggshell is broken and the larva pushes through. The first impression on watching a larva issue from the leaf is that the egg itself, or a minute white worm, is being pushed out through the epidermis, the only movement visible being a forward one. When the head and thorax are free, the larva begins a series of vigorous spiral movements which soon liberate the legs and antennæ. In some instances the antennæ retain the folded position until the larva has freed itself completely from the tissue. When the legs are free the insect pushes straight down against the leaf with the third pair of feet and, alternating with abdominal movements, brings itself into position to bend forward and clasp the leaf. It then readily pulls itself out. The entire operation requires from 5 to 10 minutes.

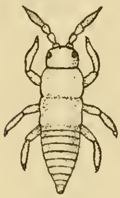


FIG. 4.—First-instar larva of the citrus thrips. Highly magnified. (Original.)

Hatching is not much affected by drying of the leaf or stem tissue. Larvæ have issued from leaves several days after the latter had become thoroughly wilted, and from stems as long as 21 days after they had been cut from the tree.

THE LARVA.

DESCRIPTION.

First-instar larva.—Just after emergence the larva (fig. 4) is colorless and translucent. The head, antennæ, mouth parts, and legs are disproportionately large, giving it an ungainly appearance. The eyes are bright red. The average length is 0.26 mm. (about 0.01 inch). The most distinctive character of the first-instar larva is the narrow, tapering abdomen. In a day or two the body becomes suffused with yellow, which gradually deepens to orange in the fully developed larva. As growth progresses, the head and appendages lose their ungainly appearance and become more symmetrical, and the abdomen grows plumper and less sharply tapering. Shortly before molting to the second instar the average length is 0.45 mm. (about 0.017 inch).

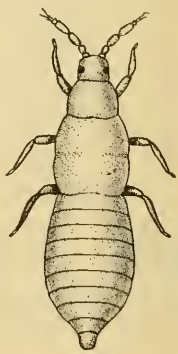


FIG. 5.—Second-instar larva of the citrus thrips. Highly magnified. (Original.)

Second-instar larva.—The second-instar larva (fig. 5) is similar in general appearance to the first, except that it is more robust, more densely pigmented, and the abdomen is broadly spindle-shaped, tapering gradually from the middle segments in both directions. The color varies from light yellow to deep orange yellow, and occasionally cream-colored individuals occur. The eyes are dull red to dark purple. The average length varies from 0.45 mm. (about 0.017 inch) at the beginning of the instar to 0.90 mm. (about 0.035 inch) just before molting to the propupa.

FEEDING HABITS.

The larva becomes active immediately after emergence, moving about over the leaf or stem, swinging the antennæ up and down, and surveying its surroundings for a place to feed. When feeding, the citrus thrips does not insert the mouth-cone itself into the plant tissues, and thus does not cause holes and raggedness in the leaves, as the pear thrips does, for example. The feeding puncture of the citrus thrips is made by bringing the tip of the cone into contact with the surface of the plant and moving the head quickly downward and slightly backward. This movement results in a slight folding, or elbowing of the cone at a point near its juncture with the head and in some way exerts a leverage upon the lancets, which are thus pushed into the tissue, starting the flow of cell sap, which is sucked up through the tubular interior of the cone.

DURATION OF LARVAL FEEDING STAGE.

The first of the two instars or stages of growth of the larva ranged from a minimum of 1 day to a maximum of 13 days, with an average of 3.7 days, in specimens in which the actual casting of the skin was observed. The second instar of these specimens ranged in duration from 2 to 9 days, with an average of 4 days. An abnormal maximum of 29 days was reached by one specimen in November, the insect ultimately dying from exposure to prolonged low temperatures, without changing to the propupa. The two larval instars may be said to be of about equal duration.

The duration of the complete or feeding stage of the larva ranged from 3 to 21 days, the average for the entire period from March 25 to November 5 being 7.8 days. Great individual variations in the length of the immature stages are to be expected and do not have any particular significance in a practical way, but a knowledge of the average variation in different periods of the season and in different seasons, due largely, as they are, to climatic factors, are of value in predicting what the severity of a given infestation will be. The principal seasonal variations in the duration of the larval stage, with a record of the prevailing temperature, which is the principal factor affecting the length of the stage, are given in Table IV. It will be seen that in seasons such as 1911 the larval stage will range from about 4½ to 7 or 8 days in the period from about the middle of May to the middle of September, and in the cooler weather of March and April and from the latter part of September to November it will range from about 12 to 14 days.

TABLE IV.—*Seasonal variations in duration of the larval stage of the citrus thrips, Lindsay, Cal., 1911.*

Period of season.	Average duration of the larval stage.	Prevailing mean temperatures.
	Days.	° *F.*
Mar. 25 to Apr. 15	13.7	59.62
May 13 to June 3	8.2	62.58
June 13 to Sept. 5	4.4	74.61
Sept. 4 to Sept. 21	6.8	67.47
Sept. 23 to Nov. 5	11.8	58.48

MOLTS.

All four molts of the citrus thrips, comprising two in the larval stage and two in the pupal stage, are accomplished in about the same manner. The first molt takes place on the leaves and fruit of the host plant, the remainder in some secure hiding place, usually on the ground. When ready to molt the larva ceases to feed and becomes inactive. Tremors vibrate the antennæ and body at brief intervals for a period of from one to three hours, and the abdomen slowly contracts and shrinks away from the old skin. Then follows an active period of from 15 minutes to an hour, in which the middle and hind legs are repeatedly stretched as far back as possible and slowly drawn forward, while the insect goes through jerky lateral motions with the body. The skin then splits from the vertex along the dorsum to the abdomen, after which the insect becomes very active, doubling down with the head between the fore feet and slowly removing the skin from the head and antennæ. The legs are then worked out of their casings and the exuvium pushed back under the body. The skin usually is attached at the tip of the abdomen to the surface on which molting occurs, greatly aiding the insect in extricating itself. The skin generally is removed entire, but occasionally antennal and leg casings are removed separately. Cool weather greatly retards the process, which is more likely to be observed when such weather prevails. Groups of larval skins resembling specks of gray dust sometimes are found on orange leaves. The molting process in the citrus thrips is similar to that observed in certain Orthoptera.

THE PUPA.

DESCRIPTION.

The propupa.—The propupa, or first instar (fig. 6), is very similar in general appearance to the larva. It is generally somewhat paler in color. The antennæ are directed forward and are 4-jointed. The eyes, at first almost colorless, finally show a red pigmentation in about two-thirds of the facets. The wing pads, which are almost colorless, transparent saclike projections, the hind pair projecting slightly farther than the fore pair, extend to or slightly beyond the hind margin of the second abdominal segment at the beginning of this instar and reach to the hind margin of the third segment before transformation to the second-instar pupa.

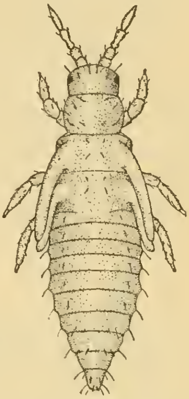


FIG. 6.—First-instar pupa of the citrus thrips. Highly magnified. (Original.)

The second-instar pupa.—The second-instar pupa (fig. 7) is at first but slightly larger than the advanced propupa. The color is pale, translucent yellowish. The antennæ are apparently 4-jointed, but the exact number of joints is confused by the ringed appearance due to transitional tissues seen through the pupal sheath. They are directed backward over the head and prothorax, extending to a point near the middle of the latter. All facets of the eyes are red pigmented. The ocelli are visible and translucent. The wing pads at first extend to the hind margin of the sixth abdominal segment or slightly beyond, but project as far as the ninth or tenth segment just before the molt to the adult. Long weak spines are moderately conspicuous on antennæ, legs, and hind angles of the abdominal segments.

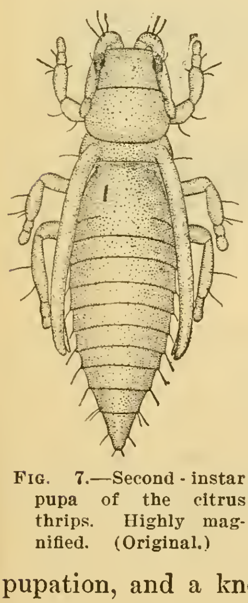


FIG. 7.—Second-instar pupa of the citrus thrips. Highly magnified. (Original.)

There is less growth in the pupal stage than in the larval stage. The average length soon after the molt to the propupa is 0.70 mm. (about 0.027 inch); shortly before the first pupal molt it is 0.72 mm. Just before the last molt it averages 0.80 to 0.84 mm. (about 0.03 inch). The wing pads increase on an average about 0.04 mm. in length during the first instar, and show a gain after molting to the second instar of 0.10 to 0.12 mm. After the molt to the adult stage the wings exceed the tip of the abdomen.

PLACE OF PUPATION.

Certain Thysanoptera, notably the pear thrips, congregate in large numbers during pupation, and a knowledge of this habit may lead to a means of effective control. The citrus thrips, however, has no definite place of pupation. The second-instar pupa is more exposed to the attacks of predatory insects than any other stage, and therefore pupation occurs in places practically inaccessible to any but the smallest insects and mites. The pupæ are scattered widely, thus limiting the possibility that any great number will be destroyed at one stroke. They have been found in the following situations: On the ground under the trees; in curled, dried leaves, and under a mat of fine cobweb and dust on dry leaves; in the split tips of leaf stems; in small crevices in the bark of dry twigs. In clean-cultivated young orchards, where but few dead leaves and twigs collect, the thrips pupate in crevices near the base of the trunks, under dead and living fluted scales (*Icerya purchasi* Mask.), and in similar obscure situations. In only two instances was pupation found to have occurred on the upper part of the tree: One in which a propupa was found in a distorted leaf, and another in which one specimen occurred under the cocoon of a caterpillar on an orange leaf. To find pupæ of the citrus thrips requires a minute and painstaking search. If no better shelter offers, the insect gathers particles of dust, wood, leaves, etc., about itself, effectively concealing it. In captivity a large proportion of the pupating specimens crawled into the cotton plugs of the rearing bottles and under the split bark at the ends of orange stems used as food. No food is taken during the pupal stage.

DURATION OF THE PUPAL STAGE.

The duration of the pupal instars may be accurately determined, as once a spot has been chosen for pupation the insect seldom moves from it, and cast skins of the last larval and both pupal transformations generally remain nearby. The first pupal instar ranged from 1 to 9 days, with an average for the entire active season, from April 1 to November 8, of approximately 2 days. The second instar ranged from 1 to 25 days, with an average of 5.5 days for the period from April 4 to December 2. The 25-day maximum period is of course exceptional, and would occur in comparatively few individuals of very late hatch.

The entire variation in duration of the complete pupal stage in the period from April 1 to December 2 was from 2 to 28 days, with an average of 7.5 days. The important general variations in the length of the pupal stage in different periods of the season are shown in Table V. It will be seen that growth of the pupa, as well as of the egg and the larva, is slow in the cool weather of spring and fall, when the temperature ranges between 50° and 60° F., and that it is considerably accelerated in midsummer, with temperatures above 60° F.

TABLE V.—*Seasonal variations in duration of the pupal stage of the citrus thrips, Lindsay, Cal., 1911.*

Period of season.	Average duration of the pupal stage.	Prevailing mean temperatures.
	Days.	*°F.*
Apr. 8 to Apr. 26	13.2	56.52
May 3 to May 13	8.4	58.08
May 22 to June 4	5.5	64.74
June 2 to Sept. 5	3.5	76.55
Aug. 31 to Sept. 26	5.3	68.20
Sept. 21 to Oct. 28	7.3	60.70
Oct. 18 to Dec. 2	15.4	51.04

THE ADULT.

DESCRIPTION.

The adult citrus thrips (fig. 8) is among the smallest of insect pests and is smaller than most of the more injurious related Thysanoptera. The female measures from 0.60 to 0.88 mm. (about one-fiftieth to one-twentieth inch) in length; the male, which is noticeably smaller, measures from 0.51 to 0.65 mm. The color of the adult is translucent

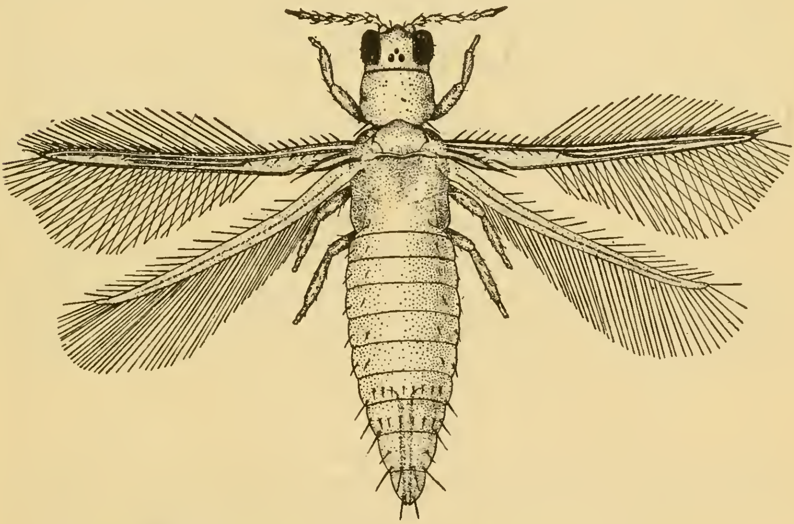


FIG. 8.—The adult female citrus thrips. Highly magnified. (Original.)

orange-yellow; the male is somewhat paler than the female. The head is small, about one-half as long as wide, and a considerable portion of it is occupied by the large compound eyes, which are dark purple to black. Three transparent ocelli, or simple eyes, bordered by reddish brown crescents, occupy the space between the compound eyes on the upper surface of the head. The antennæ are 8-jointed; some of the segments are furnished with transparent sense organs.

The rostrum, or mouth-cone, is short and blunt, not quite reaching across the prothorax, and is tipped with black. The prothorax is slightly wider than the head, slightly narrower than the mesothorax. The female is broadest through the middle segments of the abdomen, tapering gradually both ways; tip of the abdomen conical, fitted with a sawlike ovipositor. The abdomen of the male tapers gradually from the second segment to the tip, which is bluntly rounded; a pair of reddish brown testes is visible through the body wall at the sixth and seventh segments. More or less conspicuous spines occur on the wings and near the hind angles and at the tip of the abdomen. Under high magnification the abdomen is seen to be regularly beset with minute hairlike processes.

DURATION OF ADULT LIFE.

Owing to their extreme activity, minuteness, and delicacy, many of the adult thrips under observation were killed accidentally and others probably injured in changing their food. For this reason only the data upon specimens which lived 20 days or longer are considered in discussing the length of adult life. In only a small percentage of the cases considered did the length of life run as low as 20 days. The maximum duration was 49 days, which is also probably exceptional. The variation of 29 days occurring between the accepted minimum of 20 and the maximum of 49 days is probably as great as ever occurs in the field among specimens not affected by accident, disease, or enemies. In nearly 70 per cent of the cases considered the insects lived 25 days or more, and in 85 per cent they lived 35 days or less. The average age attained by the shortest-lived specimens may therefore be set safely at 25 days, and that of the longest lived at 35 days, the mean between the two being 30, which corresponds closely with the general average from all which lived over 20 days. The insects lived only from 3 to 6 days without food.

INFLUENCE OF THE WEATHER ON GROWTH AND BEHAVIOR.

The citrus thrips is purely a product of the arid Southwest and flourishes only in a hot sunny climate. The fact that it does not thrive in coastal sections nor in any part of the humid belt of the Lower Austral life zone shows its sensitiveness to conditions of temperature and moisture. The insect flourishes best on sunny hill slopes. It appears to enjoy the direct rays of the sun, and by preference seeks the more exposed leaves and fruits in the upper and southerly expansion of the trees. On bright warm days of summer the adults exhibit marked restlessness and increased reproductive activity. The duration of the immature stages is shortened, molting is accelerated, and the rate of emergence is increased greatly. The number of generations is greater in exceptionally long hot summers than in more moderate ones.

Cool, cloudy, or rainy weather, on the other hand, at once markedly diminishes the various activities of the insects. They then seek shelter in groups in the pits or curls and on the underside of the leaves, about the stem ends of the fruit, and in the crotches and angles of the stems. Growth, molting, and emergence are retarded. With temperatures ranging between 40° and 50° F., in November and December, larvæ and pupæ often live fully a month without change, scarcely feeding at all, and as the weather continues to grow colder both they and the adults die off, leaving only unhatched eggs to produce the succeeding spring generation.

PECULIARITIES OF INFESTATION DUE TO FEEDING HABITS OF THE ADULT THRIPS.

Feeding only upon the newer tissues, the adult citrus thrips are active in selecting young and healthy trees and often suddenly migrate from one set of trees to another or from one orchard to another. In localities where, owing to favorable cultural conditions and large plantings of young trees, an abundance of new shoots occurs in a close succession of growths, adults will congregate in immense numbers and remain throughout the season. The resultant damage in such localities is often entirely out of proportion to that occurring in other parts of the same district. The explanation of excess infestations in certain orchards and in certain localities is simply food preference. Areas of this sort occur typically along the foothill slopes, both in the San Joaquin Valley and near Riverside and Redlands.

In older orchards, where some of the trees have been cut back and rebudded, thrips will congregate on the watershoots and buds from every part of the orchard and in such numbers as greatly to retard the growth of the buds. The damage done in old orchards surrounded by young trees is often very slight for the reason that the thrips confine themselves almost exclusively to the latter. In seasons like 1911, when the climatic conditions are such as to minimize growth, the insects are compelled to feed to a greater extent upon the fruit with consequent greater damage.

OVIPOSITION.

DESCRIPTION OF PROCESS.

The following is a description of oviposition under natural conditions as observed in a single specimen at night during cool weather, the observations being made with the aid of an electric pocket lamp and a hand lens. Attention was first attracted to the specimen by its indifference to the light. For a half hour it remained in a space about an inch square and went through the following antics: Frequently it would elevate the abdomen, spreading the wings as in preparation for flight. Then it would crouch flat to the leaf, twisting the abdomen about with a rotary motion, at times leaning far over to one side and often moving backward, slowly turning about in a complete circle. At one time the insect turned completely over and lay on its back for a short space, the abdomen continuously moving as described. At the end of a half hour the ovipositor was slightly exserted from a point very near the tip of the abdomen, which was then arched and its tip brought into contact with the leaf surface. The ovipositor was then inserted in the leaf in a single movement from an almost vertical position to about two-thirds its length. The insect then relaxed slightly and remained quiet in this position for four minutes, when it moved away and rested. Only one egg was deposited.

PORTION OF PLANT SELECTED FOR OVIPOSITION.

The citrus thrips oviposits only in those tender tissues which are suitable for food, i. e., the new growth and the young fruit. Eggs are deposited largely in the leaves and fruit in summer and in the stems in fall, more particularly the large tender stems of the orange tree. In summer large numbers of eggs are thrust into the new leaves, leaf stems, fruit and fruit stems, and when the petals have fallen the fruit receptacles become a favorite place of oviposition, which is accomplished under the protection of the sepals. Eggs are never deposited in the blossoms.

RELATION OF QUALITY AND AMOUNT OF FOOD TO OVIPOSITION.

Eggs are never deposited in the older leaves and stems and but rarely in the fruit after it is two-thirds grown. The number of eggs deposited in a particular tree will depend exclusively upon the amount of new growth produced by that tree. It is impossible to induce the insects to oviposit in the tough leaves of potted orange trees, though hundreds have been confined upon such plants for many days. Eggs were deposited readily in the same kind of plants when one or more new leaves occurred there, even though only 20 to 25 insects were confined through one night only.

Oviposition does not occur in the minor food plants (including the Valencia orange, pomelo, lemon, pepper tree, Chinese umbrella tree, and grape), regardless of growth, in as great proportion to the number of infesting insects as in the Washington and Thompson's navel oranges.

RATE OF OVIPOSITION AND NUMBER OF EGGS DEPOSITED.

The preoviposition period in midsummer, when metabolism is rapid, is three or four days. The highest average daily rate of egg deposition was secured in two experiments, in which the insects oviposited at the rate of 0.7 egg each per day. This is probably below the normal rate in the field in summer. The largest number of eggs occurring in the ovisac at one time and developed sufficiently to be observable with the ordinary powers of the microscope is five, and it is improbable that more than this number would develop and be deposited in one day. In 1911, of 1,050 female thrips collected monthly from April to October, inclusive, developed eggs were absent from 644, which may have oviposited just before captivity and were therefore not taken into account. In the remaining 406 insects there were 493 eggs, an average of 1.2 each. The percentage of thrips with only one egg visible was 80.7 per cent; with two eggs present, 17.1 per cent; and with more than two, but 2 per cent. It may be inferred from these data that on an average a single specimen will not deposit more than one egg per day, though the number will vary slightly with the character of the season and the quality and amount of food. Rarely as many as five may be deposited.

It would seem that in cool seasons such as 1911 the citrus thrips will deposit, on an average, only from 26 to 70 eggs in the course of her life, and this is believed to be one of the chief reasons for the relatively light infestation of thrips in that season as compared with such seasons as 1908 and 1909. In such exceptionally favorable seasons as the last mentioned it is possible that a large proportion of the insects might live the maximum of 49 days and deposit the maximum of 5 eggs each per day, making a total of 245 eggs for the individual.

DURATION OF THE LIFE CYCLE.

The duration of the life cycle was determined by two methods, viz, by the complete rearing of individual specimens through all the stages and by adding together the number of days in the egg, larval, and pupal stages. Owing to difficulties in handling only a comparatively small number of insects (13 to be exact) were carried through all the stages. From this record, obtained in May and early June, 1911, a maximum life cycle of 31 days, minimum of 28 days, and average of 29.8 days were secured. From the abundant data assembled in determining the duration of the separate immature stages the life cycle was found to be 33.9 days in May and early June and 29.1 days in September, months in which the weather was moderately cool; and in the period from June to September, during the hot weather, it was 15.2 days. The data are given in detail in Table VI. The figures do not take into account the three or four days between emergence and the first oviposition, which should be added for the complete life cycle.

TABLE VI.—*Duration of the life cycle of the citrus thrips, Lindsay, Cal., 1911.*

Period covered.	Average length of egg stage.	Average length of larval stage.	Average length of pupal stage.	Average duration of life-cycle.	Mean daily temperature.
	Days.	*Days.*	*Days.*	*Days.*	°*F.*
May 3 to June 9	18.8	8.2	6.9	33.9	62.67
June 2 to Sept. 5	7.3	4.4	3.5	15.2	76.03
Aug. 31 to Sept. 26	17.0	6.8	5.3	29.1	68.12

SEASONAL HISTORY.

About the middle of October the thrips begin to diminish noticeably and as the temperature goes lower, through November and December, they gradually disappear. Occasionally adult thrips will be found on the trees as late as December, from which it has been inferred that the winter is passed in this stage. As a matter of fact none of them lives through the month of January, and even the most painstaking search has never revealed a single specimen of larva, pupa, or adult later than January 5. Dead adults occur in increasing numbers on the leaves in October and November, corresponding with the period in which the living insects disappear most rapidly. It was determined by experiment, verifying field observations, that the winter is passed successfully in the egg stage only. Large numbers of adults and larvæ confined in the fall on orange plants, practically exposed to the prevailing weather except for being sheltered from rain, began to die early in November, very few larvæ pupating and these few dying as pupæ. All specimens were dead by December 26, but the eggs deposited produced larvæ the following spring.

The earliest time at which the citrus thrips have been found in the spring was March 25. There is, therefore, a period of from 8 to 11 weeks in January, February, and March in which feeding, oviposition, and all other activities of the insect cease, but which can not be called a hibernating period in the strict sense. The late issuing larvæ, as well as the pupæ and adults found in November and December, feed during the warm part of the day until the first severe frost kills them. The date of issuance of the first spring larvæ will depend upon the character of the season, coming early when the mean temperature for February and March is high and being delayed by a late cold spring.

MOVEMENTS OF THE THRIPS IN RELATION TO THE BLOSSOM AND GROWTH PERIODS OF THE WASHINGTON NAVEL ORANGE.

As the stems from which the first spring larvæ issue harden, the insects wander in search of better food and are soon found working up onto the new spring growth, which is usually 8 or 10 inches long by the time the larvæ have attained considerable numbers. Orange growth and the appearance of thrips larvæ occur about 10 days earlier on the foothill slopes than on the valley level. Adult thrips begin to appear rapidly about the time the Washington navel trees are in full bloom, and the growth from 1 to 3 feet long, usually about the middle of April, and the resultant oviposition and feeding on the spring growth soon bring their injury into prominence. About the time one-third or more of the petals have fallen the first growth of foliage begins to harden and the thrips transfer to the little fruits. This period of transfer usually will fall between April 15 and May 30, depending upon conditions of growth and bloom.

The first injury to the fruit is caused largely by a comparatively few of the first larvæ which issue from it, feeding deeply in a circle about the stem, the injury so made eventually developing into the ring scars typical of citrus-thrips injury. Severe injury to the fruit begins as soon as the petals drop, increasing from that time until the oranges average about the size of a tennis ball. The more serious damage usually is done between the middle of April and the early part of July. Adult thrips then begin to leave the oranges, which become tough and distasteful to them, and transfer to the second growth of foliage. A few thrips feed and oviposit on the fruit practically throughout the season, however, and slight injury may often occur until the last of September. In 1911, the leaf growth was sparse and the amount of late injury to the fruit was unusual, being considerably greater than had been expected from the relative scarcity of thrips.

MIGRATION OF THRIPS TO SECONDARY FOOD PLANTS DUE TO SCARCITY OF ORANGE GROWTH.

The transfer of thrips from oranges to the secondary food plants takes place every season in greater or less degree, depending upon food conditions. The scarcity of suitable citrus food in 1911, approximately from June 30 to August 30, led to an unusual increase of the insects on certain other plants during that period. Grapes are especially subject to infestation at such times, and one case was reported to the writer in which both leaves and berries of a small vineyard were severely injured. During this period in which the thrips are scattered widely over their various food plants—roughly, during June, July, and August—reproductive activity is at its minimum.

CONGREGATION OF THRIPS ON LATE SUMMER GROWTH OF CITRUS.

Washington navel and Valencia orange trees in the San Joaquin Valley make from three to six successive new growths during the summer, depending on weather conditions, care of the grove, and age and health of the trees. In exceptionally favorable seasons there is some new growth on the trees throughout the summer, but ordinarily there are two periods in which the growths are most attractive to thrips, one occurring in May and June, the other in August and September. During the August–September period the tissues of most of the deciduous food plants and the rind of the oranges are tough and distasteful, and there is a steady, often sudden, influx of thrips from scattered locations to the new foliage of the orange and some other citrus. The insects apparently become more numerous than ever, being more closely concentrated than at any other time of year.

In this period of the season, therefore, the following conditions favorable to the thrips progeny of the ensuing spring usually occur: The food supply is abundant and concentrated. The proportion of male thrips is increased, and mating and oviposition occur to a much greater extent than at any other time. This most favorable circumstance of abundant food in comparatively small space at just the time when the insect must produce the eggs for the next summer's generation is a principal factor in the rise of the species as a pest. It has been brought about by the occurrence in recent years of large numbers of vigorous young orange trees which the thrips was able to substitute for the miscellaneous weeds previously constituting its food supply.

GENERATIONS.

It is impossible to distinguish between generations of the citrus thrips, except perhaps the first and second summer generations, when growth is slow. Throughout the middle of the summer the life cycle occupies from 15 to 16 days, while oviposition covers from 25 to 30 days. Thus the complete life cycle may be passed by any given lot of individuals and eggs deposited by them to begin another generation while their progenitors are still ovipositing. This causes an overlapping of broods, such that it is impossible to distinguish between them. The number of generations will depend, of course, upon the character of the season. An early, warm spring followed by a prolonged, hot summer may result in the production of eight or more generations. In seasons such as 1911, six full generations may be expected between the middle of April and the first of November.

NATURAL CHECKS.

FREEZES.

Practically all sections of California where oranges are grown are subject to occasional freezes of varying severity, which always occur between November 15 and March 1, when the citrus thrips are practically all in the egg stage in the leaves and stems. The shoots most severely injured by freezes are those in which a majority of the eggs are deposited, and thus it occasionally happens that a considerable number of the eggs are frozen. In the winter of 1911-12 more or less severe freezing occurred throughout the citrus-growing sections of the State. The leaves and stems of the principal summer's growth were browned and withered, and the thrips suffered a considerable reduction in numbers in many orchards. For example, an orchard which had been severely infested by thrips during the three years from 1909 to 1911, inclusive, and particularly in 1911, when the entire crop was rejected because of thrips scabbing, was frosted so badly during the winter of 1911–12 that the tender leaves and stems were wilted and blackened well down into the leaf expanse of the trees. In August, 1912, examination of the fruit from this orchard showed only 13 per cent of it to be marked by thrips, the degree of injury being noted at the time as mostly very slight stem-end rings. Thrips were very scarce and the leaves showed little injury except in scattered spots.

RAINS.

From the fact that rains are supposed to be a powerful agency in the natural control of some species of thrips, it has been argued that a season of unusually heavy rainfall would reduce greatly the number of citrus thrips. Whatever merit rainfall may have in checking thrips of other species, its effect on the citrus thrips under the conditions prevailing in the San Joaquin Valley and in Arizona could not be of the least importance, since the heavier rains do not begin there until October at the earliest, and usually not before November or December, by which time almost all the overwintering eggs have been deposited. In spring the rains cease before the thrips emerge in any considerable number. The season of 1909, following the heaviest rainfall in the three-year period from 1909 to 1911, inclusive, in the San Joaquin Valley, was the worst season for thrips injury on record.

NATURAL ENEMIES.

INSECTS.

The most important insect enemy of the citrus thrips is the larva of the common lacewing fly of California (*Chrysopa californica* Coq.).[1] In its early stages this larva feeds largely upon larvæ of the citrus thrips. In October, 1911, an examination of 10 one-year-old orange trees on which thrips were numerous disclosed an average of 25 eggs of this Chrysopa per tree. A number of the sickle-jawed larvæ were also present in the trees, and several of the smaller ones were engaged busily in feeding upon thrips. The thrips were indeed almost the only food available to the lacewings in quantity on these

[1] Identified by Nathan Banks.

trees. Adult thrips suffer from the lacewings only when the weather has become so cool as to make the thrips sluggish.

In its early larval stage, the lady beetle (*Hippodomia convergens* Guér.) feeds upon the citrus thrips. Although this Coccinellid is extremely numerous throughout the Tulare County citrus belt, it feeds mostly upon aphids and other larger insects which occur on orange trees and more particularly on truck crops, and is of no great importance in destroying the thrips.

A thysanopteron enemy of the citrus thrips which seemed to be increasingly important in 1912 was the 6-spotted thrips (*Scolothrips sexmaculatus* Perg.). The principal food of the 6-spotted thrips, however, appears to be mites which occur mainly on plants other than citrus in Tulare County and which are not numerous enough on orange to attract large numbers of the predatory thrips. This thrips is apparently just learning the possibilities of abundant food offered by the citrus thrips, and perhaps will feed more extensively upon it as time goes on. It is apparently unable to catch the adults and therefore feeds only upon the larvæ.

The younger nymphs of one of the assassin bugs (*Zelus renardii* Kolen)[1] are fairly common upon orange trees in Tulare County and have several times been seen feeding upon larvæ of the citrus thrips. The more advanced assassin bugs, however, feed principally upon larger, and often harmless, insects and it is only in their first and early second instars that they attack thrips.

The small reddish nymph of the plant bug (*Triphleps insidiosus* Say) has occasionally been seen feeding upon flower thrips in orange and several other blossoms. When imprisoned with *Scirtothrips citri* it flourished very well upon the latter, but when the flower thrips (*Frankliniella tritici* Fitch.) was also placed in the bottle the latter proved more attractive to the insect, doubtless because of its larger size and greater sluggishness of movement. *Triphleps insidiosus* has not been seen upon orange trees after the blossom period, when the flower thrips, upon which they mostly feed, have left the trees.

INTERNAL PARASITES.

Thus far no internal parasites have been found attacking the citrus thrips. Although the Chalcid parasite of Thysanoptera (*Thripoctenus russelli* Crawf.)[2] has been found by the writer in the San Joaquin Valley affecting the bean thrips (*Heliothrips fasciatus* Perg.) and the flower thrips (*Frankliniella tritici* Fitch.), for some

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[1] Identified by Otto Heideman.

[2] This parasite was first reared from *Heliothrips fasciatus* Perg. by H. M. Russell (see U. S. Dept. Agr., Bur. Ent., Tech. Ser. Bul. 23, pt. 2, Apr. 27, 1912). It was described as a new genus and species by J. C. Crawford in 1911 (see Proc. Ent. Soc. Wash., vol. 13, p. 233, 1911).

reason it does not attack the citrus thrips, although the close association of this thrips with the bean thrips on orange trees seems to be a good reason why it should do so, and it is quite possible, seemingly, that the citrus thrips may in the future become one of its hosts.

SPIDERS.

A large number of spiders, representing three or four families, capture the citrus thrips as a part of their food. The most important of these in the matter of destroying citrus thrips is a small gray spider belonging to the family Dictynidae, genus Dictynus.[1] The Dictynidæ are tubeweavers, and this particular species commonly spins a thin sheet of web irregularly across an orange leaf, in a single one of which adult and larval citrus thrips have often been counted to the number of 50 or more. It is rare to find a web of one of these young spiders with less than from 5 to 10 thrips entangled in its meshes. The little spiders have several times been seen with the thrips in their jaws.

The second most important Arachnid enemy of the citrus thrips is one of the jumping spiders (Fam. Salticidae), known as *Thiodina puerperis*. This spider is very active in seizing its prey, which it pounces upon cat fashion. From 4 to 10 or more thrips will be eaten in succession by one of these young spiders. The spider drains the juice from the body of its victim and casts the skeleton aside.

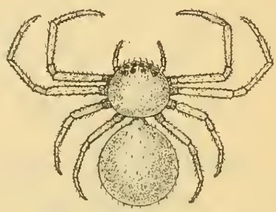

FIG. 9.—Young spider, *Misumessus* sp., which preys upon the citrus thrips. (Original.)

Another spider (fig. 9), belonging to the genus Misumessus, has often been taken in its immature stages with the citrus thrips in its possession. This spider is a yellowish, very active creature belonging to the family of so-called crab spiders (Thomisidae). It is commonly found, solitary, upon orange leaves. It does not spin a web.

A small black spider (*Erigone* sp.), less common on orange trees than any of the foregoing, is sometimes seen with adult citrus thrips in its possession. As is the case with all the foregoing thrips enemies, insects and spiders alike, except the 6-spotted thrips, this spider feeds upon thrips when it is young, but confines itself mostly to larger insects after it has become mature. The young, actually about one-twentieth inch long, is shown greatly magnified in figure 10.

FUNGUS GROWTH ATTACKING THRIPS.

The spores of an unidentified fungus have occasionally been seen about the bodies of citrus thrips which have died in captivity, but it seems probable that either this fungus attached the insects after

[1] All spiders referred to herein have been identified by Nathan Banks.

death or the attack resulted from the excessive moisture formed in the rearing jar by the orange leaves. It results only from abnormal conditions and is plainly unimportant in the field.

IMPORTANCE OF NATURAL AGENCIES IN CONTROLLING THE THRIPS.

The citrus thrips appears to be subject to controlling influences the nature of which is difficult to determine completely. The most severe infestation recorded against the insect occurred in Tulare County in 1909, when 90 per cent of the entire crop of navel oranges of that county was thrips marked, and close to 20 per cent of it was so badly scarred and distorted that it was unsalable at a profitable price. In 1910 the insects failed to appear in anything like their numbers of 1909 and the injury was less than 50 per cent of what it had been during that season. This naturally affected the results due to spraying by the growers in 1910, even where the work was done thoroughly, as in many cases unsprayed fruit was injured so slightly that the difference in returns between sprayed and unsprayed fruit was so small that very little profit was derived from the operation. In 1911, thrips were still less numerous and more scattered early in the season and it looked as though the injury would be very slight. Owing, however, to an unusually backward season, in which the trees made but slow and scanty growth, the insects were forced to depend to a greater extent than usual on the fruit for food, on which they concentrated in the latter part of the season. The marking was late in appearing, but at the end of the season proved to be somewhat more extensive than in 1910. This illustrates the fact that the abundance of thrips is not always a reliable index of the extent of expected damage to the fruit.

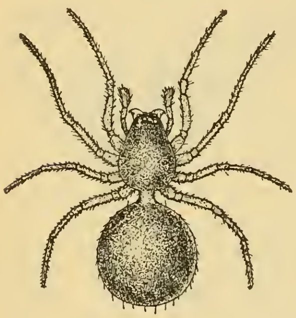

FIG. 10.—Immature spider, *Erigone* sp., which preys largely upon the citrus thrips. (Original.)

The chief factors influencing the decrease of thrips subsequent to 1909 are undoubtedly the climatic changes and relative inadequacy of the food supply. In 1910 and 1911 the late, cold spring was the cause of the slowness with which the insects increased during April, May, and June; while the same climatic condition, in retarding the growth of the trees, further checked the increase of the insects by reducing their food. Furthermore, it forced the insects to scatter widely over many food plants, thus hindering reproduction and greatly retarding oviposition by causing dearth of suitable plant tissue.

CONTROL EXPERIMENTS.

PLAN OF SPRAYING EXPERIMENTS IN 1911.

The principal experiments in 1911 were conducted in an orange orchard about 2 miles east of Lindsay, Cal., and about the same distance from the nearest foothills, lying between the latter and the town. A supplementary set of experiments was conducted in an orchard situated on the slope of the foothills about 2 miles from the first orchard, the object being to test out practically the same sprays under different conditions. The trees of the latter orchard were younger than those of the former, and, as is true of most foothill groves, worse thrips infested. The insecticides used in the two sets of experiments are listed below, Series I referring to the valley orchard and Series II to the foothills orchard. A further experiment, in which 2,550 Valencia and Joppa and a number of navel nursery trees were sprayed, was conducted in a third orchard about 2 miles from the foothills.

Series I: Valley ranch.

Plat No. 1. Unsprayed, check.
2. Lime-sulphur solution (36° Baumé), 1–28.
3. Lime-sulphur solution (36° Baumé), 1–56.
4. Unsprayed, check.
5. Tobacco extract (40 per cent nicotine sulphate), 1–800.
6. Tobacco extract (40 per cent nicotine sulphate), 1–1,600.
7. Unsprayed, check
8. Lime-sulphur solution (36° Baumé), 1–86, and tobacco extract (40 per cent nicotine sulphate), 1–800.
9. Lime-sulphur solution (36° Baumé), 1–86, and tobacco extract (40 per cent nicotine sulphate), 1–1,600.
10. Lime-sulphur solution (36° Baumé), 1–86, and tobacco extract (40 per cent nicotine sulphate), 1–2,400.
11. Cresol soap, 1–500, and tobacco extract (40 per cent nicotine sulphate), 1–800.
12. Cresol soap, 1–500, and tobacco extract (40 per cent nicotine sulphate), 1–1,600.
13. Unsprayed, check.
14. Fish-oil soap, 1–250, and tobacco extract (40 per cent nicotine sulphate), 1–800.
15. Fish-oil soap, 1–250, and tobacco extract (40 per cent nicotine sulphate), 1–1,600.
16. Sulphur-soda solution,[1] 1–25.

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[1] The sulphur-soda solution (plats 16 and 17) was prepared as follows:

Powdered sulphur	pounds	30
Powdered caustic soda (98 per cent)	do	15
Water to make	gallons	30

The sulphur was made into a paste with water and the soda added, while the mixture was constantly stirred, in sufficient quantity to cause boiling, a little water being added occasionally to retard the cooking. When all the sulphur was dissolved, enough cold water was added to make a stock solution of 30 gallons. A clear, amber liquid, much resembling good lime-sulphur, was the result.

Plat No. 17. Sulphur-soda solution, 2–25.
18. Resin wash,[1] 1–3.
19. Resin wash, 1–5.
20. Resin wash, 1–10.
21. Plain water.
22. Unsprayed, check.

Each of the foregoing plats of Series I consisted of two rows of 25 trees each, or 50 trees to the plat. The trees were 18-year-old Washington navels, and the entire experimental block was bordered on two sides by trees of the same kind and planting, and on the remaining sides by Valencias and a road, respectively.

Series II: Foothills ranch.

Plat No. 1. Lime-sulphur solution (33° Baumé), 1–75, and tobacco extract (2¾ per cent nicotine sulphate), 1–150.
2. Lime-sulphur solution (33° Baumé), 1–75, and tobacco extract (2¾ per cent nicotine sulphate), 1–100.
3. Tobacco extract (2¾ per cent nicotine sulphate), 1–100.
4. Tobacco extract (40 per cent nicotine sulphate), 1–1,600.
5. Tobacco extract (40 per cent nicotine sulphate), 1–2,400.
6. Tobacco extract (40 per cent nicotine sulphate), 1–1,600, and cresol soap, 1–400.
7. Tobacco extract (40 per cent nicotine sulphate), 1–2,400, and cresol soap, 1–400.
8. Plain water.
9. Unsprayed, check.
10. Tobacco extract (40 per cent nicotine sulphate), 1–800.
11. Tobacco extract (40 per cent nicotine sulphate), 1–1,600, and fish-oil soap, 1–200.
12. Tobacco extract (40 per cent nicotine sulphate), 1–2,400, and fish-oil soap, 1–200.

Plats 1 to 8 of Series II consisted of 4 rows of 28 trees each; plat 9, of 5 rows of 28 trees; the remaining plats, of 2 rows of 28 trees each. All trees were 4-year-old Washington navels. The only lime-sulphur available for use unmixed in Series II was a quantity which had been exposed to the air for a year. It was used, with misgivings, and the results, which are omitted as of no value, proved conclusively that it had lost most of its insecticidal power.

[1] The stock resin wash (plats 18, 19, and 20) was made fresh for each application, as follows:

Resin	pounds	20.0
Caustic soda (98 per cent)	do	3.6
Fish oil	pints	3.0
Water enough to make	gallons	50.0

All the ingredients were placed in a 60-gallon iron kettle with 10 or 15 gallons of water and brought to boiling. Melting was aided by constant stirring. Hot water was added occasionally until the mixture had boiled constantly for about 1½ hours and had reached 50 gallons.

NURSERY-SPRAYING EXPERIMENTS.

Plat No. 1. 2,550 Valencia and Joppa orange trees, sprayed with lime-sulphur, 1–50.

2. Several thousand Washington navel orange trees, sprayed with lime-sulphur, 1–75, and tobacco extract ($2\frac{3}{4}$ per cent nicotine sulphate), 1–150.

Time and number of applications.—Three applications of the insecticides were made at the valley ranch, Series I, with the object of saving the fruit from injury. Owing to a very cold and backward season and the age of the trees, growth was scant and the first application was not necessary until June 2. The second application was timed principally to catch adult thrips which had transferred to the fruit and larvæ which had issued from it since the first application and was started June 17. The third application was timed solely by the abundance of thrips on the fruit and was begun July 8.

The first application at the foothills ranch, Series II, was started May 15, and the second June 6, both about a week later than was intended, owing to failure of the ranch foreman to produce sprayer, teams, and labor promptly when requested, the writer being dependent upon the grower for these items by agreement. The difference in the time of the first application between the valley ranch, Series I, and the foothills ranch, Series II, indicates approximately the difference between the two localities in the time when the petals dropped and the thrips began to feed on the fruit.

The nursery trees were sprayed June 7, July 15, and August 31; the sprayings were timed solely by the abundance of thrips.

RESULTS FROM SPRAYING.

The determination of the relative value of the different insecticides and of spraying is based solely upon the effectiveness of the work in raising the commercial grade of the fruit. These grades represent money values, and their improvement, which was the primary object of the investigation, thus effects a tangible saving. The qualities determining the grading of oranges were studied out at the various packing houses, and in this work the writer received the willing cooperation of the managers of most of the packing houses at Lindsay, Cal. As the fruit from the experiments of Series I was graded under a different system from that of Series II, it will be necessary to state the results of each series of experiments in terms of the commercial grading of the fruit from that series.

RESULTS IN SERIES I.

The results of the spraying experiments at the valley ranch are summarized in Tables VII and VIII. The comparatively slight infestation in this orchard in 1911 is evident from the figures for the unsprayed plats, Nos. 1, 4, 7, 13, and 22, in Table VII. The variation in the percentage of fruit injured sufficiently to reduce the grade in the different check plats shows the uncertainty of the infestation and the necessity, in order to obtain reliable comparison, of several interspersed lots of unsprayed trees. The comparisons would be still more accurate if it had been feasible to leave single untreated trees interspersed among the sprayed trees of each plat, but the work of keeping the fruit from a large number of scattered trees in 17 plats separate for examination would involve too much time and expense, and there would be much risk of the pickers, paid by the box, mixing the fruit.

TABLE VII.—*Comparison of fruit sprayed for the citrus thrips with that unsprayed, Series I, Lindsay, Cal., 1911.*

No. of plat.	Treatment of trees.	Amount of fruit examined.		Commercial grading of fruit.			
		Number of loose boxes.	Number of oranges.	Number of first-grade oranges.	Number of second-grade oranges.	Per cent first-grade oranges.	Per cent second-grade oranges.
1	Untreated	20	2,386	1,981	405	83.1	16.8
2	Lime-sulphur (36° Baumé), 1-28	20	2,308	2,285	23	98.9	1
3	Lime-sulphur (36° Baumé), 1-56	20	2,243	2,225	18	99.1	.8
4	Untreated	20	2,180	1,734	446	79.4	20.4
5	Tobacco extract (40 per cent nicotine sulphate), 1-800	20	2,300	2,247	53	97.5	2.3
6	Tobacco extract (40 per cent nicotine sulphate), 1-1,600	20	2,281	2,160	121	94.6	5.1
7	Untreated	20	2,442	2,188	254	89.5	10.4
8	Lime-sulphur (36° Baumé), 1-86, and tobacco extract (40 per cent nicotine sulphate), 1-800	20	2,337	2,272	65	97.1	2.7
9	Lime-sulphur (36° Baumé), 1-86, and tobacco extract (40 per cent nicotine sulphate), 1-1,600	20	2,420	2,321	99	95.8	4
10	Lime-sulphur (36° Baumé), 1-86, and tobacco extract (40 per cent nicotine sulphate), 1-2,400	20	2,387	2,174	213	91	8.8
11	Cresol soap, 1-500, and tobacco extract, 1-1,600	20	2,345	2,071	274	88.2	11.6
12	Cresol soap, 1-500, and tobacco extract (40 per cent nicotine sulphate), 1—2,400	20	2,126	1,740	386	81.8	18.1
13	Untreated	20	2,648	1,878	770	70.8	29
14	Fish-oil soap, 1-250, and tobacco extract (40 per cent nicotine sulphate), 1-800	20	2,555	2,299	256	89.8	10
15	Fish-oil soap, 1-250, and tobacco extract (40 per cent nicotine sulphate), 1-1,600	20	2,444	2,041	403	83.4	16.4
16	Sulphur-soda, 1-25	20	2,563	2,294	269	89.4	10.4
17	Sulphur-soda, 2-25	20	2,622	2,510	112	95.7	4.1
18	Resin wash, 1-3	20	2,700	[1]	[1]	[1]	[1]
19	Resin wash, 1-5	20	2,760	[2]	[2]	[2]	[2]
20	Resin wash, 1-10	20	2,596	[3]	[3]	[3]	[3]
21	Plain water	20	2,639	2,191	448	82.9	16.9
22	Untreated	20	2,650	2,176	474	82	17.8

[1] 83.6 per cent of fruit injured by spray.
[2] 69.6 per cent of fruit injured by spray.
[3] 43.7 per cent of fruit injured by spray.

The fruit from plats 1 and 4 was considered as one unsprayed lot for comparison with the sprayed fruit from plats 2 and 3; that from plats 4 and 7 as a check on the same from plats 5 and 6, etc., in order to get unsprayed fruit as nearly as possible representative of what sprayed fruit would have been without treatment. More than

95 per cent of the grade reduction occurring in the orchard was caused by thrips injury. The efficacy of the various insecticides in raising the grade of the fruit is shown in Table VIII.

TABLE VIII.—*Efficacy of the spray mixtures in Series I.*

Unsprayed fruit.			Sprayed fruit.			Grade-raising efficacy of the sprays.
Plat No.	Number of boxes first-grade fruit.	Number of boxes low-grade fruit.	Plat No.	Number of boxes first-grade fruit.	Number of boxes low-grade fruit.	
						Per cent.
1 and 4.	81	19	2	99	1	95
			3	99	1	95
4 and 7.	85	15	5	98	2	87
			6	95	5	67
7and 13.	80	20	8	97	3	85
			9	96	4	80
			10	91	9	55
			11	88	12	40
			12	82	18	10
13 and 22.	79	21	14	90	10	52
			15	84	16	24
			16	90	10	52
			17	96	4	81
			21	83	17	19

The relative worth of the spray mixtures in Series I, as indicated in Tables VII and VIII, may be summarized as follows:

1. From 80 to 90 per cent grade-reducing injury prevented by—
   Lime-sulphur (36° Baumé), 1–28.
   Lime-sulphur (36° Baumé), 1–56.
   Tobacco extract (nicotine sulphate 40 per cent), 1–800.
   Lime-sulphur (36° Baumé), 1–86, and tobacco extract (40 per cent nicotine sulphate), 1–800 and 1–1,600.
   Sulphur-soda solution, 2–25.
2. Between 60 and 80 per cent of injury prevented by—
   Tobacco extract (40 per cent nicotine sulphate), 1–1,600.
3. From 50 to 60 per cent of injury prevented by—
   Lime-sulphur (36° Baumé), 1–86, and tobacco extract (40 per cent nicotine sulphate), 1–2,400.
   Fish-oil soap, 1–250, and tobacco extract (40 per cent nicotine sulphate), 1–800.
   Sulphur-soda solution, 1–25.
4. Less than 50 per cent of injury prevented by—
   Cresol soap, 1–500, and tobacco extract (40 per cent nicotine sulphate), 1–1,600.
   Fish-oil soap, 1–500, and tobacco extract (40 per cent nicotine sulphate), 1–2,400.
   Fish oil soap, 1–250, and tobacco extract (40 per cent nicotine sulphate), 1–1,600.
   Plain water.
5. Fruit and leaves severely injured by—
   Resin wash, 1–3; 1–5; and 1–10.

Contrary to expectation, the addition of soaps to tobacco solutions did not appear to increase their efficacy, but, on the contrary, seemed to lower it. Straight tobacco extract with 40 per cent nicotine sulphate, diluted 1–800 and 1–1,600, respectively, gave better results than at the same strengths with the addition of soaps. This fact is difficult to account for, but may be due partly to more severe infestation of the trees on which the soap was used than on those sprayed with the unmodified tobacco extracts. The soap plats were located two on either side of check plat 13, in which there was 29 per cent of low-grade fruit; but the comparison is made with the average between plats 13 and 22, in which there was 21 per cent low-grade fruit. The infestation may have been as severe in the soap plats as in check plat 13. The plats treated with straight tobacco extracts lay between check plats 4 and 7, with only 20 and 5 per cent low-grade fruit, respectively. The foregoing explanation does not hold, however, for the similar results from soap and tobacco extracts, under different conditions, in Series II, and the latter experiments seem to lend further weight to the probability that but little benefit will result from adding soaps to tobacco extracts as sprays for the citrus thrips. Experiments under very heavy and uniform thrips infestation, however, might result somewhat differently.

RESULTS IN SERIES II.

The fruit from the experimental plats in Series II was packed in three commercial grades instead of two, as was that of Series I. The results from spraying are given in percentage of fruit of each of the three grades, from all the separate plats, in Table IX.

TABLE IX.—*Comparison of fruit sprayed for the citrus thrips with that unsprayed, Series II, Lindsay, Cal., 1911.*

Plat No.	Treatment of trees.	Amount of fruit examined.		Commercial grading of fruit.		
		Number of boxes.	Number of oranges.	Per cent first-grade fruit.	Per cent second-grade fruit.	Per cent third-grade fruit.
1	Lime-sulphur (33° Baumé), 1–75, and tobacco extract (2¾ per cent nicotine sulphate), 1–150	20	2,492	40.3	51.8	7.8
2	Lime-sulphur (33° Baumé), 1–75, and tobacco extract (2¾ per cent nicotine sulphate), 1–100	20	2,504	46	44.4	9.4
3	Tobacco extract (2¾ per cent nicotine sulphate), 1–100	20	2,371	25.7	53.1	21
4	Tobacco extract (40 per cent nicotine sulphate), 1–1,600	20	2,502	33	46.6	20.2
5	Tobacco extract (40 per cent nicotine sulphate), 1–2,400	20	2,711	19.2	54	26.7
6	Cresol soap, 1–400, and tobacco extract (40 per cent nicotine sulphate), 1–1,600	20	2,336	30.2	48.3	21.3
7	Cresol soap, 1–400, and tobacco extract, 1–2,400	20	2,403	22.2	52.8	24.7
8	Plain water	20	2,582	7.4	46.7	45.7
9	Untreated	20	2,271	6.7	52	41.1
10	Tobacco extract (40 per cent nicotine sulphate), 1–800	20	2,176	42	47.6	10.2
11	Fish-oil soap, 1–200, and tobacco extract, (40 per cent nicotine sulphate), 1–1,600	20	2,147	30	51.3	18.6
12	Fish-oil soap, 1–200, and tobacco extract, (40 per cent nicotine sulphate), 1–2,400	20	2,049	27.4	50.7	21.8

The relative worth of the spray mixtures in this series may be divided roughly into four groups, according to their relative merits, as follows:

1. Sprays raising about three-fourths of the injured fruit from third to first grade:
   Lime-sulphur (33° Baumé), 1–75, and tobacco extract (2¾ per cent nicotine sulphate), 1–150.
   Lime-sulphur (33° Baumé), 1–75, and tobacco extract (2¾ per cent nicotine sulphate), 1–100.
   Tobacco extract (40 per cent nicotine sulphate, 1–800.
2. Sprays raising about one-half the injured fruit from third to first grade:
   Tobacco extract (2¾ per cent nicotine sulphate), 1–100.
   Tobacco extract (40 per cent nicotine sulphate), 1–1,600.
   Cresol soap, 1–400, and tobacco extract (40 per cent nicotine sulphate), 1–1,600.
   Fish-oil soap, 1–200, and tobacco extract (40 per cent nicotine sulphate), 1–1,600.
   Fish-oil soap, 1–200, and tobacco extract (40 per cent nicotine sulphate), 1–2,400.
3. Sprays raising about one-third of the injured fruit from third to first grade:
   Tobacco extract (40 per cent nicotine sulphate), 1–2,400.
   Cresol soap, 1–400, and tobacco extract (40 per cent nicotine sulphate), 1–2,400.
4. Without insecticidal value:
   Plain water at high pressure.

As indicated by the figures in Table IX, insecticides in the first of the foregoing groups raised from 31 to 33 per cent out of a probable 41 per cent of third-grade fruit to first grade; i. e., over three-fourths of it; those in the second group, only about 20 per cent, or about half of it; and those in the third group prevented only about one-third of the injury.

The results from the more effective sprays in Series II may be stated in terms of the gross receipts of the fruit. The difference in price per box between the grades for this particular fruit was as follows: First-grade fruit brought 67 cents more per box than third-grade and 29 cents more than second grade, which brought 38 cents more than third-grade fruit. The differences in receipts per hundred boxes between sprayed plats 1, 2, and 10 and the check plat are given below:

Plat 1.—33.3 boxes raised from third grade to first grade, at 67 cents	$22.31
0.2 boxes raised from second grade to first grade, at 29 cents	.06
Amount received per 100 boxes sprayed fruit in excess of the unsprayed	22.37
Plat 2.—31.7 boxes raised from third grade to first grade, at 67 cents	21.23
7.6 boxes raised from second grade to first grade, at 29 cents	2.20
Amount received per 100 boxes sprayed fruit in excess of unsprayed	23.43

Plat 10.—30.9 boxes raised from third grade to first grade, at 67 cents	$20.70
4.4 boxes raised from second grade to first grade, at 29 cents per box	1.27
Amount received per 100 boxes sprayed fruit in excess of unsprayed	21.97

Taking into consideration the fact that only two early applications were made in Series II, at the foothills ranch, it will be seen that in seasons like 1911, when the infestations are light, reasonably successful commercial spraying may be depended upon to insure an increase of at least 25 cents for every box of sprayed fruit over the unsprayed fruit.

RESULTS IN NURSERY SPRAYING EXPERIMENTS.

That portion of the nursery designated as Plat 1 was sprayed thoroughly with a gasoline-power outfit used in orchard work. The trees in Plat 2 were given equally careful treatment, being well drenched each time, but the spraying was done with a small, hand-power outfit, fitted with a nozzle of the Vermorel type. The results from the use of the gasoline-power outfit were greatly superior to those from the hand-power outfit, demonstrating the greater efficiency of the former. In October the trees sprayed with the gas-engine outfit looked so remarkably clean and vigorous that they attracted attention; at this time they had a good growth of about 3 feet, without curled leaves and with but little of the whitish discoloration characteristic of thrips injury to leaves. On the trees sprayed with the hand-power outfit the proportionate growth was somewhat less and thrips marking was noticeably more severe.

CONCLUSIONS FROM SPRAYING TESTS.

In the foregoing two sets of tests the following insecticides and combinations gave the best results. Any of these mixtures may be relied upon to give satisfactory control when properly applied.

1. *Lime-sulphur solution.*—If the lime-sulphur is of a density of 36° Baumé, dilute 1 gallon with 56 gallons of water; if of a density of 33° Baumé, dilute 1 gallon with 50 gallons of water.
2. *Sulphur-soda solution.*—Two gallons of the stock solution, prepared as described on page 29, diluted with 25 gallons of water.
3. *Lime-sulphur and tobacco extract (40 per cent nicotine sulphate).*—Dilute 1 part of the lime-sulphur, if 34 to 36° Baumé, with 86 parts of water; if 30 to 33° Baumé, with 75 parts of water. Then add 1 part of the tobacco extract to 1,000 parts of the lime-sulphur as diluted above.
4. *Tobacco extract (40 per cent nicotine sulphate).*—Dilute 1 part with 800 parts of water.

Lime-sulphur and soda-sulphur solutions are more effective against the citrus thrips than any other mixture thus far tested, and particularly the lime-sulphur at the strength stated above. A large percentage of the thrips can be killed by spraying with this solution, and there is a further effectiveness due to its decomposition for a long period after deposition on the leaves. In orchards sprayed with good lime-sulphur the sulphurous odor is often strong for two months or more after the applications. The decomposition products repel the thrips, which are slower to reinfest orchards so sprayed than those sprayed with solutions that soon evaporate and leave no trace.

Tobacco extracts when used at the proper strengths are also very effective. Both tobacco extract and lime-sulphur, when mixed together, are effective in weaker solutions than when diluted with water alone. Contrary to expectation, the addition of soaps to tobacco extract did not give increased value to the tobacco in these tests. Soap solutions used alone appear to be worthless at the dilutions tested.

Resin wash at any strength practicable for use on the orange trees in this section is worthless. At the greatest strength used in these experiments it failed to reduce thrips injury to an extent worthy of attention. It is, furthermore, very injurious to fruit and foliage.

Plain water spraying was utterly ineffective, demonstrating that merely striking the thrips with a liquid at high pressure to wash them from the trees has no appreciable effect in diminishing their numbers. A few hours after spraying with water there remained on the trees as many living, active thrips as before spraying.

INJURIES TO CITRUS RESULTING FROM SPRAYING.

INJURY FROM DISTILLATE-OIL EMULSION.

In experiments conducted in 1910, emulsions containing 2 per cent of distillate oil caused severe staining to ripe oranges. Dark streaks were formed on the rind where the liquid had collected in drops and run down. A patent spray emulsion caused more staining than the home product at the same strength.

INJURY FROM RESIN WASH.

On July 20, 1911, about two weeks after the final spray application, injury appeared from the resin wash in plat 18, Series I. About 3 per cent of the leaves had turned brown and fallen and most of the oranges had become spotted with the varnish. In some cases the varnish had collected in drops and run down over the surface, finally drying to a hard, gummy substance. By September 25 the injury apparently had reached its highest degree and was serious in all three plats, though noticeably decreasing with the greater dilution of the wash. The epidermal cells of fruit protected from the direct rays of the sun were killed and a shallow, brown scab was formed. This scab often peeled off, leaving a film of light gray-green tissue beneath. Where the liquid collected in large drops it formed a thick amber to black scab which did not slough off readily. The injury was most severe in places previously injured by thrips.

INJURY FROM LIME-SULPHER.

A small percentage of the fruit sprayed with lime-sulphur mixture diluted 1–28 (Series I, plat 2) developed in the rind slight hardened depressions resembling burns or scalds. Such injury occurred largely in spots previously injured by thrips, and in one case in a katydid scar. Less than 2 per cent of the fruit was spray-injured even by this strength of solution. In plat 3 (lime-sulphur 1–56) not more than one-half of 1 per cent of the exposed fruit was slightly injured in similar fashion.

In a special test on four orange trees, using lime-sulphur at the rate of 1 gallon to 15 gallons water and making the applications on the hottest days of the summer, very severe injury developed. By the first of June some of the fruit developed severe blisters, or hard, puffy, excrescences of the rind, and a small amount of the fruit fell to the ground. Unlike the injury from resin wash, that from the strong lime-sulphur soon attained its severest degree and was always most severe on oranges exposed to the direct rays of the sun, particularly the afternoon sun. It was also particularly severe in places where the fruit had been bruised or where it had been injured by insects. By fall, from 18 to 25 per cent of the fruit had developed spray injury, the average for all four trees being 21 per cent.

Lime-sulphur is harmless to fruit or leaves when used weaker than 1 part to 28 parts water. It has a remarkably stimulating effect upon the leaf growth of orange trees. In all plats where lime-sulphur was used, no matter what the dilution, the trees sprayed with it produced a growth of foliage much in excess of that produced by their unsprayed neighbors.

SUMMARY OF RECOMMENDATIONS FOR CONTROLLING THE CITRUS THRIPS.

SPRAY MIXTURE AND TIME OF APPLICATION.

Plain lime-sulphur solution, 1 to 56 of the 36° Baumé density or 1 to 50 of the 33° Baumé, is recommended as the most reliable of the four best mixtures resulting from the tests.

The thrips first occur in injurious numbers at the same time that the navel orange blossoms drop most of their petals; they transfer from the leaves to the fruit gradually as the petals fall. The first spray application therefore should be made when four-fifths or more of the petals have fallen. This will check the thrips at a time when the orange is most susceptible of deep injury. The exact date for the application can not be given, as the period when the petals fall and the thrips transfer to the fruit will be as much as 30 days later in some seasons than in others, depending on the spring weather.

The second application should be timed to prevent injury both from larvæ issuing from the very young fruits and from adults emerging from the pupal stage existent at the time of the first application. This renewed attack may be expected to reach the danger point in from 10 to 14 days after the first spraying. The second spraying should not be delayed too long, as comparatively few larvæ may, by constantly feeding in a circle about the base of the fruit, cause deep ring scarring. Special effort should be made to drench only the fruit and the remaining tender leaves.

The third application may be delayed longer if the first two have been thorough and well timed. It generally takes the insects from three to four weeks to become dangerously numerous again, as they reinfest the sprayed trees much more slowly after the second spraying.

All three applications should be completed by the time the fruit is half grown, after which it rapidly loses its attractiveness for the insects, which then find it necessary to spread out over the comparatively scant tender orange growth and miscellaneous food plants.

During the latter part of August and early in September there is usually another abundant growth of orange shoots, and upon this the thrips congregate in large numbers. A fourth application during this period is advisable in some seasons to prevent severe injury to this growth, which is often the most abundant of the season.

The first spray application to nursery stock should be made when thrips become numerous on the spring growth and before their injury becomes very evident, usually between April 15 and May 15. In the case of trees budded in the fall the shoots springing from the original stock should be cut back the following spring as soon as the bud has attained a good growth. All the prunings should be burned to destroy contained eggs and larvæ. In Tulare County this pruning and burning usually can be accomplished during April. The growing scions must then be watched closely and as soon as thrips occur in numbers spraying should begin. From two to four further applications should follow the first spraying, depending upon the number of growths and the degree of infestation.

SUGGESTIONS FOR SPRAYING.

The gasoline-power outfit, by reason of its large nozzle capacity, reliability, and comparatively low cost of operation, is recommended for spraying bearing orchards, young orchards in excess of 10 acres, and large nurseries. Hand-power outfits, when of a type capable of maintaining a pressure of not less than 125 pounds, are suitable for spraying seed-bed and nursery stock and young orchards of small acreage.

The spraying outfit should be in perfect running order not later than April 1, with the insecticide materials at hand and conveniently located near the water supply and as near as possible to the trees to be sprayed. Supplies should be ordered not later than the January or February preceding the spraying operations.

HOW TO SPRAY BEARING ORCHARDS.

It is best to use only two 50-foot leads of hose on a power outfit, with 10-foot rods each fitted with a Y which is angled to handle two nozzles. The latter should be of the larger chamber type, with disks bored to one-sixteenth inch. Each rodman should begin at about the middle of a tree, on the side away from the sprayer, and work around the tree until he reaches the starting point; he should then switch to the same point on the next tree without shutting off the nozzles and with as much economy of movement as possible.

The nozzles should be held about 2 feet from the tree so that the broad portion of the stream plays upon fruit and leaves. The trees should be swept from tip to base, special attention being given to the fruit and the tender growth, where the insects congregate. The pressure, if maintained at 150 to 200 pounds, will turn the leaves and whirl the little fruits so that all sides will be sprayed.

No attempt should be made to spray too many trees with a single outfit, and an application once commenced should be completed within 10 days. Nursery and young orchard trees will require from $\frac{1}{2}$ gallon to 2 gallons of the dilute spray each; those from 5 to 10 years old should be given not less than 5 gallons each; and those from 12 to 18 years old not less than 8 gallons each.

HOW TO SPRAY NURSERIES AND YOUNG TREES.

For large nurseries the gas-engine outfit, where it can be advantageously used, is preferable to the hand outfit. Two 25-foot or even 15-foot leads of hose and 12-foot spray rods are generally most convenient for this work, though the equipment of hose and rods recommended for orchard work will answer very well. The excess hose length should be coiled over a peg fastened to the spray tank or engine hood, so that the young trees will not be injured by the dragging hose. In setting out a nursery it is preferable to leave driveways wide enough to accommodate sprayer and team at intervals of eight rows (where the rows are 4 feet apart) throughout the length of the bed; for example, one between the fourth and fifth rows, and again between the twelfth and thirteenth, etc. Eight rows of trees, four either side of the driveway, may then be reached each trip, using 12-foot spray rods; eight more rows may be taken on the return trip, etc. Either the large chamber type or the single Bordeaux nozzles may be used to good advantage, but the delivery of the spray need not be so rapid as for orchard work. The trees will need attention only when the growth is tender.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 640

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. April 8, 1918

THE MEDITERRANEAN FRUIT FLY

By

E. A. BACK, Entomologist, and C. E. PEMBERTON, Assistant Entomologist, Mediterranean and Other Fruit Fly Investigations

CONTENTS

WASHINGTON
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1918

ONE OF THE WORST enemies of fruit grown in tropical and semitropical countries is the Mediterranean fruit fly. Constant vigilance is necessary to prevent its establishment in North America. It is particularly destructive because it is difficult to control and attacks many kinds of fruits, nuts, and vegetables. In the Hawaiian Islands, where it has caused great damage since 1910, it attacks 72 kinds of fruits. A partial list of these contains oranges, grapefruit, lemons, limes, kumquats, tangerines, peaches, apples, figs, apricots, bananas, mangoes, avocados, sapotas, loquats, persimmons, guavas, quinces, papayas, pears, plums, grapes, eggplant, tomatoes, and even cotton bolls. Most of these are now grown or can be grown in our Southern States, the Gulf region, and California and the Southwest.

The purpose of this bulletin is to give alike to the citizen of Hawaii, the fruit grower of the United States mainland, and the traveler information that will help to convey a clear conception of the difficult problem that has developed with the introduction of the Mediterranean fruit fly into the Hawaiian Islands. The pest can be kept out of the rich semitropical fruit-growing sections of the United States only by the hearty and intelligent cooperation of all.

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THE MEDITERRANEAN FRUIT FLY.

CONTENTS.

THE HORTICULTURAL DEVELOPMENT of the Hawaiian Islands has been almost stopped since 1910 by the activity of two fruit-fly pests—the Mediterranean fruit fly[1] and the melon fly.[2] [3]

These two pests are being intercepted continually by quarantine officials at our ports of entry and they are therefore feared by, and are of vital interest to, every fruit and vegetable grower in the warmer portions of the Pacific and Gulf coast States. Every possible barrier to the establishment of these pests on the mainland United States is being erected by the Federal Horticultural Board, working in cooperation with State officials. Quarantines now regulate the movement of horticultural products from infested countries; hence the greatest danger to California, Florida, and Mexican territory now lies in the unintentional spread of fruit-fly pests by uninformed travelers who may carry infested fruits upon their persons or in their baggage.

The Mediterranean fruit fly (fig. 1) is one of the recently introduced pests of Hawaii. It has found climatic and food conditions so favorable that at present there is not a family unaffected by its ravages. It is doubtful if there exist in any other place in the world conditions so favorable to the rapid spread and thorough establishment of this pest as those in the Hawaiian Islands.

[1] "The Mediterranean Fruit Fly in Hawaii," E. A. Back and C. E. Pemberton, Department of Agriculture Bulletin 536. (*Ceratitis capitata* Wied.)

[2] "The Melon Fly in Hawaii," E. A. Back and C. E. Pemberton, Department of Agriculture Bulletin 491. (*Bactrocera cucurbitae* Coq.)

[3] "The Melon Fly," E. A. Back, C. E. Pemberton, Department of Agriculture Bulletin 643.

NOTE.—The manuscript of this paper was prepared for publication as a Farmers' Bulletin, but owing to the fact that it deals with an insect which has not yet been introduced into the United States it was considered more appropriate to issue it in the series of Department Bulletins.

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DISTRIBUTION THROUGHOUT THE WORLD.

The Mediterranean fruit fly is a cosmopolitan pest. It has been known to science for 100 years and during these years has spread throughout the world, until to-day the North American continent is the only large land area upon which it has not become established. It first attracted serious attention in London, where oranges arriving from the Azores were discovered to be badly decayed and wormy. (See fig. 2.) It was recorded as a pest in Spain in 1842, in Algeria in 1858, in Italy in 1863, in Sicily in 1878, and in Tunis in 1885. In 1889 it was first reported in South Africa. It became established in the western part of Australia in 1897 and in the eastern part in

FIG. 1.—Adult male Mediterranean fruit fly. Greatly enlarged. (Howard.)

1898. In 1899 it was detected in Tasmania, in 1900 it was found attacking the apricot orchards near Paris, France, and during 1901 it was reported from New Zealand and Brazil. Compere, in 1904, found the pest in Egypt, and in Asiatic Turkey at Beirut and Jerusalem. Argentina was reported infested in 1905. Between 1909 and 1914 it was found in the eastern and western parts of Africa, and in 1915 it was first reported from the Island of Madagascar. During 1916 it caused serious damage to the orange, tangerine, peach, pear, and apple crops of the Patras consular district of Greece. It is claimed that this was the first time in 10 years or more that this pest had been noticed in this district of Greece. The Bermuda Islands became infested during 1865.

ESTABLISHMENT AND SPREAD IN HAWAII.

The presence of the Mediterranean fruit fly in the Hawaiian Islands was first discovered at Honolulu on June 21, 1910, and by the fall of that year the pest was well established in the Punchbowl district of the city. By October, 1911, it was found on the Island of Kauai, and by January, 1912, on the Island of Molokai and in the Kohala district of the Island of Hawaii (see fig. 3). During March, 1912,

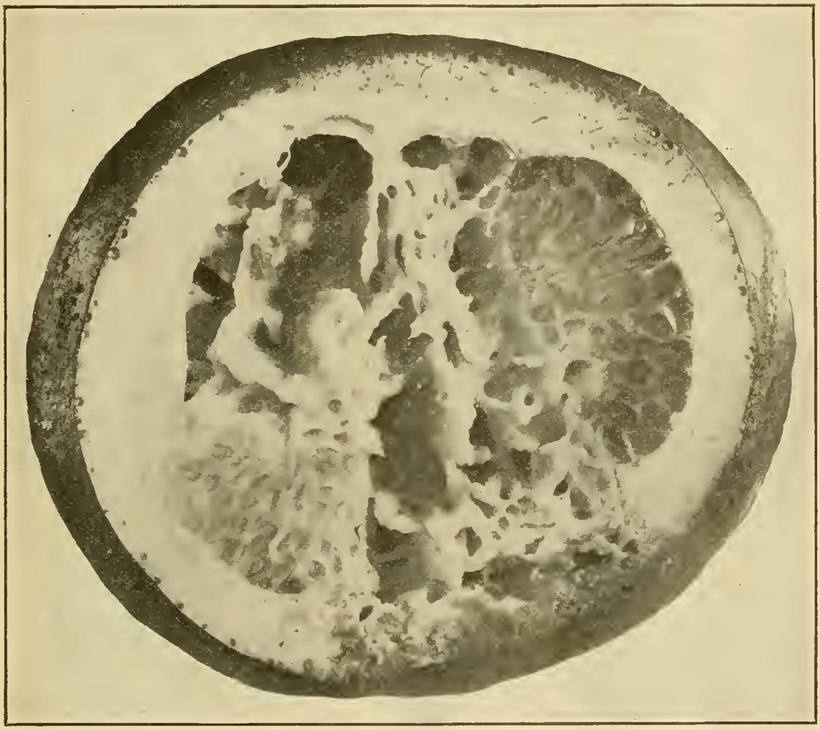

FIG. 2.—Longitudinal section of grapefruit showing destruction of pulp caused by larvæ of Mediterranean fruit fly. (Original.)

the Kona district was found infested, and by May of the same year the fruit fly was discovered for the first time on the Island of Maui. The towns of Naalehu and Hilea of the Kau district of Hawaii were infested by March, 1913, and by the early months of 1914 infestations were found in the Hilo and the Hammakua districts of the same island. By July, 1914, or four years after its first discovery at Honlulu, the pest had spread to every important island of the Territory of Hawaii and to-day is well established in every village and wild guava scrub.

HOW THE FRUIT FLY GOT INTO HAWAII.

A number of popular accounts tell how the Mediterranean fruit fly became established in Honolulu, but they are without foundation.

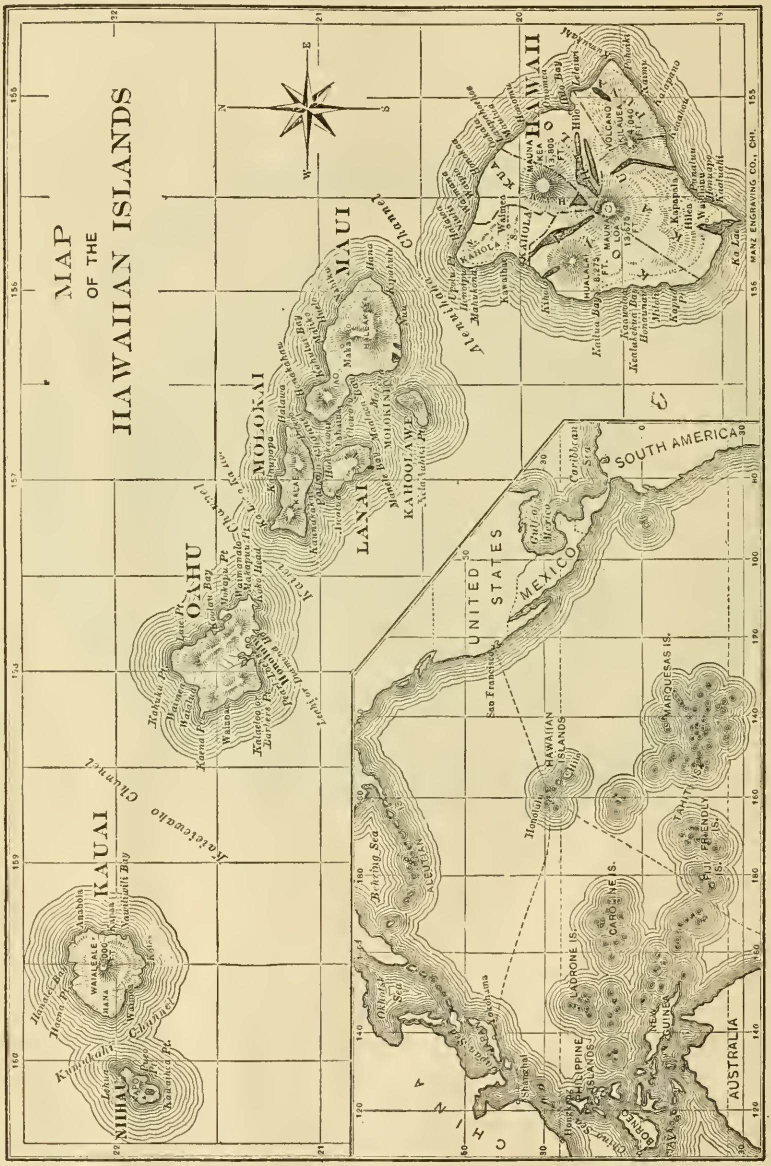

FIG. 3.—Map of Hawaiian Islands showing their relative position and relation to one another in the distribution of the Mediterranean fruit fly.

Establishment came as a natural sequence of the development of rapid ocean travel and cold storage, aided by unusually favorable shore conditions about the harbor of Honolulu. Hawaii was in no danger of infestation until 1898. Before that year ships touching at Honolulu plied between countries not infested by this pest. Eastern Australia was not infested before 1898. With the development of rapid ocean transportation and cold storage on ships, the Mediterranean countries were enabled profitably to export oranges to Australia, and it was in these shipments of fruits that the fruit fly reached Australian shores and became established about Perth and Sydney.

Establishment in Hawaii at Honolulu followed naturally the commercial jump of the pest from the Mediterranean countries to Australia. Honolulu is a port of call for ships plying between eastern Australian ports and San Francisco and Vancouver, and the voyage of about two weeks required for passage from Australia to Honolulu is through a tropical climate permitting rapid development of the fruit fly. No one ever will know just how the pest reached Honolulu on these vessels from Australia, but in view of the rigid inspection service of the Hawaiian Board of Agriculture it seems probable that larvæ falling from infested fruits in the ships' stores—in those days often kept on deck—transformed to the winged adult stage by the time of arrival at Honolulu. From 7 to 10 years ago trees bearing fruits in which the fruit fly could develop grew in greater abundance within a stone's throw of the docks than at the present time and offered an excellent breeding place for stray adults flying from the ships during the time these were in port. There is probably no port in the world where conditions were so favorable for the establishment of this particular pest as was that of Honolulu 10 years ago.

LOSSES INCURRED THROUGH THE FRUIT FLY.

The economic importance of the Mediterranean fruit fly as a pest of fruits varies with the climate of its natural abode, or habitat. Thus, in France, near Paris, where it has been known to attack apricots and peaches, it has not become a serious pest, because of climatic checks. Such checks to the severity of its attacks have been noted in portions of Australia, South Africa, and elsewhere, and would be operative in continental United States except in portions of California and the Southern States. On the other hand, in tropical and semitropical countries the fruit fly is capable of becoming a pest of first importance, and, as in the Hawaiian Islands, may be classed as the most important insect pest to horticultural development.

Practically every fruit crop of value to man is subject to attack by this fruit fly. Not only is it of importance as a destroyer of fruit, but it is the cause of numerous stringent quarantines which cost the State and Federal Governments much money to make effective and which rob countries of good or prospective markets for their fruit. Fortunately, it has been found that the Chinese banana and the pineapple, the two most valuable species of fresh fruits formerly exported from Hawaii, offer so little danger as carriers of the Mediterranean fruit fly, when they are packed for shipment, that this part of Hawaii's export trade in fresh fruits with the coast may still be carried on, provided the inspections of the Federal Horticultural Board now in force are continued. The necessary quarantines against all other host fruits, however, particularly against such fruits as the avocado and mango, has had, and will continue to have, a serious effect upon horticultural pursuits and the development of the small farmer.

FIG. 4.—Apples destroyed by larvæ of Mediterranean fruit fly. Although an apple externally may appear normal aside from the dark spots where the female fly punctured the skin in laying her eggs, the pulp is often found badly decayed and eaten out by the maggots, as shown in the lower fruit. (Original.)

At present the infestation of edible fruits in the coastal regions of Hawaii is general and about as severe as could be expected. The work of the Mediterranean fruit fly, with that of the melon fly, has put a most serious check upon the horticultural development of the islands just at a time when this development was gathering strength. In South Africa the Mediterranean fruit fly is regarded as one of the greatest drawbacks to the development of the fruit industry in Cape Colony, where, it is stated, during certain favorable seasons large areas of apricots, figs, pears, plums, apples (fig. 4), and quinces are almost all affected. Many instances of damage to citrus and other crops in southern Europe, South America, Africa, and Australia might be added to impress one unfamiliar with the ravages of this pest that it is one that can not be trifled with. The amount of damage which would result through the introduction of this fruit fly is so great that every effort should be taken to prevent its establishment in new territory.

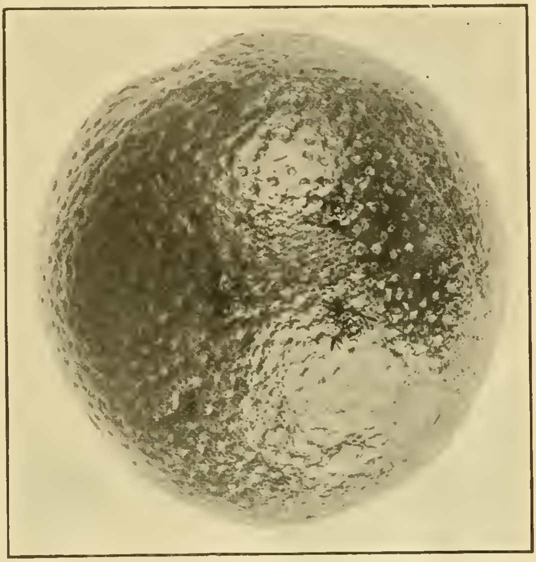

FIG. 5.—Three adults of the Mediterranean fruit fly on a sweet orange. About two-thirds natural size. (Authors' illustration.)

WHAT THE MEDITERRANEAN FRUIT FLY IS LIKE.

The adults.—The Mediterranean fruit fly is an insect that in the adult stage resembles in size and general shape the ordinary house fly, but differs greatly in the color pattern of the body and wings and in its habits. In figure 5 three adults may be seen attempting to lay eggs in an orange. The glistening black spots upon the insects' back, the two white bands on the yellowish abdomen, and the yellow and black markings of the wings at once distinguish this fruit fly from all other insects in Hawaii. The colors, brown, yellow, black, and white, predominate and form a pattern that can be recognized easily after comparison with the drawing of the adult fly (fig. 1).

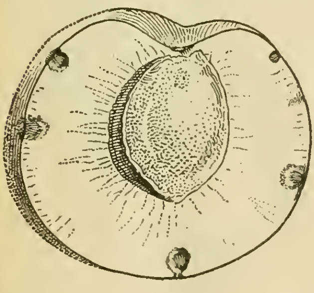

FIG. 6.—Cross section of a small apricot showing eggs laid through skin in five places. (Authors' illustration.)

The eggs.—The female fly is able to drill, with the sharp end of her body, small pinhole-like breaks or punctures in the skin of fruits, and through these punctures she lays her eggs. Naturally, these egg punctures are so small that they are not seen by the average person. Ordinarily the fly lays from one to six eggs through these holes into a small cavity made for them just beneath in the pulp or rind. In some instances several hundred of the small white eggs, which are only about one-twenty-seventh of an inch long and shaped as those illustrated in figures 6, 7, and 21, may accumulate in a single egg cavity as the result of repeated egg laying by many females through the same opening in the skin.

The larvæ.—The eggs hatch into whitish larvæ, or maggots, that burrow or tunnel in all directions through the pulp, feeding as they go and causing decays to start. When first hatched they are very difficult to detect, but when full grown they are very white and, although only four-sixteenths to five-sixteenths of an inch long, are quite easily seen. Full-grown maggots have the peculiar habit, if taken out of the fruit and placed upon a smooth surface, of curling up and jumping from 1 to 6 inches. For the general appearance of the larvæ see figures 8 and 9, *a*.

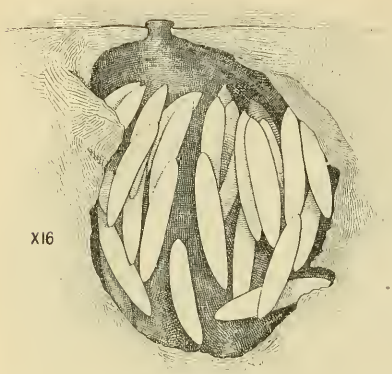

FIG. 7.—Cross section of peach showing general shriveling of walls of egg cavity and separation of eggs. Drawing made one and one-half days after eggs were laid. (Authors' illustration.)

The pupæ.—After leaving the fruit upon which they have fed, the larvæ either burrow into the soil to depths varying up to 2 inches or seek shelter under any object upon the ground and there transform to the pupa or chrysalis stage. During this stage the insect is not able to move and resembles the seedlike object illustrated in figure 9, *b*. Although outwardly appearing quite dead, inwardly the wonderful changes are taking place by means of which nature transforms the ugly maggot into the beautiful fly; and in the course of a few days the adult fly breaks forth from the pupa, pushes her way up through the soil, and, as the mother of a second generation, flies back to the tree and searches for fruits in which to lay her eggs.

FIG. 8.—Small mango fruit cut to show white larvæ or maggots of Mediterranean fruit fly and damage they have caused. (Severin.)

INTERESTING FACTS ABOUT THE ADULT FLY.

Incapable of inflicting bodily injury on man, the adult fly is, nevertheless, the fruit growers' most persistent enemy in Hawaii, for she is continuously searching for fruits in which to lay her eggs. Adults die within three to four days if they have no food; but if they can secure the juices of fruits or the honeydew of insects, which form the bulk of their food, they may live long periods. Two flies lived for 230 and 315 days, respectively. But as a rule life is much shorter, although many live to be four to six months old. Many die when they are very young, even if they have had food.

In Honolulu females begin to lay eggs when 4 to 10 days old, and, like hens, only much more faithfully, continue to develop and lay eggs in fruits almost daily so long as they live. A female may lay on an average from 4 to 6 eggs a day, 22 eggs being the largest number known to have been laid by a fly during any one day. On 10 consecutive days one fly laid 8, 11, 9, 6, 8, 3, 3, 3, 3, and 9 eggs; another laid 0, 5, 14, 8, 13, 10, 6, 4, 4, and 0 eggs. The largest number of eggs laid during life by a single female kept in the labo-

FIG 9.—Mediterranean fruit fly: *a*, Larvæ, or maggots; *b*, pupæ, or chrysalids. Twice natural size. (Original.)

ratory was 622. This fly lived only 153 days. It is probable that 800 eggs, or even more, may be laid by single hardy females under favorable conditions.

It is also important, from the standpoint of control, to know that females deprived of a chance to lay eggs in fruits for a period of four to six months when certain crops are not in season have the power to begin depositing eggs as actively as younger flies when fruits sufficiently ripe become available for oviposition. Thus one female kept in the laboratory for the first five months of her life without fruits in which to lay eggs laid 11, 4, 9, and 9 eggs during the first four days of the sixth month of her life when fruits were placed in the cage with her.

CLIMATIC CONDITIONS FAVORING RAPID INCREASE IN HAWAII.

The time required by the fly to pass through the egg, larva, and pupa stages depends very much upon the climate. The climate of Honolulu and of the coastwise regions of Hawaii in general is very favorable to fruit-fly increase. At Honolulu the temperature rarely drops as low as 58° F., and then only for a few hours during one or two nights in the year. The daily range in temperature is small, averaging between 8 and 11 degrees, while the normal monthly mean temperatures range between 70.9° F. in the winter and 79° F. in the summer. Biological work has shown that even the lowest monthly means of localities up to 1,500 feet elevation have little effect upon the fruit fly other than to retard somewhat its development. It is never cold enough throughout the coastal regions of Hawaii to render either the adults or the larvæ inactive. There are no periods of the year at any Hawaiian port when climatic conditions are unfavorable for fruit-fly increase. A continuous temperature of 58° to 62° F., or the lowest range of temperature usually experienced, does not increase the normal mortality among the larvæ.

FIG. 10.—Three important edible fruits subject to fruit-fly attack: *a*, Strawberry guava; *b*, loquat; *c*, star apple. These are grown also for their ornamental value. (Original.)

LENGTH OF TIME REQUIRED FOR DEVELOPMENT.

During the warmest Hawaiian weather, when the mean temperature averages about 79.5° F., the Mediterranean fruit fly requires as few as 17 or as many as 33 days to pass through its immature stages.

At this season by far the larger number pass through these stages in 18 to 20 days. At an average mean temperature of 68° F., which is about the coolest temperature in Hawaii where fruits are generally grown, the immature stages require 40 to 69 days.

Just what the length of the immature stages may be in cooler regions can not be definitely stated, but experiments indicate that it may be considerably increased. The egg stage has been increased from a normal of 2 days at Honolulu in summer to 25 days by the application for 22 days of a temperature of 48° to 53° F. A well-grown larva survived a temperature of 48° to 54° F. for 79 days. A newly-hatched larva remained practically dormant for 57 days at an out-of-door temperature ranging from 27° to 73° F. (mean 48° F.), whereas in Honolulu during summer it would have remained in this stage only 2 days. The fruit fly has been held in the pupa stage for about two months at an out-of-door temperature ranging between 38° and 72° F. (mean, about 54° F.). Had the mean been about 79° F., it would have remained in the pupa stage only 9 to 11 days. Three larvæ in very firm apples required 28, 58, and 74 days to become full grown and leave the fruit to pupate at Kealakekua, where the temperature ranged between 58° and 80° F. (mean, about 68° F.). Add to the 74 days required for larval maturity 4 days for the egg stage and 20 days for the pupa stage, and one has 98 days, or over three months, as the time required for the fly to pass through the immature stages under certain host conditions at a mean of 68° F. Thus while these stages may be completed in as few as 17 days, three to four months is a very conservative estimate for possible length under less favorable climatic conditions, or a period sufficiently long to outlast the coolest seasons of the semitropics.

FRUITS, NUTS, AND VEGETABLES ATTACKED.

The Mediterranean fruit fly is particularly injurious because it attacks so many more different kinds of fruits of value to man than does any other known fruit fly. In the Hawaiian Islands 72 kinds of fruits have been found infested. Fortunately, the pineapple is not infested, and the banana is free from attack when shipped under commercial conditions. The fruit fly has been reared from the following fruits: Fruits that are heavily or generally infested are marked (1), those that serve quite often as hosts or of which many escape infestation are marked (2), and those rarely infested are marked (3).

List of host fruits of the Mediterranean fruit fly.

SCIENTIFIC NAME.	COMMON NAME.
1. *Achras sapota* (3)	Sapodilla.
2. *Acordia* sp. (3)	Acordia.
3. *Anona muricata* (2)	Sour sop.
4. *Arengia saccharifera* (3)	Sugar palm.
5. *Artocarpus incisa* (3)	Breadfruit.
6. *Averrhoa carambola* (2)	Carambola.
7. *Calophyllum inophyllum* (1)	Ball kamani.
8. *Capsicum* sp. (2)	Bell peppers (fig. 17, p. 19).
9. *Carica papaya* (2)	Papaya.
10. *Carica quercifolia* (2)	Dwarf papaya.
11. *Carissa arduina* (2)	Carissa (fig. 11, *h*).
12. *Casimiroa edulis* (1)	Sapota.
13. *Cestrum* sp. (3)	Chinese inkberry.
14. *Chrysophyllum cainito* (1)	Star apple (fig. 10, *c*).
15. *Chrysophyllum oliviforme* (1)	Damson plum (fig. 11, *d*).
16. *Chrysophyllum* sp. (1)	Chrysophyllum.
17. *Citrus japonica* (1)	Chinese orange (fig. 18, p. 20).
18. *Citrus japonica* (1)	Kumquat.
19. *Citrus nobilis* (1)	Tangerine.
20. *Citrus nobilis* (1)	Mandarin.
21. *Citrus medica limetta* (1)	Lime.
22. *Citrus medica limonum* (1)	Lemon (fig. 19, p. 21).
23. *Citrus decumana* (1)	Grapefruit (figs. 2, 20, 21, 22, pp. 3, 22, and 23).
24. *Citrus decumana* (1)	Shaddock.
25. *Citrus aurantium* (1)	Sweet orange.
26. *Citrus aurantium* var. *amara* (1)	Sour orange.
27. *Clausena wampi* (3)	Wampi.
28. *Coffea arabica* (1)	Coffee (fig. 11, *b*).
29. *Coffea liberica* (1)	Liberian coffee.
30. *Cydonia vulgaris* (1)	Quince.
31. *Diospyros decandra* (1)	Persimmon.
32. *Eriobotrya japonica* (1)	Loquat (fig. 10, *b*).
33. *Eugenia brasiliensis* (1)	Brazilian plum or Spanish cherry.
34. *Eugenia jambos* (1)	Rose apple (fig. 11, *g*).
35. *Eugenia michelii* (1)	Surinam cherry.
36. *Eugenia uniflora* (1)	French cherry.
37. *Ficus carica* (1)	Fig.
38. *Garcinia mangostana* (2)	Mangosteen.
39. *Garcinia xanthochymus* (2)	Mangosteen.
40. *Gossypium* spp. (2)	Cultivated cotton (fig. 11, *e*
41. *Jambosa malaccensis* (2)	Mountain apple.
42. *Lantanis placuachulla* (3)	Palm.
43. *Lycopersicum esculentum* (2)	Tomato.
44. *Litchi chinensis* (3)	Lichee nuts (fig. 11, *c*).
45. *Mangifera indica* (1)	Mango (figs. 8, 24, pp. 8 and 25).
46. *Mimusops elengi* (1)	Elengi tree (fig. 11, *i*).
47. *Murraya exotica* (1)	Mock orange (fig. 11, *f*).
48. *Musa* spp. (3)	Banana (figs. 14 and 15, p. 17).
49. *Noronhia emarginata* (3)	Noronhia.
50. *Ochrosia elliptica* (2)	Ochrosia.

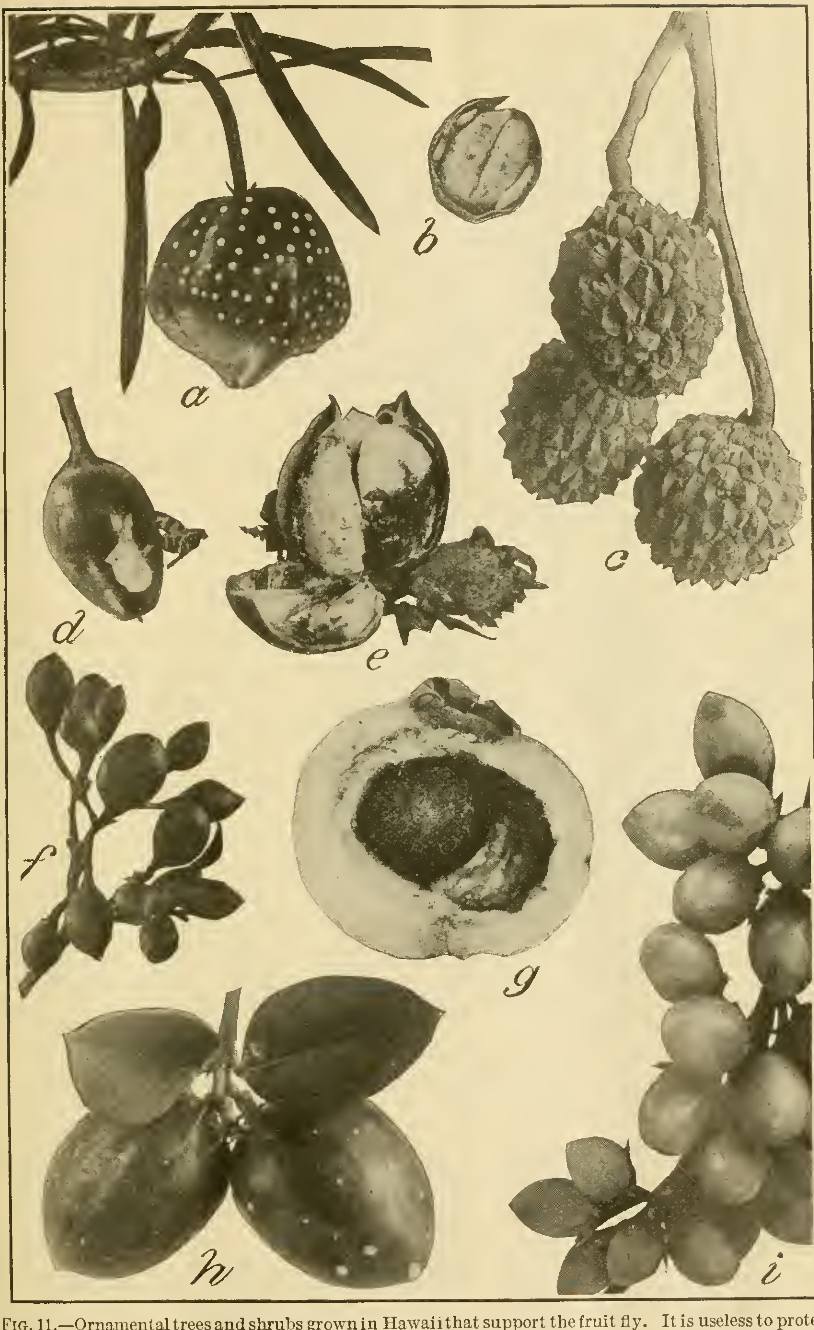

FIG. 11.—Ornamental trees and shrubs grown in Hawaii that support the fruit fly. It is useless to protect edible fruits when ornamentals are allowed to grow near by that harbor the fruit fly: *a*, The bestill, showing drops of white sap that exude when the fly punctures the skin; *b*, a coffee cherry sectioned to show the maggots feeding on the pulp; *c*, the lichee nut is not attacked by the fly unless the outer skin has broken; *d*, a damson plum, showing an adult fly caught in the sticky sap; *e*, a cotton boll infested by the pink bollworm and the fruit fly; *f*, a cluster of mock-orange berries; *g*, a rose apple sectioned to show fruit-fly attack; *h*, the carissa, showing drops of white sap that have exuded from punctures made in the skin by the fruit fly; *i*, the elengi berries, that develop many fruit flies.

51. *Opuntia vulgaris* (2)..................Prickly pear.
52. *Passiflora* sp. (3)....................Passion vine.
53. *Persea gratissima* (2).................Avocado (fig. 13).
54. *Phoenix dactylifera* (3)...............Date palm.
55. *Psidium cattleyanum* (1)...............Strawberry guava (fig. 10, *a*).
56. *Psidium guayava* (1)...................Sweet red and white lemon guavas.
57. *Psidium guayava pomiferum* (1).........Common guava.
58. *Psidium guayava pyriferum* (3).........Waiawi.
59. *Prunus persica* (1)....................Peach (fig. 7, p. 8).
60. *Prunus persica* var. *nectarina* (1)...Nectarine.
61. *Prunus armeniaca* (1)..................Apricot (fig. 6, p. 7).
62. *Prunus* spp. (1).......................Plum.
63. *Punica granatum* (3)...................Pomegranate.
64. *Pyrus* spp. (1)........................Apple (fig. 4, p. 6).
65. *Pyrus* spp. (1)........................Pear (fig. 12).
66. *Solanum melongena* (3).................Eggplant.
67. *Spondias dulcis* (3)...................Wi.
68. *Terminalia catappa* (1)................Winged kamani or tropical almond.
69. *Terminalia chebula* (1)................Natal plum.
70. *Thevetia neriifolia* (1)...............Bestill (fig. 11, *a*).
71. *Vitis labrusca* (3)....................Grape (fig. 25, p. 26).
72. *Santalum freycinetianum* var. *littorale* (3)..............................Beach sandalwood.

This list shows that practically all the ordinary useful and edible fruits in Hawaii are infested heavily. Thus peaches can not be grown at present, for they are ruined before they become well grown; Chinese oranges (fig. 18), tangerines, figs, loquats (fig. 10, *b*), rose apples (fig. 11, *g*), many varieties of mangoes (figs. 8, 24), certain avocados (fig. 13), guavas (fig. 10, *a*), coffee cherries (fig. 11, *b*), star apples (fig. 10, *c*), sapotas, persimmons, apples (fig. 4), pears (fig. 12), plums, nectarines, and quinces—all these are badly infested. On the other hand, a large percentage of the ripening fruits of the tomato, prickly pear, mangosteens, mountain apples, and wampis are free from attack, although certain fruits may be at times heavily infested. When tomatoes are wormy, the melon fly, and not the Mediterranean fruit fly, is usually the insect doing the damage. Ordinarily, sweet bell peppers are not generally infested, and cotton bolls become infested only after they have been damaged by some other insect (figs. 17 and 11, *e*).

The pomegranate, breadfruit, eggplant, wi, grape (fig. 25), date, certain seeds of palms, lichee nuts (fig. 11, *c*), and the Chinese inkberry are very rarely infested, even in Honolulu. For practical purposes they may be said to be immune. Lichee nuts ripening on the tree become infested only when the outer shell breaks, thus exposing the white pulp to attack.

Hawaiian fruits, nuts, and vegetables not listed are free from attack.

ORNAMENTALS SERVING AS HOSTS.

Not only does the Mediterranean fruit fly attack the ordinary cultivated fruits, but in Hawaii it has shown a preference for the fruits of many ornamental trees and shrubs. Thus the nuts of the winged kamani, the ball kamani, the rose apple, damson plum, star apple, Brazilian plum or Spanish cherry, the Surinam and French cherries, the berries of the mock orange and elengi tree, the fruits of the Natal plum, and the mature fruits of the bestill are all usually well infested. Even the fruits of certain palms and the beach sandalwood may harbor the fly. Ornamentals less subject to attack may be found in the foregoing complete list.

FIG. 12.—Bartlett pear, the pulp of which has been entirely eaten out by the maggots of the Mediterranean fruit fly. The fruits often remain on the tree and shrivel up after they have been ruined. (Authors' illustration.)

HOST FRUITS OF COMMERCIAL VALUE.

PINEAPPLES.

Many experiments have been carried on to determine whether the Mediterranean fruit fly can live in the pineapple. It has been found that even under forced laboratory conditions the fly can not live or mature in green or ripe pineapples. No person has ever found a pineapple infested by this pest in Hawaii.

PAPAYAS.

The papaya is one of the commonest plants about Honolulu. Its fruit is the universal breakfast fruit. Probably not one person in a thousand in Honolulu, however, knows that papayas become infested. Unless the fruits are allowed to remain upon the trees until overripe, the fruit fly can not mature in them. The milky juice, which exudes copiously from breaks in the skin of the fruits up to the time when the fruits can be cut for ripening in the house, contains a digestive principle that is fatal to the eggs and larvæ of the fly. This juice protects the fruits from infestation when immature. But as the fruits become overripe, and also unfit for the table, the juice flows less abundantly from breaks in the skin made by the fly when she attempts to lay her eggs, and the eggs which she then lays can mature. As many as 205 flies have been reared from single overripe fruits. So while the papaya is a host fruit, it is practically never infested until too ripe or otherwise unfit for the table.

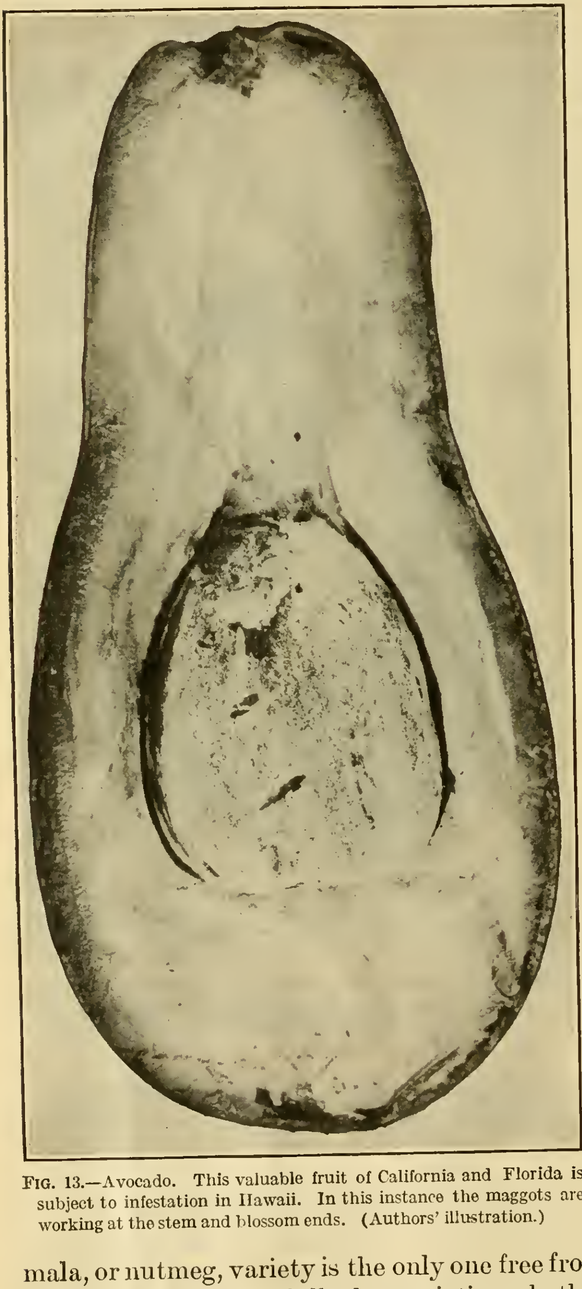

FIG. 13.—Avocado. This valuable fruit of California and Florida is subject to infestation in Hawaii. In this instance the maggots are working at the stem and blossom ends. (Authors' illustration.)

AVOCADOS.

With the exception of one or two early varieties, the infestation of the avocado is so obscure that the general belief prevails in Honolulu that this fruit is free from attack. The Guatemala, or nutmeg, variety is the only one free from attack when growing uninjured. The skin of all other varieties, whether thin or of usual toughness, can be punctured by the adult fly, as proved by many examinations of fruits. The avocado, like the ordinary pear, is best when picked

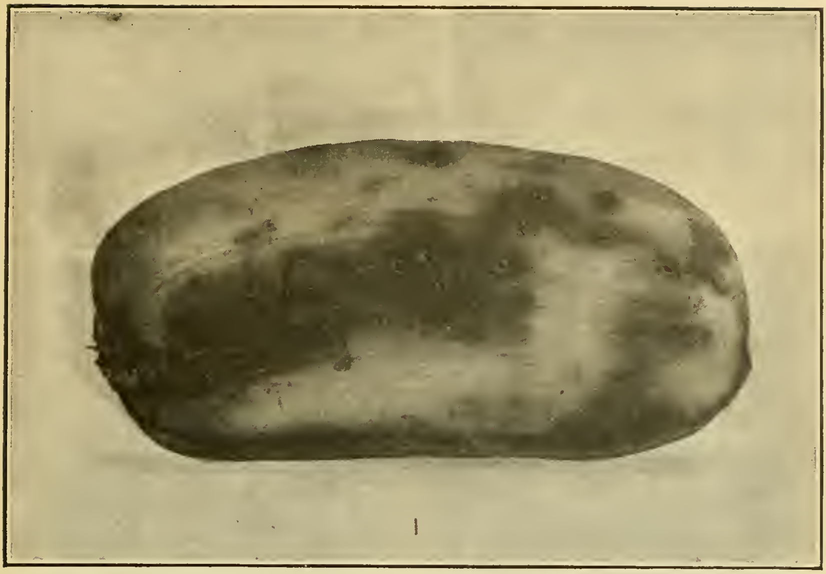

FIG. 14.—Cooking banana of the Popoulu variety taken from tree in an infested condition. Note small round holes in the skin through which maggots left the fruit when they became full grown. (Authors' illustration.)

FIG. 15.—Cooking banana of the Moa variety cut to show destruction of pulp by maggots of the Mediterranean fruit fly. (Authors' illustration.)

while still hard, though mature, and allowed to soften in storage. With most varieties it is not until the fruits are mature enough for gathering or dropping that adults lay eggs in them. Many fruits upon the market are not in the least affected. While avocadoes are not usually a favorite host for the fly, they are sufficiently infested to warrant the quarantine prohibiting the shipment of them to the mainland. (See fig. 13.)

BANANAS.

Experimentation during the past four years in Hawaii has proved that the Chinese banana [1] and the Bluefields banana [2] are practically immune from attack if harvested and shipped to the coast in accordance with the demands of the trade and the Federal Horti-

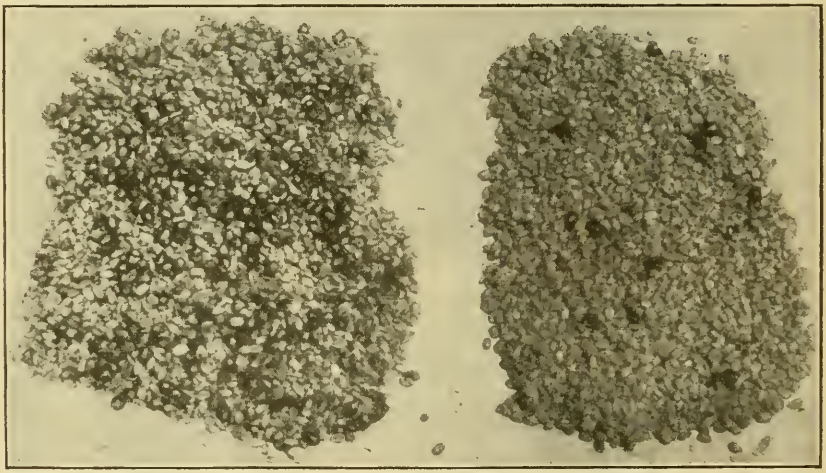

FIG. 16.—Loss to coffee-mill owners due to infestation of coffee cherries by Mediterranean fruit fly. Coffee beans to left pulped from uninfested cherries; beans to right pulped from infested cherries. Cherries failing to pulp, because infested, appear as black; pulped beans are grayish white. (Original.)

cultural Board. Persons wishing the results of careful experimental work used as a basis for these conclusions may obtain them in printed form by applying to the Bureau of Entomology. The immunity of commercial varieties of bananas has been shown to be due to the fact that neither the eggs nor the newly-hatched larvæ can survive in the tannin-laden peel of the green though mature fruit. Indeed, the copious and sudden flow of sap from egg punctures made by the female fly in unripe bananas renders the successful placing of eggs in such fruits difficult and rare.

No fruits of the Chinese variety ripening prematurely on bunches in plantations have been found infested. But of the cooking bananas, flies have been reared from the ripe and yellowish fruits of the thin-skinned Popoulu variety (fig. 14) growing in the field, and from the

[1] *Musa cavendishii.* [2] *Musa sapientum.*

well-grown though green-colored fruits of the Moa variety, the peel of which had become cracked, thus causing a break in nature's normal protection to the pulp. Figure 15 is a cross section of a Moa banana, showing the tunnels made through the pulp by the larvæ, and the darkened decayed areas about the tunnels. Adults have been reared also from another variety of cooking bananas.

Because flies have been reared from cooking bananas, it is not considered safe to permit their export to the coast, and they have been placed on the list of quarantined fruits by the Federal Horticultural Board. The Chinese and Bluefields bananas may still be exported from Hawaii, provided they are grown and inspected before shipment in accordance with Federal regulations. So far as is known, the "apple" and the "ice-cream" bananas common in Hawaii are not infested.

FIG. 17.—Sweet bell pepper infested by Mediterranean fruit-fly larvæ. Note that the upper right-hand portion of fruit has decayed as a result of attack. This decay later extends to all parts of the fruit. (Original.)

COFFEE.

Coffee cherries as they ripen are favorite hosts of the Mediterranean fruit fly. Fortunately, the larvæ attack only the pulp surrounding the beans or seeds, and in no way affect the value of the latter (see fig. 11, *b*). Chemical analyses of beans from infested and uninfested cherries, tasting tests of coffee made from similar roasted beans, and weighings made of dried beans have failed to reveal any ill effect to the beans themselves due to fruit-fly attack.

The unrestricted development of larvæ within coffee cherries, however, does bring about certain losses to the grower and mill owner. Before parasites were introduced cherries became infested as soon as they began to turn white from green in the final ripening process, and the larvæ, numbering from 2 to 8, were able to become nearly full grown by the time the cherries had turned red. The pulp surrounding the beans varies from two to seven fifteenths of an inch in thickness, or is scarcely thicker than the well-grown larva of the fruit fly (see fig. 30, p. 39). Therefore, by the time the cherry is ordinarily ready for harvesting, the larvæ have devoured practically all the pulp, leaving the seeds hanging more or less loosely within a sack comprised of the thin skin of the cherry. If the weather happens to be dry, the skin shrivels and hardens about the beans and the cherry remains on the branch indefinitely and resembles those killed by disease. However, should the harvesting season be rainy, the skin decays rapidly, and under the weight of the beans the cherry falls to the ground. A slight jar may at such times cause many cherries to fall to the ground, where they are lost. This type of loss necessitates extra pickings and greater cost for labor. Since the successful introduction of parasites the fruit fly has been so reduced in the coffee field that the infestation of cherries occurs so late in the ripening process that extra pickings are not necessary, and the cherries on reaching the pulping mills during the height of the harvesting season contain chiefly eggs or young larvæ which have not had an opportunity to reduce the pulp.

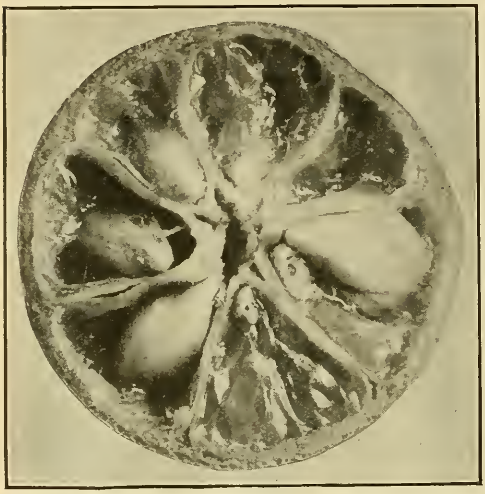

FIG. 18.—Chinese orange sectioned to show damage by Mediterranean fruit fly. Chinese oranges, kumquats, tangerines, satsuma oranges, and many limes are easily and generally infested because of their loose peel and lack of a thick protective rag. (Original.)

Badly infested cherries do not pulp as readily when run through the pulping mill, and naturally weigh much less than sound cherries. (Fig. 16.) The loss in number of cherries in a given weight of badly infested fruit has been found to vary at times from 27 to 59 per cent. This loss in weight, which takes place only in the worthless pulp, and in no way affects the bean, which alone is of commercial value, brought about a financial loss to growers who sold their fruit by weight according to prices obtained before the fruit fly was introduced. This has been appreciated and has caused a readjustment of prices paid for coffee "in the cherry" and has been responsible for the erection of many small pulping mills throughout the Kona coffee district.

It seems reasonable to believe that the remarkable success of introduced parasites in checking the infestation of coffee will free the coffee grower from further worry so far as the Mediterranean fruit fly is concerned.

CITRUS FRUITS.

While all citrus fruits are favorite hosts of the Mediterranean fruit fly, certain of them are found to contain larvæ more often than others. No citrus fruits are too acid for fruit-fly development. Larvæ have been reared from the sourest lemons. Adult flies are fond of laying eggs in large numbers in all citrus fruits. Thus 13 punctures in one grapefruit contained 76, 153, 32, 25, 18, 8, 46, 113, and 9 eggs, respectively. Thirty-nine oranges, either yellow or orange in color, contained an average of 32 egg punctures, with a maximum of 108 and a minimum of 7 punctures. In 50 ripe lemons 1,422 eggs were laid in 185 punctures. Yet no adult flies developed from this grapefruit or from the oranges and lemons. On the other hand, well ripened Chinese oranges (fig. 18), thin-skinned limes, kumquats, and tangerines are so generally infested with larvæ in the pulp before they become well ripened that they are always regarded with suspicion.

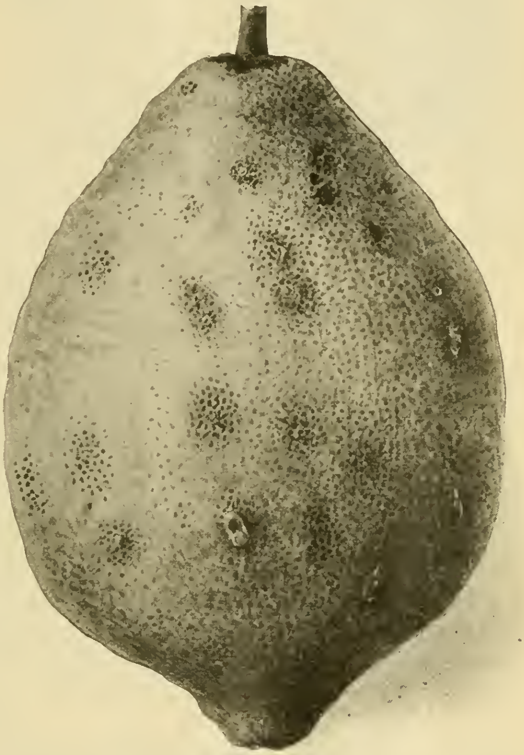

FIG. 19.—Lemons of commercial varieties have never been found with larvæ of the Mediterranean fruit fly destroying the pulp unless they have had the rind cut or broken previous to attack. The adult flies may puncture the skin and lay eggs, as indicated by the discolored spots, but the eggs and larvæ die in the peel. (Original.)

Although many eggs are laid in lemons, it is rare that lemons are found with maggots in the pulp even when the fruits are so ripe

FIG. 20.—Ripe grapefruit showing copious gummy secretions that may, though more often do not, follow attack by Mediterranean fruit fly. (Original.)

that they fall to the ground. Why, then, are Chinese oranges and tangerines easily infested with larvæ in the pulp whereas lemons, grapefruit, and oranges ward off fatal attack either entirely or until after they are overripe?

The reason is that a great mortality occurs among the eggs and newly hatched larvæ in citrus fruits having a thick peeling or rind. In Chinese oranges the peel is so thin that the fruit fly can lay her eggs through it into the pulp itself or between the pulp and the rind, so that the larvæ on hatching can at once begin to feed on the pulp. As a result the pulp of the Chinese orange (fig. 18) is almost always infested with larvæ. The case is different with lemons (fig. 19), grapefruit (fig. 20), and ordinary seedling oranges. In these fruits the peel is so thick that the fly must deposit her eggs in the outer part of the white rag as illustrated in figure 21. In making the puncture she often ruptures an oil cell in the rind, and the oil thus liberated kills the eggs. But if the eggs are laid between oil cells, the young larvæ have difficulty in making their way through the rag to the pulp, and a very high percentage of them die in the attempt.

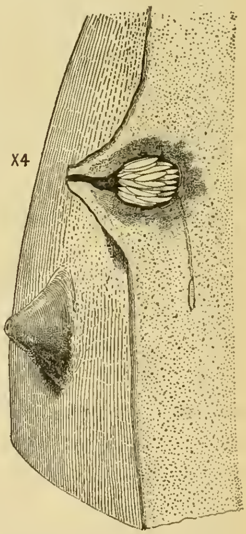

FIG. 21.—Section of grapefruit rind, showing two egg cavities, one in cross section. Drawing made one week after fruit was picked. Note conical elevation about egg cavities left by withering of rind; also thickened walls of egg cavity and single larval channel in the rag. (Authors' illustration.)

Then, too, a gall-like hardening develops quite rapidly about the egg cavity in oranges, grapefruit, and lemons, as indicated by the darkened area about the egg cavity in figure 21. This hardening often makes of the cavity a prison from which the young larvæ can not escape and in which they are literally starved to death.

It thus happens that the larvæ that succeed in entering the rag of the peel from the egg cavity are able to reach the pulp of grapefruit and oranges in astonishingly small numbers because of the imperviousness of the rag. It is the persistent attack of successive families of larvæ hatching from different batches of eggs laid in the same punctures that finally breaks down the barrier between the young larvæ and the pulp. A fuller discussion of the infestation of all citrus fruits may be had on application to the Bureau of Entomology.

Regardless of what has just been stated concerning the great mortality that occurs among the eggs and young larvæ in the rind

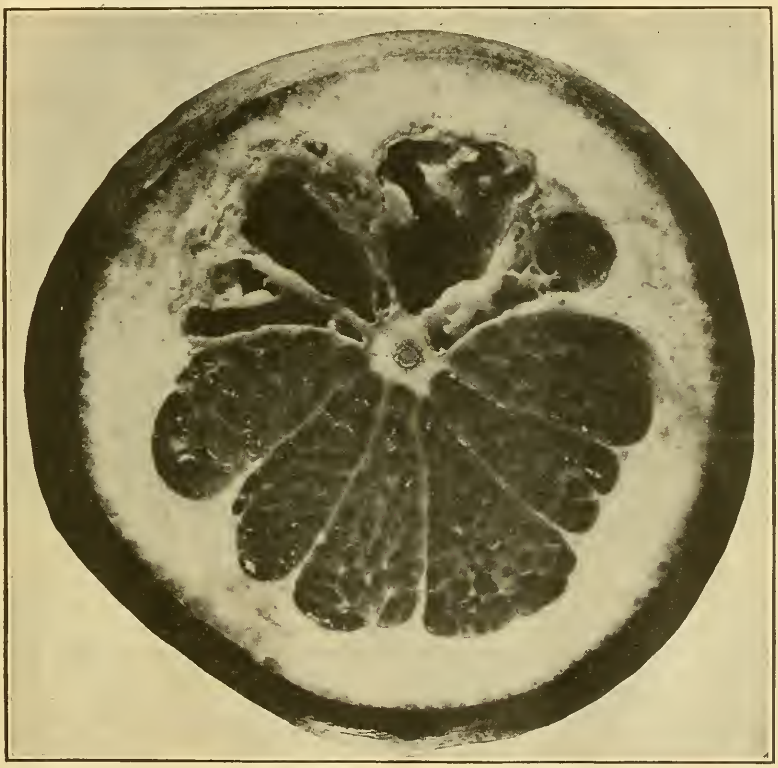

Fig. 22.—Cross section of grapefruit to indicate difficulty of always telling from exterior appearance of a fruit that maggots are eating out the pulp. (Authors' illustration.)

of grapefruit, oranges, and lemons, adult flies have been reared from them all. Lemons, however, have never been known to be infested in the pulp unless the rind has first become broken by thorn pricks, decays, or in some other mechanical manner. And in spite of the fact that oranges and grapefruit may become very wormy, as illustrated in figures 2 and 22, they are usually uninfested in the pulp, and are fit for table use if they are gathered as soon as they ripen. But if citrus fruits were grown commercially in Hawaii in large orchards as they are in Florida and California, and were severely attacked as they are in Hawaii to-day, they could not be shipped profitably, for, although they might not contain larvæ within the pulp, the many breaks in the rind made by the flies while laying eggs would make possible the entry of various molds (see fig. 23) that

FIG. 23.—Orange injured by Mediterranean fruit fly. Each black spot represents a place where the fruit fly has punctured the rind to lay eggs, but the maggots were not able to eat through the peel, and died. About the injured spot decays have started which at first affect only the peel. Blue mold grows rapidly in these injured spots. (Original.)

would cause unprecedented decays while the shipments were en route to market.

ARTIFICIAL METHODS OF CONTROL NOT SATISFACTORY UNDER HAWAIIAN CONDITIONS.

It is unfortunate that the satisfactory methods of control used against the Mediterranean fruit fly in several other countries, particularly in portions of South Africa and Australia, have failed in Hawaii. There are, however, several good reasons for such failures. The great money-making crops of Hawaii at present are sugar, pineapples, rice, coffee, taro, bananas, and cattle. But sugar, pineapples, and taro are not attacked by this fruit fly, and, as already shown, coffee and bananas are not sufficiently attacked to injure their commercial value. With one exception, including a small number of avocados, no commercial orchards exist in Hawaii. Still there is hardly a family, unless it be in the business section of Honolulu, that does not grow a number of fruit trees, such as oranges, lemons, papayas, peaches, avocados, limes, grapefruit, guavas, bananas, mangoes, etc., that bear prodigally under normal Hawaiian cultural conditions, and, until the advent of the fruit fly in 1910, formed a most welcome addition to the food supply.

Much of the native-grown fruit that is sold in the local market is grown on trees scattered here and there in dooryards and is in excess of what the owner needs. Practically no one depends on growing fruit for his living. No developed fruit industry exists such as one finds on the mainland, and no moneyed interest concerns itself with steps for fruit-fly eradication. In other words, there are no impelling incentives to solidify public opinion for the consistent and cooperative use of artificial remedial measures that could be made effective if their application would yield returns warranting the expenditure.

FIG. 24.—Improved mango sectioned to show havoc caused by maggots of Mediterranean fruit fly. (Authors' illustration.)

The situation also is made more difficult by reason of the large amount of vegetation, bearing fruits of little or no value to man, that grows throughout the islands and that can not be eradicated without the expenditure of prohibitive sums of money.

But this great abundance of dooryard and wild host vegetation has had such a vital part in the undoing of artificial control measures and in the success of parasite introductions that it is worthy of further attention. Aided by a favorable climate, it has made of Hawaii a fruit-fly paradise that is not duplicated elsewhere on the earth.

THE CAMPAIGN AGAINST THE FRUIT FLY IN HAWAII.

HOST CONDITIONS IN HONOLULU AND HILO.

The residents of Honolulu and Hilo are justly proud of their magnificent vegetation and have taken great pleasure in growing an

FIG. 25.—This bunch of grapes, apparently perfect, contains one berry that is decayed and contains a larva of the Mediterranean fruit fly. The Isabella grapes in Hawaii are seldom attacked, even in Honolulu, yet they are likely to carry the fly to California. (Original.)

unusually large assortment of trees and shrubs on their properties. An inventory of such trees and shrubs in the portion of Honolulu bounded by Liliha, Punchbowl, Beretania, and School Streets gave a total of 4,610 that bore fruits in which the fruit fly can develop.

TABLE II.—*Number and species of host trees of the Mediterranean fruit fly growing in that portion of Honolulu bounded by Liliha, Punchbowl, Beretania, and School Streets.*

Apricot	1
Avocado	653
Breadfruit	58
Carambola	48
Chinese inkberry	6
Chinese orange	148
Coffee	298
Coffee, Liberian	8
Cotton	11
Custard apple	1
Damson plum	4
Fig	201
Guava, common	94
Guava, strawberry	73
Java plum	80
Kamani, ball	4
Kamani, winged	13
Kumquat	4
Lemon	22
Lichee	40
Lime	10
Loquat	33
Mandarin	28
Mango	1,154
Mangosteen	7
Mountain apple	41
Mock orange	33
Orange, sweet	372
Papaya	687
Peach	69
Pear, Bartlett	2
Pomegranate	128
Pomelo	15
Rose apple	25
Sapodilla	5
Sapota	30
Sour sop	57
Spanish cherry	1
Star apple	4
Surinam cherry	63
Wi	19
Waiawi	60
Total	4,610

In this area of 60 blocks of varying size, 712 dooryards, or estates, averaged 6.5 host trees or shrubs.

In Hilo, island of Hawaii, host conditions are quite as favorable for fruit-fly increase as in Honolulu. Thus the following numbers of host trees and shrubs were found in certain yards during March, 1914.

YARD 1.

Rose apple	1
Surinam cherry	4
Japanese plum	2
Mountain apple	6
Star apple	1
Coffee trees	34
Common guava	20
Brazilian banana	15
Avocado	4
Mango	3
Papaya	2
Orange	5
Peach	1
Grape	1
Winged kamani	1
Mangosteen	1
Fig	1
Mimusops	1

YARD 2.

Surinam cherry	2
Papaya	2
Thevetia	1
Orange	2
Strawberry guava	2
Coffee	14
Bananas.	
Avocado	2
Peach	1
Fig	3
Mountain apple	2
Lichee nut	2
Common guava	3

YARD 3.

Rose apple	11
Mango	2
Thevetia	3
Avocado	1

YARD 4.

Peach	4
Mango	6
Loquat	1
Winged kamani	3
Surinam cherry	2
Strawberry guava	1

The great variety of host vegetation which ripens its fruit at different seasons leaves no time in Hawaii when fruits are entirely out of season. The fact that certain hosts, such as the Chinese orange, Surinam cherry, and mock orange, bear several crops a year and others, such as specimens of the ball and the winged kamanis and the bestill, appear to be seldom entirely free from ripening fruits, assure food for the fruit fly the year round. The succession of fruits also is increased by the individuality of trees of the same species, or even of certain branches of a single tree, which results in a very uneven ripening of the fruit. While the data in Table III do not indicate the seasonal abundance of host fruits, they have been summarized from the collections of clean-culture inspections during 1913 to show the remarkable succession of host fruits ripening in greater or less abundance throughout the year in Honolulu. The presence of so much ripening fruit, much of it on tall trees such as those illustrated in figures 26, 27, and 28, has made it possible for the fruit fly to multiply with unprecedented rapidity and thwart artificial remedial measures.

TABLE III.—*Data indicating the seasons of the year when inspectors of the clean-culture campaign collected various fruits infested by the Mediterranean fruit fly.*[1]

Fruit.	Jan. 1–11.	Jan. 13–18.	Jan. 20–25.	Jan. 27–Feb. 1.	Feb. 3–8.	Feb. 10–15.	Feb. 17–22.	Feb. 24–Mar. 1.	Mar. 3–8.	Mar. 10–15.	Mar. 17–22.	Mar. 24–29.	Mar. 31–Apr. 5.	Apr. 7–12.	Apr. 14–19.	Apr. 21–26.	Apr. 28–May 3.
Avocado	....	....	....	×	....	....	....	×	....	....	....	....	....	×	....	....	....
Carambola	×	×	×	×	×	×	×	×	×	×	×	×	×	....	×	×	....
Chinese orange	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Chrysophyllum spp	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coffee	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Damson plum	×	×	×	×	×	×	×	×	×	×	....	....	....	....	×	×	×
Surinam cherry	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Fig	×	×	×	×	....	×	×	×	×	×	×	×	×	×	×	×	×
Grapefruit	×	×	×	×	×	×	....	×	×	×	×	×	....	×	....	....	....
Guava	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Kamani, ball	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Kumquat	....	×	×	×	....	×	×	....	....	....	×	....	....	×	....	....	×
Lime	×	×	×	×	×	×	×	×	×	×	....	×	×	....	×	×	....
Loquat	×	×	×	×	×	×	×	×	×	×	×	....	×	×	....	×	×
Mango	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Mock orange	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Mountain apple	....	....	×	×	×	....	×	×	....	×	....	....	....	....	×	×	×
Orange	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Papaya	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Peach	....	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Pepper	×	×	×	....	×	×	×	×	×	×	×	×	×	×	....	....	....
Prickly pear	....	....	×	....	....	×	....	....	....	....	....	....	×	....	....	×	....
Rose apple	....	×	....	×	×	×	×	×	×	×	×	×	....	×	×	×	×
Star apple	....	....	....	....	....	....	....	....	×	×	×	×	×	....	×	....	×
Bestill	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Sour sop	....	....	....	×	×	×	×	×	....	×	×	×	×	×	×	×	×
Mandarin	×	×	×	×	×	×	×	×	×	×	×	....	×	×	×	×	×
Lemon	×	×	....	×	....	×	....	×	×	×	×	×	....	×	×	×	×
Kamani, winged	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Spanish cherry	....	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Bartlett pear	....	....	....	....	....	....	....	....	....	....	....	×	×	×	....	....	....

[1] This table is not intended to indicate the seasonal abundauce of host fruits.

TABLE III.—*Data indicating the seasons of the year when inspectors of the clean-culture campaign collected various fruits infested by the Mediterranean fruit fly*[1]—Continued.

Fruit.	May 5–10.	May 12–17.	May 19–24.	May 26–31.	June 2–7.	June 9–14.	June 16–21.	June 23–28.	June 30–July 5.	July 7–12.	July 14–19.	July 21–26.	July 28–Aug. 2.	Aug. 4–9.	Aug. 11–16.	Aug. 18–23.	Aug. 25–30.
Avocado	....	....	....	×	....	....	....	....	×	×	×	×	×	×	×	×	×
Carambola	×	....	....	....	....	....	....	....	....	....	×	×	×	×	×	×	×
Chinese orange	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Chrysophyllum spp	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	×	....
Coffee	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Damson plum	×	×	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....
Surinam cherry	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Fig	×	×	....	×	×	....	....	....	....	×	×	....	×	....	×	×	....
Grapefruit	×	×	....	....	×	....	....	....	....	....	....	....	×	....	....	×	....
Guava	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Kamani, ball	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Kumquat	×	×	....	....	×	....	....	....	....	....	....	....	....	×	....	×	×
Lime	....	....	×	....	×	×	×	....	×	×	....	×	×	×	×	×	×
Loquat	....	....	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....
Mango	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	....	....
Mock orange	×	....	×	×	×	×	....	×	....	×	×	....	×	....	×	×	×
Mountain apple	×	×	×	×	×	....	....	×	....	....	....	....	....	....	....	....	....
Orange	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Papaya	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Peach	×	×	×	×	×	×	×	×	×	....	×	×	×	....	×	....	....
Pepper	....	....	....	....	....	....	....	....	....	×	×	....	....	×	....	....	....
Prickly pear	....	×	....	....	....	....	....	×	×	×	×	×	×	×	×	×	×
Rose apple	×	×	×	×	×	×	×	×	×	×	×	×	×	....	×	×	....
Star apple	×	×	....	×	×	....	....	....	....	....	....	....	....	....	....	....	....
Bestill	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Sour sop	×	×	×	....	×	×	×	×	×	×	×	....	×	×	×	×	×
Mandarin	×	×	×	....	....	....	....	×	....	×	....	×	×	....	×	×	×
Lemon	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Kamani, winged	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Spanish cherry	....	....	....	....	×	×	×	×	×	×	×	×	×	×	×	×	×
Bartlett pear	....	....	....	....	....	....	....	×	....	....	....	....	×	....	....	....	....

Fruit.	Sept. 1–6.	Sept. 8–13.	Sept. 15–20.	Sept. 22–27.	Sept. 29–Oct. 4.	Oct. 6–11.	Oct. 13–18.	Oct. 20–25.	Oct. 27–Nov. 1.	Nov. 1–9.	Nov. 11–16.	Nov. 18–23.	Nov. 25–30.	Dec. 2–7.	Dec. 9–14.	Dec. 16–21.	Dec. 23–31.
Avocado	×	×	×	×	×	....	....	×	....	....	....	....	....	×	×	×	×
Carambola	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Chinese orange	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Chrysophyllum spp	....	×	×	....	×	....	....	×	....	....	....	....	....	....	....	....	....
Coffee	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Damson plum	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Surinam cherry	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Fig	×	×	....	×	....	×	....	....	....	×	....	×	×	×	×	....	×
Grapefruit	....	....	....	....	×	×	....	×	×	×	×	....	×	×	×	×	×
Guava	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Kamani, ball	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Kumquat	....	×	×	×	×	×	×	×	×	....	....	....	×	×	....	....	×
Lime	....	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Loquat	....	....	....	....	....	....	....	....	....	×	×	×	×	×	×	×	×
Mango	×	....	....	....	....	....	....	....	×	×	×	×	....	×	×	×	×
Mock orange	×	×	....	×	×	×	×	×	×	×	×	×	....	×	×	×	×
Mountain apple	....	....	....	....	....	....	....	....	....	×	....	×	....	×	....	....	×
Orange	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Papaya	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Peach	×	....	....	....	×	....	....	....	....	×	....	....	....	....	....	....	×
Pepper	×	×	....	×	....	....	....	×	×	×	×	×	×	×	×	×	×
Prickly pear	×	×	×	×	×	×	×	×	....	....	....	....	....	×	×	×	×
Rose apple	....	....	....	×	×	....	×	×	....	....	....	....	....	....	....	×	×
Star apple	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....
Bestill	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Sour sop	×	×	×	×	×	×	×	×	×	....	....	....	×	....	×	....	×
Mandarin	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Lemou	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Kamani, winged	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Spanish cherry	×	×	×	×	×	×	×	×	×	×	×	....	....	....	×	×	×
Bartlett pear	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

HOST CONDITIONS IN THE COUNTRY.

While host conditions within the city limits render useless such artificial control measures as can be applied under existing conditions, country host conditions are almost, if not quite, as discouraging. Here the fruit fly has been able to establish itself, often miles from towns, in some one or more of its hosts which have escaped cultivation and have spread over uncultivated and uncultivable areas. Of such hosts, the common guava is the most abundant. It has taken possession of the roadsides, pastures (as shown in fig. 26), vacant town lots, mountain gulches and hillsides, and even crevices on precipices. So easily does the plant grow from seed and so thoroughly distributed are its seeds by cattle, birds, and man,

FIG. 26.—Men cutting down a dense thicket of guava bushes. In such a guava scrub ripening fruits are present throughout the entire year and in them the Mediterranean fruit fly breeds, often far from cultivated fields. (Authors' illustration.)

that it is seldom that in the lowlands, except in very arid areas, a bush can not be found within a stone's throw. In pastures and mountain gulches up to an elevation of at least 1,500 feet, particularly where sheltered from strong winds and well watered, the guavas may become very treelike and form dense thickets. While the guava fruits most heavily during the spring and fall months, the bushes are continuously in bloom and ripen a sufficient number of fruits to support the fruit fly every month in the year.

Second to the guava as a host occurring in the wild uncultivated areas is the prickly-pear cactus. Though the fruits of this plant are not preferred by the fruit fly, they are sufficiently infested in the absence of more favored hosts to serve as food, and, as in the case of the guava, there is almost no time during the year when a few ripe fruits can not be found in any cactus scrub.

Other host fruits, wild or escaped, are not so generally distributed. As a few of the many examples, there may be mentioned a grove of ball kamani trees in an isolated valley on the Island of Molokai, gulches overgrown with the passion vine and the damson plum on the island of Maui, the thickets of winged kamani growing along the windward shores of the island of Oahu, and the wild coffee in the forests of Oahu and Hawaii.

In addition to the wild fruits in country places, the fruit fly finds strongholds in the many, and often isolated, native home sites scattered throughout the coastal region. About these may be growing the mango, rose apple, orange, peach, ball and winged kamanis, etc. The Kona district of Hawaii has large areas containing thousands of acres of coffee under cultivation in which the fruit fly finds food at all seasons of the year, because of the uneven ripening of the crops due to the varying altitudes at which coffee is grown.

CLEAN CULTURE A FAILURE IN HAWAII.

Clean culture in its broadest sense includes not only the detection, collection, and destruction of all infested fruits, but also the elimination of useless or unnecessary host vegetation. In some one or all of its phases it has been recommended and practiced in every country where the fruit fly is a pest, but in nearly all of these the apparent indifference displayed by the majority of the people, no matter how much they may have lamented their losses, has rendered clean culture inefficient.

The clean-culture campaign instituted by the Hawaiian board of agriculture during the fall of 1911 and continued by the Federal Bureau of Entomology from October, 1912, until April, 1914, was a failure from the very start in that it did not protect fruits from attack. There were minor contributory causes, but the main reason for failure was the insurmountable difficulties placed in the way of success by territorial legislation, adverse host and climatic conditions, and the lack of any commercially grown crop worth protecting. This method of control proved hopeless after the first few months' trial from the standpoint of alleviating the Hawaiian situation, and while the destruction of fruit was encouraged, in the absence of a better plan for lessening the opportunities for spread of the pest to the coast by means of infested fruits carried on board ships sailing from Honolulu, it has since been discontinued.

It is doubtful if any clean-culture campaign against the fruit fly has ever been organized so efficiently or on so large a scale as was that organized by the Hawaiian board to include Honolulu. That this method should prove a failure under Hawaiian conditions is no reflection upon the ability of those directly in charge of the work. The law prohibited inspectors from gathering and destroying the fruits unless they could first prove to the satisfaction of the property holders that each fruit was infested. This restriction placed upon the activity of the inspectors led to numerous difficulties between inspectors and those opposed to clean culture. This law also prohibited a systematic gathering of all host fruits within a given area, thus necessitating many examinations for the removal, as they ripened, of the fruits of each single tree. As fruits ripen rapidly in the semitropics, it proved a physical impossibility to arrange visits of inspectors frequently enough to prevent infested fruits from falling to the ground.

The data of Tables II and III demonstrate the immense number and diversity of host trees and shrubs in Honolulu and the ease with

FIG. 27.—Ball kamani trees grown for shade and ornament. This tree grows to a large size, and sometimes in dense thickets in the forest. Its fruits ripen at all seasons of the year and are badly infested by the Mediterranean fruit fly. (Authors' illustration.)

which the fruit fly, uncurbed by climatic conditions, finds fruit for egg laying during any day of the year. It is absurd to endeavor to remove all the fruit from many of the huge trees of the islands. There are numerous large trees (figs. 27, 28) beneath which infested fruits may be gathered each week in the year, yet the trees are so tall and brittle that no inspector can remove the fruits before they ripen. One yard in Hilo has 15 host trees from 20 to 50 feet high. To these examples might be added many others in which the removal of fruits is equally impracticable. Often the fruits of the star apple, for instance, ripening in the tops of tall trees do not fall until long after they have shriveled up and until after the many larvæ developing within have matured and dropped from them to the ground. One acre of guava or of coffee can support the fly throughout the year without the aid of other host fruits and form a center for the reinfestation of surrounding areas. Notwithstanding the fact that the bulk of the ripening and infested fruits can be collected except during the mango season, lasting from May to July, and fruit-fly conditions unquestionably improved from the standpoint of the numerical abundance of adult flies, the important fact remains that the number of fruit flies that succeed in reaching maturity is sufficiently large to infest practically every fruit ripening within the city.

Clean culture can not be made effective under present conditions. The islands are thoroughly overrun with the fruit fly, and this applies

Fig. 28.—The fruits of this tree, the winged kamani, ripening throughout the year, are badly infested by the Mediterranean fruit fly. The nuts of this one tree are enough to supply adult flies for an entire neighborhood. (Authors' illustration.)

quite as much to the guava scrubs in pastures or lava flows and in mountain gulches as within city limits. By far the larger proportion of the host trees and shrubs are grown more for protection from the tropic sun and for their ornamental value than for their fruits. Large numbers of the host fruits are not edible. The destruction of host vegetation is out of the question until it can be proved that some worth-while advantage can be gained. To cut down all host trees in Honolulu at present would mean the removal of a large percentage of her prized vegetation without giving her citizens any adequate compensation.

VALUE OF ELIMINATING HOST VEGETATION.

In Honolulu many mango and orange trees were either cut down or severely trimmed, but those cut formed too small a percentage of the entire host vegetation to serve a practical purpose. The only places where the elimination of host vegetation yielded favorable results were about banana and pineapple plantations where the work was done in accordance with the regulations of the Federal Horticultural Board. In these instances the destruction of vegetation did not eliminate the adult flies, for these came in from surrounding areas. It did, however, lessen the danger of immature stages becoming attached to the packing material of bananas and pineapples shipped to the mainland.

Should the Mediterranean fruit fly ever become established in California or the Southern States, however, where there is no such wealth of native host fruits and where climatic conditions will prove an important factor in control, the elimination of host vegetation will play a most valuable part in remedial measures. In Algeria the infestation of oranges greatly increased after such crops as peaches and persimmons were grown. These fruits furnished food for the fly during the summer and early fall months, which were for the fly starvation months previous to the cultivation of these crops. Aided by these summer crops, the fruit fly was able to increase greatly, so that when the orange crop began to ripen during the fall and winter months the pest could attack it with increased force. In Bermuda the elimination of a comparatively few host trees, numerically speaking, would mean the elimination of breeding places for considerable areas. The destruction of unnecessary and valueless host trees will not only restrict the breeding ground, but will often so break up the sequence of ripening hosts that many adult flies will die while attempting to bridge the starvation periods when no fruits can be found for egg laying.

DESTRUCTION OF INFESTED FRUITS AND SPRAYING.

The destruction of infested fruits and spraying are remedial measures that should go hand in hand. In Honolulu they have not given satisfactory results for reasons beyond the control of man, as set forth on pages 24 to 33. Nevertheless, they can be made successful in commercial orchards, if applied with intelligence and persistence throughout a neighborhood. One indifferent neighbor can spoil the work carried on in surrounding orchards. A community of growers must determine in what crop their interests are centered and impartially eliminate nonessential fruits. Then, and, as a rule, not until then, will labor spent on the destruction of infested fruits and on spraying prove worth while. Sprays are applied to kill the adults; fruits are destroyed to kill the eggs and contained larvæ.

DESTRUCTION OF INFESTED FRUITS.

Larvæ infesting fruits may be killed by submerging the fruits in water or by burying, boiling, or burning the fruits. The choice of method will depend largely upon the quantity of fruit to be handled and upon local conditions. The surest way to kill all immature stages of the fruit fly is to boil or burn the fruits. Burning the fruits is often expensive and, when trash in compost holes is depended upon to furnish the fuel, the burning operation is likely to be unsatisfactory; for in Honolulu, at least, the amount of fruit to burn is so greatly in excess of the trash that the work is incompletely done. Bringing infested fruits to the boiling point will kill all forms of the fruit fly. Submerging fruits in ordinary cold water for five days will either kill all larvæ and eggs or prevent their further development.

Burial in soil is a satisfactory method, provided the fruit is buried deep enough and afterwards cracks are prevented from developing in the earth above the fruits as the latter decay and settle. It should be remembered that just after transforming from the pupa the adults are so soft that they have the remarkable ability to force their way through incredibly small openings. Hence, a crack in the soil extending down to the fruit, even though it be no wider than the thickness of ordinary blotting paper, is wide enough to permit the adults to reach the surface and so thwart the purpose of fruit burial. Adults can not make their way through 1 foot of well-tamped soil, but because burial or burning is left to subordinates, who may slight the work, boiling or submergence of fruit in water is more highly recommended.

SPRAYING.

As adult flies can not lay eggs until 4 to 10 days after they emerge from the pupa, anything that will kill them during this period is useful. Such a remedy has been found in poisoned-bait sprays. These are composed of a sweet substance attractive to the flies, a poison, and water. Mally, who first used a poisoned spray in controlling this pest, used a formula containing: Sugar, 3 pounds; arsenate of lead, 4 ounces; water, 5 gallons. This he applied at the rate of 1 to 1½ pints to each 10-year-old peach or nectarine tree. Lounsbury used 6 pounds of brown sugar, 6 ounces of arsenate of lead paste, and 8 gallons of water. Severin used the Mally formula but increased the poison to 5 ounces. Weinland used 3½ ounces of arsenate of lead, 10 pounds of brown sugar, 5 gallons of plantation molasses, and 50 gallons of water. All of these formulas have proved to be efficacious.

Attempts to control the Mediterranean fruit fly under Honolulu conditions were unsuccessful. The number of adults killed was great, yet a sufficient number survived to infest all fruits that ripened. From what is known, however, of the benefits derived from these sprays in other countries, there is no question but that poisoned-bait sprays, when intelligently applied under such commercial conditions as exist in California and Florida, will prove successful. Thus Mally in South Africa states that a "severe outbreak of the pest in a commercial peach orchard was brought to a sudden and practically complete halt, and the fruit maturing later was marked under the guarantee of freedom from maggots," while the infestation among fruits on check trees increased until all fruits became infested. Newman in Western Australia estimates the cost of spraying an acre when one application of one pint of spray per tree is made every 12 to 14 days to be from $1.50 to $2 per fortnight, and states that this sum is a mere bagatelle to the loss of fruit during a similar period over a like area. Both Mally and Newman, working under conditions of less rainfall than obtained at Honolulu, and more like those of California and of fall and winter in Florida, believe that good results will follow the consistent application of poisoned bait sprays, particularly when supplemented by the proper destruction of infested fruits.

Honeybees are not endangered by the application of poisoned-bait sprays.

COLD-STORAGE TEMPERATURES.

Cold-storage temperatures do not lessen the damage already done fruits by larvæ within them, but they may become of inestimable value in guarding fruits against further attacks while in storage or transit and in freeing them from suspicion as carriers of the fruit fly.

For the details of the effect of cold-storage temperatures upon eggs, larvæ, and pupæ of the Mediterranean fruit fly, application should be made to the Bureau of Entomology for articles already published. Fruits of almost any variety commonly held in storage are held at temperatures varying from 32° to 45° F., with preference shown to a range of 32° to 36° F. It may be said that no immature stages of the Mediterranean fruit fly can survive refrigeration for seven weeks at 40° to 45° F., for three weeks at 33° to 40° F., or for two weeks at 32° to 33° F.

It seems reasonable to conclude that sooner or later the certification of properly refrigerated fruit will be practicable. When an association of fruit growers, or a people, find it financially worth while, there is no reason why they can not operate a central refrigeration plant under the supervision of an official whose reputation shall be sufficient to guarantee all fruits sent out from the plant to be absolutely free from danger as carriers of the fruit fly.

PROTECTIVE COVERINGS.

The only certain method now known of protecting fruit from fruit-fly attack in Hawaii is to cover them, when still very green, with some type of covering through which the fly can not lay her eggs. In many places ordinary cheesecloth sewed into bags, large enough to be slipped over the tree and tied about the trunk, have been used. These have been tried in Honolulu, but difficulty was experienced in putting the bags on soon enough and in making certain that no adult female flies were inclosed during the process. Considering the cost of material and the real danger of inclosing flies, the impossibility of covering many trees, and the breakage due to winds, this method of protection is not recommended.

The protection of the fruit on individual branches with coverings of cloth or paper is entirely feasible and very popular in Hawaii. Individual fruits inclosed in ordinary paper bags (fig. 29) are well and cheaply protected. Coverings of cheesecloth for separate fruits are not as good as paper, for the fruit fly can lay her eggs through certain coarser-woven kinds after the cloth has become matted against the fruit by rains.

FIG. 29.—Quince fruit protected from fruit-fly attack by a paper bag. The bag is slipped over the fruit while it is still quite green. Although this method of protection is not practical on a large scale, it is used much in Hawaii for the protection of dooryard or experimental fruits. (Original.)

Orange and small mango trees with their fruits inclosed in paper bags are often seen in Honolulu. Though this method of covering each fruit gives protection, it involves much labor and patience, and its practicability can be determined only by the value placed upon the fruit by the owner. So severe, however, is fruit-fly attack in Hawaii that this method, or some one of its many modified forms, must be used if fruits are to be brought to maturity uninfested.

NATURAL CONTROL OF THE FRUIT FLY.

No striking examples of control by natural agencies were evident in Hawaii previous to the introduction of parasites. Larvæ are killed in large numbers within fruits which are permitted to remain on the ground exposed to the direct sunlight in summer, but many larvæ escape even from such fruits. An examination of 17 mangoes exposed over sand on shallow trays to the sun for two days in August revealed 17 living and 98 dead well-grown larvæ in the fruit, and 103 that succeeded in safely leaving the fruit to form pupæ in the sand beneath. The small brown ant,[1] so common about the lowlands of Hawaii, unquestionably is a factor in natural control. It is frequently found swarming over and in fallen fruits and kills many larvæ as they leave the fruits to pupate. Ants were observed to remove from a fallen ball kamani nut 86 medium-sized larvæ during a 40-minute period, but they failed to reach 34 other larvæ in a firmer portion of the fruit.

No natural checks upon fruit-fly increase in Hawaii, aside from introduced parasites, are of practical value; but in many other lands climatic checks are unquestionably of great value, and, as in many places in Spain, for instance, are the only checks that make fruit production possible without the use of remedial measures.

CLIMATIC CHECKS.

Observations made in various countries indicate that the Mediterranean fruit fly will not be a serious pest when the monthly mean temperature falls to or below 50° F. for from three to four consecutive months during the year. In Hawaii the climate is not cold enough throughout the fruit-growing regions to act as a serious check on fruit-fly increase. Development progresses most rapidly after the Hawaiian means reach 75° to 79° F. At a mean of 68° F. development requires about twice the time. A temperature of 58° to 62° F. may increase the period of development to three to four times the normal period for the warmest weather. Larval development in apples stored outdoors at temperatures ranging from 31° to 64° F. (mean, about 51° F.) was slow and was attended by no unusual mortality. No development occurred at 26° to 70° F. (mean, 48° F.), and nearly all larvæ were dead at the end of six weeks. Very few fruit flies can develop at 49° to 50° F., and none at temperatures below this point. Complete mortality will follow continued exposure to temperatures below 50° F. An exposure for two to three weeks at 32° F. will kill all stages of the fruit fly, but an exposure to this low temperature for four days has practically no effect upon the fly. Sixty-two of 248 larvæ survived an exposure for five days to 21° to 28° F. These facts indicate that the Mediterranean fruit fly is a very hardy and persistent enemy in spite of the quickness with which it responds to checks upon its development resulting from the low temperatures ordinarily experienced in semitropical countries.

[1] *Pheidole megacephala* Fab.

PARASITES.

The very climatic and host conditions that have made the Mediterranean fruit fly an unusually serious pest in Hawaii and that, with crop conditions as they are, have made artificial methods of control impracticable, have been most favorable for an attempt at control by means of parasites. An abundance of the fruit fly upon which to feed and a climate permitting increase each month in the year have made conditions ideal. The search for and discovery of parasites, and their introduction and establishment where previously there had been none, has been one of the entomological romances of the present time. The parasites now at work killing the fruit fly in Hawaii have been introduced by the Hawaiian Board of Agriculture and Forestry as a result of the Silvestri and the Fullaway-Bridwell expeditions to Africa.

These two expeditions resulted in the establishment in the islands between May, 1913, and October, 1914, of four promising parasites: one from South Africa,[1] one from eastern Australia,[2] and two from Nigeria,[3] West Africa. Of these, only one, the South African Opius, was discovered as a parasite of the Mediterranean fruit fly. The three others were found parasitizing other fruit flies, and they have adapted themselves in Hawaii to the Mediterranean fruit fly. None of them, however, has been known to attack the melon fly in the gardens in Hawaii. Large numbers of all the parasites have been reared and have been liberated in all parts of the islands, until to-day they are well able to care for themselves. They have multiplied with remarkable rapidity and have unquestionably reduced the numerical

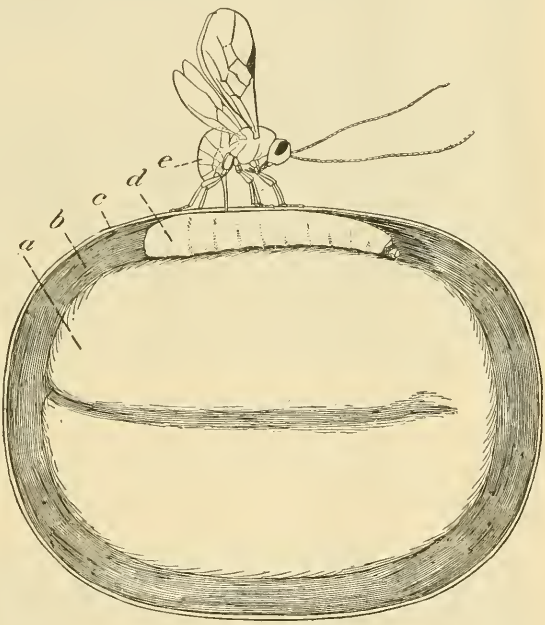

FIG. 30.—Diagrammatic drawing of a cross section of a coffee cherry to illustrate comparative ease with which the South African parasite can lay eggs in the fruit-fly larva: *a*, Coffee bean; *b*, pulp destroyed by maggot; *c*, skin of cherry; *d*, maggot of fruit fly; *e*, parasite forcing its stinger through skin of cherry into maggot. (Original.)

[1] *Opius humilis* Silv. [2] *Diachasma tryoni* Cam. [3] *D. fullawayi* Silv. and *Tetrastichus giffardianus* Silv.

abundance of the fruit fly. To-day no batch of infested fruit can be collected from which fruit-fly parasites can not be reared.

Only a beginning has been made in determining the effectiveness of parasites as a control factor against the fruit fly in Hawaii. The rapidity of establishment and the increase of the parasites have been very gratifying, yet the data already published recording the percentages of parasitism during the years 1914, 1915, and 1916 indicate that while parasitism in thin-meated fruits, such as coffee (see (fig. 30), may be consistently very high, in thicker fruits, like the orange, it is consistently very low. Thus the parasitism among larvæ developing in coffee may range between 90 and 100 per cent, while that among larvæ of the Chinese orange is more likely to range from almost nothing to 30 per cent. High parasitism among larvæ in such fruits as coffee is due to the fact that the larvæ are within reach of the parasite. On the other hand, the larvæ within such fruits as the orange may feed about the seeds and therefore remain safe from attack so long as they stay at the core, and are subject to attacks only when they come to the surface of the fruit.

Since adult fruit flies can live many months and lay eggs quite regularly, they have been able, with the aid of the unprecedented variety and abundance of host fruits in Hawaii, thus far to keep such an ascendancy over their parasites that they cause the infestation of practically all fruits ripening. It would appear that unless effective pupal and egg parasites are introduced, or more care is given to the elimination of host fruits which more thoroughly protect the larvæ from parasite attack, or to the planting of fruits which make possible the reproduction of large numbers of parasites, little practical value will result from the work of the parasites from the standpoint of rendering host fruits free from attack.

Though it seems evident that the favored host fruits will always be well infested if present cultural conditions continue, it is hoped that the efficiency of the parasites may be sufficiently enhanced to free from attack such fruits as the avocado and the better varieties of mangoes. In Kona, Hawaii, where the percentage of parasitism in coffee cherries (see fig. 30) has been phenomenally high for three years, it has not been high enough to free more than an occasional cherry from attack. The control exerted by parasites has, however, effected a benefit to coffee growers which probably already has repaid the Territory of Hawaii for all money expended in the introduction of parasites.

The general effectiveness of control by parasites can be increased best by the discovery and introduction of a good egg parasite.

QUARANTINE MEASURES TO PREVENT INTRODUCTION.

To prevent the Mediterranean fruit fly from becoming established in the mainland of the United States, the Federal Horticultural Board has promulgated Quarantine No. 13, which provides that its agents,

FIG. 31.—Chinese laborers inspecting bananas. Each bunch of bananas exported from Hawaii to California is inspected for bruised, cracked, or suspicious looking fruits. (Original.)

both in Hawaii and at the mainland ports of entry, shall have strict supervision over the movements of all fruits permitted entry to the mainland from Hawaii. Quarantine No. 13 makes it unlawful for a

FIG. 32.—Inspecting bananas as they are unloaded on the docks at San Francisco: Inspector making certain that each bunch bears an inspection tag and has been wrapped in material permitted by law. (Photo by Maskew.)

person to ship or carry any fruit from the Hawaiian Islands except ordinary eating bananas, pineapples, taro, and coconuts, and these will not be passed by inspectors at ports of entry, such as San Francisco, Los Angeles, or Seattle, unless they have been inspected by the

Federal agents in Hawaii and bear a Federal certificate of inspection. (Fig. 31.)

In Hawaii every precaution is taken to have bananas and pineapples grown under conditions that will prevent spread of the fruit fly. Plantations, packing sheds, and packing materials are inspected sufficiently often to insure their being in keeping with the regulations of the Federal Board. No fruit can be lawfully accepted for transportation to the mainland by any transporting company in Hawaii until it has been inspected and passed and permits for its acceptance have been issued to the transporting company by agents of the Board. Furthermore, no fruit can be lawfully removed from ships at ports of entry at the mainland unless the permit issued the transporting company in Hawaii is found attached to the bill of lading by the

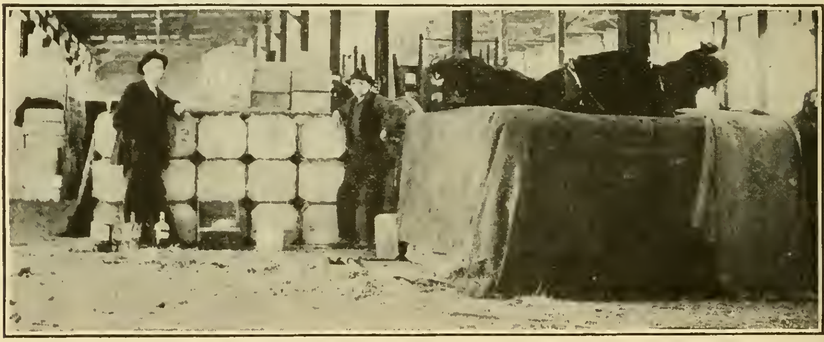

FIG. 33.—Pineapples never breed fruit flies in Hawaii. To be doubly certain that the packing material contains no fruit-fly pupæ, all crates of pineapples unloaded on the docks at San Francisco are fumigated with gas after tarpaulins have been thrown over the crates to prevent the gas from escaping. (Photo by Maskew.)

Federal agent, and unless each package or crate of fruit bears the inspection tag above referred to. (Figs. 32 and 33.)

Passengers and ships are permitted to take on board in Hawaii fruits of all descriptions for consumption while en route to the coast. All contraband fruits, however, must be eaten or destroyed before the ship comes within the 3-mile limit of the mainland. Otherwise the transporting company, or the individual passenger, whichever is the offender, is subject to fine or imprisonment, or both.

SUMMARY.

The Mediterranean fruit fly has become so thoroughly entrenched in Hawaii as a result of favorable climatic and host conditions that artificial remedial measures for its control are not practicable. Introduced parasites have multiplied wonderfully well and already have proved of practical value in safeguarding the coffee crop from losses due to fruit-fly attack. Though it is certain that the parasites can

never exterminate the fruit fly or cause the raising of the quarantine against Hawaiian fruits, much ultimate good is expected of them. It is hoped that by lessening the abundance of the fruit fly many fruits that now become badly infested before they are ripe enough to eat may be able to mature uninfested to a point where they will be useful to man. At present almost all edible fruits in Hawaii, and many ornamentals, making a total of 72 kinds of fruit, are subject to attack.

Judging from the past history of the Mediterranean fruit fly, only the vigilance of quarantine officials and the hearty cooperation of travelers will prevent its establishment in California and the Gulf States. Every barrier possible has been erected by State and Federal quarantines, so that there is now little danger of the pest gaining entry through the medium of commercial shipments of fresh fruits. But quarantine officials have found the pest in fruit concealed by tourists and in mail and express packages sent from infested countries by uninformed persons, and it is by such avenues that the pest is most likely to be introduced. These avenues, also, are the most difficult of detection, and their closing is dependent mainly upon educational campaigns to convince the public of the necessity of quarantine measures, and upon the unselfishness and personal honesty of travelers. At present only bananas, pineapples, taro, coconuts, and certain other vegetable products not subject to attack, are permitted entry from Hawaii, and these only after the regulations of the Federal Horticultural Board have been fulfilled.

PUBLICATICATIONS OF THE U. S. DEPARTMENT OF AGRICULTURE RELATING TO INSECTS INJURIOUS TO CITRUS AND OTHER SUB-TROPICAL FRUITS.

AVAILABLE FOR FREE DISTRIBUTION BY THE DEPARTMENT.

Control of the Citrus Thrips in California and Arizona. (Farmers' Bulletin 674.)
Carbon Disulphid as an Insecticide. (Farmers' Bulletin 799.)
Common Mealybug and its Control in California. (Farmers' Bulletin 862.
Fumigation of Ornamental Greenhouse Plants with Hydrocyanic-acid Gas. (Farmers' Bulletin 880.)
Fumigation of Citrus Trees. (Farmers' Bulletin 923.)
Control of the Argentine Ant in Orange Groves. (Farmers' Bulletin 928.)
Spraying for the Control of Insects and Mites Attacking Citrus Trees in Florida. (Farmers' Bulletin 933.)
Citrus Fruit Insects in Mediterranean Countries. (Department Bulletin 134.)
The Mediterranean Fruit Fly in Bermuda. (Department Bulletin 161.)
Katydids Injurious to Oranges in California. (Department Bulletin 256.)
Argentine Ant: Distribution and Control in the United States. (Department Bulletin 377.)
The Melon Fly in Hawaii. (Department Bulletin 491.)
Fumigation of Ornamental Greenhouse Plants with Hydrocyanic-acid Gas. (Department Bulletin 513.)
The Mediterranean Fruit Fly in Hawaii. (Department Bulletin 536.)
The Citrus Thrips. (Department Bulletin 616.)
The Mellon Fly. (Department Bulletin 643.)
Some Reasons for Spraying to Control Insect and Mite Enemies of Citrus Trees in Florida. (Department Bulletin 645.)
The Argentine Ant in Relation to Citrus Orchards. (Department Bulletin 647.)
Preparations for Winter Fumigation for Citrus White Fly. (Entomology Circular 111.)
Spraying for White Flies in Florida. (Entomology Circular 168.)

FOR SALE BY THE SUPERINTENDENT OF DOCUMENTS, GOVERNMENT PRINTING OFFICE, WASHINGTON, D. C.

Mango Weevil. (Entomology Circular 141.) 1911. Price, 5 cents.
Fumigation for Citrus White Fly, as Adapted to Florida Conditions. (Entomology Bulletin 76.) 1908. Price, 15 cents.
Fumigation Investigations in California. (Entomology Bulletin 79.) 1909. Price, 15 cents.
Hydrocyanic-acid Gas Fumigation in California. (Entomology Bulletin 90, 3 pts.) 1913. Price, 20 cents.
Fumigation of Citrus Trees. (Entomology Bulletin 90, pt. I.) 1913. Price, 20 cents.
Value of Sodium Cyanid for Fumigation Purposes. (Entomology Bulletin 90, pt. II.) 1913. Price, 5 cents.
Chemistry of Fumigation with Hydrocyanic-acid Gas. (Entomology Bulletin 90, pt. III.) 1913. Price, 5 cents.
White Flies Injurious to Citrus in Florida. (Entomology Bulletin 92.) 1911. Price, 25 cents.
Orange Thrips, Report of Progress. (Entomology Bulletin 99, pt. I.) 1911. Price, 5 cents.
Red-banded Thrips. (Entomology Bulletin 99, pt. II.) 1912. Price, 5 cents.
Natural Control of White Flies in Florida. (Entomology Bulletin 102.) 1912. Price, 20 cents.

UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 643

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. ▼ March 8, 1918

THE MELON FLY

By

E. A. BACK, Entomologist
and C. E. PEMBERTON, Assistant Entomologist
Mediterranean and Other Fruit Fly Investigations

CONTENTS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1918

THE MELON FLY is a truck-crop pest that in the course of international commerce has been spread from its native home in the Indo-Malayan region to the Hawaiian Islands, and has become so thoroughly established that it can not be eradicated. Owing to its destructive work, such fruits as musk-melons, watermelons, pumpkins, squashes, cucumbers, vegetable marrows, and tomatoes can not be grown to-day in many parts of the Hawaiian Islands unless the plants are screened. Cantaloupes and watermelons, instead of being common and cheap delicacies, as in former years, are now a luxury even for the wealthy; and cantaloupes, formerly grown in quantities about Honolulu, are now imported from California. Owing to the danger of introducing the melon fly into countries where it does not now exist, quarantines prohibit the export of Hawaiian-grown eggplant, bell peppers, and tomatoes, thus shutting off an income formerly enjoyed by the small farmer. In short, it is not possible to exaggerate the seriousness of this insect under Hawaiian coastal conditions.

The problem, however, is not entirely a local one to be fought out by the people of Hawaii. Should the melon fly once break through the Federal quarantine barriers and become established on the mainland of the United States, it will exact a large annual toll of the truck crops of the South. It is important, therefore, that truck growers learn something about this pest, so difficult of control, in order that they may become actively interested in keeping it out.

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THE MELON FLY.[1]

By E. A. Back, *Entomologist*, and C. E. Pemberton, *Assistant Entomologist, Mediterranean and Other Fruit Fly Investigations.*

CONTENTS.

THE MELON FLY is a serious pest that never should have gained access to the Hawaiian Islands. Its establishment in Hawaii came naturally enough, as in the case of many of our worst insect enemies, along with the development of unrestricted modern commerce, and owing to the lack, in earlier days, of a knowledge of pests in other lands likely to be introduced into ours, or of any quickened public opinion which, at last thoroughly alive to the great financial losses that may be averted, is to-day heartily supporting Federal quarantines directed against just such pests as the melon fly.

The melon fly is now established thoroughly throughout the coastal regions of the Hawaiian Islands and never will be eradicated. It attacks many vegetables that otherwise could be grown readily by the poorer people, who are least able to purchase them. Melons, pumpkins, squashes, cucumbers, and tomatoes, and some

[1] *Bactrocera cucurbitae* Coq.; order Diptera, family Trypetidae.

For a more extended account of the melon fly see Back, E. A., and Pemberton, C. E. The melon fly in Hawaii. U. S. Dept. Agr. Bul. 491. 64 p., 24 pl., 10 fig. 1917. This may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 25 cents.

NOTE.—The manuscript of this paper was prepared for publication as a Farmers' Bulletin, but owing to the fact that it deals with an insect which has not yet been introduced into the continental United States it was considered more appropriate to issue it in the series of Department Bulletins.

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other vegetables to-day can not be grown in many parts of the islands except with great effort; they must be imported from across the sea, as a result of melon-fly attack.

The melon fly is capable of living and causing damage throughout the warmer portions of the mainland United States. As it is

FIG. 1.—Tip of watermelon vine, showing adult melon fly laying eggs in ovary of a flower still in bud, an unaffected male bloom, and withered and drooping growing tip of vine. A female melon fly has deposited eggs in the vine at base of leafstalk, and the young larvæ hatching have nearly severed the vine at this point. (Authors' illustration.)

being intercepted rather frequently by official inspectors at California ports on ships from Hawaii, the importance of cooperation by all in making the quarantine of the Federal Horticultural Board a success in keeping out this very serious pest will be readily appreciated.

WHAT THE MELON FLY IS LIKE.

The melon fly, like other so-called "fruit flies," is similar to the ordinary house fly in some respects; the adult lays small white eggs from which hatch larvæ, or maggots, which when full grown transform into pupæ. Later the adult emerges from the pupa, as the butterfly does from the chryalis, and the cycle of life—adult, egg, larva, pupa—is repeated with each successive generation. Figure 1 shows an adult melon fly about to lay eggs in the bud of a watermelon. Note the relative size of the fly and the bud. The adult female, greatly enlarged, is shown in figure 2. When it is remembered that the adult is from one-fourth to one-third of an inch long, that its body is of a yellowish to a yellowish-brown color,

FIG. 2.—Adult female of the melon fly. Greatly enlarged. (Authors' illustration.)

and the markings between the wings, which appear white in the figure, are bright canary yellow in the living insect, and that the wings are banded with dark brown, it will not be difficult to recognize this pest.

The female fly drills small, pinhole-like openings in the skin of vegetables with the sharp tip of her body, called the ovipositor. Through these punctures she lays her white eggs, which are about one twenty-fifth of an inch long. If a small squash flower be cut open after the female fly has laid her eggs, a small cavity containing the eggs, such as is illustrated by figure 3, is shown. The larvæ, or maggots, that hatch from the eggs feed in various parts of the host plant. They have two black hooklike processes in the head that serve as jaws in aiding them to break up their food and to force their way through the plant tissues. But as the larvæ, even when full grown, are only about two-fifths of an inch long, a detailed description of them is of little value. It is enough to know that they differ very little from the ordinary white maggots, of equal size, with which the reader is doubtless familiar. The larvæ when full grown leave the host to transform to the pupa stage just beneath the surface of the soil, or beneath any protecting object. They even may transform to the pupa within the host fruit, but this is a rare occurrence. Figure 4 shows larvæ and pupæ about twice natural size. In figure 6 are shown well-grown larvæ feeding in the root of a young watermelon plant. Figure 5 represents an enlarged larva.

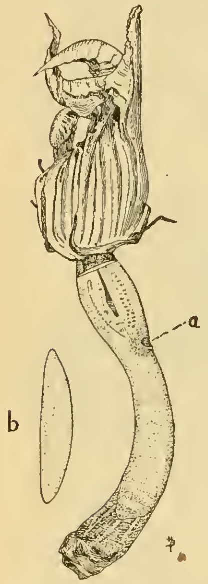

FIG. 3.—The melon fly: *a*, Eggs deposited in cavity in young pumpkin flower; *b*, single egg, much enlarged. (Authors' illustration.)

As the melon fly usually first forces itself upon the attention of the market gardener by the damage it does, it is more important to be able to recognize it by its work than by a mere description of the different stages. The reader, therefore, is directed particularly to the illustrations, for, besides showing types of injury, they make clear that it is in the larva stage that the melon fly causes its greatest damage.

ORIGIN AND DISTRIBUTION.

The original home of the melon fly is the Indo-Malayan region. At present it is known to occur in various parts of India, in Ceylon, Java, Macao, Timor, northern Australia, about Singapore, in southern China at Canton and Hongkong, in the Philippine Islands, in Formosa, and in the Hawaiian Islands. There is some doubt at present about its occurrence at Nagasaki, Japan.

It is believed that the melon fly was introduced into the Hawaiian Islands at Honolulu from Japan or China. It probably arrived in the larva stage in vegetables brought along as food from Japan by Japanese coolies emigrating as steerage passengers to work on the sugar plantations in Hawaii.

ESTABLISHMENT AND SPREAD IN HAWAII.

The melon fly was first observed in Hawaii, so far as records show, by Mr. Byron O. Clark, who, during October to December, 1897, found it almost impossible to grow cucumbers, squashes, melons, and similar vegetables in the Kalihi district of Honolulu and about Pearl City. During August, 1898, the pest already was established at Laupahoehoe, Island of Hawaii. Indications are that the melon fly was introduced as early as 1895.

That the melon fly is an introduced pest is proved by the interesting fact that the gourd calabashes used by the Hawaiian natives during the past century, many of which are preserved in various

FIG. 4.—Melon fly: *a*, Well-grown larvæ; *b*, puparia. Twice natural size. (Original.)

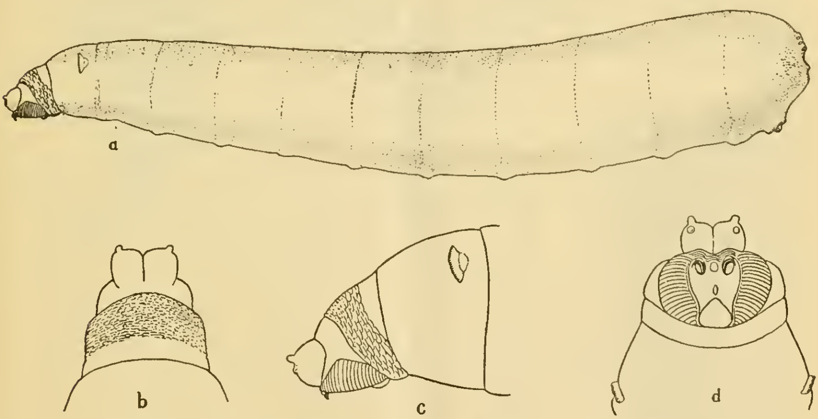

FIG. 5.—The melon fly: Third-instar larva. *a*, Lateral view of entire body; *b*, dorsal view of anterior end; *c*, *d*, lateral and ventral views of same. Much enlarged. (Authors' illustration.)

museums and private collections, are free from evidences of melon-fly attack. Modern utensils largely have superseded calabashes during these later days, but the few that are grown show the surface defects due to the attack of the melon fly.

Although no satisfactory record has been made of the spread of the melon fly to the various islands of Hawaii, it is now a well-

FIG. 6.—*1*, Watermelon seedling destroyed by larvæ of melon fly feeding in taproot, crown, and leaf petioles; *2*, work of larvæ in root, enlarged. (Authors' illustration.)

established and serious pest throughout all the coastal regions. It has been known even to attack cucumbers and squash at altitudes ranging up to 4,000 or 4,500 feet.

METHODS OF SPREAD.

The melon fly probably is carried more often from one locality or country to another in the larva stage than in any other form. Quarantine officials at San Francisco have found living larvæ in host fruits arriving at San Francisco on ships from Honolulu, and records prove that the melon fly in the larva stage is able to bridge the six or seven days required by the slower vessels to cover the 2,000 miles between the Hawaiian Islands and California, since infested fruits have been intercepted and condemned at least once a year since 1912. Host fruits taken on board ships as ship's stores are capable of carrying the melon fly as larvæ, or later as pupæ, in the fruit containers, for voyages occupying a longer time than is required to cross the Pacific Ocean, and thus may become a factor in spreading the pest through vessels plying between almost all countries where climatic conditions are favorable for the establishment of the fly.

The spread from one country to another at a considerable distance probably starts with the fly in the larva stage, but the spread from town to town, or over short distances, as between islands of the Hawaiian group, may occur in the adult or pupa stage. A female fly has been observed to alight on an automobile top and be carried 16 miles from the country into the city of Honolulu. On another occasion an adult was seen flying about an interisland boat en route from Honolulu to Hilo, on the island of Hawaii. This fly was not observed after the boat weighed anchor at the port of Lahaina, on the island of Maui, or 72 miles from Honolulu. These two instances will explain the spread of the pest, in the adult stage, about the islands of Hawaii, even if it could not be transported in the larva stage.

When larvæ form their puparia on bare surfaces, and particularly on a cloth surface, the puparia may adhere sufficiently well to make it possible for them to be transported considerable distances under favorable circumstances. Although no definite instances are known where the melon fly has been spread thus, distribution in this fashion is quite feasible and to be expected.

ECONOMIC IMPORTANCE.

The melon fly is the most important pest of varieties of melons, squashes, and curcurbits in general grown in the Hawaiian Islands, and probably elsewhere. Its persistent attack has caused many persons to abandon the growing of the more susceptible host fruits.

Other fruits can be grown for the most part only under cover and at increased cost. The unrestricted cultivation of fruits and vegetables in Hawaii has been ruined by the melon fly and the Mediterranean fruit fly. Though the latter is probably the more to be feared, many persons regard the melon fly as of greater importance from an Hawaiian standpoint, for it attacks with the greatest persistency such crops as squashes, pumpkins, vegetable marrows, tomatoes, and beans, all of which could furnish under the ideal Hawaiian climatic conditions an abundance of food for the poorer people. Such vegetables as muskmelons, watermelons, pumpkins, squashes, and tomatoes can not be grown to-day in many parts of the islands unless the plants are screened carefully.

FIG. 7.—Older squash vine with abnormal growths due to work of melon-fly larvæ. (Authors' illustration.)

Cantaloupes and watermelons, instead of being common and cheap delicacies, as in former years, are now a luxury for even the wealthy. Cantaloupes, once grown in large quantities about Honolulu, now are imported from California. It is no longer possible to grow pumpkins as stock food on idle land. Quarantines prohibit the export of early shipments of eggplant, bell peppers, and tomatoes, thus shutting off an income formerly enjoyed by the small farmer. The loss to market gardeners in Hawaii as a result of melon-fly attack has been placed conservatively at three-fourths of a million dollars annually. It is not possible to exaggerate the importance of the melon fly as a serious pest under Hawaiian coastal conditions.

NATURE OF INJURY CAUSED BY THE MELON FLY.

The melon fly does not confine its attack to the fruits of its host or food plants. It may attack the young seedling, the flower, the root, the stem, or the fruit.

INJURY TO SEEDLING PLANTS.

The melon fly attacks with severity the young succulent seedling plants of watermelon and cantaloupe. The female fly lays her eggs in the crown of the plant, and the larvæ, on hatching, feed there first. They later burrow down into the taproot and upward into the petioles of the leaves, and even into any young runners that are forming. The capacity of the melon fly for injuring a watermelon seedling is shown in figure 6 (p. 6). The enlarged figure of the root shows four full-grown larvæ eating their way into the root. In the figure of the seedling the larvæ have almost severed the leaf to the left, and have tunneled completely through one of the petioles and so destroyed it that the weight of the leaf has caused its stem to break over. Injury to a seedling runner is shown in figure 8. In certain places in Hawaii where the melon fly is very abundant, entire

FIG. 8.—Seedling watermelon showing runner killed back by burrowing melon-fly larvæ. (Authors' illustration.)

fields of watermelons may be killed before the plants can develop runners. Squash, pumpkin, cucumber, tomato, and bean seedlings almost never are attacked. Larvæ never are found in the roots of older plants.

INJURY TO THE STEM.

As the plant becomes older, it is still subject to attack. The female fly lays her eggs in the rapidly growing pumpkin and squash vines, but the larvæ after hatching do very little damage, although they are able to mature. They often cause abnormal swellings or cancerlike spots where a colony of them are feeding, as illustrated by figure 7; but if the injury threatens the stem, the plant throws out roots on either side of the part affected to offset the damage. Such attacks upon the stem are not of importance, except in the case of watermelon and cantaloupe.

But in the two plants last mentioned the injury resulting from attack upon the stems may be very serious, and in many cases cause a complete failure of the crop. Figure 9 shows a portion of a canta-

Fig. 9.—Cantaloupe vine attacked by melon fly in eight places, including stalk, leaf petioles, and young fruit. (Authors' illustration.)

loupe vine that has been attacked in eight places. So persistent is attack upon cantaloupe in Hawaii that the vine can not be grown satisfactorily except in isolated spots or under cover.

Figures 1 and 10 show a common condition found in watermelon fields. The female fly usually chooses the growing tip of the runners in which to lay her eggs. In making a place in the vine for her eggs she practically severs the tip of the vine so that it may fail to grow

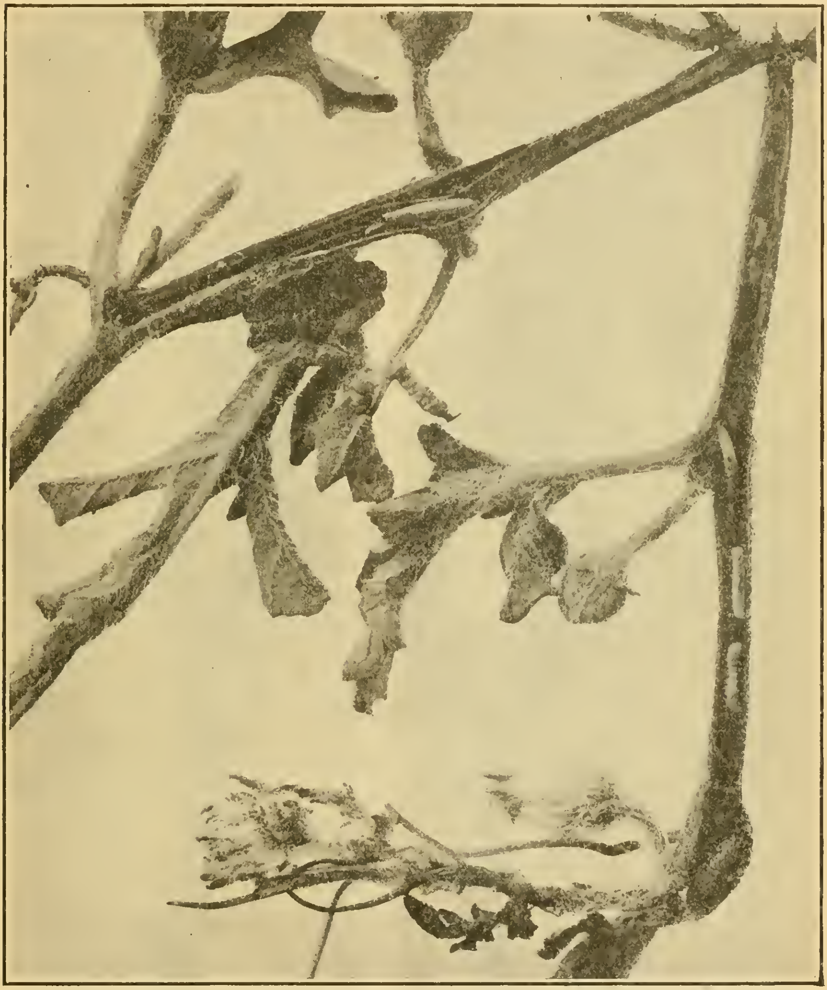

FIG. 10.—Succulent watermelon vine sectioned to expose five well-grown larvæ of the melon fly which have eaten out the interior, causing the vine to wither and die back to the point of original infestation. (Authors' illustration.)

beyond the point of injury. The growing end of the vine, however, usually is ruined, for, if the egg-laying process does not cause serious damage, the larvæ hatching, numbering from 2 to 10, begin to feed and bring about a hasty destruction. Figure 1 shows the drooping, withered, growing tip. In this case the eggs were laid just beyond the leaf and flower stalks.

When the eggs are laid in the older though still very young and succulent watermelon vine, the larvæ, on hatching, tunnel their way

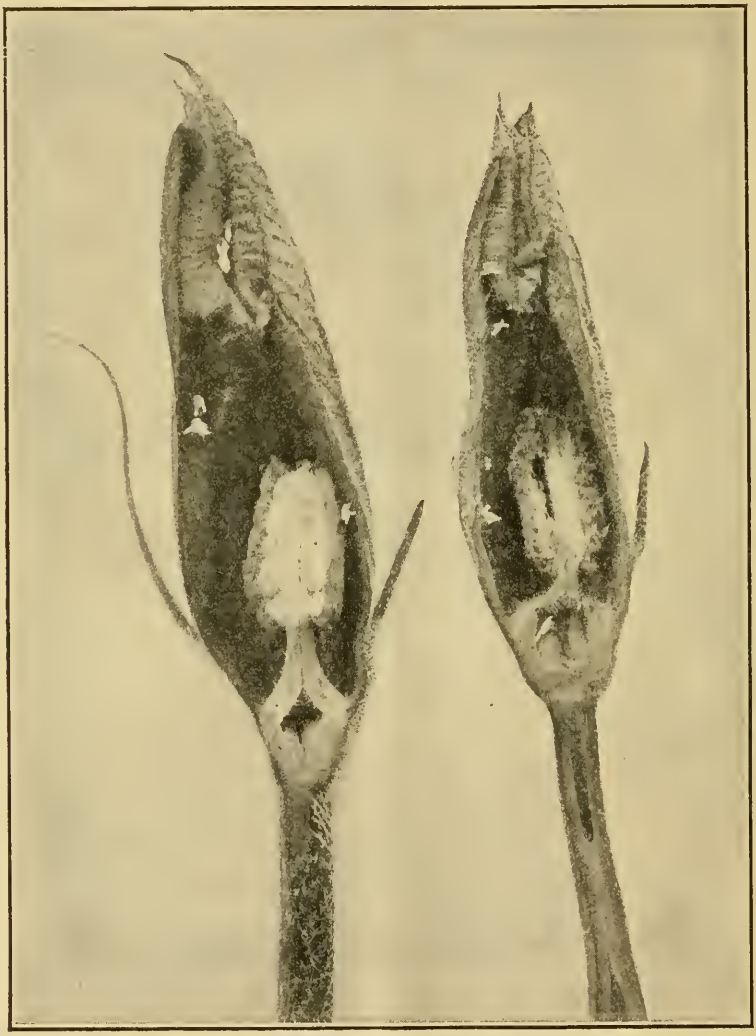

FIG. 11.—Melon-fly eggs in blooms of pumpkin. Two buds of the male bloom sectioned to show the eggs deposited through the corolla. (Authors' illustration.)

through the vine, eating out the center and causing it to wilt and die. Figure 10 shows a vine sectioned to expose the five well-grown larvæ which have killed it beyond the base of the leaf in the upper left-hand corner of the illustration. The serious setback to vine development that this type of injury causes is readily apparent. Such pruning back of the vines, repeated over and again, may prevent the formation of sufficient growth for the development of fruits.

INJURY TO THE BLOOM.

Although injury to the seedling plant and to the growing stem is greatest in watermelon and cantaloupe and is of little importance among squashes, cucumbers, and pumpkins, the injury to the bloom is very serious among all these crops except that of the cucumber. Among pumpkins and squashes both the male and female blooms are affected; but among the watermelons, cantaloupes, chayotes, and Chinese marrows the male or staminate bloom escapes attack. It is not uncommon to examine luxuriantly growing fields of squashes and pumpkins during the warm months and not find a single unaffected bloom. Uninformed growers often question why their vines set no fruits. The condition of the blooms illustrated in figures 11 to 14 is the answer.

FIG. 12.—Work of melon-fly larvæ in bringing about destruction of ovaries of pumpkin bloom even before the corolla has entirely withered.

The unfertilized ovaries of all cucurbit blooms are especially attractive to female melon flies. The flies lay eggs in the undeveloped and unfertilized ovaries of the bloom before the blossom unfolds, and the larvæ, on hatching, often so ruin the ovaries, as indicated by their burrows shown in figure 12, that the flower never unfolds. In those varieties having long, narrow fruits the ovaries are many times so eaten out and decayed that the weight of the upper part of the bud causes the ovary to break (see fig. 13). So complete is the destruction of the ovaries of watermelon bloom that in dry weather the remains of the bloom wither and become mummified, as shown in figure 15.

An examination of the buds of the male bloom in any field throughout the coastal regions of the Island of Oahu, particularly during the months from March to November, will reveal the severity of attack centered on this portion of the plant. Wherever the buds have been attacked, a whitish gumlike excretion exudes which hardens about the point of attack. On cutting the buds lengthwise, batches of eggs can be seen among the folds of the corolla, or in the stamens and receptacle, as shown in figure 11 (p. 12). As the eggs are pure white and are in clusters of 2 to 10 or more, they are seen easily without the aid of a lens. If the eggs have been laid from 2 to 6 days, the inside of the bud may have been already eaten out by the rapidly developing larvæ. Buds attacked before they are half grown usually are destroyed completely before the blossom unfolds. Figure 14 shows three stages in the destruction of the staminate bloom. The bud *a* is a mass of decay within; the stamens have been devoured and the larvæ already have begun to burrow about the base; *b* shows a bud that has been severed by the feeding of the larvæ and has fallen over under its own weight; and *c* is the upright stem of the bud, after the essential parts of the bloom have been ruined and have fallen to the ground. Although attack may occur so late in the development of the male bloom that the corolla can unfold, it is more often than not that eggs, or even young larvæ, can be seen on the inside of the corolla when the flower is in full bloom. The melon fly never attacks the bloom after the corolla has unfolded.

FIG. 13.—Pistillate bloom of squash in which larvæ of the melon fly have so devoured the unfertilized ovary that the bloom is destroyed before the flower can unfold. (Authors' illustration.)

INJURY TO NEWLY SET FRUITS.

The greatest destruction among fruits usually occurs when they are very young, either before they are fertilized or just after they have set. At this stage of development the young fruits are expanding very rapidly. Figure 16 shows the damage done to three young pumpkin fruits. About the damaged areas calluses are formed by the fruit in an attempt to repair the damage, but this attempt seldom prevents secondary decays from starting, and these bring about the destruction of such portions as escape the larvæ. The sectioned pumpkin in figure 17 shows how a colony of larvæ may eat into a young fruit, become full grown, and leave it without causing a complete destruction. It also shows how smaller, weaker colonies may develop in the outer portion of the pulp.

INJURY TO OTHER FRUITS.

Complete destruction of fruits by larvæ of the melon fly rarely occurs after they have become 4 to 5 inches in diameter, for then

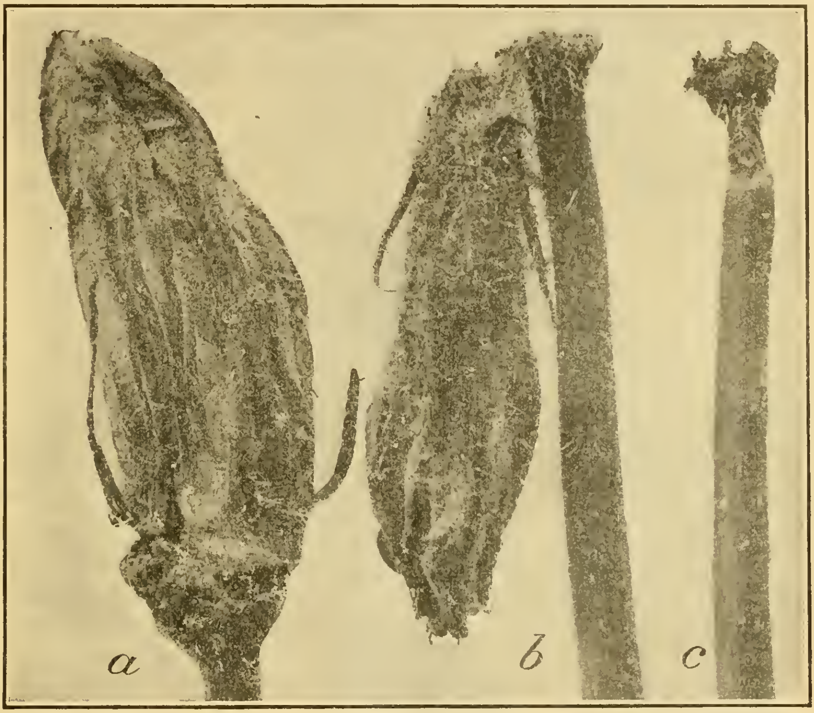

FIG. 14.—Buds of male flowers of pumpkin damaged by larvæ of melon fly, *a*, *b*, and *c* representing various stages in the destruction of the bloom. (Authors' illustration.)

the portion of the fruit containing the seeds, or the part preferred by the larvæ, is well protected by the outer meaty pulp and by the rind. Such colonies of larvæ as are then able to become established in pumpkins and squashes usually develop in the outer portions of the fruit and do not penetrate to the center. In cantaloupes, watermelons, cucumbers, and marrows, however, the larvæ more easily may work their way down to the softer, central portions and there complete their development, while the outer portion of the fruit remains quite firm. Figure 19 (p. 20) shows the cross section of a watermelon that had the general external appearance of being sound.

Yet, when cut open, it was found that its center had been eaten away entirely and the well-grown larvæ had made tunnels, shown somewhat reduced, throughout the rind.

Numerous similar examples of destruction might be described. But it is important to remember the fact that melon-fly attack upon the older fruits is far more likely, except in the case of the cantaloupe, cucumber, and tomato, to result in larval development in open surface wounds and in deformities.

FIG. 15.—Section of watermelon vine, showing two fruits so devoured by larvæ of the melon fly that they have become mummified during dry weather following attack. Note that the remains of the blossom still persist. (Authors' illustration.)

One of the squashes of figure 21, the cucumbers of figure 18, and the watermelon of figure 20 illustrate types of deformities very common in Hawaii. Wherever the fruits have been only slightly damaged by melon-fly attack, deformities result. It is seldom that a perfectly formed cucurbit is seen in the markets of Honolulu unless the fruit was grown under protective coverings. Although deformities do not completely ruin the fruit, they restrict development and prevent the fruit from reaching its normal size, as illustrated by the unaffected squash and the badly deformed squash of figure 21 (p. 22). Cucumbers and watermelons so badly deformed as those shown in figures 18 and 20 are not salable, even though they contain no larvæ. The purchaser of fruit has learned from experience that deformed cucumbers must be viewed with suspicion, for, although they may be fit for the table, they may contain maggots.

FOOD OR HOST PLANTS.

The food or host plants of the melon fly may be divided into those preferred and those occasionally infested and may be listed as follows:

CULTIVATED.

Preferred.

1. Cantaloupe.	6. Chinese cucumber (*Momordica* sp.).	10. Tomato.
2. Watermelon.	7. Chinese melon.	11. String beans.
3. Pumpkin.	8. Chayote.	12. Cowpeas.
4. Squash.	9. Cucumber.	
5. Gourds.		

Occasionally infested.

1. Eggplant.	3. Orange.	6. Peach.
2. Water lemon (*Passiflora* sp.).	4. Fig.	7. Mango.
	5. Papaya.	8. Citrullus (Java).

WILD.

1. *Sycos* sp.	2. *Momordica* sp.

Erroneously recorded host fruits.

1. Kohlrabi.	2. Cabbage.	3. Peppers.

CUCURBITACEOUS PLANTS.

All the cucurbitaceous plants are subject to severe infestation, particularly of the young fruits. Cantaloupes are the most susceptible, since the vines as well as the fruit are attacked badly at all stages of growth, and the fruits do not appear to develop the resistance to attack found among the older watermelons, pumpkins, and squashes. Ordinarily the cucumber is resistant to attack when very young, although it is rare that cucumbers offered for sale in Honolulu do not show some evidence of attack, even when very carefully collected. Cantaloupes and cucumbers may be used successfully by the female fly for egg laying up to the time

FIG. 16.—Various deformities of very young pumpkins caused by infestations started before or just after fertilization of the ovary. These fruits persist for a time, owing to calluses developing about points of attack, but they never reach a much larger size and are ultimately destroyed by fungi and secondary attack. (Authors' illustration.)

they are ready for market. Although cantaloupe growing has been abandoned practically in Hawaii since the advent of the melon fly, cucumbers are grown without protection of any sort. Practically all fruits reaching a size fit for salad use show evidences of attack at one or more spots, but the percentage of fruits rendered unmarketable is not large enough to force the oriental growers to cover the young fruits, although it would appear disastrously large to American market gardeners, who place a high value on their time. During midwinter 150 out of 153 cucumbers, ready for the market at Moiliili, were found infested variously.

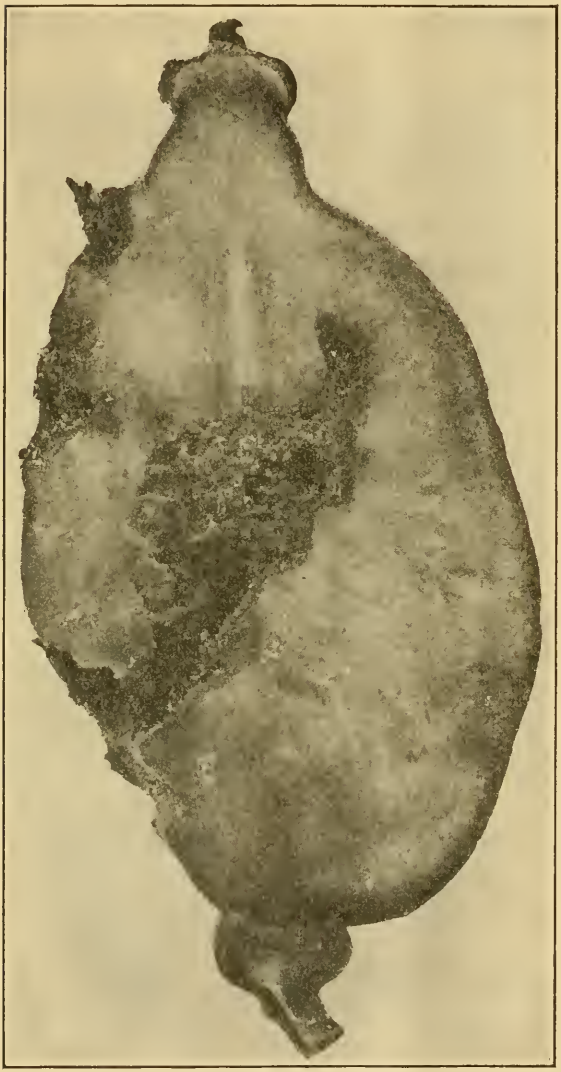

Fig. 17.—Cross section of young pumpkin, showing work of larvæ of melon fly. Each affected area represents the location of a colony of larvæ. (Authors' illustration.)

All cucurbits grow with such rapidity in Hawaii that the oriental is willing to permit the pest to destroy fully 50 per cent of the fruits rather than go to the expense of covering each fruit as soon as or before it sets. To prevent wholesale injury, all cucurbits except cucumbers must be covered before or just after blooming.

Aside from the fact that the seedlings and vines of all cucurbits except cantaloupe and watermelon are attacked but slightly, there is little difference in the susceptibility to attack of the young fruits under

Hawaiian conditions. Inasmuch as the fly has been permitted to increase unchecked since its introduction, it has become so abundant that slight differences in inherent resistance to attack are not evident

FIG. 18.—Damage to cucumbers by larvæ of melon fly. (Authors' illustration.)

among host fruits growing in the field. The infestation is excessive in all unprotected fruits. If by chance pumpkins, squashes, and watermelons escape infestation until they are from 4 to 6 inches in diameter they may reach maturity, although before they reach maturity pumpkins and squashes may support numerous colonies of larvæ in open surface wounds and become badly deformed. Out of 254 nearly full-grown pumpkins growing at Kahuku during the winter months, 250 were found variously deformed. As many as 650 adults have been reared from a pumpkin not more than 4 inches long; the staminate bloom while still a bud may support as many as 37 well-grown larvæ.

TOMATOES.

Tomatoes are very susceptible to attack. All tomatoes offered for sale in Honolulu are likely to be infested, as shown by the reports of

FIG. 19.—Cross section of young watermelon, showing destruction of interior by larvæ of melon fly. Reduced one-fourth. (Authors' illustration.)

the market fruit-fly inspector covering several months. Fifteen ripe or partly ripe fruits examined at Hauula on March 21, 1915, contained eggs or larvæ. Such severe infestation is so general during the warmer months that data are superfluous. Under climatic conditions less favorable for the increase of the melon fly the tomato probably would be found to be less susceptible to attack than cucurbitaceous crops. The fruits of the small wild tomatoes and the spiny yellow-fruited Solanum, common in Hawaii, all are found growing about fields of cucurbitaceous crops, but never yet have been found infested. During January and February fields of tomatoes may produce a large percentage of sound fruits, owing to the effect of the cooler weather upon the activities of the fly. Only the fruits of the tomato are subject to attack.

STRING BEANS.

The ordinary varieties of string beans grown on the mainland as a rule are not infested by the melon fly. Of the variety commonly known as the Yellow Wax bean, 375 pods sufficiently ripe to have turned color were examined at Haleiwa and were found free from attack, although growing close to a field of badly infested pumpkins, in March. Examinations of string beans in other localities, particularly about Honolulu, indicate that seldom are any of the varieties infested except the more fleshy, long-podded Chinese variety. This variety may be attacked very badly when grown near other favored host fruits or on land recently cleared of such crops, as illustrated by figure 22. As many as 36 well-grown larvæ have been found within a single pod.

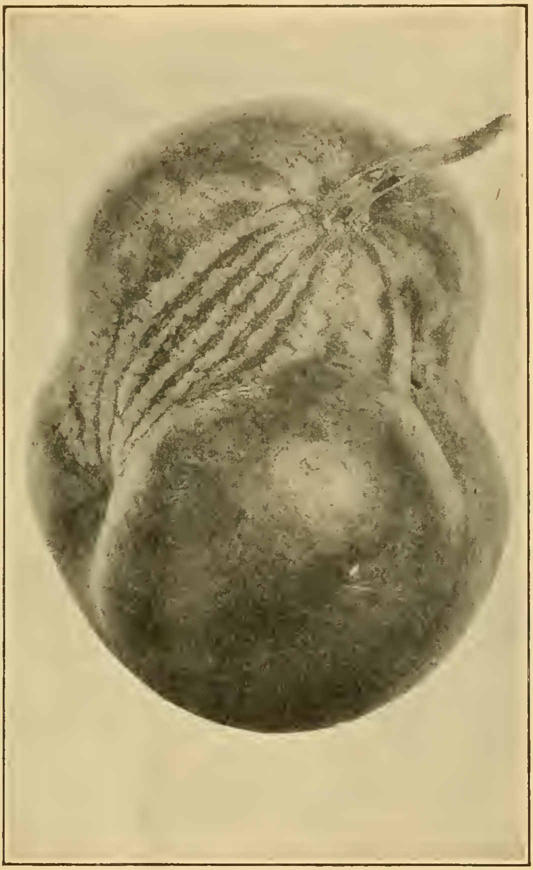

FIG. 20.—Deformed watermelon resulting from late infestation by larvæ of melon fly. (Authors' illustration.)

Although the Chinese variety is the only one at times generally and badly affected, beans of all varieties except the Lima bean should be included in quarantine lists. The Lima bean never has been found infested. Only the pods of beans usually are infested. The larvæ prefer to feed upon the fleshy portions of the pod, but sometimes attack the seeds. In badly infested pods, attacked before the seeds are well grown, the larvæ may eat out the seeds and leave nothing but the outer portion untouched. This also is true of cowpeas.

COWPEAS.

Although cowpeas are not grown to any great extent in Hawaii, they are subject to melon-fly attack. Only the pods are affected. As many as 37 larvæ have been taken from a single pod. When infestation occurs early the young seeds may be devoured, but attack is centered more often upon the pod itself. Some varieties of cowpeas appear to be less liable than others to attack by the melon fly.

FRUITS AND VEGETABLES THAT ARE SELDOM OR NEVER ATTACKED.

Several observers have stated that the melon fly attacks eggplant, bell peppers, cabbage, and kohlrabi. During a period of three years the representatives of the department have not found any of these vegetables affected. The Mediterranean fruit fly has been found attacking eggplant and bell peppers, but only in small numbers. Even in the laboratory eggplant was found immune to melon-fly attack if the fruits were sound. Adult melon flies, however, were reared from fruits first weakened by decays.

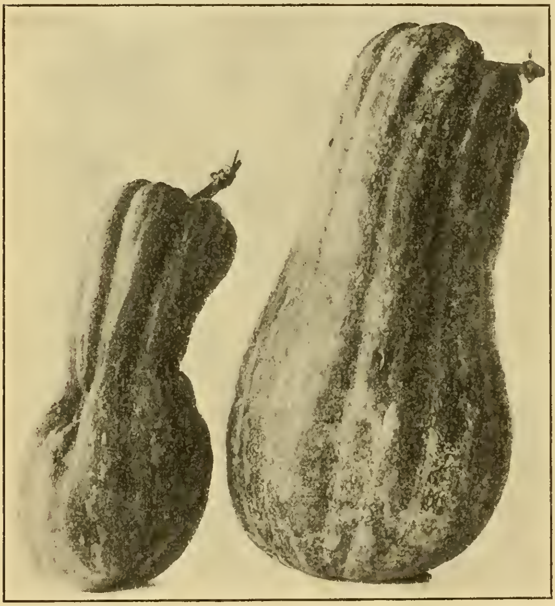

FIG. 21.—Damage to squash by larvæ of melon fly. Of the two fruits illustrated, the one to the right is normal, and the one to the left, the stunted and deformed fruit caused by melon-fly attack. (Authors' illustration.)

Adults have been reared from orange, mango, fig, papaya, peach, apple, and water lemon. These fruits, however, do not serve regularly as hosts of the melon fly. Only in rare instances does the melon fly attack them, and then only slightly. For practical purposes aside from quarantines all the fruits and vegetables listed under this subheading are free from attack by the melon fly.

INTERESTING FACTS CONCERNING THE ADULT FLY.

The most interesting facts about the adult melon fly center about the length of life and the capacity to lay eggs. No flies have been known to live longer than $4\frac{1}{2}$ days without food and water, or longer than 5 days with water but no food. But if they can feed upon plant juices, such as the sap that exudes from cut or broken surfaces of pumpkin vines, cucumber fruits, papayas, etc., or the sap exuding from the breaks made in host plants during egg laying, adults may live many months. One female lived from February 17, 1914, to April 4, 1915, or $13\frac{1}{2}$ months. The length of adult life is variable

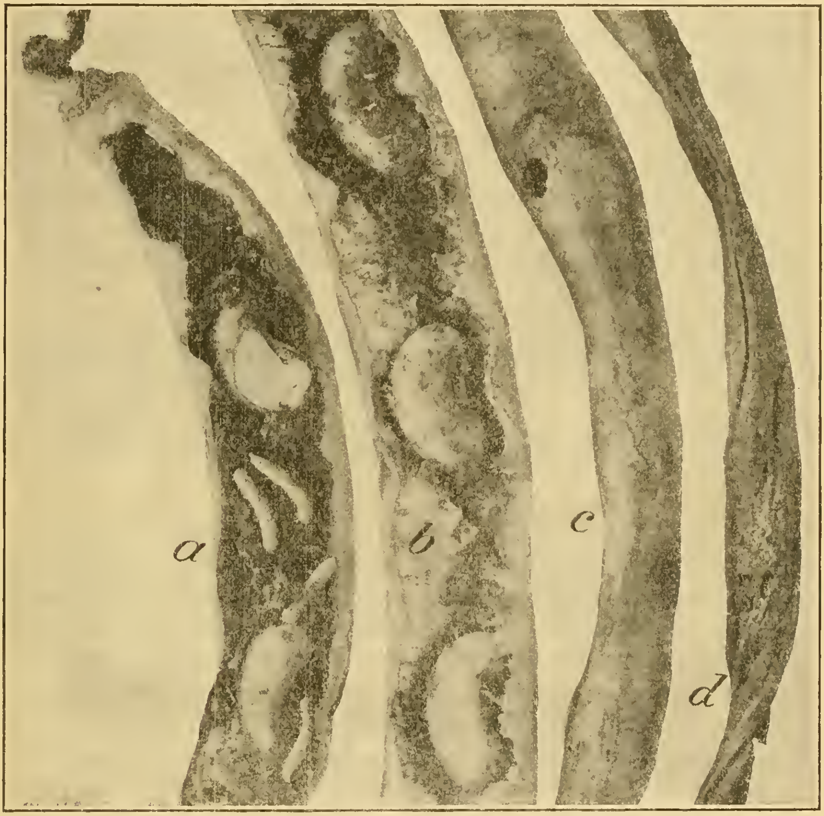

FIG. 22.—Destruction of green bean pods by larvæ of melon fly. In *a* and *b* a portion of the pods has been removed to expose larvæ and their work. In *a* are shown four well-grown larvæ. Pods in different stages of drying out after the larvæ have left them are shown in *c* and *d*. (Authors' illustration.)

under like conditions. From the standpoint of longevity the chief interest centers about the fact that certain adults may live long periods and thus keep the pest alive during seasons when host fruits are not in season.

Female flies may begin to lay eggs as soon as 14 days after they emerge from the pupa during the warmer months, when the mean temperatures range from 75° to 79° F. During the winter, at a mean of about 71° F., many adults may not lay until 44 days after emergence. The season of the year and the nature of their food have an influence upon the rapidity with which eggs are formed.

But once the female fly begins to lay eggs, she may continue to do so throughout life. The largest number of eggs laid by any female in confinement is 687, but 1,000 probably may be laid by vigorous long-lived flies. While 37 is the largest number of eggs laid by a single individual during any one day, the number varies, and may be as few as 1. On many days no eggs are laid. Unlike the female of the Mediterranean fruit fly, which lays a few eggs almost daily, the female melon fly lays more eggs per day, but at greater intervals. Thus one fly deposited 14, 19, 13, 29, 16, 19, 16, 12, 17, 7, 9, 16, 7, 12, 37, 25, 24, 21, 28, 6, and 18 eggs, respectively, per day during the first three months (summer months) after depositing her first eggs; she laid no eggs in fruits until she was 51 days old, and, after she began laying, laid eggs on only 21 out of 90 days. During the seventh, eighth, and ninth months of her life (winter months) she deposited 10, 2, 18, 14, 15, 20, 13, 9, and 3 eggs.

Female flies can resume normal egg laying after periods of scarcity of host fruits. Females that have not been given an opportunity to lay eggs within fruits for periods ranging from 3 to 9 months after emergence have begun to deposit eggs at a normal rate as soon as fruits were placed with them in the laboratory rearing cages.

WHY THE MELON FLY IS A SERIOUS PEST.

The melon fly is a serious pest in Hawaii because it finds in the coastal areas a favorable climate and plenty of food. Regardless of the great discouragement due to its ravages, the oriental market gardeners, and others to a less extent, plant its host vegetation in rotation on the same or neighboring plats of ground. No attempt is made to prevent the flies from maturing in infested fruits. The decaying and infested fruits of the cucumber crop, for instance, are left on the field that is to be planted to tomatoes, or the flies developing from the cucumbers migrate to attack the melons just coming into bearing in the near-by field. No system of control, aside from covering successfully a small portion of the fruit that sets, is practiced.

It thus happens that large numbers of adults mature, and, as the climate is favorable, they multiply rapidly. During the warmest Hawaiian weather, when the mean temperature averages about 79° F., the egg, larva, and pupa stages may be passed in as few as 12 or as many as 29 days, according to the individual and its host. The complete life cycle is subject to great variation, according to the longevity of the adult. Since one female fly has been known to live 431 days, it is evident that the complete life cycle from the laying of the egg to the death of the fly may be 443 to 460 days when the immature stages are passed during the warmer portions of the year. At an average mean temperature of about 68° F., which is the coolest temperature found in Hawaii where fruits are available in numbers for study, the immature stages are passed in 40 to 45 days. It is difficult to state just what the variation in the life cycle may be in colder climates, but it may range between 3 and 4 months.

This rapidity of increase throughout the coastal regions permits from 8 to 11 generations of the melon fly a year, when a generation is considered to extend from the time the egg is laid until the female of the next generation begins to deposit eggs. As the females are capable of living many months and of depositing eggs at frequent intervals throughout life, the generations become hopelessly mixed. It is possible for a female ovipositing on January 1 to be still alive and laying eggs the following January along with the progeny of 11 generations of her descendants. It is, therefore, small wonder that the melon fly, under such favorable conditions, swarms throughout the market gardens of Hawaii and leaves little unaffected that is not protected by man.

CONTROL MEASURES.

NATURAL CONTROL.

No agencies at present are working in the Hawaiian Islands to bring about, even periodically, a very large natural reduction in the abundance of melon flies. The mortality among the immature stages, or among the adults, is not sufficiently high to be of practical value, although sometimes 90 per cent of the larvæ may be found dead in certain decaying fruits.

In climates colder than that of the Hawaiian coastal areas mortality due to cold temperatures will play a particularly active part in reducing the pest. While the cooler weather of the winter months does prolong the period of development throughout the coastal regions, the long life of the adult flies and the capacity of females for continued egg-laying make it difficult for market gardeners to benefit to any marked extent from the effects of cool weather if they allow their fruits to remain unprotected. The cooler weather in the more isolated gardens holds down the number of adults and limits their activity to a fewer hours during the day when it is warm enough for them to attack fruits, and in this way makes possible greater success in saving fruits by the use of various protective coverings than follows the use of the same measures during the summer months.

PARASITES.

Hawaii has no native parasites that attack the melon fly, but the Hawaiian Board of Agriculture and Forestry has introduced a parasite from India. This parasite[1] was introduced at Honolulu during the early part of 1916, and has been reared and distributed in large numbers, but it is not known yet whether it will check the ravages of the melon fly in a practical manner. It has become established, however, and promises to be useful.

ARTIFICIAL CONTROL.

Individual growers of vegetables in Hawaii are likely to be discouraged in the application of remedial measures for the control of the melon fly. Host fruits are grown in rotation in the numerous garden spots and market-garden areas chiefly by uneducated orientals, who do not appreciate the necessity for a united fight against the fly. The usual custom among these laborers is to permit infested fruits to decay in the field. In certain uncultivated areas the wild Sycos and Chinese cucumbers run wild and furnish fruits in which the melon fly can breed throughout the year, even though no cultivated crops are grown. This abundance of cultivated and wild host fruits, coupled with a climate favorable for rapid multiplication, produces many adult flies which spread in all directions to render valueless all remedial measures except those that involve protective coverings for the fruits.

It thus happens that no artificial control measures have been applied successfully in controlling the melon fly under Hawaiian conditions. The only means now employed to safeguard fruits is that of protecting the young fruits with some type of covering until they are large enough to withstand attack. Trapping adults has proved a failure, and killing them by spraying thus far has given poor results. If all growers would cooperate systematically (1) in the destruction of the eggs and larvæ by submerging infested fruits in water or by boiling and (2) in the destruction of the adults by spraying, the value of spraying with a poisoned bait and of covering the young fruits would be enhanced to a point where either might be sufficiently effective to be recommended as satisfactory. But so long as the cultivation of host plants is largely in the hands of orientals and others who do not appear to be amenable to instruction as modified by western standards, no relief can be expected.

SPRAYING.

Since adult melon flies do not deposit eggs for 2 to 4 weeks after emergence during the summer, and only after relatively longer periods

[1] *Opius fletcheri* Silv.

during the winter, but feed continuously throughout this period, it is evident that any spray that will kill them before they begin to lay eggs is valuable. A poisoned-bait spray, containing 5 ounces of lead arsenate in paste form, 2½ pounds of brown sugar, and 5 gallons of water, is very effective in killing adults. This spray, used at the rate of 30 gallons to the acre, was applied by means of a knapsack sprayer. About 2 acres of Chinese melons and cucumbers in a field fairly well isolated, from the Hawaiian standpoint, which means that no host fruits were growing within 500 yards, were sprayed on May 21, 26, and 28, June 1, 4, 8, 14, and 23 during typical summer weather. Six hours after an application many adults were sluggish and flew with difficulty, but within 24 hours many dead adults could be found among the vines. Although the adults were lessened numerically by the spray, the young fruits were punctured as badly at the end of the experiment as at the beginning.

Although negative results have followed the use of poisoned-bait sprays in Hawaii, failure has been due to the peculiar conditions surrounding the fields sprayed that permit an influx of female flies. Under commercial conditions, where cantaloupes, pumpkins, and watermelons are grown in large quantities in fairly dry climates, it is reasonable to believe that sufficiently good results will follow the use of poisoned sprays to make their application practicable as a method of control.

DESTRUCTION OF INFESTED FRUITS.

Larvæ and eggs may be killed by submerging the infested portions of the plant in water, or by burying, boiling, or burning. Choice of method will depend largely upon the amount of fruit to be handled and upon local conditions. There is no surer way to kill all immature stages than to boil or burn the fruits. Burning is often expensive, and, when trash in compost holes is depended upon to furnish the fuel, is likely to be unsatisfactory, particularly where, as in Honolulu, the quantity of infested material is so great. Bringing infested fruits to the boiling point will kill all forms. The submerging of fruits in ordinary tap water for five days will either kill all larvæ and eggs or stop further development.

Burial in soil is a satisfactory method, provided the fruits are buried deep enough and cracks are prevented from developing in the earth above the fruits as the latter decay and settle. It must be remembered that just after transforming from the pupa the adults are so soft that they can force their way through very small openings. A crack in the soil extending down to the fruit, even though it be no wider than ordinary blotting paper, is still wide enough to allow the adults to reach the surface and thwart the purpose of fruit burial. Adults can not make their way through a foot of well-tamped soil, but have been known to force their way through 2 to 3 feet of dry loose sand beneath which their pupæ had been buried.

Because burial and burning may be left to subordinates who may not have the interests of the owner so much at heart, boiling or submergence in water is more highly recommended. The larvæ will not injure cattle if the fruits are used as feed, but many larvæ may escape before they are eaten; hence this method of destruction is not recommended unless the fruits have a real value as a food.

PROTECTIVE COVERINGS.

The protection of fruits and plants by covering with soil, paper, or cloth is a great labor-consuming operation, yet this is the only method that will protect under present Hawaiian conditions. Even

FIG. 23.—Protecting cucurbits from attack by melon flies. Each fruit (in this case of *Momordica* sp.) is placed, immediately after it has been fertilized, within a long envelope made of newspaper. (Authors' illustration.)

as practiced to-day, less than 25 per cent of all fruits covered, except certain Chinese marrows, are actually saved from attack. In a slightly cooler climate than that of coastal Hawaii a high percentage of the fruits could be saved. As it is, the great attraction of the unfertilized ovaries of the bloom makes it difficult to put on coverings before the flowers are infested. During the warmer portions of the year the bloom of cucurbits, with the exception of the cucumber, should be protected at least three to four days before the flower unfolds. At present many fruits are covered, but rather indifferently and ineffectively. During April only 9 out of 43 fruits of the Chinese melon that had been covered were sound, while on the same date 119 out of 692 young protected watermelons were actually free from infestation.

Certain Japanese growers ward off attack by burying the young fruits in the soil or by surrounding them with straw or trash until they are sufficiently old to withstand fatal attack. In certain light soils cantaloupes are kept buried in the soil until they are ripe and they appear upon the market almost white in color. The most successful of protective coverings are those shown in figure 24. In this case the Momordica vines are grown over bushes, hence the young fruits can be found easily and inclosed in long cases made from newspapers and resembling envelopes cut across at both ends. These cases are left open at the lower end, but are never entered by the adult flies.

MEASURES TAKEN TO KEEP THE FRUIT FLIES OF HAWAII FROM GAINING A FOOTHOLD IN CONTINENTAL UNITED STATES.

The Federal Horticultural Board, by means of its Quarantine No. 13, entitled "Mediterranean Fruit Fly and Melon Fly," issued March 23, 1914, is doing all that man can do to prevent the two fruit-fly pests of Hawaii from becoming introduced into mainland United States. The regulations of the quarantine practically have put a stop to the movement of fruits and vegetables from Hawaii. Certain fruits and vegetables, however, such as bananas of the noncooking type, pineapples, taro, and coconuts, and others, when it can be shown to the satisfaction of the Department of Agriculture that in the form in which they are to be shipped they are not and can not be a means of conveying either the Mediterranean fruit fly or the melon fly, may be moved or allowed to move from Hawaii into or through any other State, Territory, or District of the United States when they have been inspected by the United States Department of Agriculture, certified to be free from infestation, and marked in compliance with the regulations. Pineapples, taro, and coconuts do not support the fruit flies of Hawaii, neither do bananas when shipped according to trade requirements. In practice the quarantine eliminates all shipments of fruit except the four just mentioned, and of these pineapples and bananas only are regularly shipped.

The enforcement of the quarantine is divided between the representative of the board in Hawaii and those at the ports of entry to the mainland, notably San Francisco, San Pedro, and Seattle. In Hawaii it is the duty of the inspector to see that the fruit is grown under conditions reasonably sanitary from a fruit-fly standpoint, that each package or bundle offered for shipment is inspected and bears a certificate to that effect, and that transporting companies do not receive for shipment consignments of fruit unless they have received from the Federal Horticultural Board a permit for such action. These permits, which give data on the kind, amount, and origin of fruit, the name and address of consignor and consignee, and dates, are issued in triplicate; the duplicate and triplicate remain in the files of the transporting company and the Federal Horticultural Board, respectively. The original is attached to the bill of lading accompanying the shipment and no consignment of fruit is permitted to leave the ship at the port of destination unless this permit is presented to the Federal inspector.

The duty of the inspector at the mainland ports is to make certain that no express or freight consignments leave ships arriving from Hawaii unaccompanied by the permit above mentioned, and that no quarantined fruits or vegetables are present either in the ship's lockers as ships' stores or in the possession of passengers, for all such are contraband after the ship passes within the 3-mile limit of the mainland. The inspector of the port of entry also must receive from each passenger a statement that he has in his baggage no contraband fruits or vegetables. Inspectors also have the right to search the personal belongings of passengers and members of the crew.

There seems little danger of fruit-fly pests reaching the mainland from Hawaii in commercial consignments of fruit since Quarantine No. 13 went into effect. *The greatest danger at present lies in the careless introduction of the pests by uninformed travelers who, without appreciating the great financial losses the Government is attempting to avert, persist in concealing about their persons and baggage contraband fruits, or in sending these by express or post in packages the contents of which are not stated truthfully.* These are the avenues of introduction that no law can close thoroughly. To close them, honesty and cooperation with the Federal Horticultural Board on the part of all are necessary.

SUMMARY.

The melon fly, a native of the Indo-Malayan region, is one of a number of very destructive pests that are likely to be introduced into the mainland United States. The quarantine officers of the Federal Horticultural Board and of California are each year intercepting it in infested fruits at California ports on ships from the Hawaiian Islands.

The melon fly was introduced into Hawaii about 1895 by Japanese immigrants in fruits which they brought with them as food from Japan. Before its arrival in Hawaii, cantaloupes, watermelons, tomatoes, and all kinds of cucurbitaceous crops, such as pumpkins, squashes, cucumbers, etc., were grown in large quantities and were cheap. They could be grown in every dooryard. Because of the ravages of the pest, these crops can not be grown now by the average person, and only with great difficulty in market gardens. Many fruits must be imported, and the cost of all has been increased as a result of melon-fly attack. Even cowpeas and string beans may be infested. It is impossible to overstate the destructiveness of the melon fly to cucurbitaceous crops under Hawaiian coastal conditions, where none of these can be brought to maturity except with the exercise of the greatest care on the part of market gardeners.

Since there are as many as 8 to 11 generations of the melon fly a year, and the female flies may live to be over a year old and lay eggs throughout life, the pest can multiply very rapidly. No agencies have been found to be working at present in Hawaii that bring about, even periodically, a great natural reduction in the abundance of melon flies. No native parasites are known to attack the melon fly, but it is hoped that the parasite introduced from India during 1916 may prove effective. In colder climates cold weather will prove a marked and valuable control factor. Predacious enemies and several forms of mortality recorded are of no practical value under Hawaiian conditions.

No satisfactory artificial measures have been applied successfully in combating the melon fly under Hawaiian conditions. Poisoned-bait sprays promise to yield effective results under other cultural conditions. In Hawaii these sprays would be effective if they were used consistently and universally, but they are not. At present cucurbits can be grown only by the use of coverings of various sorts for the protection of the very young fruit. Killing the immature stages by submergence in water, by burial in soil, or by boiling are not applied as methods of control, although they are effective when intelligently applied. Artificial methods of control are not likely to prove satisfactory in Hawaii so long as the growing of the chief host plants remains in the hands of uneducated oriental laborers who do not practice clean cultural methods or cooperate in applying remedial measures.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 645

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. January 26, 1918

SOME REASONS FOR SPRAYING TO CONTROL INSECT AND MITE ENEMIES OF CITRUS TREES IN FLORIDA.

By W. W. Yothers,
Entomological Assistant, Tropical and Subtropical Fruit Insect Investigations.

CONTENTS.

GRADUAL ADOPTION OF SPRAYING.

Among Florida growers there have been developing during late years what may be called two schools for the control of citrus pests. One of these favors dependence upon natural enemies; the other, upon artificial methods, particularly spraying. The relative merits of these two general methods of control are not discussed here, since, as time passes, it becomes more and more evident that there is room for both under the widely varying conditions surrounding Florida groves. Enthusiastic supporters of control by natural agencies such as entomogenous fungi do not believe that the lowering of the grade and the reduction in the size of the fruits and of the yield, if any, are of sufficient importance to demand attention. Or perhaps the case may be stated more fairly by saying that they believe that it is more profitable to use no measures for the control of pests, contending that it pays better to grow the lower grades of fruit without treatment than the better grades with treatment.

It is interesting, however, and very encouraging to note the gradual adoption of a system of spraying for the improvement of orchard conditions by men who, only a few years before the Federal Bureau of Entomology began its demonstration work, believed in, and depended upon, natural agencies as the best all-round method of control. This change has come partly through a realization that fungi parasitic on certain injurious insects, excellent as they are, have fallen short of what was expected of them, but more as a result of a spraying system developed by the writer, which, by taking all pests into consideration instead of merely the white flies, has proved the direct financial gain that will follow the intelligent application of spray mixtures. It is to certain advantages of this system of spraying that attention is called in this bulletin. Perhaps the best argument in favor of spraying is to be found in the difficulty experienced in securing the same grove for demonstration purposes two or three years in succession. Once the owner has seen with his own eyes the benefits resulting from careful and well-timed spraying, he refuses to accept the losses that he knows will come to him or his company through the setting aside of blocks of trees to serve as checks in community demonstration work.

PESTS OF IMPORTANCE.

Of the total damage caused by insects and mites to citrus in Florida, more than 95 per cent may be attributed to six species. In the order of their destructiveness, these are the citrus white fly,[1] the purple scale,[2] the rust mite,[3] the red scale,[4] the cloudy-winged white fly,[5] and the red spider.[6] There are several other pests of secondary importance, such as the woolly white fly,[7] the purple mite,[8] and the chaff scale.[9] The citrus white fly now infests nearly all the groves in the State. The purple scale is found in greater or less numbers on every citrus tree.

INJURY TO TREES AND FRUIT.

The presence of these pests on the trees and fruit produces blemishes which cause fruit to be placed in a much lower grade than would be the case if these blemishes were not present. While the excellent methods of washing the fruit remove nearly all the sooty mold which follows attacks of the white fly, usually some of it is left near the stem end. When this is present the fruit is placed in a grade lower than if it were absent. The presence of scale insects on the fruit lowers the grade, and, when these are abundant, makes the fruit practically unmarketable unless the scales are removed by hand washing. Perhaps the greatest cause for lowering the grade of fruit is the blemish following rust-mite injury. All these pests devitalize the trees, and this type of injury is much more important than the lowering of the grade of the fruit, because the yield is reduced. This

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1 *Dialeurodes citri* Ashmead.

2 *Lepidosaphes beckii* Newman.

3 *Eriophyes oleivorus* Ashmead.

4 *Chrysomphalus aonidum* Linnæus.

5 *Aleyrodes nubifera* Berger, now known as *Dialeurodes citrifolii* Morgan.

6 *Tetranychus sexmaculatus* Riley.

7 *Aleurothrixus howardi* Quaintance.

8 *Tetranychus citri* McGregor.

9 *Parlatoria pergandii* Comstock

devitalization is well known and admitted by the citrus growers, but few really appreciate the magnitude of this type of damage. Thousands of trees have been seen so injured by the purple scale that all the inside foliage and small limbs had been killed, and only a mere "shell" of foliage remained. In one small community in 1915 it was estimated that the damage amounted to $30,000. It cost four times as much to remove the dead wood resulting from insect attack as it would have cost to prevent the damage, and two crops of fruit were lost in addition. At least 75 per cent of the total damage could have been prevented for less than $2,000. Many citrus growers, realizing that this injury to the trees follows severe scale infestation, apply extra fertilizer so that the trees may have enough nourishment not only for the production of a good crop of fruit, but also to meet the demands made upon their vitality by the feeding scales. The belief is general that more fertilizer is required to get results in a grove heavily infested with scale insects and white flies than in one that is comparatively free from these pests.

To express the extent of this devitalizing effect in a statistical way or on a percentage basis is very difficult. In the two instances given below the damage caused by insect pests and mites is most strikingly shown. Although it is only proper to admit that these two cases represent extreme injury by pests, they indicate that the devitalizing effect which results in diminished yield is much greater, on an average, than most growers have thought possible.

In one instance a row of 16 trees was left unsprayed for three seasons, 1913, 1914, and 1915. The remainder of the grove was sprayed. The citrus white fly was making its first appearance in the grove. During the year 1913 there was little or no difference in the yields of the sprayed trees and the unsprayed check trees. In 1914 the unsprayed row had about 5 boxes of fruit, and the adjoining row of 16 sprayed trees about 60 boxes. All common species of fungi parasitic on the white fly and scale insects were present in great abundance. In 1915 the difference was not so great; the unsprayed row had about 20 boxes of fruit, and the adjoining sprayed row about 50 boxes.

As another instance, in a grapefruit grove at Safety Harbor 84 trees left without treatment during the summer of 1914 averaged two-thirds of a box per tree less than the trees adjoining which were sprayed. The reduction in the yield due to failure to spray was caused by the smaller size of the fruit resulting from rust-mite attack. There seems to be no evidence that the actual number of grapefruit on the unsprayed trees was less than on the sprayed trees.

During the year 1915 the same trees received the same treatment as during 1914. The sprayed trees had at least a good half crop, or about four boxes per tree. The trees adjoining which were left unsprayed during both years yielded only from one-half to one box per tree. This difference was so marked that all the laborers in the grove noticed it as early as August 1.

THE GRADING OF FRUIT.

PRESENT STATUS.

The percentage of first-grade fruit shipped out of Florida is not as great as it should be. To illustrate this point several tables have been prepared which give the percentages of the various grades shipped. These data have been obtained with difficulty. At first it was thought that information could be obtained from the growers. As a matter of fact the growers, as a class, do not know the percentage of the fruit in the different grades or the price received for the respective grades, for the reason that a large percentage of the citrus crop is sold on the tree, and shipped by those commission firms owning groves.

No information regarding the percentages of the various grades shipped could be obtained from the shipping companies. One important firm wrote that such large quantities of their fruit had been sold at so much per box, regardless of grade and size, that they were unable to give any information about grades and prices. The reports of the New York auction and the Florida Citrus Exchange were available.

The grading of fruit in Florida is in a most chaotic state. Certain grades marked "fancy" bring less money than third or fourth-grade brands. There are no standards for the various grades of fruit; the different grades vary as the season advances, and from year to year. It is very difficult to place each brand of fruit in its proper place. Attempt, however, was made to place it just as the shipper had intended. The Citrus Exchange key to the various brands was followed for all Exchange fruit. Wherever the word "fancy" occurred, this was placed in the first grade, "bright" in the second, and so on. This was strictly adhered to. The following table will explain this more fully:

First grade.	Second grade.	Third grade.	Fourth grade.	Fifth grade.
Fancy	Bright	Golden	Russet	Plain.
Stripes No. 1	Stripes B	Stripes R	Stripes Y	Big Cypress.
	Blue	Red	Yellow	Plain.
Deerfield F	Deerfield B	Deerfield G		
J. R. W. Fancy	J. R. W. Choice	J. R. W. Golden		
	Balls of J	Florida Sunshine	Apex	

In order to arrive at the best estimate of the grades of fruit shipped from Florida at present it seemed best to adopt two fairly distinct methods to determine this for New York City and compare the results with those obtained from other sources.

By the first method the records of fruit sold on four days of each month in New York City were taken into consideration. Usually the days selected were the 3d, 10th, 20th, and 28th or 30th of each month, but other days might have been chosen just as well. The percentages of the various grades of fruit shipped, based upon the records for these representative days, are given in Table 1.

TABLE 1.—*Percentages of various grades of oranges and grapefruit shipped from Florida to New York City during the season of 1915–16.*

Month.	Oranges.					Grapefruit.				
	First grade.	Second grade.	Third grade.	Fourth grade.	Fifth grade.	First grade.	Second grade.	Third grade.	Fourth grade.	Fifth grade.
November	8.17	48.55	37.14	5.63	0.5	13.85	55.6	26.61	4.43	0.0
December	13.93	43.79	40.18	1.87	.25	20.02	33.68	39.55	6.73	.0
January	12.26	38.30	40.89	7.58	.95	9.44	46.72	35.31	8.7	.0
February	2.60	32.28	47.07	14.66	2.38	2.58	21.46	48.90	18.77	8.3
March	.25	25.89	52.64	17.39	3.81	.6	9.7	50.6	33.4	5.65
April	1.16	20.91	50.80	25.51	1.60	.0	17.0	58.57	20.36	4.33
Entire season.	6.68	34.82	45.07	11.80	1.62	6.92	29.86	44.74	15.24	3.25

The data in Table 1 are based upon the sale of 128,487 boxes of oranges and 31,479 boxes of grapefruit. In the second method for determining the percentage of fruit shipped to New York City in the various grades, the fruit was placed in only three grades instead of five. The fruit was classified by the same method used for Table 1, except that fruit marked "fancy" and "No. 1" was placed in the first grade, and all "plain," fourth and fifth grade fruit was left out. The results, based upon a study of the auction sales, including 400,806 boxes of oranges and 126,193 boxes of grapefruit, showed that the percentages of fruit in the three grades were 35.56, 44.33, and 20.10 for oranges, and 34.43, 45.61, and 20 for grapefruit.

These data and those of Table 1 show that the two methods for determining the grades shipped give about the same results. The better grades are shipped during November and December; the poorer grades, toward the close of the season. To a considerable extent this due to the demand of the holiday trade, which calls for the best fruit obtainable. This demand causes such a keen competition among packers that it is difficult for any but the better grades to find a market until after Christmas.

Since the fruit sold in New York City grades much higher than that sold in other markets, and, in fact, better than the average fruit of the State, the percentages of the different grades of fruit of this market and those of other markets must be compared, in order to arrive at a just conclusion as to the amount of fruit in the different grades shipped from the entire State. Such a comparison of grades sold in New York City and other markets, including Baltimore, Boston, Chicago, Cleveland, Philadelphia, Pittsburgh, and St. Louis, is made in Table 2.

TABLE 2.—*Percentages of various grades of oranges and grapefruit shipped from Florida to New York City and other markets during the season of 1915–16.*

Market.	Oranges.				Grapefruit.			
	First grade.	Second grade.	Third grade.	Total boxes.	First grade.	Second grade.	Third grade.	Total boxes.
New York City	35.56	44.33	20.10	868,541	34.43	45.61	20.00	272,621
Other markets	8.30	44.57	47.13	5,096,817	8.85	36.2	54.9	1,544,929
Totals and weighted percentages	12.39	44.53	43.08	5,965,358	12.67	37.62	49.69	1,817,550

Taking into consideration all sources of information regarding oranges and grapefruit shipped out of Florida, the conclusion is reached that for the purpose of this bulletin the percentages of fruit in the first, second, and third grades approximate 13, 41, and 46, respectively.

RAISING THE GRADE OF FRUIT BY SPRAYING.

Since by no means all Florida fruit is graded so well as that shipped to New York, the problem of raising the standard is an important one. Is it worth while? Will it pay? From the results of work in Florida it may be asserted confidently that it is worth while and that it will pay in a very large number of Florida groves. Table 3 gives the percentages of the grades of fruit shipped from the same grove during 1914, 1915, 1916 and during 1917, up to January 15. In 1914 the small amount of spraying done came too late to prevent blemishes caused by rust mites. In 1915 and 1917 the spraying was done at the proper time, but in 1916 the application was made a little too late to produce the best results. The data resulting from this experimental work are so striking that comment is unnecessary.

TABLE 3.—*Result of spraying upon the percentages of grapefruit in the various grades.*

Grade of fruit.	Year and treatment.			
	1914	1915	1916	1917
	Not sprayed.	Well sprayed.	Sprayed too late for best results.	Well sprayed.
First	2.7	34.3	15.8	33.7
Second	15.8	51.5	51.6	46.3
Third	50.0	10.2	17.3	14.2
Fourth	31.5	3.7	15.3	5.9

In a second grapefruit grove during the season of 1913–14, when no spraying was done, the percentages of fruit in the four grades ran 0, 13.8, 65.5, and 20.8, respectively. During the season of 1914–15 the fruit from the same trees after having been sprayed ran for the same grades 12.4, 73.1, 14.5 and 0 per cent, respectively. These data, presented by Mr. S. F. Poole before the Florida Horticultural Society,[1] show that spraying raised the percentages of fruit in the first two grades from about 14 to 85.5 per cent, while the same treatment lowered the percentage in the inferior third and fourth grades from 86.37 to 14.5 per cent and raised all fruit above the fourth grade.

In a third grove the grapefruit of the season of 1913–14, which had developed without protection by spraying, gave 0.6, 24, 59, and 16.4 per cent, respectively, in the four grades. The same trees, properly sprayed during 1914, yielded fruits during the 1914–15 season which graded for the same grades 27.4, 67.5, 5, and 0 per cent, respectively. In other words, spraying increased the amount of fruit in the first two grades from 24.6 to 94.9 per cent and reduced that in the lower grades from 75.4 to 5 per cent; increased the first grade from 0.6 to 27.4 per cent and reduced the fourth grade from 16.4 per cent to zero. The fruit in the two groves upon which data have been given were graded by the Winter Haven Citrus Growers' Association, and the spraying was done under the direction of Mr. S. F. Poole, of Winter Haven.

The foregoing data, secured in the same grove two or more years in succession, may raise the question whether the relative abundance of pests, or more favorable climatic conditions, may not have been an important factor in the better crops secured after spraying. Without discussing this point at length the data secured in various groves are given below:

Grove 1.—During 1913, 900 boxes of fruit picked from unsprayed orange trees in the community graded 32.6 per cent "bright" and 67.3 per cent "russet," while 914 boxes picked from a sprayed grove and apparently equally well cared for in other respects graded 90.4 per cent "bright" and 9.5 per cent "russet."

Grove 2.—In the Hill grove at Winter Haven, which was sprayed during 1914, the oranges shipped 60 per cent first, 35 per cent second, and 5 per cent third grade; and the grapefruit, 30 per cent first, 67 per cent second, and 3 per cent third grade. The general run of fruit grown in the same vicinity, upon trees in the same general state of culture except that many had not been sprayed at all and others sprayed only indifferently, and packed by the same packing house, may be taken as a fairly good index to the grade of fruit produced during the same season. This fruit shipped 10 per cent first, 62 per cent second, and 28 per cent third.

Grove 3.—In this grapefruit grove one block of trees was sprayed, a second block was left unsprayed after June, while a third block was kept as a check. Aside from spraying, the trees received practi-

[1] Florida Horticultural Society Report, 1915, pp. 130–132.

cally the same treatment as regards cultivation and fertilization. The fruit in the sprayed and unsprayed blocks grew on trees about 30 feet apart, or in adjoining rows, and was picked and packed on the same day. The carload of sprayed fruit shipped 87.4 per cent first and second and 12.6 per cent third and fourth grades; the unsprayed carload shipped no first, 3.3 per cent second, and 96.6 per cent third and fourth grades. A more striking example of what a maximum infestation of rust mites will do and the benefits derived from spraying can scarcely be conceived. The carload of fruit left unsprayed after June shipped 80.3 per cent first and second and 19.6 per cent third and fourth grades, thus indicating that if rust mites are controlled thoroughly until the 1st of July on grapefruit little damage will result. In other groves russeting has been observed in January and February.

Grove 4.—In this grapefruit grove, 1 mile distant from grove 3, sprayed and unsprayed fruit was grown during 1914 in adjoining rows. The fruit from the sprayed trees shipped 18.8, 58.1, 15.1, and 7.9 per cent, respectively, in the four grades known as "fancy," "bright," "russet," and "plain." The fruits from the unsprayed trees shipped 6.6, 43.6, 49.7 and 6 per cent, respectively, in the same four grades. The percentage of second grade, or "bright," fruit from the unsprayed trees is much greater than from unsprayed trees of grove 3, since the rust mites did not do so much damage in this grove. It will be noticed that 15.1 per cent of the fruit from sprayed trees was russeted, whereas 49.7 per cent was russeted on the unsprayed trees. In grove 4 the poorer results were due to the inefficiency of the spray solution.

The foregoing data, under the general head of grades of fruit, should convince any grower that it is possible to raise the grade of fruit by killing pests so that the fruit will grade at least 35 per cent first, 50 per cent second, and 15 per cent third, instead of the present average for the State, which is 13 per cent first, 41 per cent second, and 46 per cent third. Fruit usually will grow to a remarkable state of perfection on healthy trees if only the insects and mites are controlled. One grove, the fruit of which was packed by an association noted for its high-class work, produced 90 per cent "Blue," or A No. 1 grade. The writer has seen 120,000 boxes of grapefruit from sprayed trees that graded 60 per cent first and 25 per cent second.

REDUCTION IN SIZE CAUSED BY INSECTS.

Insects and mites not only lower the grades of the fruit by the blemishes they cause, but reduce the size to a considerable extent. In raising the grades of the fruit by spraying, large benefits are obtained in preventing the pests from reducing the size. In commercial grading it is very difficult to show the difference in size of oranges that have been damaged by mites and those that have not, since in commercial houses all large, coarse fruits, as well as more or less fruit that is inferior, are always placed in the second or third grades with the "russets." This reduction in size is so great, however, that even in commercial grading the difference in size in the respective grades is considerable. Thus, in 941 boxes of oranges of the first grade, 7,111 boxes of the second, and 3,376 boxes of the third there were, on an average, 184.2, 197.9, and 200.4 oranges per box; a difference of 7 per cent in the number of fruits per box in the first and second grades, and of 8.8 per cent of those in the first and third grades.

The difference in size of the fruit of the various grades ranges from 4 to 14 per cent. In one community the general run of "bright" fruit (unaffected by mites) averaged 203.8 oranges per box, and the russeted fruit 222.2, or a difference of 9.28 per cent in favor of unaffected fruit. In another near-by grove that was sprayed the "bright" fruit averaged 214 and the "russets" 228 fruits per box, which is a difference of 6.6 per cent.

The number of grapefruit in 360 first, 970 second, and 279 third-grade boxes of fruit averaged 53.2, 57.5, and 51.9, respectively. In this instance the difference in number of fruits per box in the first and second grades is 8.2 per cent. Undoubtedly so many large, coarse fruits were placed in the third grade that these made the average number of fruits per box less than even in the first grade.

It is much better, however, to make comparison of fruit of the same variety from the same grove, and data are given here for this purpose. Table 4 shows the numbers of grapefruit per box for the various grades in a car of sprayed and of unsprayed fruit and of fruit which was not sprayed after June. These are the same carloads of fruit referred to on page 7, grove 3.

TABLE 4.—*Number of grapefruit per box from trees sprayed and unsprayed and from trees unsprayed after June.*

Grade.	Number of grapefruit per box.		
	Sprayed.	Not sprayed after June.	Not sprayed.
1. Fancy	42.2	46.6	0.0
2. Bright	43.6	49.7	48.4
3. Russet	45.2	52.3	49.3
4. Plain	38.8	43.2	46.1
General average	42.8	49.0	49.1

It will be seen that the sprayed fruit averaged 42.8 and the unsprayed fruit 49.1 fruits per box. This difference may not appear to be very great at first sight, but if the unsprayed fruit had been as large as the sprayed, there would have been 344.1 boxes of fruit instead of 300, or a gain of 14.7 per cent. The "russet" grade is smaller in all cars than either the "fancy" or "bright." All large, coarse fruits, were packed in the "plain," although they might be classed as "brights." Table 4, although it contains the data given by a commercial concern, does not indicate as great a difference as really existed. On the unsprayed trees there were many fruits so small and of such poor quality that they were never sent through the packing house.

Grapefruit grown about 1 mile from that discussed in Table 4 was sprayed with a different material, soda-sulphur. The sprayed and unsprayed fruit was picked on the same day. The number of fruits per box from the sprayed trees averaged, for the same grades given in Table 4, 47.8, 51.7, 56, and 53.4 per box, respectively; from the unsprayed trees, 52.3, 56.7, 59.5, and 0, respectively. The "russet" fruit in both cases was much smaller than any of the other grades. Taken as a whole, the fruit from the sprayed and unsprayed trees averaged 51.5 and 57.8 fruits per box, respectively, which gives a percentage difference of 12.3 in the number of fruits in favor of spraying. In another instance grapefruit from sprayed trees averaged 50.2 fruits per box as compared with 57.8 fruits from unsprayed trees in adjoining rows; a difference of 15.2 per cent in favor of sprayed fruits.

The reduction in size following rust-mite attack accounts, to a certain extent, for the small number of boxes produced in 1911, when practically all the unsprayed citrus fruit was "russet," and about half was "black russet," or about two sizes smaller than it would have been had it not been affected by rust mites. One test shows that 66 sprayed fruits filled the same box as 99 unsprayed fruits picked from an adjoining row, or a difference of 33⅓ per cent. From orange trees sprayed with lime-sulphur, 1–25, April 22, 1911, 338 fruits averaged 3.29 inches in diameter. The skin of this fruit was smooth and the texture good. From unsprayed adjoining orange trees 1,234 fruits averaged 2.58 inches. It would require 112 of the former to fill the average orange box and 226 of the latter, or twice as many.

The reduction in size in also shown by the average weight of the fruit. In a miscellaneous lot of oranges, graded commercially, 575 "brights" weighed 241 pounds and 575 "russets" weighed 225¼ pounds, which made a difference of 6⅓ per cent. This fruit, of course, had been picked at the same time and from the same grove and the collection represented all the different sizes. The fruit had not received any spraying. In another lot, 75 "bright" grapefruit which had been sprayed thoroughly throughout the season weighed 99.75 pounds, and 75 fruits which had received no spraying throughout the year weighed 88 pounds, which makes a difference of 11.77 per cent.

The foregoing data show that the loss resulting from the reduction in size of the fruit is close to 12.5 per cent, or about one size. About half the citrus crop of Florida suffers this loss. The data also confirm the observations made on the size of "brights" and "russets" when packed. When fruit is graded in a packing house and then run through the sizer the full bin on the "bright" side is invariably one size larger than the full bin on the "russet" side. These facts also substantiate the statement of Mr. S. O. Chase, of Sanford, Fla., who figured out more than 25 years ago that the increase in size which results from spraying pays for the cost of spraying. They also confirm the statements of Mr. F. D. Waite, of Palmetto, and Mr. A. B. Harrington, of Winter Haven, that rust mites reduce the size about 12½ per cent.

The belief is general in Florida that "russet" fruit will ship better, or with less decay, than "bright" fruit. If this is the case it is possible that the supposedly superior shipping qualities of the "russet" fruit might outweigh any advantages which the "bright" fruit might possess. While the data given in the following paragraphs may not be entirely conclusive, they certainly show that bright fruit, which retains its natural "waxy" coating for protection, ships equally as well or better than "russet" fruit, or fruit that has been injured by rust mites to the extent of losing its normal protection.

Test 1: Grapefruit—On January 30, 24 brights and 24 russets were picked and placed in the laboratory. These were examined from time to time, and on April 7 46⅔ per cent of the bright fruit had decayed and 58⅓ per cent of the russets.

Test 2: Fifty-one grapefruit each, of brights and russets, were picked on the same day as the preceding and placed in the laboratory. On April 7, 49 per cent of the brights had decayed and 75½ per cent of the russets.

Test 3: Oranges—One box of bright oranges and one box of russet oranges, each containing 200 fruits, were purchased at the packing house on March 9. These fruits were picked from the same grove. On April 7 the bright oranges showed 48½ per cent decay and the russet oranges 59 per cent.

Test 4: One box of brights and one box of russets containing 160 oranges each were set aside March 9. On April 7, 29.3 per cent of the bright fruit had rotted and 30.6 per cent of the russets.

Test 5: One box each of brights and russets, containing 150 oranges each, were used on March 3. On April 7, 50 per cent of the bright fruit had decayed and 66 per cent of the russet.

Test 6: One-half box each of brights and russets were put under observation on March 3. On April 7, 54 per cent of the brights had rotted and 74 per cent of the russets.

In the spring of 1917 another series of experiments was conducted to determine the relative merits of bright and russet fruit with reference to their carrying qualities. Twelve lots of oranges, each containing an equal number of brights and russets, were picked and carefully selected so as to avoid any mechanical injuries. So far as possible, the brights and russets from each lot were taken from the same tree. Examinations were usually made every seven days. Table 5 gives the percentage of decay for each period of all the lots.

TABLE 5.—*Percentage of decay of "brights" and "russets."*

Number of days.	"Brights."				"Russets."			
	Number of sound fruits.	Number of decayed fruits.	Total number of decayed fruits.	Per cent decay.	Number of sound fruits.	Number of decayed fruits.	Total number of decayed fruits.	Per cent decay.
	95	0	0	0.0	95	0	0	0.0
5	94	1	1	1.05	95	0	0	.0
12	93	1	2	2.10	95	0	0	.0
19	89	4	6	6.31	87	8	8	8.42
26	79	10	16	16.84	78	9	17	17.90
33	71	8	24	25.26	56	22	39	41.05
40	60	11	35	36.8	40	16	55	57.90
47	59	1	36	37.89	31	9	64	67.36
54	50	9	45	47.36	12	19	83	87.36
61	34	4	49	51.57	11	1	84	88.42

The above experiment was terminated about 2½ months after it was started. At that time 27 of the bright fruits were sound, 25 of which were eaten, and only 3 of the russets were sound, none of which were edible. The 95 bright fruits had averaged 51 days and the 95 russet had averaged 36 days before developing decay. In 11 of the 12 lots the brights lasted longer than the russets. According to weight, the percentage of decay was 45.3 in the brights and 64.8 in the russets.

The rate of evaporation of the juices is also much greater in russet fruit than in bright. From January 30 to April 7, 1915, 24 bright grapefruit lost 4.7 per cent and 24 russet lost 13.6 per cent from evaporation. During the same time 51 bright grapefruit lost 5.9 per cent, and the 51 russet lost 9.5 per cent. One box of bright oranges lost 10.4 per cent, and another box of russets containing the same number of fruits lost 15 per cent. Another box of brights lost 14.8 per cent by evaporation and the box of russets lost 17.9 per cent. In one box of half brights and half russets the brights lost 17.4 per cent and the russets 21 per cent. In one box of brights the loss from evaporation was the same as that sustained by the russet box. In 8 of the 12 lots mentioned under "decay" (Table 5) the percentage of evaporation was greater from russet than from bright fruit and the total of the 12 lots showed the russets evaporated 23.12 per cent and the bright 22.68 per cent.

There seems to be an impression among consumers and retail dealers that russet fruit is a variety of citrus instead of being the result of the former presence of thousands of rust mites. The responsibility for this erroneous idea rests with the salesman. It is considered good salesmanship to sell what goods there are on hand and to convince the purchaser of the merits of the same. Since more than half the crop is russet, some explanation must be made to the consumer as to the quality of the fruit he purchases. The explanation that russet fruit is a variety fulfills all the requirements of good salesmanship. The necessity for this exercise of shrewd salesmanship, as well as its continuation, rests with the Florida citrus grower.

One also hears frequently in Florida that russet fruit is sweeter than bright. So far as is known, no analyses indicate that such is the case. Since the russet fruit is not sold before the holidays, it has ample opportunity fully to ripen, so no russet fruit is ever sour. In some tests made March 25, 1914, several russet and bright oranges were peeled so that they could not be told apart by the taster. These were given to a person to taste. In both cases where bright and russet fruit were compared, the person pronounced that the bright was the sweeter. On January 29, 1915, five men pronounced sprayed fruit sweeter and possessed of a greater refinement and delicacy of flavor than unsprayed fruit from adjoining rows.

BETTER GRADES OF FRUIT BRING BETTER PRICES.

Obviously it is useless to raise the grade of fruit if second and third grade fruit sell for as much as the first grade. There is no reason to spend money to make first-grade fruit unless the improved fruit brings a good yield on the investment required to produce it.

In order to show the difference in price received for different grades of fruit Tables 6 and 7 have been prepared. The data of Table 6 are based upon the returns from the 128,487 boxes of oranges and the 31,479 boxes of grapefruit, and these data are given in Table 1.

TABLE 6.—*Difference in the price received in the New York market for different grades of oranges and grapefruit during the season of 1915–16.*

Month.	Difference in price received between the grades of—									
	Oranges.					Grapefruit.				
	First and second grade.	Second and third grade.	Third and fourth grade.	Fourth and fifth grade.	Total difference.	First and second grade.	Second and third grade.	Third and fourth grade.	Fourth and fifth grade.	Total difference.
November	$0.39	$0.28	−$0.01	$0.39	$1.06	$0.66	$0.36	$0.29	$0.00	$1.30
December	.57	.08	.09	.05	.79	.55	.57	.26	.00	1.36
January	.23	.14	−.00	.37	.74	.37	.36	.34	.00	1.08
February	.73	.14	.14	.37	1.38	.68	.25	.25	.03	1.21
March	1.36	−.09	−.16	.49	1.59	2.22	.43	.47	.29	[1]1.20
April	.96	.14	.06	.67	1.82	.00	.18	.17	.25	.60

[1] Difference between second and fifth grades; first grade is unusual sale.

The dash (—) placed before the difference in price indicates that a lower grade sold for more than the next higher grade. This occurred several times among the grades of oranges, but not among those of grapefruit. The only explanation that can be offered for this irregularity is that the lower grades had the sizes desired by the trade at the particular time of the sale.

Table 7 shows the differences in price for the grades of 400,805 boxes of oranges and 126,193 boxes of grapefruit when these are divided into three instead of five grades.

TABLE 7.—*Differences in the price receved in the New York market for different grades of oranges and grapefruit during the season of 1915–16.*

Month.	Difference in price received between the grades of—					
	Oranges.			Grapefruit.		
	First and second grades.	Second and third grades.	First and third grades.	First and second grades.	Second and third grades.	First and third grades.
November	$0.342	$0.044	$0.385	$0.517	$0.314	$0.831
December	.243	.136	.379	.369	.654	1.023
January	.221	.117	.338	.237	.362	.599
February	.168	.114	.282	.378	.325	.703
March	.099	.054	.045	.295	.569	.864
April	.226	.110	.336	.059	.279	.338

If the difference in price received for the first and third grades be added and the sum be divided by the number of months, an average difference of 30 cents in price received for the oranges and 72 cents for the grapefruit is obtained. In a miscellaneous lot of 5,427 boxes of fruit, the first grade averaged 48.8 cents more than did the second grade, and the second averaged 8.3 cents more than did the third grade.

Opportunity is seldom presented for comparing the price of sprayed and unsprayed fruit from the same grove. Through the cooperation of Mr. J. A. Stevens, of De Land, this was done with two carloads of grapefruit shipped in 1914 from sprayed and unsprayed trees, that were picked and packed on the same day and sold in the same market. The sprayed fruit sold for $1.94 per box; the unsprayed fruit for $1.69. These respective prices are disappointing. It had been anticipated that there would be at least a difference of 75 cents instead of 25 cents in favor of the sprayed fruit. The net profits due to spraying, however, were sufficient to pay one-fourth of the freight charges. Although the difference is slight, it is more than four times what it cost to spray the trees. The prices of the respective grades of the fruit could not be obtained.

In a grove about 1 mile distant from the grove previously mentioned 516 and 300 boxes of grapefruit, respectively, were picked from sprayed and unsprayed trees in adjoining rows. It is not known whether all the fruit was sold in the same market. The sprayed fruit brought 98 cents per box, the unsprayed fruit 85 cents per box. The difference in price, though small, was twice the cost of spraying. Because of the vagaries of the market, due to the daily fluctuation in supply and demand, it can not be stated that the better grades will always bring the better price, yet the data presented leave no doubt that spraying raises the grade of the fruit and largely overcomes the devitalized effect caused by insects, and that, other things being equal, the better grades bring better prices.

SPRAYING SCHEME FOR CONTROLLING CITRUS PESTS.

As a general proposition the time to spray for the control of all pests of citrus trees is when they are present in such numbers that, if left to reproduce without artificial hindrance, they would soon become injurious. In other words the pests should be killed before they can do much damage to either the tree or the fruit. The pests should always be kept in such a state of repression that they can do little or no damage. In case the various pests of citrus are permitted to become so abundant as to cause injury, the profits which may be expected from artificial treatment, such as spraying with an insecticide, are, to a certain extent, lost. Fortunately the life history and habits of nearly all citrus pests are such that good results can be obtained at any time of the year when the spray is applied. Nevertheless there are times when spraying is more opportune than at others. These periods come when the largest number of the insects are very young, for then they are killed most easily.

The following spray scheme has been used very extensively for four summers in Florida and generally has given satisfactory results. It must be admitted, however, that no hard and fast scheme can be recommended, and that to a large extent the number of sprayings depends on the thoroughness of the work.

I. *Paraffin-oil emulsion; Government formula, 1–66 or 1 per cent of oil. May.*—The main object of spraying at this time is to kill white flies, scale insects, and, to a large extent, rust mites. This treatment, however, must not be relied upon to control rust mites. The spraying should be done after the adults of the first brood of white flies have disappeared and before the appearance of those of the second brood. The fruit should be an inch or more in diameter. Since this treatment is given before the beginning of the rainy season, it does not interfere with the work of the beneficial fungi in reducing those insects not killed by the spray.

II. *Lime-sulphur solution, 32° Baumé, 1–50 to 1–75. June to July.*—The main object of this treatment is to kill rust mites, and the correct time for its application varies with the appearance of the maximum number of the rust mites. It should be applied before the mites get very abundant and before any russeting appears. It will also kill some scales and white flies, but is not of great value for that purpose.

III. *Paraffin-oil emulsion; Government formula 1–66, or 1 per cent of oil. August 25 to October 31.*—This is the second spraying for white flies and scale insects. The object of spraying at this time is to kill the white-fly larvæ which are the progeny of the third and last brood. It is this brood that causes nearly all the damage from the white flies, and the earlier they are killed the better it is for the trees. This spraying also will remove the sooty mold from the trees and a sufficient amount from the fruit to permit the fruit to be colored up by the sun. *Soda-sulphur, 1–50*, may be added to this spraying to increase its effectiveness in killing rust mites.

IV. *Lime-sulphur solution, 32° Baumé, 1–50 to 1–75. November or December.*—The object of this spraying is to kill rust mites, and it may or may not be necessary, depending on the abundance of the mites.

It may be necessary to spray for rust mites before Treatment I is given. This is especially the case with grapefruit in the more southern counties. In case the red spider becomes abundant enough to cause injury, an application of lime-sulphur solution should be given. In case of heavy scale-insect infestation it may be necessary to spray three times with the oil sprays, in which case the treatment can be given in midsummer or in winter. If the red scale is very abundant, two sprayings with the oil emulsions should be given at intervals of about a month.

The paraffin-oil emulsion may be made according to directions given in Circular No. 168, Bureau of Entomology.

In addition to the foregoing there are three highly satisfactory miscible-oil sprays on the market in Florida.

The soda-sulphur solution is made according to the standard formula: 30 pounds of sulphur, 20 pounds of caustic soda, and 20 gallons of water. This tests about 16° Baumé and may be used 1–40 instead of lime-sulphur solution, but it is not so effective in controlling rust mites. It has an advantage over lime-sulphur solution in that it mixes readily with the oil emulsions.[1]

COST OF SPRAYING.

The cost of spraying depends upon many different factors, such as the size of the trees, nearness to water, convenience of operation, type of spraying outfit employed, insecticide used, and character of

[1]For directions for making lime-sulphur solution see Farmers' Bulletin 908.

the labor. No grower should expect to spray a bearing tree for less than 3 cents for each application. It would be better to place the minimum at 4 cents. It should not require more than 10 cents to spray the largest trees in the State if any considerable number are present in one grove. An average cost per tree should not exceed 5 to 6 cents. If one figures the cost per box, a minimum would be 1 cent per application for oil spray and somewhat less for lime-sulphur. A maximum would be 1½ cents for either insecticide. An expenditure of more than 6 cents per box for the entire year should be unnecessary.

PROFITS AND BENEFITS.

It is impossible to express accurately the percentage of profit to be expected from spraying to control pests on citrus. The same condition applies to cultural and other grove operations in Florida. The data at hand are sufficiently accurate, however, to be worth presenting.

It has been shown that the better grades bring more money than the lower, yet it would be fallacious to assume that if the entire crop were of a high grade the grower would receive correspondingly higher prices. The trade will consume only so much high-grade fruit. It is reasonably certain, however, that the Florida crop has not yet reached the high standard where it would be no longer profitable to produce more high-grade fruit.

At present 13 per cent first, 41 per cent second, and 46 per cent third grade oranges are shipped from the State, and it is possible and practicable to raise this standard to 35, 50, and 15 per cent for first, second, and third grades, respectively. It is assumed that the trade would handle fruit of this quality. Thus, the first grade is increased 22 per cent and the second 9 per cent. If 7,600,000 boxes are taken as the basis for the crop of 1915–16, there would be 1.273,987 boxes more in the first grade if spraying were done. These would sell, according to Table 7 (oranges) for 21.6 cents[1] more per box, or an increase of $275,181. There would also be 9 per cent more second grade, or 521,177 boxes. These would sell for 9.6 cents more, or an increase of $50,033.

The percentage of the various grades of grapefruit was not very different from that of the oranges, so 13, 41, and 46 per cent may be used to represent the first, second, and third grades of grapefruit, respectively. The standard for grapefruit also can be raised to grade 35, 50, and 15 per cent. There would then be 22 per cent, or 399,685 boxes, which would sell for 30.9 cents per box more, an increase of $123,559. There would be 9 per cent, or 163,508 boxes, which would

[1] New York City prices. Other prices could not be obtained.

sell, according to Table 7 (grapefruit), for 41.7 cents more per box, or an increase of $61,182.

The total increase in value by raising the grade would be $509,955 for the entire crop of oranges and grapefruit.

Elsewhere in this bulletin it has been shown that "russet" fruit is of about one size, or about 12.5 per cent smaller than normal fruit. If it is estimated that one-half of the crop is "russet" there would be a reduction of 475,000 boxes, which, valued at $1, would produce a loss of $475,000. This is extremely conservative. As a matter of fact, 100,000 boxes of fruit in Florida are thrown away because the fruit is too small!

In regard to the reduction in yield caused by the devitalization of the trees, it is very conservative to estimate this at 10 per cent, or 760,000 boxes. In reality it is probably 20 to 25 per cent, and many sprayed groves prove this to be true, but for this estimate it is placed at 10 per cent. This amount of fruit is valued at $760,000.

This would make a total of $1,744,955 as a minimum estimate for the increase that could be expected from spraying the entire crop. The cost of spraying groves producing 7,600,000 boxes would be not more than 6 cents per box, or $456,000. This would be a net gain of $1,288,955 in the value of the crop produced. This gain could be divided in half and still a handsome profit would follow spraying.

In addition to the direct profit, there is the satisfaction, which every enthusiastic orange grower must feel, in maintaining healthy trees and producing high-grade fruit.

CONCLUSION.

Of the total damage caused by insects and mites to citrus in Florida, more than 95 per cent may be attributed to six species. These, in the order of their destructiveness, are the citrus white fly, the purple scale, the rust mite, the red scale, the cloudy-winged white fly, and the red spider.

Aside from the satisfaction of growing fine fruit and owning healthy trees, it is estimated from the data reported in this bulletin that had the 1915–16 crop of oranges and grapefruit been sprayed according to the schedule recommended, the growers of Florida would have increased their net returns by $1,288,955.

There is no reason why the standard percentage of fruit in the higher grades can not be raised so that the percentage in the first, second, and third grades will be 35, 50, and 15 instead of, as at present, 13, 41, and 46. In one of several instances given, spraying increased the amount of fruit in the first and second grades from 24.6 to 94.9 per cent, and reduced that in the third and fourth from 75.4

to 5 per cent; increased the amount in the first grade from 0.6 to 27.4 per cent, and reduced that in the fourth from 16.4 per cent to zero.

The better prices which, in most instances, can be obtained for the better grades of fruit fully warrant the adoption of a spray system that improves the grade and the amount of fruit produced. The data presented leave no doubt as to the practicability of making such improvement in the Florida citrus crop if the grower will adhere to the spray schedule outlined.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 647

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. ▼ May 3, 1918

THE ARGENTINE ANT IN RELATION TO CITRUS GROVES

By

J. R. HORTON, Scientific Assistant, Tropical and Subtropical Fruit Insect Investigations

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THE ARGENTINE ANT[1] IN RELATION TO CITRUS GROVES.

By J. R. HORTON, *Scientific Assistant, Tropical and Subtropical Fruit Insect Investigations.*[2]

CONTENTS.

INTRODUCTION.

The Argentine ant (*Iridomyrmex humilis* Mayr) is a native of tropical America, occurring in Argentina, Brazil, Chile, and Uruguay. It was first introduced into the United States at New Orleans about 30 years ago and was fairly numerous in parts of that city as early as 1891.[3] A few years later it had become established thoroughly in and around New Orleans and was causing great annoyance as a household, garden, and field pest. Early it was carried to California, where it has become established widely. It is especially numerous in parts of the citrus districts of Los Angeles and Riverside Counties and in the city of Los Angeles and occurs as far north as San Francisco and as far south as San Diego.

[1] For a discussion of other phases of the Argentine ant problem see Department of Agriculture Bulletin No. 377, by E. R. Barber, entitled "The Argentine Ant: Distribution and Control in the United States."

[2] Transferred to Cereal and Forage Insect Investigations, Oct. 1, 1917.

[3] Foster, Ed. The introduction of *Iridomyrmex humilis* into New Orleans. *In* Jour. Econ. Ent., v. 1, p. 289–293. 1908.

NOTE.—This bulletin is of especial interest to citrus growers in the southeastern States and generally to the public in that section.

The Argentine ant has been the subject of special study by this bureau for several years, more particularly as to its activity as a house pest, but also as to its general economy in relation to garden, orchard, and field cultures. The facts secured in the investigations[1] prior to 1913 indicated a very important injurious relationship of this ant to citrus culture in Louisiana. As a result of this apparent condition and in response to numerous complaints of injury to citrus trees occasioned directly and indirectly by this ant, a special investigation was instituted in 1913 under the supervision of Mr. C. L. Marlatt, Assistant Chief of the Bureau of Entomology, to determine the exact economic importance of the ant as a citrus pest and to devise effective means of preventing damage in citrus orchards.

GENERAL BELIEF AS TO DAMAGE TO ORANGE TREES.

It has been recognized generally that a few species of ants may injure orchard and other crops either directly, by feeding on plant parts, or indirectly, through their symbiotic relations with scale insects and aphids.

The important features of the activities of ants toward certain scales and aphids, viz., soliciting "honeydew" excretion from them, carrying them about, constructing shelters over them, and combating their enemies, were pointed out more than a century ago by Pierre Huber,[2] some of whose observations were made upon orange-infesting species. Huber, however, makes no mention of injury caused to orange trees by these habits.

Direct injury by ants, so severe as to cause the death of the trees in orange, cacao, coffee, and cotton plantations in the West Indies, is cited by the French historian Robin,[3] contemporaneous with Huber. Robin probably referred to leaf-cutting ants, *Atta* spp., several species of which destroy trees in tropical America by defoliation.

Although the habits of ants in relation to plants and plant pests have been studied by many observers since these early writers, extreme views as to damage to orchard trees by ants, especially through the fostering of insect pests, have developed only since the Argentine ant became established thoroughly in southern Louisiana. This ant made the greatest impression upon people by its unusual abundance and aggressiveness, and became the subject of study by many laymen as well as entomologists. Interest in ants, especially as orchard

[1] Titus, E. G. Report on the "New Orleans" Ant. U. S. Dept. Agr. Bur. Ent. Bul. 52. 1905.
Newell, Wilmon, and Barber, T. C. The Argentine Ant. U. S. Dept. Agr. Bur. Ent. Bul. 122, 1913.

[2] Huber, Jean Pierre. Recherches sur les Moeurs des Fourmis Indigènes. Paris, 1810.

[3] Robin, C[laude] C. Voyages dans l'Interieur de la Louisiane . . . 1802–1807, Tome I, p. 215. Paris, 1807.

pests, as indicated by the number of titles on this subject appearing in entomological literature, has increased greatly throughout the world in the past 10 years.

The principal convictions which had arisen, on the influence of the Argentine ant on citrus fruit trees in Louisiana, are expressed in the writings of Dr. Titus[1] and Messrs. Newell and Barber.[2] Titus states, substantially, that the ants aid in the distribution of aphids and scale insects on citrus and other trees, remove young scales to new territory, establish colonies of certain species, and appear to have become caretakers for all kinds of scales and plant-lice.

Newell and Barber, in addition to expressing the belief that the ants shelter and protect scale insects, aphids, and white flies, and establish them upon other plants, are of the opinion that it is in the orange groves that this ant has inflicted probably the most serious injury. They note that ant invasion is followed by so rapid an increase of scale insects that, unless prompt measures are taken against the ants, the second year of infestation shows a severe reduction in the crop, the third year almost complete loss, and the fourth or fifth year witnesses the death of many of the trees. These authors state further that the ants are particularly severe in their attacks upon the blossoms of the orange.

The opinion of the Louisiana orange growers themselves on this subject may be summarized from the answers received to inquiries made and submitted in 1914 as to whether the ant injures the trees and in what ways. Of those growers replying to the question, about 61 per cent believed it to be injurious, 33 per cent stated that they did not know, and about 6 per cent believed that it was not injurious. The prevailing beliefs as to the nature of the injury were, (1) that it prevents bearing, (2) destroys blossoms and roots, (3) eats feeder roots, (4) destroys the fruit, (5) takes the sap out of the new growth, (6) causes the death of limbs by traveling continuously over the same spot, and (7) injures the bloom, causing the oranges to drop. It was believed also that the ants increase, disseminate, and protect scale insects and drive out lady-beetles. One answer, however, was to the effect that the ants are beneficial because they destroy other insects. It was generally agreed that the ant causes most severe injury to the orange trees, resulting in a complete loss of crop and culminating in the death of the trees.

A preliminary survey of the orange orchards of Louisiana made it plain that many of them were suffering from some undetermined noxious influences. The trees were, as a rule, undersized, poorly shaped, lacking in the abundance of clear, dark green foliage which

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[1] Op. cit., p. 79–84. [2] Op. cit.

characterizes the healthy orange tree, and production was far below the standard for trees of their average age. During the blossoming period the flowers were often somewhat too numerous and conspicuous, a condition which characterizes a "sick" tree, and dying and dead trees were numerous throughout the district.

The apparent cause of the diseased condition of the trees was often traced to heavy infestations by scale insects and white flies, but obviously, in some cases, other factors contributed to this condition. Many orchards not invaded by ants exhibited the same symptoms as those overrun by ants. Manifestly, the amount of injury done by the ant must be distinguished from that due to other causes, and this involves a knowledge of the general conditions characterizing citrus culture in Louisiana.

The investigation therefore was planned to cover, first, a thorough study of the habits of the Argentine ant in relation to orange trees, and, second, a study of the cultural practices and other conditions which might affect the successful raising of oranges in Louisiana. An experiment in the reclamation of an ant-invaded and practically abandoned orchard was conducted to determine what might be done in the way of making such orchards profitable. The problem of ant destruction and control in the orchards was taken up at the beginning of the investigation and continued throughout its course.

GENERAL ACCOUNT OF ORANGE CULTURE IN LOUISIANA.

Louisiana is, perhaps, the oldest citrus-producing State in the Union. Orange trees have been cultivated there for at least 200 years and, perhaps, longer, at least one introduction having been made from Cape Haitien (Cap Francois), Santo Domingo, by the original French concessionaires, who arrived in Louisiana in 1718,[1] and it is probable that citrus trees had been grown there by the Spanish colonists previous to this introduction.

During the long period that has elapsed since this introduction orange trees have suffered occasionally from severe freezes, and several times have been killed to the ground. Freezes of this extreme sort, occurring in the period from about 1718 to 1806, are mentioned by Le Page du Pratz,[2] Robin,[3] and several other writers. Similar killing freezes have occurred during the past century, one, in 1835, killing every orange tree from the shores of the Atlantic to the Mississippi;[4] others, the last one of which at least was equally dis-

[1] Le Page du Pratz. The History of Louisiana. Translated from the French of M. Le Page du Pratz, v. 2, p. 17–18. London, 1763.

[2] Op. cit., v. 2, p. 17.

[3] Op. cit., p. 474.

[4] De Bow, J. D. B. *In* Review, v. 18, p. 609. New Orleans, 1855.

astrous, occurred in 1886,[1] 1895, and 1899.[2] These freezes had the effect largely to discourage the commercial growing of oranges in Louisiana. Many of the succeeding citrus orchards consisted mainly of volunteer sprouts from the old roots allowed to grow at will without care or culture. After the later freezes considerable nursery stock, untrue to name and poor in quality, was imported into the State. The present citrus industry of Louisiana has developed since the great freeze of 1899, and all the trees now growing have sprung from old roots or have been planted during or subsequent to that year.

Considerable damage also has been sustained by some of the orange orchards from floods due to excessive rainfall and high water and from tidal waves blown in from the Gulf of Mexico and the Barataria section by hurricanes and lesser storms.[3] An orange grower informed the writer that such storms had, by washing salt water from the Gulf over the orange trees on the left bank of the river below Pointe a la Hache, caused almost complete abandonment of orange growing in that section. Of the 8 or 10 severe storms of this nature, occurring in the past several years, those of 1893 and 1915 probably caused the greatest damage to citrus orchards. The storm of 1893 was followed by a tidal wave which "engulfed everything before it,"[4] the water sweeping over the orange groves to a depth of from 3 to 5 feet or more in places, and remaining there for several days. While the present investigation was still in progress there occurred the most severe hurricane of all, that of September 29, 1915. Besides destroying more than 90 per cent of the entire orange crop of the State, and extensively damaging many of the trees by stripping off their leaves and breaking branches, this storm blew water in, at first directly from the Gulf and river; and, on its recurve, brought brackish water, laden with millions of tons of rushes from the Barataria swamps. The water remained about the trees in parts of the orange section for several days, and the rushes were deposited from 3 to 4 feet deep on the ground, many of the trees being laden with them. It is difficult, at present, to estimate the damage that will result from this storm to trees not actually killed; but one way in which it will manifest itself will be in the increased number of poorly formed trees due to killing of the branches by defoliation.

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[1] Stubbs, W. C., and Morgan, H. A. The Orange and Other Citrus Fruits. La. St. Agr. Exp. Sta. Special Bul., p. 5, 1893.

[2] Records of the freezes of 1886, 1895, and 1899 are contained in U. S. Weather Bureau reports.

[3] See Humphreys, Capt. A. A., and Abbot, Lieut. H. L., "Report upon the Physics and Hydraulics of the Mississippi River," Washington, 1861, for a record of the earlier floods along the lower Mississippi; and Cline, Dr. I. M., in articles in the U. S. Dept. Agr. Weather Bur. Buls. M (1904) and Y (1913), by H. C. Frankenfield.

[4] Garriott, E. B. West India Hurricanes. U. S. Dept. Agr. Weather Bur. Bul. H, p. 40. Washington, 1900.

The principal source of damage to the present citrus plantings is, however, neglect of a proper routine of nursery and orchard practice, including control of insect pests. Pruning in the nursery to produce symmetrical trees with the greatest possible production of fruit-bearing wood has been neglected. Later, when planted in the orchard, branches of various sizes are allowed to die from one cause or another, often from scale insects, and the dead wood removed, leaving a misshapen tree. The trees are nearly always planted too close. Owing to the shallowness of the soil[1] the orange roots must spread to a great distance close to the surface, those of the different rows thus meeting and forming a network over the entire orchard. The branches of the various trees in the row also interlace in many cases, resulting in comparatively puny and undersized trees and low production. Furthermore, it is often impossible, at least always difficult, to get about in the orchard to give it the proper cultivation and spraying, and in cultivating the bark frequently is bruised and branches of varying sizes are broken.

Cultivation, fertilization, and spraying are neglected very often or practiced only intermittently. As stated by their owners, about 38 per cent of the orchards are not cultivated at all, the weeds in many of them growing almost as high as the trees. About 10 per cent of the orange groves receive such cultivation as is necessary for the raising of vegetables, which are grown between the rows.

Several classes of fertilizer are used, regularly by some, and intermittently by others. The chief kinds used are cotton seed, either meal or whole, commercial mixed fertilizer, stable manure, and shrimp hulls; sometimes two or more of these are used together. Approximately 37 per cent of the orchards, however, had received no fertilization of any kind for several years. A considerable proportion of the orchards, about 30 per cent, are sown with a cover crop, generally cowpeas.

No standard program of controlling insect pests has been followed, except by a very few of the more progressive growers. According to reports received from 97 per cent of the orange growers of the State, spraying against scale insects, the white fly, and the rust mite has been practiced at one time or another in the last five years by only 15 per cent of those who reported. Some of those who sprayed made only 1 application a year, others as high as 5, and 11 different combinations of insecticides had been used with an

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[1] The water table in Plaquemines Parish, where over 90 per cent of the citrus fruit of Louisiana is produced, lies from 1 foot beneath the surface in some orchards to 7 feet in others, but the average depth throughout the parish is only 2¾ feet. Draining usually is accomplished by open ditches, from 1 to 2½ feet deep and from 2 to 3 feet wide at the top, leading to an outfall canal, which connects with a bayou of the swamps. In some cases there is a pump, propelled by a gas engine, to hasten the outflow and care for exceptionally heavy rains; and around some groves rear and side levees are constructed. About 40 per cent of the groves, however, have no drainage system.

array of spraying machinery that was even more diversified and inefficient than the insecticides. About 6.5 per cent of those who reported had at one time or another treated for the white fly by spraying the spores of the three or four entomophagous fungi known to attack this insect.

After becoming familiar with the relations of the Argentine ant to the trees and the infesting scale and other insects, the history of the plantings, the natural conditions, and the widespread neglect of good cultural practices, one is forced to conclude that the latter are factors of much greater importance than the ant as causes of damage to and the destruction of citrus trees in Louisiana. The progressive decrease of production occurring in the last five or six years,[1] as well as most of the more severe forms of injury to the trees, is due to a combination of the causes here enumerated. The several armored scales, the white fly, and the rust mite, which, of course, cause much injury to the trees, can be controlled without difficulty in the presence of the ants and regardless of them, as will be shown later. It is possible that under new conditions the citrus mealybug and the fluted scale may become serious pests in the orange groves of Louisiana. The mealybug might become abundant on trees kept clean of other scales and white flies or in the event of a scourge overtaking its natural enemies. The fluted scale, from all reports, already has become a serious pest to ornamental orange and other trees in the city of New Orleans since the present investigation was discontinued, and later may be expected to infest the orange groves.

DISTRIBUTION OF THE ANT IN THE ORANGE GROVES OF THE UNITED STATES.

LOUISIANA.

Data on the distribution of the Argentine ant in the orange groves of Louisiana have been received from the owners or by actual inspection of 99 per cent of the groves of the State. The ants are present in 26.1 per cent, or about one-fourth of these groves. On the west bank of the Mississippi River, from McDonoughville to Home Place, in Plaquemines Parish, the ants are in 62.9 per cent of the groves; from Home Place to Buras, exclusive of the latter, they are present in 77.3 per cent of the orchards; from Buras to Venice, inclusive, they have invaded only 5.5 per cent. On the east bank of the river, in Orleans, St. Bernard, and Plaquemines Parishes, 23.8 per cent of the orchards between New Orleans and Olga, La., are infested with the Argentine ant. Over 95 per cent of the citrus

[1] The actual reduction of the orange crop of Louisiana, based on complete data as to number of bearing trees and amounts of greatest and last (i. e., 1914) crops of 80 per cent of the bearing trees of the State, is 36.8 per cent. The present production, in other words, is only 63.2 per cent of what the orange trees have proved themselves capable of producing.

fruits of the State are produced in these three parishes, so the above figures give an accurate idea of the proportion of the orange groves that come under the influence of the ants. The ant has not yet gained an entrance into any of the seedling orange groves of Cameron Parish.

CALIFORNIA.

In California the ants are present in a considerable number of the groves at Riverside, Corona, Uplands, Duarte, Monrovia, Sierra Madre, Alhambra, San Marino, South Pasadena, Pasadena, and Altadena. They have gained a foothold in one spot in the town of Pomona, but have not yet been reported in any of the orange groves. When they do arrive there, however, they undoubtedly will bring the mealybug into great prominence, as a minor outbreak occurred during the summer of 1916, and conditions are the same there as at Alhambra. They are distributed pretty thoroughly throughout parts of the cities of Los Angeles and Pasadena. In Ventura County they infest some of the groves at Santa Paula and occur in several groves in one block at Fillmore. They have every appearance of having been introduced into this section within the last three or four years. In San Diego County they have not yet gained a foothold in any of the orange groves, but they have been introduced into the fair grounds, in the city of San Diego, where they overrun many of the ornamental plants both out of doors and in the conservatories.

FEEDING HABITS OF THE ANT.

The damage to orange trees by the Argentine ant must be either direct, through habits of feeding upon plant parts and tunneling and nesting about the roots, or indirect, through its relations with harmful insects and as a carrier of citrus diseases, or both. Not only were the nature and amount of the injury inflicted by the ant learned through a study of its foraging and nesting habits, but a successful method of controlling it as well.

It is not the intention here to specify all the foods which the ant has been observed to utilize, or to describe its well-known ravages into household supplies, but rather to describe its feeding habits in the orange groves and particularly in their bearing upon the orange trees. The ant is omnivorous, and though much of its food is derived from plant sources, it exhibits a distinct need for animal food and utilizes not only the flesh but also the excreta and other effluvia of animals as well. Its need for flesh food is so marked that in the artificial formicary, when flesh food is not furnished, it almost always will feed to some extent upon its own young.

FOODS OF THE ANT DERIVED FROM PLANT SOURCES.

Method of the Ant in Obtaining Plant Nectar.

The floral, and occasionally extra-floral, nectar of many kinds of plants forms the most dependable food of the ants from a direct plant source. The flowers of citrus and many other cultivated and wild plants are visited habitually for their nectar, which is lapped up from the area around the base of the stamens and petals, this area being evidently the location of the principal nectar-producing glands, at least in citrus.

With the aid of a hand lens the tube-shaped tongue of the feeding ant may be seen moving rapidly and continuously, in conjunction with the labial palpi, over the surface of the floral organs, while the food apparently is being pushed back by a thin, elbowed member that moves constantly within the tube. The ant often continues lapping up the liquid until a full crop is indicated by the distended semi-transparent gaster, this requiring from 15 to 30 minutes. It then usually rests for a period in the flower, or it may at once start its descent toward the nest. On their way down the tree forage-laden ants frequently rest in any sheltered location serving to exclude light and breezes, and almost invariably a group of ants resting motionless may be discovered in such places along the trails.

Ants Poisoned by Floral Nectar.

Occasionally the ants are poisoned by the nectar from loquat blossoms. On one occasion attention was attracted to a certain group of blossoms by the fact that most of the ants in that neighborhood were assisting sick comrades, carrying dead ants, or standing sluggishly about. Close observation of many of the last mentioned showed them to have the mandibles wide open—rather an unusual attitude. Under a hand lens one was seen finally to open the mouth so wide that the mandibles extended at right angles to the sides of the head and to regurgitate a drop of yellowish fluid. Obviously it was a sick ant. It did not attempt again to feed. The loquat blossom has a heavy, sweet odor peculiarly its own, but suggesting that of the peach or almond, and it seems probable that at times the nectar may contain traces of prussic acid. In addition to obtaining the nectar from the flowers, the ant gets a good proportion of its flesh food there, as will be shown later.

Utilization of Plant Sap and Fruit Juices as Food.

The ant also utilizes the unmodified plant sap from orange and some other trees whenever it is able to obtain it. It habitually feeds upon the sap from wounds in the bark and often has been observed working in considerable numbers on every freshly made cut of the pruning saw in the orange groves, lapping up the sap, just as it does the nectar from flowers, and the sap-laden ants passing from the wounds to the nest in the soil. This habit of visiting cuts and bruises on orange trees may be of importance in the carriage of certain disease germs to places where they may infect the trees readily through wounds.

The ant is very fond of the juice of many kinds of fresh fruits and makes the most of the rotting oranges on the ground and the split fruit on the tree. It may be laid down as a practically infallible rule that the ants do not make the initial break into the rind or peel of fruits. This fact was announced long ago as true of European ants in general by Forel,[1] who, as a result of his observations of these ants on pear, apple, peach, and orange trees, concluded that they never make the first incision through the skin of these fruits. The same is true of the Argentine ant as regards the orange, fig, plum, peach, and loquat in Louisiana. In some orange groves in winter the juice from bruised, decaying, and split oranges forms the ants' principal source of food. The ants also feed to a large extent upon figs when the fruits become soft upon the trees and many fall to the ground. Entrance to even this soft, thin-skinned fruit is gained almost invariably through wounds made by birds and the adult wood-boring beetle *Ptychodes trilineatus* Fab., or through a minute break in the calyx cup or the wrinklelike cracks which commonly form in the skin of the Louisiana fig. As a rule the ants do not carry away particles of the flesh of fruits. The flesh gradually disappears from an attacked fruit because deprived of the juice which constituted most of its mass. On entering a fruit the ants first lick up all the juice ready at hand. A shred of the flesh then is taken in the mandibles and the juice squeezed out and simultaneously lapped up by the tongue. This is repeated until all the flesh of that particular fruit has disappeared.

Direct Injury to Blossoms and Other Plant Parts.

INJURY TO BLOSSOMS.

The ant sometimes chews into the stamens and petals of the orange and other flowers, but by no means habitually, and it is rare indeed that so many blossoms are injured as to cause any loss of importance. After examining thousands of blossoms in the worst ant-infested orchards during three seasons for such injury, it has been necessary to conclude that this activity of the ant is of no economic consequence. In certain situations where the ants are very numerous and desirable food relatively scarce some damage may occur in this way. It occurs

[1] Forel, Dr. Auguste. Les Fourmis de la Suisse, p. 422. 1875.

almost exclusively on isolated trees, where the number of blossoms and of host insects of the ant are low in comparison with the number of visiting ants.

The following points have been noted as being generally true where the ants do use the mandibles on the blossoms: The parts attacked are usually the petals and stamens of open and presumably pollenized blossoms, and in most cases there is no evidence that the fruit is injured thereby. The attack usually begins in a wound made by other insects, and the work of destruction proceeds slowly. As many ants as could be accommodated by the blossoms have been observed to work steadily for one-half day without being able to destroy two petals completely. The ants never have been detected carrying away particles of the blossom tissue; evidently they desire only the juice. The mandibles are used to squeeze the juice out of a portion of the petal or stamen, that it may be lapped up by the tongue. The work of other insects often may be mistaken for that of the Argentine ant in the orange groves of southern Louisiana. Thus the blossoms of both the orange and the loquat may be found badly chewed and ragged, with tunnels cut into the unopened buds, while all are covered with ants inside and out, seeming to make a positive case against the ant. When such cases have been examined with a determination either to see the ants cutting the holes or to discover what did cut them, the real culprit always turned out to be a bud moth,[1] *Uranotes melinus* Hübn., an unidentified case-bearing lepidopterous insect, or katydids.

A few of the flowers other than citrus more commonly visited by the ants in the Louisiana orange groves are those of the loquat or so-called Japanese plum (*Eriobotrya japonica* Lindl.), peach, cowpeas, clovers, dock, goldenrod, and aster.

INJURY TO ROOTS.

The possibility of the ant causing direct injury to plant parts other than the blossoms and fruit, and particularly to the roots, was investigated. In the orange groves the ants habitually nest in the ground near the base of the trees, and often the entrance to the nest will be found directly against the trunk. Many nests in these situations were examined, and both the underground tunnels of the ants and some of the roots of the trees traced for a considerable distance. Dead and dying trees which were said to have been injured or killed by the ants and healthy but heavily infested trees were selected for these examinations.

The principal facts brought to light were as follows: The ants never were found nesting directly in the root clusters of young

[1] Identified by Dr. Harrison G. Dyar.

orange trees. They never were found to have tunneled along the principal roots of the older trees, nor were nests found near enough to these roots to affect them. The smaller roots of sickly and dying trees were generally deficient in number. The most evident cause of the poor condition of these trees was gummosis, the trees in some cases being almost completely girdled by it at the crown, and the bark in this section and for some distance along the principal roots being in a rotten condition. No orange roots were found harboring insects of any kind; there were no host insects of the ant there. In a word, the roots had not the slightest injury traceable to the ants.

FOODS OF THE ANT DERIVED FROM ANIMAL SOURCES.

Animal Food Other Than Insects.

A considerable proportion of the food of the ant in the orange groves, even aside from the excretions of scales, aphids, and treehoppers, is of animal origin. The ant habitually feeds upon the flesh of all animals, from the round worms to the vertebrates, that become available to it. In addition to the dead and injured insects, which it finds in all sorts of locations, there is a more or less regular supply of the very prevalent crustacean known as the fiddler crab, which constantly is being crushed underfoot, and of certain small fishes occasionally left in the drainage ditches by the sudden removal of water by pumping. The ant also commonly visits piles of discarded oyster shells and feeds upon the particles of flesh adhering at the point of attachment of the oyster. Occasionally it also finds dead birds, field mice, rats, etc. It is unable to break the skin of a rat, as was proved by an experiment, but will clean out the liquids about the eyes and inside the mouth. The ant does not appear to eat muscular tissue in solid form, but shreds it off with the mandibles, lapping up the juices as it works, in the same manner as with fruits. In the artificial formicaries the particles of muscle not eaten are piled up in one of the chambers, and it seems possible that these may be drawn upon at times when meat is scarce.

In the stable the ant constantly visits the manure and captures the larvæ of house flies and other insects. It also visits human excrement, whether directly feeding upon it or solely for the capture of scatophagous insects is uncertain. Large trails have been found of ants carrying dung from chicken coops to the nest, and it appears that the ant may utilize this dry excrement for food. Often it is seen visiting bird's nests for the same purpose, though it also finds among the feathers certain refuse that is attractive to it and, perhaps, captures bird lice to some extent. It also has been seen feeding upon the liquid portion of freshly voided chicken excrement.

It is especially fond of sputum and the mucous secretion from the bronchial and nasal passages, particularly if voided by persons afflicted with a cold. The habit of the ant in getting into the mouth, ears, and nose of infants, whenever opportunity offers, is probably due to its fondness for mucus. Activities such as these, which are habitual with the ants to the full extent that opportunity offers, under certain circumstances obviously may be very important in relation to sanitation.

Living Insects as Ant Food.

The flesh food most esteemed by the ants seems to be made up of the insects which they capture alive. It is not solely for nectar that they visit the flowers of citrus and other plants, but also for the thrips, gnats, and other insects which they are able to capture there. A certain proportion of the ants foraging in the trees almost invariably are found to be carrying insects. The number so engaged will depend upon the availability of these insects. In a large number of observations on this habit, in all seasons, it was found that from as low as 0.49 per cent to as high as 45.8 per cent of the ants foraging in orange trees carried insects. Usually, however, less than 1 per cent will be engaged in capturing insects, and when the proportion is larger than 5 per cent it is because a special opportunity is offered. For example, on fig trees in Louisiana there is usually a period of emergence of psocids in the spring when other ant food is scarce, and the ants hang around the psocid groups and capture the insects as they emerge. Again, during the blossoming period of the small-leaved privet the ants are able to capture numerous thrips from the blossoms. The blossoms are narrowly campanulate, and the ants, unable to pass between the stamens, await and capture the thrips as they attempt to leave. Large numbers of foraging ants are found carrying white flies at each emergence period of the flies, on both orange trees and privets. All these insects, of course, may be captured from the same trees at the same time. For example, on one occasion, when all the ants carrying insects on a privet tree in one and one-third hours' time were captured and their prey examined, it was found that 32.7 per cent of the prey were thrips (*Frankliniella* sp.), 46.5 per cent nectar-feeding gnats, 13.8 per cent white flies, and 5 per cent psocids. Often, however, they are engaged almost exclusively in the capture of one particular species.

Large numbers of insects are captured on the ground, on weeds and ornamental trees, and in manure piles in the orange orchards of which no special account is taken because their capture has no bearing on the relation of the ants to orange trees. The ants also capture living and dead mealybugs, immature soft brown and black scales, aphids, immature stages of the white fly, and adult aphid and scale parasites, but so rarely that this activity is unimportant. The more important relationship of the ant as an enemy of the white fly in the adult stage is discussed on pages 38–40.

Insect Excretions or Honeydew as Ant Food.

The most dependable, if not the most abundant, supply of food of animal origin utilized by the ants in the orange groves is the honeydew excreted by the several species of soft scales, plant-lice, and tree-hoppers which it attends.

METHOD OF OBTAINING HONEYDEW FROM THE SOFT SCALES, APHIDS, AND TREE-HOPPERS.

The ants can be best observed obtaining sweet excretions from their host insects on the warmer days of winter, as fewer ants are running at such times and they can be observed more closely without disturbing them. The process is essentially the same with one species of host as with another. Taking the black scale, for example, the ant approaches a mature or immature but settled insect and strokes the body with one antenna after the other, rapidly and rhythmically. If no liquid appears after 15 or 20 strokes, the ant usually passes on to another scale or rests motionless by the first. Unless the scales are very numerous a proportion of the ants always are waiting, and the principal function of the small shelter structures found over scale groups is believed to be to protect the waiting ants from light, breezes, and, sometimes, the too copiously falling honeydew and its attendant mold. When the scale is ready to excrete the anal plates open slowly outward and from between them is extruded a tubular organ, at the extremity of which appears a droplet of colorless fluid. This the ant takes and swallows at once. The tube is then retracted and the anal plates close. The whole operation requires only a few seconds, not allowing time for closer examination of the mechanism. The extreme lightness of the antennal stroke suggests the possibility of the presence of minute sense hairs on the body of the scale, which, if they occur, probably are distributed over the entire surface, as the stroking is not confined to the immediate region of the excretory pore. Attempts to induce excretion by stroking with a hair in imitation of the ants failed. From scales under the microscope there was no response to palpation with hairs of various stiffness. When the shell was pierced with a needle the anal plates half opened reflexly, but not far enough for further observation.

The process is very similar with the mealybug, as the following observation will illustrate: The droplet of mealybug excretion is considerably larger in proportion to the size of the individual insect than that of either the black or the soft brown scale. Two ants were watched as they simultaneously stroked a mature mealybug on fig. Soon the posterior pair of spines moved slowly apart and a fleshy, pyramidal organ was extruded, at the tip of which there slowly appeared a droplet of colorless excretion. This both ants grasped with their mandibles, one standing at each side, and held until it slowly disappeared down their throats. The excretion was distinctly viscous, as shown by the plainly visible indentations made in the globule by the two pairs of mandibles, and the slowness with which it was swallowed. Ants often have been captured carrying down the tree semisolid globules of mealybug excretion. These they carried in their jaws, as they would carry insects. The excretion of the fluted scale also is voluminous and viscid.

The ants also have been seen to obtain honeydew from a species of treehopper (family Membracidae) occurring on goldenrod in the Louisiana orange orchards. Only the larvæ of this insect (identified by the late Mr. Otto Heidemann as *Entylia bactriana* Germ.) were attended by the ants so far as observed. When ready to excrete, the tip of the abdomen was elevated and a droplet of translucent yellow liquid appeared. This was taken by the ants and carried in the jaws like a minute ball of jelly.

The ants will take the body juices of scales and aphids as readily as their excretions, and the aphids often have been cut with a needle for the purpose of observing this fact.

The ants induce excretion in aphids by stroking with the antennæ, in much the same manner as they do the scale insects. The consistency of the excretion of aphids varies considerably, that from some kinds being thick and jellylike, while from others it is almost watery. An aphid occurring on cypress in Louisiana, for example, excretes a very thick honeydew which the ants swallow slowly and with apparent difficulty. The ants often are seen carrying these semisolid globules of honeydew in their jaws to the nest. Usually the ant hastily seizes the droplet the instant it appears, the liquid being flipped off to a distance if not promptly taken. The black scale also appears to throw the excretion to a distance, though not observed, as much of the sooty mold collects on the upper surface of the leaves which are under the scales. Some of the aphids attended—for example, the common orange-infesting species—have well-developed abdominal protective siphons, but these organs are absent from others.

RELATIONS WITH INSECTS INJURIOUS TO CITRUS TREES.

It has been shown that the Argentine ant is rarely directly injurious to citrus, either through its feeding or its nesting habits. Through the one persistent habit of visiting freshly made wounds on the trees it may be of great importance as a conveyor of citrus diseases, but the actual extent to which it increases the spread of diseases as yet remains to be determined. Since almost all the damage so far caused by the ant has been through its relations with the injurious citrus insects, this damage must be solely in the nature of an intensification of the work of these insects. Only that portion of such injury in excess of that normally caused by these insects can be due to their relations with the ants. It is, therefore, necessary to bear in mind that only a few of the citrus-infesting insects are of importance, and they cause practically all of the insect injury. The ant must be proved to enhance greatly the damage done by these major pests before a case can be made against it as a destroyer of orange trees. The major pests of citrus in Louisiana are four species of armored scale insects, the citrus white fly, and the rust mite, any one of which will cause more loss than all of the lesser pests, including the soft scales and the aphids, together.

RELATIONS WITH THE AR ORED SCALES.

Status of the Armored Scales of Citrus in Louisiana.

The four important armored scale insects of citrus in Louisiana are, in the order of their importance, the purple scale (*Lepidosaphes beckii* Newm.), the chaff scale (*Parlatoria pergandei* Comst.), the long scale (*Lepidosaphes gloverii* Pack.), and the white scale (*Chionaspis citri* Comst.). The purple scale is the most numerous and destructive of the citrus scales, infesting fruit, leaves, branches, and trunk, and generally incrusting the branches and trunk along with the chaff and long scales. The chaff scale infests nearly every budded bearing tree in the State, incrusting especially the trunk and larger branches, and at times overflowing onto the fruit and leaves in considerable numbers. The long and white scales also occur on most of the trees, but do not become so numerous as the first two, either of which would outrank them both as pests. The status of these scales does not seem to have changed much, excepting perhaps that of the white and chaff scales, in the last 12 or 15 years. The purple scale, according to Morgan,[1] was considered one of the most dangerous scales in the State at that time (1893). The white scale, however, considered by Morgan [2] as one of the most destructive of the scales, causing bursting of the bark, does not now get so numerous as the others and causes little damage. The chaff scale, which Morgan states was not recognized as very destructive,[3] now must be accorded second place to the purple scale as a scale pest of citrus in the State. Dr. Howard states that the chaff scale was the preponderating scale of citrus at a certain plantation on Bayou Têche as early as 1880.

[1] See Stubbs and Morgan, op. cit., p. 57. [2] Ibid., p. 64. [3] Ibid., p. 62.

It is worth noting here that the sweet seedling trees of Cameron Parish, which are apparently of Sicilian origin, are much more resistant to these scales than the budded trees. Although the more important scales occur on this type of tree, the infestation is always very light. The citrus white fly, likewise, has not become a pest on the Sicilian seedling trees, and these appear to be especially well adapted to the conditions found in southern Louisiana.

The status of other armored scales of citrus occurring in Louisiana is about as follows: The Florida red scale, which Morgan noted as occurring only at New Orleans and Southport,[1] just across the river, in 1893, is now found scatteringly throughout Orleans, St. Bernard, and Plaquemines Parishes on citrus, palm, banana, oleander, privets, camphor, and other trees. It never has been of more than very minor importance. The California red scale (*Chrysomphalus aurantii* Mask.), a very serious pest in parts of southern California, has been reported on an ornamental tree (*Podocarpus japonica*) in Audubon Park, New Orleans,[2] and has been observed there by the writer, but does not occur in the orange groves.

The Ant Does Not Attend the Armored Scales of Citrus.

The armored scales do not excrete honeydew or any similar liquid attractive to the ants, and are not, therefore, attended by the latter. On the contrary, they probably would become the prey of the ants if it were not for their protective shield or scale. Many hours of observations, extending over a period of nearly three years, on the actions of the ants toward the armored scales have shown conclusively that they do not directly attend the scales either in the expectation of receiving honeydew or of capturing emerging parasites, which, by the way, are neither numerous nor effective. In the course of these observations ants several times have appeared to be palpating armored scales with the antennæ, but on closer examination the real subject of their attentions always has proved to be a young mealybug or other soft scale resting close to the hard scales. The predominance of the armored scales makes impossible that their attendance should escape notice if it occurred.

It was discovered early that ant shelters sometimes occur over large and small groups of the diaspine scales, but this activity could not afford protection of the least consequence to these scales, for the number thus covered is infinitesimally small in comparison with those not covered. That even those scales under the shelters receive only dubious protection from them is shown by the fact that they are often infected with some of the prevailing scale fungi. The fre-

[1] See Stubbs and Morgan, op. cit., p. 60.

[2] Barber, T. C. The scale insects of Audubon Park. *In* Jour. Econ. Ent., v. 4, p. 450. 1911.

quent occurrence of living soft scales or of remains indicating that such had occupied these shelters is evidence that they generally were built while the ants were attending these scales and had no relation to the armored scales which they covered.

The forced conclusion is that any protection afforded the armored scales by the ants must be incidental and due merely to their presence on the trees and their very manifest habit of attempting to prey upon all insects not supplying honeydew with which they come in contact. For this protection to be so effective as to be of great economic importance the scales must have enemies so efficient as usually to keep them greatly reduced. The fact is, however, that these scales are not kept under reasonable control by their enemies, even in orchards where there are no ants.

Parasites and Predators of the Armored Scales of Citrus in Louisiana.

Although there was not time for a thorough study of the enemies of the armored scales of citrus in Louisiana, great batches of scale material from ant-free orchards have failed to produce more than a sprinkling of internal parasites. The more common hymenopterous parasites, reared from purple and chaff scale material selected because of the frequency of exit holes, were *Aspidiotiphagus citrinus* Craw. and *Coccophagus flavoscutellum* Ashm.[1] A small black lady-beetle,[2] *Hyperaspis signata* Oliv., with wing covers marked with a spot of red about the middle of each, feeds upon these scales to some extent, and a still smaller ladybeetle, *Scymnus puncticollis* Lec., is suspected of it. Larvæ, pupæ, and adults of a large coccinellid, *Chilocorus bivulnerus* Muls., frequently are found in large numbers upon trees overrun by ants, and a minute black species, *Microweisia misella* Lec.,[3] also often occurs on some of the trees by the hundreds. Both of these insects are suspected of feeding upon the early stages of the armored scales, but neither of them seems to be deterred greatly by the ants. At all events, they are found in considerable numbers on trees infested by the ants.

Influence of the Ant on Abundance of Armored Scales in Louisiana.

In addition to prolonged field observations on the relations of the ants to the armored scales, experiments were conducted for the same purpose by excluding the ants from certain trees and noting the effect of their presence or absence on the scales. Thus the ants were excluded from one of two vigorous young orange trees having an approximately equal infestation of the purple scale and allowed free access to the other. Notes were made at intervals on the number of

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[1] Identifications by Dr. L. O. Howard.
[2] Identified by Mr. E. A. Schwarz.
[3] Identified by Mr. H. S. Barber.

ound and parasitized scales, the presence or absence of scale enemies, nd the activities of the ants. This experiment was started on April 8 and concluded October 24, 1914. There was a large colony of the nts about the base of the nonbanded tree throughout the experiment, ut the ants did not visit the tree, except to keep it patrolled by couts, until several soft brown scales became established there, and t no time were they discovered paying the slightest attention to he purple scales. No scale enemies of any consequence were seen n either tree, and there was never any evidence of parasitism. The esults of this experiment are summarized in Table I.

'ABLE I.—*Experiment to discover the effect of ants upon the armored scales of citrus. Louisiana, 1914.*

Date.	Ants present.			Ants excluded.	
	Number of sound scales present.	Number of scales showing parasitism.	Number and activities of ants on trees.	Number of sound scales present.	Number of scales showing parasitism.
'ay 7	97	0	Only 3 scouts in tree	283	0
ıne 3	125	0	None on tree	591	0
ıne 19	198	0	do	591	0
ıly 17	276	0	8 ants capturing white flies.	530	0
ug. 13	1,130	0	A few scouts	1,372	0
ept. 25	5,700 (estimated)	0	10 ants attending soft brown scale only.	7,200 (estimated)	0
ct. 24	Trunk and main branches literally covered.	0	50 ants, all attending soft brown scale only.	Trunk and main branches literally covered.	0

Reference to Table I will show that on May 7 there were 97 scales n the ant-invaded tree and 283 on the tree from which ants were excluded. The number gradually increased on each tree from June o October, except that there was a slight and unaccountable decrease n the tree from which ants were excluded during June and July.)n September 25 it was estimated that there were 5,700 scales on the nt-invaded and 7,200 on the ant-free tree. By October 24 the trunk nd main branches of both were literally covered with the scales, nd it was impossible to distinguish between the two as to infestaion. The scales had increased at approximately the same rate on oth trees. The health of the trees remained good throughout, except or a few yellow spots made on the leaves by the feeding of scale roups.

In another experiment the ants were excluded from a block of nore than 200 bearing orange trees for several months, while an qual number of trees adjoining were left untreated as checks. The olor of the trees in the treated block showed improvement over hose in the check block, and this improvement was attributed to the cultivation and pruning received by the trees. There was no apparent difference between the two sets of trees as to abundance of armored scales.

RELATIONS WITH THE SOFT SCALES.

Status of the Soft Scales of Citrus in Louisiana.

Only four of the six principal citrus-infesting species of soft scales occurring in Louisiana have been discovered in the orange section of Plaquemines Parish. These are the soft brown scale (*Coccus hesperidum* L.), the citrus mealybug (*Pseudococcus citri* Risso), the Florida wax scale (*Ceroplastes floridensis* Comst.), and the barnacle scale (*C. cirripediformis* Comst.). No injury to citrus, serious or slight, ever has been attributed to the last two scales in the history of the orange industry in the United States, nor do they now cause noticeable injury to citrus in Louisiana. The first two are the only citrus soft scales occurring in sufficient numbers in the orange groves to attract attention.

Morgan[1] states that the citrus mealybug was very abundant in some of the orchards of Louisiana in 1893, especially in those well protected from winds and in thick-growing trees such as the mandarin, but was not a particularly serious pest at that time. These statements apply equally well for all practical purposes at present. The mealybugs occur scatteringly throughout the groves of Plaquemines, St. Bernard, and Orleans Parishes. They usually make a strong start in the spring and early summer and threaten seriously to infest certain orchards, but between the middle of June and the first of August they are brought under control by their natural enemies. Infestation goes the same course on fig trees in yards in New Orleans, except that the mealybugs are at times somewhat slower in being subdued there than in the orange groves.

Regarding the soft brown scale, Morgan's statement that "it appears and disappears, being kept in check by parasites, and for this reason has not attracted the attention of the orange growers"[2] also applies to-day. Its status is still essentially the same, though it is undoubtedly true that this scale will now be found in larger groups, in places, because of abundant attendance by the Argentine ant. It occurs upon nearly every budded orange tree over 3 years of age in the State, and also on banana, rose, and loquat in the orange groves. The important thing is, however, that it does not cause death or serious injury even to the twigs which it inhabits, does not blemish the fruit, and is not of noteworthy economic importance even in orchards overrun by ants.

[1] Op. cit., p. 69.

[2] Ibid., p. 68.

The black scale (*Saissetia oleae* Bern.) apparently was first noted in Louisiana in 1910, when it was taken upon certain plants in Audubon Park, New Orleans, by Barber.[1] It occurs commonly on oleander in many places about the city, but not a single specimen has been found in the orange groves.

The fluted scale (*Icerya purchasi* Mask.), according to Mr. Ed. Foster, who for many years has been an enthusiastic and discerning observer of insect life about New Orleans, occurred in places near present spots of infestation in and near that city as early as 1891, and this is confirmed by the statements of certain nurserymen and growers. It now occurs in many yards in the uptown districts of the city and in several nurseries, but has not been discovered in the orange groves.

THE ANT AS A PROTECTOR OF SOFT SCALES.

INFLUENCE OF THE ANT ON ABUNDANCE OF MEALYBUGS ON CITRUS IN LOUISIANA.

It was not possible to find sufficiently heavy infestations of mealybugs in the orange orchards of Louisiana during the years 1913 to 1915 to make experiments to determine the relative increase on ant-infested as compared with ant-free trees. Even in orchards overrun with ants the mealybug infestations were scattering and did not persist long enough to permit the desired experiments and observations to be made. The nonimportance of the mealybug as a pest in the orange groves of the State, however, seemed to make it unnecessary to conduct special experiments on them. Nevertheless, mealybugs were fairly abundant on fig trees in the laboratory grounds in New Orleans, and experiments of this nature were conducted on these trees and also on vigorous young orange trees, which were especially colonized with mealybugs for this purpose. The ants first began to frequent the fig trees in large numbers early in April, at which time mealybugs were rare and could be found only in small numbers in the most hidden places, such as old wounds, under dead bark, etc.

On April 27 several groups of mealybugs which still occurred only in hidden places on the trunks and larger branches of the fig were transferred to each of two orange trees. By May 7 they had settled themselves permanently on the trees. Thereafter ants were excluded from one of the trees; in the case of the other, in addition to the ants patrolling it from the ground, a large colony, including 25 queens and many eggs and young, was transferred to the soil in the pot, where the ants took up their abode near the base of the tree. Observations were made at frequent intervals. The number of sound and parasitized mealybugs was counted and notes made on the

[1]Barber, T. C. The Coccidae of Audubon Park, New Orleans, La. *In* Jour. Econ. Ent., v. 3, p. 424. 1910.

known or suspected enemies, while the activities of the ants were observed on the unprotected tree. The results are summarized in Table II.

TABLE II.—*Influence of the Argentine ant on abundance of mealybugs on orange, Louisiana, 1914.*

Date.	Ants present.			Ants excluded.		
	Number of sound mealybugs on tree.	Number of parasitized mealybugs.	Number and kind of mealybug enemies on tree.	Number of sound mealybugs on tree.	Number of parasitized mealybugs on tree.	Number and kind of mealybug enemies on tree.
May 7	593	0	1 T	1,126	1	1 T.
May 13	234	110 (31.9 per cent).	2 T	859	209 (19.5 per cent).	4 T, 3 L.
May 21	214	3 (1.3 per cent).	4 D, 3 T, 1 L, 1 S, 1 C.	727	90 (11 per cent).	3 L, 1 C, 1 S.
June 3	20	0	0	7	0	2 D, 1 L.
June 12	3	0	1 P	0	0	0.
July 29	6	0	0	0	0	0.
Aug. 15	2	0	0	0	0	0.

Symbols: T=tubuliferan thrips; L=larva of the pyralid moth *Laetilia coccidivora* Comst.; D=larvæ of the dipteron *Leucopis griseola* Fallén.; C=coccinellids; S=Syrphus fly larvæ; P=the mealybug parasite *Paraleptomastix abnormis* Gir.

At the time of beginning the experiment, May 7, there were 593 mealybugs on the ant-invaded and 1,126 on the ant-free trees. The mealybugs gradually disappeared from both trees, as shown in Table II, until by June 12 there were practically none. There was considerable parasitization and the continuous presence in the mealybug groups of several different predacious enemies. On May 13, for example, 31.9 per cent of the mealybugs on the ant-invaded tree were found to be parasitized, and 19.5 per cent of those on the protected tree also were parasitized. On May 21 the percentage of parasitism among the ant-attended mealybugs was 1.3 per cent, whereas among those on the protected tree it was 11 per cent. Predatory enemies occurred among or near the mealybugs on both trees as long as the mealybugs lasted. The more common ones were predacious thrips, coccid-feeding larvæ of the moth *Laetilia coccidivora* Comst. (identified by Dr. Harrison G. Dyar), and the two-winged fly *Leucopis griseola* Fallén (identified by Mr. Frederick Knab), unidentified lady-beetles, and larvæ of syrphus flies. At least one parasite, *Paraleptomastix abnormis* Gir. (identified by Mr. A. A. Girault), was found on one of the leaves of the ant-infested tree. There was no evidence that the mealybugs were being attacked by fungus or other disease.

The slightly greater persistence of the mealybugs on the ant-frequented tree has little practical significance and in part was accounted for by the following circumstance: On June 12 a strip of cloth was tied about the branch on which 3 mealybugs still remained on the ant-infested tree to mark their location, and the persistence of mealybugs in this tree after June 12 was due to their being sheltered by this cloth. The instinct for hunting shelter is much stronger in the young mealybugs than in any other of the soft scales and doubtless results from their being the preferred food of predatory insects.

During the course of the foregoing experiment on orange trees the mealybugs on the bearing fig trees, under constant attendance by the ants, had increased gradually, and during May overflowed their hiding place in the crevices of the bark and began to infest some of the smaller branches and leaves. On the branches they formed small groups and infested a considerable number of leaves, spreading along the underside, mostly in singles, twos, and threes. The period of maximum infestation of the fig trees extended from about the middle of May to the latter part of July. On June 26, while at its height, six of the trees were banded and the ants excluded for a period of 98 days, or until October 2, while six others were left unbanded and used as checks.

The work of the enemies and parasites had become evident by the middle of June, however, and it was apparent that the mealybugs were having a struggle to make further headway. By about the middle of July they had begun to lose ground, and from that time very rapidly disappeared from all unsheltered portions of all trees, banded and unbanded alike. The mealybugs very rarely, if ever, succeed in reaching maturity on fig leaves, even on ant-infested trees. A heavy parasitization was indicated early in July, due principally to a small, yellow-brown hymenopterous parasite.[1]

After August 15 the few mealybugs remaining on the large fig trees were in protected situations in the bark of the trunk and larger branches. The ant trails also had become thin in the unbanded trees by that time because of the scarcity of mealybugs. As for injury to figs by mealybugs, though a few small groups appeared on some of the fruits of ant-infested trees during this experiment, the percent of fruits so affected was so small as to be negligible. Practically all the fruit was clean and bright at picking time. The

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[1] This insect (*Paraleptomastix abnormis* Gir.) measures about 1 mm. long, some specimens less; general color yellow, marked on head, thorax, abdomen, and wings with smoky gray, the wings with three rows of dusky, broken, transverse stripes near base, middle, and tip, respectively, giving them a spotted appearance; legs and antennæ very long and slender, the former light yellow, the latter smoky brown. The insect has the peculiarity of keeping the wings elevated and in movement when running about on the leaves, which aids in distinguishing it in the field. The technical description by Girault is given in The Entomologist, v. 48, p. 184, London, 1915. While this parasite has been introduced into California, in localities in Alhambra, Duarte, and Sierra Madre, it has not yet become established as thoroughly there as in Louisiana, but if it does become so it will be an important factor in reducing the ant-attended mealybug infestations in that State.

leaves were of a clear, bright green, with very little sooting at any time. These trees, however, were receiving better attention than the average yard trees about the city. They had been kept well pruned and braced; weeds had been kept down, and the trees had shown vast improvement over their condition when first taken in charge. At no time during the three seasons in which they were under care was there any large amount of sooting of figs due to mealybugs. The fruit infestations usually were confined to one or two mealybugs in the calyx depression and the collection of a small group at this point on a small number of them.

The mealybug conditions for the years 1913 and 1915 were the same as described for 1914, both on fig trees and on orange trees in the city of New Orleans and in the orange groves proper of Louisiana. The sweet seedling trees of Cameron Parish are apparently not susceptible to the attacks of the citrus mealybugs at all; at least none ever was found on these trees.

Although certain groups of mealybugs may become larger because of heavy ant attendance in Louisiana, the status of this insect does not appear to have been changed by the protection received from the Argentine ant. The mealybugs usually appear in some trees in some of the orange groves as well as on fig trees during April. At times they become numerous enough to attract attention for a few weeks in May, June, and July, but in the last-named month they rapidly disappear, while their enemies increase, and by the last of July or early in August hardly any mealybugs can be found.

The most important enemy of the mealybug in Louisiana appears to be the Sicilian mealybug parasite (*Paraleptomastix abnormis* Gir.). Of the numerous predatory enemies, the most conspicuous were certain lady-beetles, larvæ of the green lacewing flies, larvæ of the small gray fly *Leucopis griseola* Fallén, and lepidopterus larvæ, of which the most prevalent was *Laetilia coccidivora* Comst. The last-named insect has the habit of spinning a more or less tubular web over the mealybug groups and feeding under its protection through the larva period, thus effectively defending itself against ants and other enemies. Another mealybug enemy of less importance, but sometimes fairly prevalent among mealybugs and other coccids, is a species of tubuliferan thrips which has not been identified.

INFLUENCE OF THE ANT ON ABUNDANCE OF MEALYBUGS ON CITRUS IN CALIFORNIA.

In parts of Los Angeles County, Cal., the attendance of the Argentine ant upon the citrus and other mealybugs has a much more pronounced effect in favoring persistent, heavy infestation than in Louisiana. This is especially the case with healthy trees that are comparatively free from other infesting insects. Several experiments were conducted in that county in the summer of 1916 which bring out pretty well the varying effects of ant attendance on the mealybugs under different conditions.

EXPERIMENT I.

The subject of Experiment I was an orange tree whose 6 main branches had been cut back to stubs about 2 to 3 feet long. Three of the stubs, with 28 new shoots, were banded to exclude the ants, while the other 3, with 27 shoots, were left free to the ants. Mealybug infestation, prevalence of mealybug enemies, ant attendance, and vigor of tree were noted at intervals from the beginning of the experiment, April 14, to its conclusion, September 2, 1916. The results are summarized in Tables III and IV.

TABLE III.—*Effect of the Argentine ant on abundance of mealybugs on orange. Los Angeles County, Cal., 1916.*

Date.	Ants present.		Ants excluded.	
	Mealybug infestation.	Number of mealybug enemies seen.	Mealybug infestation.	Number of mealybug enemies seen.
Apr. 14	74 clusters and groups	28	73 clusters and groups	35
May 3	106 groups	89	83 groups	76
May 17	361 groups of 10 to 150 bugs each	19	45 groups of 10 to 30 bugs each	38
July 6	112 groups, 10 to 50 ovipositing females with egg masses	38	12 ovipositing females only with egg masses; 9 masses of destroyed mealybug material	15
July 17	As on July 6, but more young scattered over leaves	301	No living mealybugs	0

The larger groups or clusters of mealybugs at first occurred on the main branches, where they had passed the winter, but the migrating young formed smaller but populous groups at the bases of the smaller branches and of the leaves. It will be noted that at the outset of this experiment there was nearly complete uniformity in the amount of infestation between the branches from which ants were excluded and those to which ants had access. Substantial uniformity of infestation persisted up to May 3, when there was a somewhat greater number of groups of mealybugs and more scattered individuals on ant-invaded branches than on those kept free from ants. Between May 3 and July 17 the mealybugs rapidly diminished to complete disappearance on the branches from which ants were excluded, whereas on those to which ants had access mealybugs continued to increase rapidly for a time, reaching the high point of infestation on May 17. Thereafter the infestation decreased on these branches also, but much more slowly than on those from which ants were excluded, remaining, on July 17, about one-third as heavy as on May 17.

Up to July 17, therefore, the presence of the ants had a very notable effect in increasing and maintaining mealybug infestation. On this date the band was removed from one of the branches so that reinfestation under ant attendance might be observed, and one of the branches previously free to ant attendance was banded. No marked results were obtained from this test. As indicated in Table IV, a slight reinfestation of mealybugs occurred on all the branches free from infestation on July 17, but there was a general decrease of infestation on both types of branches and on the entire tree throughout August. The only living mealybugs remaining on either set of branches during August were young which were scattered over the leaves, the insects being destroyed by their predatory enemies before reaching maturity, and by September 2 the entire infestation on the tree was reduced to an insignificant amount. In other words, on this particular tree the effect of the ant in increasing and maintaining the mealybug was marked up to the middle or end of July, but this effect was practically lost during August.

TABLE IV.—*Effect of the Argentine ant on abundance of mealybugs on orange. Los Angeles County, Cal., 1916.*

Date.	Ants present.								Ants excluded.							
	From Apr. 14 to Sept. 2.				From July 17 to Sept. 2.				From Apr. 14 to Sept. 2.				From July 17 to Sept. 2.			
	Number of leaves examined.	Number of living mealybugs.	Average number of mealybugs per leaf.	Number of mealybug enemies.	Number of leaves examined.	Number of living mealybugs.	Average number of mealybugs per leaf.	Number of mealybug enemies.	Number of leaves examined.	Number of living mealybugs.	Average number of mealybugs per leaf.	Number of mealybug enemies.	Number of leaves examined.	Number of living mealybugs.	Average number of mealybugs per leaf.	Number of mealybug enemies.
Aug. 7	50	1,000	20	9	189	21	0.111	0	405	81	0.2	0	150	30	0.2	1
Aug. 16	153	575	3.6	31	382	71	.18	1	251	122	.4	2	128	19	.14	17
Sept. 2	[1] 1,750	216	.12	0	[1] 1,465	50	.03	0	[1] 1,690	43	.02	0	[1] 645	49	.07	0

[1] All of the leaves examined.

The efficiency of natural enemies, as affected by the ant, was seen in the first period of the experiment, from April 14 to July 17. From April 14 to May 17 the number of mealybug enemies occurring on the branches from which ants were excluded did not differ widely from that on branches to which ants had access; yet, although by the latter date these enemies had reduced greatly the number of mealybugs on branches kept free from ants, their effect on mealybugs attended by ants was negligible. It appears that the mealybug predators are able to avoid capture by the ants, but are incapable of reaching the mealybug groups closely attended by them.

From May 17 to July 17 the mealybug enemies rapidly decreased and disappeared from branches kept free from ants and greatly increased on those where ants were present, following, as would naturally be anticipated, the available food supply. In the succeeding period of the experiment, from July 17 to September 2, after a certain amount of fluctuation, depending upon the supply of host insects, the natural enemies finally disappeared from all branches with the practical disappearance of their prey.

Experiment II.

The second experiment was conducted in the same locality, at Alhambra, Cal., on eight bearing navel-orange trees, four of which were banded with adhesives on April 24 and kept free from ants, while the alternating four were left accessible to ants for comparison. The results of this experiment, which are summarized in Table V, were similar to those in the preceding experiment, except that on the ant-invaded trees heavy mealybug infestation persisted throughout the experiment, or until September 12.

Table V.—*Effect of the Argentine ant on abundance of mealybugs on orange trees, Los Angeles County, Cal., 1916.*

Date.	Ants present.				Ants excluded.			
	Mealybug infestation.				Mealybug infestation.			
	On fruits.			On other parts of trees.	On fruits.			On other parts of trees.
	Total number examined.	Number infested.	Per cent infested.		Total number examined.	Number infested.	Per cent infested.	
May 24	800	[1] 200	25	Approximately as on Apr. 24.	800	[1] 150	18.7	Approximately as on Apr. 24.
July 10	1,405	328	24	242 groups of 1 to 5 mealybugs.	1,154	5	.43	12 groups of 1 to 5 mealybugs.
July 24	1,261	766	60.7	296 small groups, many scattered young.	1,263	34	2.6	7 small groups, many scattered young.
Aug. 7	1,596	923	57.8	206 small groups, many scattered young.	1,288	91	7.	Many scattered individuals.
Aug. 31	1,310	728	55.5	Many scattered	1,086	59	5.4	None.
Sept. 12	1,249	421	33.7	do	1,282	64	4.9	Do.

[1] From 1 to 5 mealybugs hidden under the sepals only of each infested fruit.

At the beginning of this experiment, April 24, mealybug infestation was slight, only 103 scattered individual mealybugs and small groups occurring on the trees from which ants were excluded and 70 individuals and small groups on those to which ants were allowed access, the ant-excluded trees being slightly more infested.

On May 24 young mealybugs were found concealed under the sepals of 25 per cent of the young fruits on the ant-invaded trees and 18.7 per cent of those on ant-excluded trees, showing a slight tendency toward worse infestation under ant attendance. The marked tendency of mealybugs to establish themselves under the sepals of the young fruits and in similar situations to secure sheltered feeding places must be taken into account when considering the subject of the transfer of mealybugs by ants to establish new colonies.

Between May 24 and July 24 mealybug infestation rapidly increased on the trees to which ants had access, while it decreased, with slight fluctuations, to an almost insignificant amount on those from which ants were barred. From July 24 to September 2 there was a slow reduction in the amount of mealybug infestation on the ant-traversed trees, an increasing number of mealybugs' remains indicating increased effectiveness of the natural enemies, which had become more numerous following the food supply. On the trees from which the ants were barred the mealybug infestation in the same period, with minor fluctuations in which the highest point was slight infestation of 7 per cent of the fruit, was maintained at a negligible amount.

The most important early activity of mealybug predators occurred on the very small fruits, these insects occurring with mealybugs under the sepals as soon as the mealybugs arrived there and preventing the growth of infestations from these spots. From July 24 to the close of the experiment, September 12, the number of predatory enemies, again following the available supply of food insects, was greater on the trees traversed by the ants than on those from which ants were barred, there being from five to eight times as many on the former as on the latter trees at the times examined. The principal enemies of the mealybugs occurring on these trees were Coccinellidae, Hemerobiidae, Chrysopidae, Pyralidae, and Syrphidae. During this latter period of the experiment, following the decrease in percentage of infested fruits on the ant-traversed trees, the increasing effectiveness of the mealybug enemies was manifested in the occurrence of an increasing number of fruits which had been rid of mealybugs, their previous infestation being indicated by bits of cottony secretion, sooty mold, etc.

Experiments III and IV.

Two other experiments conducted at Alhambra, Cal., with nursery trees and potted seedling orange trees brought out very similar results. The nursery trees, owing to too late transplanting, failed to thrive and did not become very heavily infested with mealybugs, but showed less plainly but quite as certainly the results of ant attendance in increasing these insects.

In the experiment on potted orange seedlings, 6 of the young plants were infested artificially with mealybugs, and on May 17, after the mealybugs had become located, the ants were excluded from 3 of the plants on which there were 4,573 young bugs and allowed free access to the remaining 3, on which there were 3,094 mealybugs. On August 21 there were only 577 mealybugs left on the plants from which ants were excluded, 40.6 per cent of the leaves being infested with an average of 3.2 mealybugs each; whereas on the plants traversed by ants there were 5,461 mealybugs, 74.5 per cent of the leaves being infested with an average of 29 mealybugs each.

Experiment V.

In the fifth experiment, which was conducted at Duarte, Cal., it was demonstrated that the effect of the ants in increasing the abundance of mealybugs may be largely neutralized in the presence of unchecked infestation by the black scale (*Saissetia oleae* Bern.). Ten bearing naval-orange trees of about equal condition and equal mealybug, ant, and black-scale infestation, the last-named being heavy, and with fully 90 per cent of sooting of the leaves, the trees not having been fumigated since 1913, were selected for this experiment. On April 20 five of the trees were banded with adhesive mixture to exclude ants, and the alternating five left accessible to ants for comparison. The results of this experiment are summarized in Table VI.

Table VI.—*Effect of the Argentine ant on abundance of mealybugs on orange trees heavily infested with the black scale (Saissetia oleae). Los Angeles County, Cal., 1916.*

Date.	Ants present. Mealybug infestation.				Ants excluded. Mealybug infestation.			
	On fruits.			On other parts of trees.	On fruits.			On other parts of trees.
	Total number examined.	Number infested.	Per cent infested.		Total number examined.	Number infested.	Per cent infested.	
			Per ct.				Per ct.	
May 25	100	80	80	Many scattered mealybugs and small groups.	100	94	94	Many scattered mealybugs and small groups.
July 7	437	156	35.6	11.4 per cent of new shoots infested.	304	165	54.2	33.1 per cent of new shoots infested.
July 21	455	154	33.8	51 groups of 1 to 30 young and 17 adults with egg masses.	382	193	50.5	36 groups of 1 to 15 young and 47 adults with egg masses.
Aug. 15	409	143	34.9	81 groups of 1 to 5 mealybugs each.	376	165	43.8	20 groups of 1 to 5 mealybugs each
Sept 11	364	198	54.5	79 groups of 1 to 5 mealybugs each.	340	137	40.2	41 individual mealybugs only.

The initial mealybug infestation, on April 20, was much greater on these trees than on those used in experiment No. 2, there being on the trees left free to ants 1,661 individual mealybugs and small groups, and 10 infested ripe fruits; and on those from which ants were excluded, 1,896 individuals and small groups and 4 infested ripe fruits.

There was no appreciable increase of infestation between April 20 and May 25, but on the latter date a few mealybugs occurred under the sepals of many of the little fruits, a larger percentage of infestation occurring on the trees from which ants were excluded than on those to which they had access.

Between May 25 and July 7 the intensity of fruit infestation increased on all trees, though the percentage of fruits infested decreased. On July 7 about 18 per cent more fruits and 22 per cent more new shoots were infested on the trees protected against ants than on those frequented by them; and, while several fruits on the latter were infested more severely than any on the former, the trees free from ants continued to suffer a larger amount of fruit infestation from July 7 to August 15.

From August 15 to the close of the experiment, on September 11, the infestation was slightly worse on the trees to which ants had access. With the exception of such minor fluctuations as those indicated, however, the amount of mealybug infestation remained practically the same on ant-invaded trees as on those free from ants throughout the period from July 7 to September 11.

The struggle of the mealybugs to find suitable spots to feed and avoid their natural enemies on these scale-infested trees was marked. Every available spot free from sooty mold was occupied by them, and groups often occurred under sheets of the mold where it had lifted from the leaf. Even on the fruits the mealybugs were crowded by the black scale, and the practically equal and slight infestation on both sets of trees was due largely to this crowding.

Mealybug enemies were numerous on both sets of trees throughout the experiment, especially the green and the brown lacewings, and larvæ of the green frequently were seen feeding upon larvæ and cocoons of their own kind and of the brown lacewings. Bits of cottony secretion of the mealybugs entangling the exuviæ of mealybug enemies were numerous at every examination. Others of the more numerous mealybug predators were the lady-beetles *Hyperaspis lateralis* Muls. and *Rhizobius ventralis* Erh.,[1] the predacious caterpillar *Holcocera iceryaeella* Riley,[2] the predacious fly *Leucopis bella* Loew, and the predacious bug *Zelus renardii* Kolen.

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[1] *R. ventralis* is primarily a black-scale enemy, but it also feeds upon mealybugs.
[2] Identified by Mr. Carl Heinrich.

Experiment VI.

In the following experiment, verifying the results of the one preceding, 4 trees longer subject to unchecked black-scale infestation were used, 2 of them being banded on June 2, the other 2 left free to ants.

Table VII.—*Effect of Argentine ant on abundance o fmealybugs in the presence of heavy black-scale infestation on orange. Los Angeles County, Cal., 1916.*

Date.	Ants present.			Ants excluded.		
	Fruit infestation.			Fruit infestation.		
	With mealy-bugs.	With black scale.	With sooty mold.	With mealy-bugs.	With black scale.	With sooty mold.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
June 2	37.5	....	....	32.5	....	....
July 7	32.9	94.4	100	20.2	100	100
Aug. 15	48.1	53.5	100	20.5	45.7	100
Sept. 11	39.6	91.7	100	21.2	98.7	100

The fruit infestation on different dates, summarized in Table VII, shows that mealybugs were always somewhat more numerous on the fruit patrolled by ants, but that almost no change in degree of infestation occurred on either lot of trees. Most of the fruit on all trees was infested with young black scales, and all was sooty throughout the experiment.

RELATION OF THE ANT TO MEALYBUG OUTBREAKS IN SOUTHERN CALIFORNIA.

The foregoing experiments establish beyond a doubt that the attendance of ants upon mealybugs in Los Angeles County, Cal., has the effect of greatly increasing their abundance, particularly during the first half of the summer, upon healthy trees comparatively free from other scale insects, causing severe infestations where otherwise they would be so scarce as hardly to come to notice at all.

This does not mean, however, that the mealybug outbreaks do not occur in southern California except in the presence of ants. More than 300 outbreaks of the citrus and other species of mealybugs were reported during the summer of 1916 in and about Pasadena by Dr. A. G. Smith, the local county inspector. The writer inspected 167 of these for ants, but, while the Argentine ant was present in 72 of them, and other ants in 16 more, there were no ants in the remaining 79. Nevertheless, it is a fact that in Los Angeles County the enemies of the citrus mealybug bring it under control early in the season and generally cause its almost complete disappearance when there are no ants present to prevent.

Most of the mealybug outbreaks in Los Angeles County orange groves which came to attention during the summer of 1916 did not long remain very severe unless the Argentine ant was in attendance. An outbreak that occurred at Pomona may be cited as an example of what usually occurs under such circumstances. The mealybugs appeared in the orange trees in a certain locality and on walnut trees bordering the groves in April and May and were rather numerous on many trees during the latter month. By June 23, however, they had become so scarce that it was difficult to find them at all. None could be found on the walnut trees, and though some orange trees were found on which 15 out of 18 of the young oranges were infested, there were only from 1 to 10 mealybugs per fruit, hidden under the sepals. Predacious caterpillars, tubuliferan thrips, and small lady-beetles (*Scymnus* sp.) were also rather common under the sepals of these fruits and apparently feeding upon the mealybugs. The Argentine ant did not occur in this section, and there were no other ants in the worst infested trees at the time of this examination.

In San Diego County, on the contrary, the mealybug infestations were very bad in some of the groves where there were no ants in attendance at the time of the inspection, June 27 and 28. In the Lemongrove district three orchards were inspected, and all trees examined were infested very badly with mealybugs. In two of the orchards there were no ants of any species on the trees examined, but in the third a few small red ants occurred on some of the trees. The Argentine ant is not yet present in any of the orange groves of this county, although it has been introduced into the fairgrounds at San Diego. In the Sweetwater Valley the lemon trees inspected also were infested very badly with mealybugs, but while two species of ants were fairly common on some of the trees, the Argentine ant was not present. The infestations were equally as bad on a number of trees on which there were no ants as on those where the ants occurred.

In the Chula Vista district the infestation in the last two or three years had been quite as severe as at Lemongrove and in the Sweetwater Valley, but during the summer of 1916 it was so slight as to give no apprehension. This fact is attributed locally to the occurrence of mealybug enemies, and especially the lady-beetle *Cryptolaemus montrouzieri* Muls., in much greater numbers this year than usually.

In the El Cajon Valley, which is considerably farther inland than the three orange districts previously mentioned, and is almost completely shut in from air currents from the coast by the surrounding foothills, no mealybugs could be found, and Mr. H. M. Armitage, horticultural commissioner of San Diego County, stated that none had been found by the local inspectors.

In San Diego County, therefore, the conditions are such that the mealybug infestation is just as persistent in trees where there are no ants as in other localities overrun by them. This infestation may remain severe for from one to several seasons, and then there will come a period when the mealybugs will disappear almost wholly. This fact has just been illustrated in the Chula Vista district, and is no doubt due to variations in abundance of the mealybug enemies in that section.

INFLUENCE OF THE ANT ON ABUNDANCE OF OTHER MEALYBUGS IN CALIFORNIA.

The number and severity of outbreaks of other species of mealybugs in Pasadena have been increasing during the last three years. Dr. A. G. Smith, county horticultural inspector for the Pasadena District, states that in an inspection five years ago, covering the district bounded by Fairoaks, Colorado, and Lake Streets and the Altadena boundary line, only one mealybug infestation was found. An inspection three years ago of the same section of Pasadena produced 18 infestations, mostly on rice-paper plants. During the summer of 1916, up to the time this information was given, only the north half of this section, or from the Altadena line to North Orange Grove Avenue, had been inspected, but infestations were found in numerous places and on many more host plants than ever before. The worst of these outbreaks have occurred in territory invaded by the Argentine ant, and undoubtedly have been especially severe and persistent only where attended by this ant.

A number of the outbreaks discovered by Dr. Smith's inspectors early in the summer of 1916 had been greatly reduced, and the mealybugs had almost disappeared by August where there were no ants in attendance. The species concerned in these outbreaks and the host plants most commonly infested in this section are as follows: *Pseudococcus citrophilus* Claus. on pittosporum, bignonia, tecoma, citrus; *Pseudococcus bakeri* Essig. on Chamaerops and Washington palms, peppers, laurestinas, nightshade, tomato, banana, aralia, fig, camphor, and various garden plants; *Pseudococcus longispinus* Targ. on Dracaena palms, citrus, and some shrubs; *Pseudococcus ryani* Coq. on cypress hedge. Outbreaks of these species of variable degree occur every spring, but are less persistent and usually are controlled early by their natural enemies where no ants are present.

Another species, known as the golden mealybug (*Pseudococcus aurilanatus* Mask.), attacks the Araucaria tree in many localities about Pasadena and remains numerous throughout the summer, regardless of whether ants are present or not, and often causes the defoliation of the trees. This mealybug either is not controlled by the various predators to the same extent as are the others mentioned above, or there may be some relation between it and its favorite food plant which makes this insect distasteful to these predators.[1]

INFLUENCE OF THE ANT ON ABUNDANCE OF THE FLUTED SCALE IN LOUISIANA.

The fluted or cottony cushion scale (*Icerya purchasi* Mask.) ranks second only to the mealybugs as to preference by the Argentine ant, owing, as with the mealybugs, to the large amount of viscid excretion given off by the insect. In spite of heavy attendance by the ant, however, the fluted scale has not been able to thrive and become abundant in Louisiana, except during the last season in New Orleans. This scale is believed by some, as previously stated, to have occurred on Metairie Ridge and in various places in New Orleans prior to the destructive freeze of 1895. Whether this is true or whether the insect has been imported into Louisiana only in very recent years is not certain. At all events the insect did not come to attention in the State until the fall of 1912, when it was found by the State inspector.[2] During the years 1913 to 1915, inclusive, closer attention was paid to the insect, and it was found at various places in New Orleans. Still it did not occur in the orange groves, and the infestations in and about the city were very scattering. Whenever they occurred in some numbers on a plant, they were viewed with such apprehension that extermination was attempted. It was, therefore, impossible to get a sufficient infestation under suitable conditions for experiments to determine the influence of the ant on their increase. During the summer of 1916, judging from reports received from New Orleans, the fluted scale spread more rapidly and became more numerous about the city than at any previous time, but the exact part played in this increase by the ant is not known.

INFLUENCE OF THE ANT ON THE FLUTED SCALE IN CALIFORNIA.

The status of the fluted scale in California in recent years is given by Quayle,[3] who states that the infestations become as bad at times in some localities as when at their height in earlier years. As a rule, however, the insect does not become numerous enough to be considered of economic importance.

No citrus orchards or trees could be found sufficiently infested with the fluted scale in southern California to serve for any adequate tests as to the influence of the Argentine ant. The scale occurred

[1] A condition such as this apparently occurs in the case of the fluted scale on Spanish broom in Ventura County, Cal.

[2] Tucker, E. S. Suppression of the Cottony Cushion Scale in Louisiana. La. Agr. Exp. Sta. Bul. 145. 1914

[3] Quayle, H. J. Citrus Fruit Insects. Cal. Agr. Exp. Sta. Bul. 214, p. 470. 1911.

very scatteringly and, as a rule, was parasitized or had been destroyed by its natural enemies. This was true in orchards overrun by ants and in orchards free from ants, indicating, at least, that so far in southern California the helpful influence of the ant, if any, in relation to this scale insect has not overcome the effective control of the scale by its natural enemies.

Aside from the well-known effectiveness of the Australian lady-beetle (*Novius cardinalis* Muls.), this control seems to be due, in Los Angeles County, chiefly to the parasitic fly *Cryptochaetum monophlebi* Skuse, aided, however, by hymenopterous parasites and the larvæ of lacewing flies.

INFLUENCE OF THE ANT ON ABUNDANCE OF THE BLACK SCALE IN LOUISIANA.

As already stated, the black scale (*Saissetia oleae* Bern.) does not yet occur in the orange groves proper of Louisiana, and, therefore, as with the fluted scale, no extensive tree-banding experiments could be conducted in this State during the seasons 1913 to 1915 to determine the effect of ant attendance on its abundance.

The black scale occurred in moderate numbers on oleander in New Orleans, and from these trees was transferred and colonized on young orange trees and an experiment of this nature attempted. The progeny of the colonized scales made an equally good start on both ant-free and ant-invaded orange trees. Nevertheless, the scales failed to reach maturity in a single instance, even where constantly attended by ants, and although they decreased a trifle more slowly where attended than where not attended by ants, all scales had disappeared from both banded and nonbanded trees within six weeks from the starting of the experiment.

INFLUENCE OF THE ANT ON ABUNDANCE OF THE BLACK SCALE IN CALIFORNIA.

The black scale has been rated as the most economically important of the citrus scales in California,[1] where it is generally controlled by fumigation. The observations on the relation of the ant to this scale were made in orchards in which fumigation had been temporarily neglected. In an experiment in which five scale-infested orange trees were banded to exclude ants in April, and a similar five left accessible to them, the amount of scale infestation remained practically equal on both sets of trees throughout the summer, from April to September.

In other words, after excluding the ants from five of these trees for a period of nearly five months but little difference in the amount of black-scale infestation or in quantity of sooty mold could be detected between them and five similar trees very heavily invaded by

[1] Quayle, H. J., op. cit., p. 445.

ants during the entire period. What difference existed was unfavorable to the view that the ants cause greater increase of the black scales. None of the trees had been fumigated since 1914.

In another experiment two more black-scale infested trees were banded against ants in June and two similar trees left accessible to them. These trees had not been fumigated for three years. As in the case of the first experiment, the amount of black-scale infestation remained practically equal on both banded and nonbanded trees throughout the remainder of the season.

Sometimes there is a greater amount of black-scale infestation on trees where there are no ants than on other trees of the same age and condition overrun by ants. Thus, in a block of orange trees not fumigated for two years more than half the fruit on a number of the trees on which there were no ants was scaly, while on a number of trees overrun by ants less than one-fourth of it was scaly. In this case the greatest scale infestation occurred on trees located next to older and heavily infested ones from which the scales had come by the usual means of dissemination, but there was no indication that the ants caused an increase of the scales on the trees on which they occurred.

In various orchards in Los Angeles and Ventura Counties, in which there were no ants and in which fumigation had been neglected for from two to four years, the black-scale infestation was quite as severe as is ever seen where the ants are present. In fact, in order to keep the black scale from reaching injurious numbers it has been found necessary every year to fumigate some orchards in which there were no Argentine ants and very few of other kinds. Sometimes a second fumigation is needed in the same season because of rapid reinfestation by what is called an offhatch, or an extra generation of scales, caused by their more rapid development on especially suitable trees.

It is evident, therefore, that the black scale in southern California is capable of reaching a very injurious degree of infestation in a single season, regardless of whether ants are present or not. Its natural enemies are not sufficiently numerous to prevent severe infestation, even though there is no interference from ants. The effect of the ant in accelerating the increase of this scale is therefore of little practical importance and does not compare with its importance as affecting the mealybugs.

INFLUENCE OF THE ANT ON ABUNDANCE OF THE SOFT BROWN SCALE IN LOUISIANA.

As was the case with the black scale, it was impossible to find a sufficient number of orange trees in Louisiana heavily infested with the soft brown scale (*Coccus hesperidum* L.) to conduct extensive experiments to determine the effect of the ants. In a test conducted upon young orange trees colonized with the scales, two of the trees, on which there were 5,425 and 334 young scales, respectively, were banded to exclude ants, while a third, on which there were 3,100 scales, was left accessible to the ants for comparison. The number of scales gradually diminished on all the trees, accompanied by a corresponding increase of parasitized scale remains, until within two months from the time of starting the experiment practically all had been destroyed.

The destruction of these scales was caused almost exclusively by parasites, the percentage of parasitized scales increasing, with slight fluctuations, at the same rate on the tree frequented by ants as on the two trees from which ants were excluded. There was nothing in the condition of the trees or in their suitability as a food plant of this scale to prevent the scales from thriving, as was shown by the fact that a few sound scales which had secured perfect shelter from parasites remained on the trees as late as October, three and one-half months after all those not sheltered had been destroyed.

It was plainly seen in this experiment, and many other observations bear out this conclusion, that the internal parasites are the most effective enemies of the soft brown scale in Louisiana and that the Argentine ant does not extensively prevent the work of these insects. A considerable number of adult parasites were seen on these trees during the examinations, and fully as many on the ant-invaded trees as on the noninvaded ones. Two species of chalcids,[1] viz, *Eupelmus coccidis* Gir. and *Coccophagus coccidis* Gir., were reared from ant-attended soft brown scales in Louisiana.

While an orange tree occasionally would be found in Louisiana with one or more small branches very heavily infested with the soft brown scale, assiduously attended by the ants, the worst infestations that came to notice were on plants other than citrus. For example, in an orange grove at Buras, where this scale was present in small numbers and scattered on orange trees, one limb of a rosebush was found infested so severely that in a space 1 foot long on a branch about one-eighth inch in diameter there were 1,440 scales.

Large groups of this sort sometimes are found in which there is very little evidence of parasitism, but usually from 2 to 60 per cent or more of all the scales occurring in such groups either contain the parasites or show their exit holes.

The soft brown scale undoubtedly is held in check in Louisiana orange groves, regardless of whether ants are present or not, by its natural enemies and particularly by the internal parasites.

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[1] Identified by Mr. A. A. Girault.

INFLUENCE OF THE ANT ON ABUNDANCE OF THE SOFT BROWN SCALE IN CALIFORNIA.

There was no opportunity during the season of 1916 to study the effect of the ants on abundance of the soft brown scale in the orange groves of southern California because of the scarcity of the scales. Larger groups of this scale occur on various ornamentals where attended by the ants than where there are no ants, and its abundance on camphor, bottle, and pepper trees and many others along some of the streets of Pasadena where the Argentine ant occurs makes it appear that the ant has the effect of greatly increasing the infestations there. Neither the soft brown scale nor the closely related citricola scale [1] occurred in any greater number in the ant-invaded orange groves of Los Angeles County than in those where the ant did not occur. In Riverside County, on the contrary, large groups of the soft brown scale were found more easily in the ant-invaded than in the noninvaded orchards. Quayle [2] has noted that the soft brown scale becomes especially serious under the influence of the ant in that county. Several orchards were mentioned by Mr. D. D. Sharp, Riverside County horticultural commissioner, in which the soft brown scale had become so numerous as a result of attendance by the ant as to attract general attention. In one of the most severely ant-infested orchards, however, which it was said had not been fumigated for several years, there was a large parasitization of the soft brown scale, as high as 82 per cent of them being found destroyed by parasites in a group under heavy ant attendance.

It appears, therefore, that the Argentine ant may afford enough protection to the soft brown scale at times on certain trees or in certain localities to cause the formation of larger groups than is customary and retard the destruction of the insect by its natural enemies. This effect has not, however, been marked enough either in California or Louisiana to change the rank of the scale as a citrus pest of merely minor importance. This is due to the fact that internal parasites and not predacious enemies are the chief factor in the natural control of the scale.

RELATIONS WITH THE CITRUS WHITE FLY.[3]

The Ant as an Enemy of the White Fly.

The only direct relation which the Argentine ant bears to the citrus white fly is that of predator. The first knowledge of this fact came as a result of observations made in an orange grove at Happy Jack, La., in April, 1913. At that time the prevailing belief, which

[1] *Coccus citricola* Campbell.

[2] Quayle, H. J. *In* Jour. Econ. Ent., v. 9, p. 472. 1916.

[3] The citrus white fly (*Dialeurodes citri* Ashm.). The cloudy-winged white fly (*Dialeurodes citrifolii* Morgan) also occurs in Louisiana, but is greatly outnumbered by the first-named species.

was shared by the writer, was that the ants fostered the white fly for its excretions, and when many ants were seen carrying adult white flies down an orange tree it was taken as evidence that they were transferring this pest to other trees and colonizing them thereon. As a principal occupation of the ants on nearly every tree was carrying white flies, however, and the reason for carrying only adults was not clear, the opportunity was taken to observe this work more closely.

It was noticed that comparatively few ants were carrying white flies up the trunk, but that a very large majority, certainly over 95 per cent, were carrying them down only. If the ants were establishing the white flies on other trees, it seemed that at least there should be somewhere near the same proportion carrying them up as were carrying them down the trees. Many of the ants therefore were traced as they carried the insects up and down the trees. Invariably those going up trees were traced to some cranny, where they poised in the dark for a rest or to avoid a breeze, or they would go up a short distance and then turn and go down again. Invariably those going down the tree were traced to the entrance to an underground nest, where they disappeared from view. Some of these entrances were directly at the base of the tree, but digging out such tunnels proved that the ants were not nesting about the roots of the trees or other plants on which the white fly might feed. It also disclosed the complete absence of underground colonies of living white flies and the presence of piles of dead remains of adults in the ant tunnels.

The next step was to examine white flies carried by the ants to determine whether they were living or dead. Some of them were living, and a good many more were dead, but the most important discovery was that a very large majority still had their wings crumpled, as they are immediately after emergence from the pupa case, showing that they were captured just as they emerged.

The percentage of white flies which the ants destroy must vary widely in the various groves at different times, and is probably never high enough to be of great economic importance. In a series of ten examinations to determine what proportion of the ants descending orange and privet trees with forage had captured white flies, the following data were gathered on the subject:

All the ants passing a point on the trunk going down the tree in a certain length of time, usually from 10 minutes to a half hour, were counted and classified as to whether or not they carried forage. Those carrying liquid forage could be distinguished by the distended gaster. The kinds of insects carried were noted without disturbing the ants where possible; otherwise the prey was collected. In these examinations it was found that from as low as 0.7 per cent to as high as 54 per cent of the ants which had any kind of forage carried white flies. Other of the lower percentages were 0.9 per cent, 3.1 per cent, 3.2 per cent, and 13.8 per cent; while other higher percentages were 21 per cent, 21.7 per cent, 34.7 per cent, and 38.4 per cent. Most of these examinations were made at times when the foraging was not too heavy, so that the ants could be counted without danger of confusion, and the number of ants carrying white flies was often too large to count. The percentage of ants with forage in their possession in these examinations ranged from 16.1 per cent to 75.8 per cent.

The above phenomena, which were observed many times on citrus and other plants every season spent in Louisiana, always may be seen during the emergence periods of the white flies in orange groves invaded by the ant. At times the ants with their captives are so numerous that the most casual glance will discover them as they go wavering down the trunks with the white-fly wings spread above their heads like diminutive sails. At times, when such a caravan is suddenly struck by a light breeze, the little sails will scatter in every direction as the ants hunt for temporary shelter to prevent being blown out of their course. The only possible direct part played by the ant in its relations with the adult citrus white fly in Louisiana is that of predacious enemy.

Relations of the Ant with Immature Stages of the White Fly.

Investigation of the behavior of the ants toward larvæ and pupæ of the citrus white fly brought out the fact that, although they hover about these immature stages more or less, they do not palpate the larvæ or directly obtain their excretion, but that they watch over the pupæ solely for the purpose of capturing the emerging adult insects. Although the ants do not capture living white-fly larvæ, and only a comparatively few pupæ, they are occasionally seen carrying the latter. The pupæ taken are nearly always those in which the transformation to the adult is almost completed, the ants becoming impatient at waiting for the adult to appear or being impelled to attack by its attempts to extricate itself from the puparium. In some instances as many as 8.7 per cent of the white flies taken from the ants have been pupæ, but this proportion is doubtless above the average.

When most of the white flies on a heavily infested tree overrun with ants are in the larva stage the ants never are found in attendance in considerable numbers on the worst infested leaves. The ants have been seen to lick the leaf surface in the vicinity of white-fly larvæ and they undoubtedly secure a certain amount of white-fly excretion in this secondary manner, especially when other food is scarce in the trees. If any large proportion of the white-fly excretion were taken by the ants, however, the sooty-mold fungus would be by so much the less prevalent in ant-invaded trees; this, however, is not the case. The ants do prevent to a very large extent the collection of excretory matter and the formation of sooty mold after mealybugs, even inducing such rapid excretion in certain young stages that the mealybug is unable to form the wooly covering, its body remaining almost naked and pink.

Effect of the Ant on Abundance of the White Fly.

An experiment to determine the effect of the ants on abundance of white flies was started on April 25, 1914, a young orange tree with 838 white-fly eggs being banded to exclude ants and a similar tree with 1,474 eggs kept accessible to ants for comparison. The percentages of young stages of the white fly dying from unknown causes and the quantity of new growth on the two trees were noted at every examination to make sure that the difference in white-fly infestation was not due to varying food conditions.

On May 13 there were on the tree from which ants were excluded 949 sound and 113 dead larvæ and pupæ and 189 unhatched eggs; on the tree that was accessible to ants there were 434 sound and 109 dead larvæ and pupæ and 112 living eggs. Between May 13 and June 12 the nonbanded tree was merely kept under surveillance by scouting ants, but on June 12 white-fly emergence was at its height and the ants had formed a heavy trail into the tree, where they were capturing the emerging adults. Living white-fly larvæ and pupæ were comparatively scarce and about equal in number on both trees. The remarkable thing was, however, that on the ant-invaded tree there were 167 empty pupa cases from which white flies had emerged and only 8 of the adult white flies, whereas on that from which ants were excluded there were 151 empty pupa cases and 130 of the emerged adults. In other words, the nonbanded tree was swarming with ants, some of which were carrying adults, and only 4.51 per cent of the emerged adults remained on the tree, whereas on the tree from which ants were excluded almost the same amount of emergence had occurred and 86 per cent of all the emerged white flies were still on the leaves.

From June 12 to about the middle of August the white flies increased faster on the tree from which the ants were excluded than on the other. On July 1 there were 5,435 living young on the former and only 1,919 on the latter. The percentage of dead was practically the same on both, being 12.9 per cent of all young on the tree from which ants were excluded and 10.4 per cent on the tree to which they had access.

On July 17 the banded tree still led in white-fly infestation, there being 3,711 living young on this tree to 1,497 on the ant-patrolled tree, and by the 13th of August white-fly eggs, larvæ, and pupæ were too numerous on both plants to count. This final heavy infestation of both trees was expected, as it was improbable that complete white-fly control in the height of its breeding period could be accomplished by the ant.

The relations of the ants to emerging white flies brought out in the foregoing experiment led to similar observations on other trees On June 12, at the height of a white-fly emergence period, two more trees from which ants were excluded and two on which they were present were inspected. On the first two trees there were 431 empty pupa cases from which white flies had emerged, and 369 adult white flies, or 85.6 per cent of all which had emerged, still remained upon the trees. On the ant-invaded trees there were 600 empty pupa cases with emergence slits, but only 36 of the white flies, or 6 per cent of the emergence, remained upon the trees.

These observations indicate that the principal direct effect of the Argentine ant upon the citrus white fly in Louisiana is to destroy a varying proportion of them, thus entitling this ant to be called a white-fly enemy.

RELATIONS WITH APHIDS.

The relation of the Argentine ant to aphids has been observed principally on the orange-infesting species, chief of which is *Aphis gossypii* Glov. In Louisiana, however, certain observations have been made upon the relations of this ant with aphids on loquat, elder, privet, oak, cypress, and certain weeds.

THE ANT AS A PROTECTOR OF APHIDS.

The orange aphid appears in considerable numbers, sometimes very large numbers, on the newer growth early in the spring, often increases throughout April and May, causing some of the leaves to curl, and thereafter rapidly disappears, while a heavy parasitization is indicated by numerous dried skins punctured by the exit holes of the parasites. This condition, which has long existed both in California and in Louisiana, has not been altered materially even in groves and trees overrun by the Argentine ant. In Louisiana it occurs in scattered groups in January and February, often greatly increases in March, and becomes numerous on tender leaves and some of the blossoms in certain orchards during April and May. Even where heavily attended by the ant, however, its natural enemies, and chiefly the internal parasites, have so reduced it by July or August that it is difficult to find specimens.

The following examples will serve to illustrate the ineffectiveness of the ant against the parasites of the orange aphis: On April 22, 1914, in an orange grove overrun with ants at Happy Jack, La., aphids were very numerous, averaging about 34 per leaf of the worst infested leaves, and undoubtedly would have done much damage had their increase continued long at the same rate. Even at this time, however, the aphid shells punctured by parasite exit holes indicated a parasitization of 29.7 per cent. Three hymenopterous parasites seen ovipositing in the aphids among the ants were watched until they had parasitized nearly every aphid on their respective leaves. While ovipositing in the aphids these little insects nimbly avoided the ants without flying. On May 15 living aphids could be found on these trees only with difficulty. In the meantime, too, many of the parasitized remains previously seen had been blown from the leaves, so that there was very little evidence that aphids had ever been numerous there.

On April 28, 1915, 15 per cent of the ant-attended aphids in an orange grove at Ollie, La., had been parasitized, but living aphids were still rather numerous, averaging 20 per leaf on those leaves examined. By May 12 the aphis infestation in this grove had decreased more than 50 per cent, and 49 per cent of the remaining aphids were parasitized. On May 27 an examination of twenty-five times as many suitable leaves as before revealed an average of only about two aphids per leaf, and 92.6 per cent of these were parasitized. The foregoing observations are merely examples of what may be seen annually in almost any grove in Louisiana in which ants and aphids occur.

At Alhambra, Cal., early in April, 1916, a trail of ants was found leading to flourishing small colonies of aphids on the new sprouts of an orange tree that had been cut back about 4 feet from the ground. The aphids were very numerous and not more than one per group showed evidence of parasitism. On April 21 fully half of the aphids had disappeared from this tree and 79.6 per cent of the remainder were parasitized. Ten aphid-feeding lady-beetles (*Hippodamia convergens* Gúerin) and a few syrphid-fly larvæ also occurred on the tree.

At Duarte, Cal., 20 young ant-invaded orange trees, badly infested with aphids on the new leaves about the middle of April, were almost completely free from them when examined on May 19. The few aphids remaining alive were being attended by the ants, but not one-tenth of 1 per cent of what had previously been present remained on the trees at this time, and discolored and dried shells with their parasite exit holes were everywhere present.

Again, at Sierra Madre, Cal., on June 16, scattered groups of aphids attended by ants on several trees revealed a parasitization of 92.1 per cent. On one of these trees 14 syrphid larvæ with 1 coccinellid larva and 15 or 20 ants were found working on the same groups of aphids.

The relations of the Argentine ant to an aphid commonly occuring on elder in Louisiana were observed especially because of the exceptional abundance attained by this plant-louse early in the summer and its abundant attendance by the ants. During March and April the aphids become too numerous for the trees to support and thousands fall to the ground, covering the grass under the trees and crawling back up the trunks in large numbers for days at a time. This aphid is progressively destroyed by predacious enemies and especially by parasites, until by the middle of June it invariably has been reduced to an insignificant number, which gather about the bases of the stems and leaves, where the best possible shelter occurs. On April 24, 1914, the comparatively few shells and aphids remaining on one of these trees were counted. There were only 1,667 in all, 529 of which were living, 68.4 per cent being parasitized. The principal parasite concerned was identified by Dr. L. O. Howard as a species of Aphidencyrtus.

On March 24, 1914, 9 robust young elder plants in pots were infested with the aphids and placed where the ants could get to them. About a month later, May 7, there were on all plants 2.436 living and apparently sound aphids and 985, or 28.7 per cent, parasitized. All parasitized shells were removed, and, on May 13, 1.18 per cent more aphids, parasitized since the previous examination, were removed, after which ants were excluded from 4 of the plants, on which were 418 sound aphids, and allowed access to the remaining 5, on which were 535 aphids.

On June 3 only 47 living aphids remained on the ant-free plants, but 119 were on the ant-invaded plants; and by June 16, at which time most all the aphids had disappeared from the large elder trees thereabouts, not a living aphid was left on any of the little plants.

In another experiment 2 robust elder plants were colonized with aphids on March 24. One plant was given 187 aphids and placed in a large trail of ants, and the other was given 185 aphids and placed where the ants could not get to it. By April 8 there were 3,194 living, apparently sound aphids on the ant-attended plant, an increase in 15 days of 1,708 per cent; and on the ant-excluded plant there were 2,514, an increase of 1,364 per cent. The more rapid rate of increase on the ant-attended plant seemingly was due to the activities of the ant, other factors being apparently the same in both cases. The number of living sound aphids soon began to decrease on both plants, and as in the beginning it had increased more slowly on the ant-free plant, it now decreased more rapidly on that plant.

On April 25 the number of aphids on the ant-attended plant had decreased to 2,043, on the ant-free plant to 802, and, from that date on the decrease continued as follows: On the ant-attended plant there remained, on May 6, 182 aphids; on May 20, 18; on June 3, 23; while on the ant-free plant, on May 6, there were only 52 aphids, and on May 20 all had disappeared. The ants, therefore, appeared to give a slight advantage to the aphids up to this time, but by June 16 all had disappeared from both plants, the parasites having won in the struggle for their possession. It is seen therefore that although the ant attends the orange and certain other species of aphids having very efficient internal parasites, it is unable to prevent the destruction of these aphids and cause any noteworthy increase in their number.

TRANSPORTATION OF APHIDS AND COCCIDS.

Although at times nearly 50 per cent of the ants foraging in citrus and some other trees capture insects and carry them down the tree, taking it throughout the season the average is less than 1 per cent. About 8 per cent of the total foraging workers counted in all examinations were engaged in carrying all kinds of insects, but this is, of course, above the average, as counts were made only upon trees where the ants were engaged conspicuously in the transportation of insects. Only a fraction of 1 per cent, viz, 0.5 per cent, of the insects carried by the ants were scales and aphids, and only under exceptional circumstances is the number carried worth considering.

Extended observations on the activity of the ants in transporting scales and aphids have led to the following conclusions:

(1) The ants feed to a slight extent upon the surplus insects when its host scales or aphids are very numerous, upon those that have died from parasitism or some other cause, and upon male scales as fully as their ability to capture them allows.

(2) The ants utilize dead shells of the black and some of the armored scales for the construction of shelters and feed upon the softer by-products and detritus of these scales.

(3) Direct dissemination of orange scales and aphids by the ant is only incidental and is negligible. Indirectly the ants aid in the dissemination of some of these insects by greatly increasing them on particular trees, and from these points of heavy infestation they spread by the usual means.

Some of the facts which lead to the foregoing conclusions are as follows: A large majority of the scales and aphids carried by the ants are dead. Thus about 94 per cent of the mealybugs taken from the ants were dead or discolored and scarcely able to move, while with the black scales and aphids carried the percentage of dead was still higher. On the other hand, of those insects which do not furnish honeydew to the ants most are alive when taken from their captors. Nearly all captive white flies are alive, as are the psocids, and even such fragile insects as thrips may be handled so lightly by their captors as to remain apparently uninjured. Thus, on one occasion, a thrips dropped by an ant at once started to run, when another ant seized and bit it viciously several times, after which the only sign of life was a twitching of legs and antennæ.

The ants almost always carry their scale and aphid hosts, as well as all other captured insects, to the nest, which is rarely if ever so situated as to afford living conditions to these insects. On rare occasions, in Louisiana, living mealybugs had been found in ant trap-nests, containing only dried straw and manure, but this happened in winter, when the mealybugs left not only the trees where there were ants, but also those in a part of the orchard where no ants occurred, and located on Bermuda grass. The soft scales found in ants' nests almost always have been dead. On one occasion when an exceptionally large number of ants carrying mealybugs down an orange tree could be traced to the nest in the rotting wood, many dead and discolored mealybugs and mealybug particles were found and 80 whole bugs counted. There were only 2 living mealybugs, and these appeared to be diseased, being unable to move except for twitching the legs a little.

The ants carry their host insects in considerable number only when these insects are exceptionally numerous, at which times they are able to supply a great deal more honeydew than the ants actually require. In Louisiana the ant attendance on the black scale and the citrus mealybug was nearly always in greater number than could obtain honeydew from them continuously. In California, however, the black scale, where unchecked by fumigation, becomes very numerous, overflowing the trees and covering them with sooty mold. On such trees the ants carry many scales at times. Thus in one orchard, in which both ants and black scales occurred in exceptionally large numbers, an unusually large number of ants were so engaged. Fortunately for observation, many of the nests to which ants could be traced were in the rotting stubs of cut branches. In these nests the scale phase most readily seen (that is, shells of mature scales) was scattered throughout the ants' galleries. Many nests, with their contents, were removed and examined, and the remains of numerous insects found there, but the black scales, of which there were 118 young stages, all dead, and 97 shells of mature scales, outnumbered all others. Ants, with scales, also were traced to underground tunnels, which led neither to tree roots nor to any plant roots on which the scales could live.

Aphids, too, are transported only when the infestation is very heavy. The largest numbers carried were upon maple and elder trees, on which aphis infestation persisted somewhat longer than on orange trees because of more rapid parasitism of the orange-infesting species. A great majority of the aphids carried were dead. Since almost all are destroyed by parasites, some undoubtedly contain parasites when taken by the ants, but the number thus destroyed is too small to reduce the effectiveness of these enemies. The destination of the aphids carried was generally the underground nest. Only a very small percentage of the ants carry these insects up tree, and, when traced, these always have gone into one of the ant shelters for rest or, ultimately, retraced their steps down the tree.

Experiments have been tried several times to induce the ants to remove scales and aphids from unsuitable food to a place where they could thrive. As an example of these experiments, about two dozen elderberry stems, very heavily infested with aphids, were on one occasion placed in the midst of thousands of ants at the base of an elderberry tree and examined at intervals thereafter. At the end of an hour aphids were leaving the stems, many were scattered about in the short grass, and a considerable number of others were traveling up the tree trunk. A great majority of the ants paid no attention to these wanderers, but a few followed and stroked individual aphids while in motion. One such ant, becoming impatient after a few minutes of unrewarded effort, seized an aphid by a leg and pulled it about this way and that for a distance of fully a foot, when it let go and went its way.

Similar experiments were performed with mealybugs, infested stems being cut and placed among numerous ants in pots containing vigorous young orange trees. The ants would attend and stroke these mealybugs indefinitely, but in not a single instance did one transport a mealybug from a dying stem to the flourishing growth of the young orange tree. Many of the mealybugs would wander off the dry stems, and some of them would find their own way sooner or later into the healthy tree.

On one occasion, in California, a good opportunity was presented to the ants to assist mealybugs to regain trees from which they had been knocked by spraying with water under high pressure. The ant invasion was from "very heavy" to "extremely heavy" in about 70 per cent of the trees examined, the remainder having "light" or "very light" trails. Some of the mealybugs hit by the water were knocked from one part of the tree to another, often landing on the trunk or larger branches. From 10 to 17 trees were examined each time, and in all these inspections only 8 ants were found carrying mealybugs, 7 of which were dead. In from one-half to 3 hours after spraying an average of 3 mealybugs per tree were crawling up the trunk; 18 hours after spraying the number had increased to 5 per tree average; at about 48 hours after spraying there was on an average only 1 mealybug returning to every 4 trees. Certainly the ants did not assist to any appreciable extent in their return.

The ants occasionally become impatient with aphids and scales that fail to excrete and seize these insects, just as at times they become impatient at waiting for an adult white fly to emerge and seize the pupa. The pile of mealybug remains found in the tree nest previously referred to indicates that the mealybugs were utilized as flesh food. There is little doubt that if sufficient time and pains were taken the ants actually might be observed eating occasional aphids and scale insects.

RELATIONS WITH INSECT ENEMIES OF SCALES AND APHIDS.

EXTENT OF CAPTURE OF PREDATORY AND PARASITIC INSECTS.

The ants are antagonistic to all the predacious and parasitic insect enemies of coccids and aphids, but not more so than they are to all other insects which do not furnish them with honeydew. The ants are habitually carnivorous and view all other insects, excepting perhaps some of the myrmecophiles, either as their cattle, furnishing them with liquid food, or as their prey, useful as flesh food. Although the ants take every opportunity to capture both predators and parasites of the scales and plant-lice, the number of this class of insects captured is very small. The close and constant attendance of the ants at scales and aphids, by preventing free oviposition and feeding of the natural enemies, accounts mainly for the ants' effectiveness as protectors of these pests, although the ants do feed to some extent upon eggs of certain scale predators.

A large number of insects have been taken from the ant and identified, and only 0.72 per cent of all the insects carried have been predatory on species attended by the ants. These consisted of larvæ of the Leucopidae, the brown lacewings, Syrphidae, and Lepidoptera, the last very rarely, indeed. It is seen, therefore, that the number of predatory enemies of the soft scales and aphids which the ant is able to capture is insignificant. The number of internal parasites captured is still smaller, being only one one-hundredth of 1 per cent of the insects taken from the ants.

MEANS OF DEFENSE OF THE LACEWING INSECTS.

The following observation will illustrate the methods of defense of certain of the predatory enemies of soft scales and aphids. The larvæ of the lacewing flies when attacked emit a fluid from the tip of the abdomen which, though so small in amount that it can scarcely be seen, strongly affects the ants. The larvæ will avoid the ants if possible by keeping out of their trails when moving, and when feeding upon mealybugs take up a position under the groups, where they are protected by their prey. On a tree in which many cocoons of *Chrysopa californica* Coq. occurred and which was overrun with ants a larva of the Chrysopa was seen crawling up the trunk on the opposite side from the ant trails. The larva was teased over into the midst of the ants, with the following result: An ant seized it by a foreleg, when it brought the tip of its abdomen forward and touched the ant, which then dropped to the ground. A second ant ran up, but as the chrysopid brought the tip of the abdomen forward, backed away, and the larva resumed its journey. Another ant took hold and, receiving the same treatment, backed hurriedly away in a circle, frantically brushing its head with the forefeet. Four ants then made a combined attack. The larva deliberately waited until they had a good hold, probably to be sure of its mark and conserve the secretion, when it touched them, and they acted precisely as had the preceding one. All these ants soon ceased to move and acted as if very sick. In the meantime the chrysopid passed out of the ant trail and proceeded up the tree. The larvæ of the brown lacewings defend themselves in precisely the same manner, emitting a minute globule of bright amber to red fluid that is evidently injurious to the ants.

MEANS OF DEFENSE OF THE LADY-BEETLES.

The larvæ of various coccinellids are protected by a covering of spines or of cottony excretion and by a thick yellowish material exuded from pores situated along the margins and dorsum of the body. Ants many times have been seen attempting to seize larvæ of the mealybug-feeding species *Hyperaspis lateralis* Muls., but not in a single instance did they succeed in capturing one. This larva, when feeding in the midst of mealybugs, usually remains perfectly motionless and does not attract the attention of the ants. When moving and attacked by them it flattens first one side to the surface, and, if attacked by several ants at once, it flattens down all around, leaving only the cottony filaments exposed. Sometimes the ants then will pull out masses of this cotton, and on one occasion they were observed to pull out so much of it that the thorax of the lady-beetle was made completely bare. In spite of this the object of the attack was able to escape. At another time several ants were attacking one of these larvæ at once and each of them pulled out a mass of cotton from time to time. It soon was seen that some of them were unable to loosen the material from the jaws and were thus kept out of the contest.

The larvæ of such species as *Coccinella californica* Coq. and *Hippodamia convergens* Guér. rely principally upon immobility, flattening out, and their spiny covering for protection. The larva of *Rhizobius ventralis* Erichs. depends upon immobility, its natural flatness of body, and, in the presence of the black scale, which is its preferred food insect, the honeydew from the scales collects in the setæ on its body and becomes coated with sooty mold, blending to some extent with the sooty, sirupy leaf surface. The final emergency protection of all these larvæ, after having exhausted the defensive means of protection, is the so-called "reflex bleeding," or excretion, of a poisonous, repellent substance from the glands of the body. This occurs whenever the larva is roughly handled or there is danger of enemies actually destroying it.

The adult coccinellids defend themselves principally by flattening out, thus presenting the wing covers to the enemy, and by kicking. The kick consists of a sharp jerk of the leg by which the ant, threatening to seize it, is prevented from so doing. The ants often have been observed trying to capture adult lady-beetles, but never have they been seen to succeed. A single instance will illustrate the method of defense: On an orange tree overrun by the ants and also harboring numerous lady-beetles (*Coccinella californica*), one of the lady-beetles was seen traveling up the trunk in the trail of ants. Most of the ants were passing hurriedly by, swerving aside to avoid contact with it, but one ant was following and trying to seize one of its legs. This ant moved from side to side of the coccinellid, its jaws wide open, rushing it whenever there appeared to be an opportunity. Every time the ant would attempt to take hold, however, the lady-beetle would either give a quick snap of its leg or would lower the body on that side. This ant finally was joined by a second, and both tried for 10 or 15 minutes, without success, to capture the insect. There seems to be evidence that adult coccinellids also sometimes secrete a repellent fluid in very small amounts when attacked by ants, for the ants often back suddenly away on coming into contact with them. As a last resort adult coccinellids also have recourse to "bleeding," which seems capable of repelling many ants at once and even much larger enemies.

Lady-beetles often occur in large numbers on trees overrun by ants. This was commonly the case in Louisiana with a minute, shiny black lady-beetle, *Microweisia misella* Lec., which occurs in large numbers on trunk and branches of orange trees at certain times of the year. This insect apparently feeds upon eggs and young of the chaff and purple scales and is entirely oblivious of the ants. The same is true of the large twice-stabbed lady-beetle, *Chilocorus bivulnerus* Muls., which often occurs in large numbers in all stages upon heavily ant-invaded trees.

In California, large numbers of adult *Hippodamia convergens* and *Coccinella californica* and all stages of the black lady-beetle (*Rhizobius ventralis*) occur at times on orange trees overrun by ants. On one occasion more than 1,000 adults of the first two and the ashy gray lady-beetle (*Olla abdominalis* Say), all of which feed extensively on the excretions of the black scale, were counted upon 10 trees on which the ants were exceptionally numerous. Again, more than 60 of the black lady-beetles were found upon each of a number of young orange trees overrun by ants. A certain click-beetle, *Limonius subauratus* Lec.,[1] which feeds upon this excretion, is also fearless of the ants.

MEANS OF DEFENSE OF THE PREDACIOUS PYRALIDAE.

The principal means of defense of the larvæ of the predacious Lepidoptera which feed upon soft scales and mealybugs consists in moving the body rapidly from side to side like the cracking of a whip. The larva of *Laetilia coccidivora* Comst., however, protects itself chiefly by means of a tubular web which it spins over itself and its prey and through which ants can not pass. The nearly mature larvæ are protected rather effectively also by the spines on their bodies, and several times have been seen moving among numerous ants, apparently hunting for a place to pupate, without being molested.

MEANS OF DEFENSE OF THE SYRPHIDAE.

The larvæ of aphid and mealybug feeding syrphids also often are found on the leaves and fruit among the ants. The ants, though once or twice they have been found with very young larvæ of an unidentified species of syrphid in their possession, apparently never disturb them under ordinary conditions. The immobility and the spines of those species which have been observed working among aphids and mealybugs among ants appear to protect them adequately from the ants.

[1] Identified by Mr. J. A. Hyslop.

INTERFERENCE OF ANTS WITH THE WORK OF PREDACIOUS INSECTS.

Although the ants are unable to capture in more than insignificant numbers the insects predatory on the soft scales of citrus, to a considerable extent they do interfere with their work of destroying scales, as has already been indicated. This is particularly true of those scales which occur in groups, such as the citrus mealybug and soft brown and some other scales, the predators being unable to oviposit in groups closely attended by the ants. Under normal conditions the citrus mealybug, in Los Angeles County, Cal., is held in almost complete control by its predacious enemies, chief of which are some three or four species of lady-beetles, the brown and green lacewings, and at least three kinds of predacious flies.[1] Rearings of enemies from a number of large batches of mealybug material collected among the ants at intervals from April to September, 1916, from scattered localities in Los Angeles County gave 71.8 per cent external feeders and 28.1 per cent parasites.

Against the internal parasites, however, the ants appear to be much less effective, as has already been indicated. Of the internal parasites reared from citrus mealybugs in California by the writer, only 9.7 per cent are known to be primary parasites of the mealybugs.

NESTS AND PROTECTIVE STRUCTURES OF THE ANT.

LOCATION AND PURPOSE OF THE NEST PROPER.

The Argentine ant, which is very ingenious at construction, builds its nest to meet the requirements of a comparatively few simple needs, a primary one of which is darkness. Aside from any special aversion which the ant may have to light, it seeks the darkness for safety, and it is only in the dark that the workers ever rest "off guard." The queens, especially the older ones, spend nearly all their time where the darkness is greatest, and when moving in the trails of the foragers, which they frequently do, invariably pass rapidly from shelter to shelter, spending as little time as possible in the open places. The ants never permit their young to remain in the light for long at a time, and both they and the great mass of the queens always are found in the darkest, most obscure parts of the nest.

Another requirement of the ant is a proper regulation of temperature and moisture to suit its young and itself. In exceptionally dry weather, such as often occurs in Louisiana from February to April or May, and in California throughout every summer, the nest will

[1] The natural enemies of the mealybugs of citrus in southern California are being studied by Mr. R. S. Woglum and are referred to here only in a general way, as necessary to show their relationships to the Argentine ant.

be tunneled into the ground. The depth will depend upon how far it is necessary to go to find the needed amount of moisture. It is in the underground nest also that the most comfortable temperature can be found, both in summer when it is very hot and in winter when it is very cold. In the cities the walls of buildings often are utilized, the ants taking advantage of the artificial warmth and shelter afforded. In rainy weather, when the soil is very damp, the underground nest will be abandoned for a location above ground, in buildings, trees, piles of dry weeds, piles of lumber, etc., and under almost any kind of shelter. When the ants are caught in the ground by a sudden rain, in situations where there are no convenient trees, buildings, or other shelter, "sheds" are constructed out of particles of soil and trash along the surface of the ground. These sheds are sometimes very large and are elaborately tunneled into galleries and pavilions. They dry out much more rapidly than the packed soil of the ground, and the young are kept in them until the ground again becomes dry.

OFFSHOOT NESTS AND RUNWAYS.

The ants habitually construct temporary quarters and utilize natural shelters along the foraging trail, especially if the food supply is distant from the nest, as places in which to rest, secluded from light, heat, and wind, and in which wandering queens may hide.

If the food supply is large, attracting many ants for a long period, the ants gradually construct runways, or series of shelters, between the nest and the food source, tunneling them in the ground or building them up of particles of soil and trash, according to circumstances. As these structures are built toward the sources of food and the queens are more or less constantly traveling in the trails of the foragers, it is in this direction that the colony expands. Whenever one of these wandering queens finds a suitably dark and secluded spot along the trail she makes her abode there permanently, deposits eggs, and starts a secondary colony. Queens, eggs, and young occur almost constantly in the larger, more secluded shelters along the foraging trails. This is the most important means of local spread of the colony.

A good illustration of the formation of offshoot nests in the ground occurred in the field poisoning tests at New Orleans. A supply of poisoned sirup kept near a fig tree for several months in 1913 attracted ants from three colonies in turn, all of which finally deserted the neighborhood. On October 2 workers from a fourth colony, nesting in an outbuilding 72 feet distant, arrived, and by October 8 the file of ants from nest to jar had increased enormously.

The ants soon began tunneling into the ground at short intervals along the entire course of the trail, and by October 15 these shafts were numerous. The foragers still followed the original trail along the surface of the ground, but could no longer be traced for its entire length, as they were continually disappearing into the tunnels. Queens gradually separated from the original colony and took up their abode in the tunnels, until finally there was a string of small colonies all along the trail from mother colony to sirup. The original purpose of the tunnels doubtless was to protect the workers from light and heat while they rested from their labors, but the queens found them well adapted for nesting purposes.

SHELTER STRUCTURES, OR "COW SHEDS."

In the trees the ants invariably utilize such natural shelters as cracks and depressions in the bark, abandoned tunnels of borers, the space between touching leaves and fruits, etc., often further excluding light by piling particles of trash along the edges of cracks and walling in the space between nearly touching leaves, fruits, and branches. A portion of the ants foraging in trees almost invariably may be seen retracing their steps up the tree, carrying either liquid forage or prey with them. If traced, these ants usually will be found seeking a rest in the nearest shelter of the sort mentioned. Sometimes, while resting, their forage is deposited nearby and occasionally thereafter forgotten; at other times it is held indefinitely in the jaws.

The erection of the so-called "cow sheds" over scale insects and aphids is a further extension of this habit of building shelters in which the worker ants can rest. The number of ants attending aphid and coccid groups is almost always greater than can secure honeydew continuously. Some of them, therefore, always must be waiting until their hosts have a fresh supply ready. During this period of waiting and unrequited solicitation the "cow sheds" serve the usual ant-protective purpose. These structures, of course, may protect from enemies the particular insects covered by them, but, even if this protection were absolute, no great number would benefit by it, because comparatively so few are covered. The occasional occurrence of parasitized remains of scales under these "cow sheds" indicates, furthermore, that the protection afforded even those comparatively few scales is often faulty.

On orange trees badly infested by the black scale shelter structures sometimes are found over groups of mealybugs, and in this case their most important function happens to be protection of the ants and mealybugs against the honeydew of the scale and its accompanying sooty and green mold. Again, it seems to be primarily the ants that are protected, as they await the excretion from the mealybugs.

Perhaps the clearest proof that these shelters are built mainly in response to the needs of resting worker ants is the fact that under certain circumstances they will be built on the tables supporting artificial formicaries, where no scales or aphids occur. Six formicaries of the Janet type were kept on small tables set in pans of oil (see Pl. IV). Food, poisoned sirup, and water were placed on the tables outside the formicaries. When sick from a poison, the ants are very eager for water with which, perhaps, to wash out the crops, and numerous sick ants constantly hung about the water plate. Whenever sufficient trash was allowed them they would build a shelter tent from the edge of the formicary to that of the water dish, and this tent always would be full of ants regurgitating the poison and cleaning each other's mouth parts.

THE HABIT OF BURYING NOXIOUS SUBSTANCES.

Another activity of the ant somewhat along this line is the habit of piling débris upon noxious substances. On rare occasions they bridge bands of sticky material placed on the tree trunks in this manner. Generally, however, this is done only where the substance is actually injurious. In the field poison tests frequent cases were observed where the shelter-constructing and trash-piling habit merged into one. When foraging at the poison jars it was of common occurrence for the ants to construct out of particles of soft soil elaborate shelters about the sides of the jars, and sometimes completely over them. (Pl. I.) As they learned the effects of the sirup they often would deposit more and more particles on the sponge within the jar and finally fill the entrance hole completely. In one case, for example, they partly covered the sponge and filled the entrance to one of the jars nine times in the course of several months. In an experiment with moth balls placed in a saucer with sirup poured over them, the ants eagerly took the sirup for a week, at the end of which time there were large numbers of dead in the mixture. The ants then became engaged principally in removing the dead. The saucer had been placed on a piece of white crepe paper, and when this accidentally got wet the ants bit out particles of the paper and constructed an elaborate shelter completely around the edge of the saucer. Under this large numbers of workers might be found at all times. As they continued to feed and get poisoned, however, they began piling bits of paper on the moth balls and finally completely covered them with the "confetti."

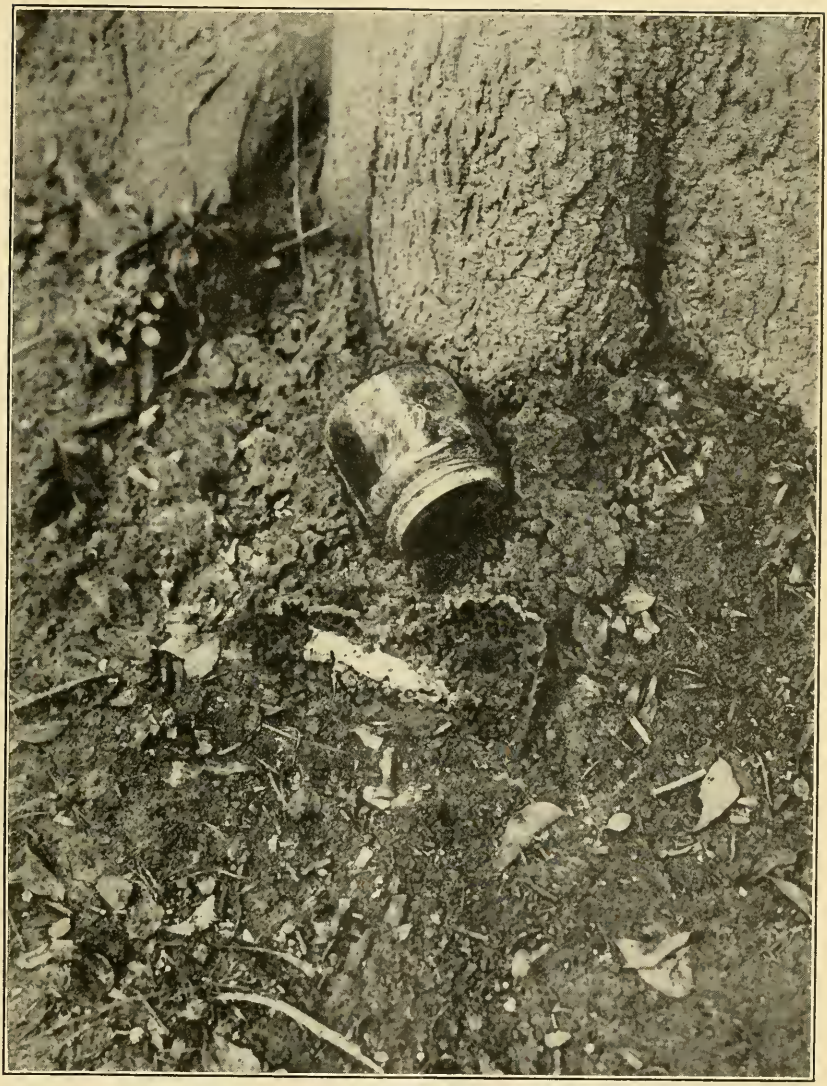
CULTURAL CONDITIONS IN ANT-INVADED VS. ANT-FREE ORANGE GROVES IN LOUISIANA.[1]

As already stated, the Argentine ant infests only slightly more than 26 per cent of the orange groves of Louisiana as yet. It was found that 40.7 per cent of the groves that had never had the ants in them were in "poor" condition, while about the same proportion (43.9 per cent) of those that were infested with ants were in good condition. In other words, about 15.4 per cent more of the ant-invaded groves were in "poor" condition than of the noninvaded groves, but this is probably in large part due to the greater neglect of the ant-infested trees because of that infestation, many of the owners becoming discouraged as soon as they found the ants present. A considerable number of groves had been abandoned completely because the ants had gotten into them. A slightly greater reduction in crop had occurred in the groves infested by ants, this reduction being, however, only about 0.22 box per tree greater than in those free from ants. Both the maximum and the last (1914) crops were far below what they should be in both ant-invaded and ant-free orange groves for trees of their age, being in each case less than 1 packed box per tree. In Cameron Parish the large sweet seedling orange trees, in which the Argentine ant does not occur, helped to raise the production average for the groves free from ants, as these trees produce from 5 to 15 boxes each.

Thus it is seen that there is practically no difference between those groves in Louisiana where the ants are present and those where they are not, either in the condition of the trees or in the amount of fruit produced. It is undoubtedly true, however, that where the scale, white-fly, and rust-mite infestations are heavy and no attempt is made to control them the crop will be reduced considerably. The effect of these insects also will be unusually pronounced on trees that are weakened by too close planting, poor drainage, and cultural neglect. The ants appear to have no effect on the rust mite.

That groves completely overrun with the ants and in a badly run-down condition from neglect can be revived and brought back to their normal bearing condition without treating the ants or keeping them from the trees has been demonstrated. The principal features of this work will be related here briefly.

[1] The data on conditions affecting the culture of orange trees in Louisiana were obtained partly by means of questions submitted to the orange growers, partly by personal inspection of the groves, and are complete on about 96 per cent of the groves of the State. Those groves with a large percentage of trees fairly large for their age, symmetrical, with moderately dense foliage, of good color, and bearing an average-sized crop according to local standards, were classed as "good." Those showing a large percentage of undersized trees, with thin foliage, many dead and dying branches, poor color, lack of growth, and poor crop were classed as "poor."



PROTECTIVE "SHEDS" OF THE ARGENTINE ANT.

Surface shelter of soil particles constructed by the Argentine ant about a poison jar. (Original.)

LOUISIANA BUDDED ORANGE TREE.

Peculiarity of growth of the *Citrus trifoliata* stock, and a comparatively very slight incrustation of lichens. (Original.)

DEMONSTRATION IN IMPROVEMENT OF ANT-INVADED GROVES IN LOUISIANA.

If preventing the Argentine ant from getting into the orange trees would effect the practical commercial control of the chief armored scales and the white fly in Louisiana, as it does that of the citrus mealybugs in Los Angeles County, Cal., the problem of controlling these insects would be simply one of getting rid of the ants. The natural enemies of the principal pests of Louisiana, however, are unable, even in the absence of ants, to prevent severe infestation. On the other hand, if thorough measures of control were practiced against these insects, there should be no reason to worry about the ants. If the citrus mealybugs in California orange groves were as thoroughly controlled by the regular fumigations as are the armored and black scales, the ants could do only a negligible amount of harm through these insects.

DESCRIPTION OF DEMONSTRATION ORCHARD.

The orchard reclamation work about to be described was conducted on a grove at Ollie, La., practically abandoned, except for the harvesting of the crop. The grove consisted of about 1,055 sweet, naval, mandarin, tangerine, and jaffa trees, a block of 603 of which were treated, the remaining 452 being left as checks. All the trees were very thinly foliaged, with small tops, and many of them with multiple trunks. Many of the leaves were yellow and a moderate number of branches were dead. The trees were poorly shaped, and branches were much tangled as a result of bad pruning. Many of the trees were suffering badly with gummosis,[1] some being almost completely girdled about the base of the trunk and larger roots by this disease. (See Pl. III.)

The ant infestation was as heavy as has ever been seen in any orchard. All the trees were very badly infested with chaff, purple, and long scales, the first named being exceptionally numerous. Almost all the fruit had been very badly discolored by the rust mite every year, and, in some years, infestations of the citrus white fly were also severe.

The largest crop ever produced by the full orchard of 1,055 trees was 1,400 boxes, occurring in the year 1911. The crop of the 1914 season had been only 400 boxes; or, in other words, the orchard had suffered a crop reduction of 71.4 per cent in three years.

TREATMENT OF THE ORCHARD.

The demonstration work of improving this grove was started in February, 1915, and continued until interrupted by the hurricane of

[1] Also called "sore shin" disease.

September 29, 1915. The treatment consisted solely of spraying, cultivation, and tree surgery.

Spraying was conducted against the chaff and purple scales, citrus white fly, and rust mite, and for the destruction of the lichens and moss which covered the trees (see Pl. II). The trees were sprayed only three times, the first application, for scales and the white fly, being started February 12; the second, for lichens and moss, May 12; and the third, almost exclusively for scales and rust mite on the fruit, on July 26. Two different brands of paraffin-base lubricating oil made into emulsions containing 1 per cent of the oil and 0.5 per cent of soap were used in the insecticidal work. A commercial lime-sulphur preparation was used in the fungicidal work.

The tree surgery consisted of pruning to improve the shape of the trees, the removal of wood diseased with gummosis, and the cutting back of Jaffa trees preparatory to rebudding. In some cases where the trees branched from the ground into several trunks, those trunks with poor tops which gave no promise of improvement were removed entire. The pruning of smaller branches was very light and consisted in the removal of all dead ones and thinning out of those entangled. All wood infected with gummosis was gouged out with a chisel and mallet and the wounds painted with a mixture of 1 part of creosote to 2 parts of coal tar. This work was all conducted in the spring, from March to June.

The demonstration plat was clean cultivated throughout the season by plowing and cross-plowing, followed by disking both ways of the orchard, four cultivations, March 8, May 12, June 21, and August 26, respectively, being necessary. Close to the trees, where the plow could not reach, the weeds were kept down by hoeing. As the orchard had never before been cross-plowed, a good many fairly large roots were broken in this work, but the trees did not suffer any apparent ill effect from this rough treatment. The drainage ditches surrounding the plat were all deepened about a foot and the weeds choking them removed.

RESULTS OF ORCHARD TREATMENT.

Within three weeks after the application of the lime-sulphur solution most of the lichens with which the trunks and larger branches were coated had fallen off completely, a solution of 30° Baumé, at 1 volume to 50 volumes of water, accomplishing this result.

Owing to the thinness of the trees and scarcity of food in proportion to the number of scales in this orchard, an exceptionally large number of these insects settled on the fruit. A count of the chaff and purple scales on 100 fruits from each of the two blocks on June 23 gave 112 on the sprayed fruits and 3,365 on the unsprayed, representing a reduction of 96.7 per cent by spraying. By May 27 the leaves of the unsprayed trees had become quite badly infested with white flies. A count of those on 100 leaves picked at random from these trees gave 26,200 larvæ and pupæ, while on an equal number from the sprayed trees there were only 73, a reduction, therefore, of 99.7 per cent.

The rust mite began to appear on the fruit in June, and by the 23d of that month there were 50 to 60 mites per fruit on unsprayed trees, while on the sprayed they could only be found on the row of trees adjoining the unsprayed block and then only to the number of 10 per fruit.

On August 5, after the second insecticidal application, examination of 100 fruits on the sprayed trees gave 987 scales, or an average of about 9 per fruit, and 89 rust mites, the latter being so scarce that they were difficult to find. The unsprayed fruits were so badly infested that scales could be counted in the time available on only 10 fruits, on which there were 6,982, and the rust mites were quite too numerous to count. Fully 75 per cent of the unsprayed fruit had by that date become discolored by the rust mites.

By September the trees in the experimental block had responded beautifully to the treatment, and many persons commented on their improved appearance.

About ten times as much new growth occurred on these trees as on the untreated trees. The fruit was larger, and a very large percentage of it entirely clean. The storm of September 28–29, however, blew down and broke many of the trees and knocked approximately 87.2 per cent of the fruit to the ground, preventing bringing the work to a completely satisfactory conclusion.

It was possible, however, to count most of the fruit on the ground and that on the trees and examine it for insect injuries. There were practically twice as many fruits per producing tree left on the treated as on the untreated trees. Owing to the morass of weeds in the untreated block and to much of the fruit having been removed and sold by the owner, it was impracticable to count the fallen fruit in that block. In the treated block all the fruit which was not washed out of the orchard was counted and examined for insect injury. There were on the ground and on the trees 69,672 sweet oranges, tangerines, and mandarins, which, averaging about 200 to the box, made approximately 348 packed boxes of fruit. It was estimated that nearly one-fourth of the fruit was not recovered. The production was, therefore, about 435 boxes, or more than as much fruit as the entire orchard had produced the previous year, as a result of only one season's treatment.

The cost of the full treatment for the season was about 33 cents per tree. It is scarcely necessary to say that complete destruction of the ants would not bring about these results, nor did the ants in any degree prevent their attainment.

EXPERIMENTS IN CONTROLLING THE ARGENTINE ANT.

POISONING TESTS.

In the poisoning work conducted against the Argentine ant in Louisiana the following 16 poisons were tested: Strychnine sulphate, potassium cyanid, oxalic acid, arsenic trioxid, lead arsenate, Paris green, tartar emetic, oxid of antimony, mercuric chlorid, mercurous chlorid, copper sulphate, sulphate of iron, chrome alum, sodium arsenite, chloral hydrate, powdered extract of belladonna. As 14 of them were given a thorough trial at three different strengths in the field, and 20 further tests were made on imprisoned colonies, there were 62 experiments in all.

Methods of Conducting Poisoning Tests.

The receptacle used for the poisoned sirup was a deep-shouldered fruit jar of the type illustrated in Plate IV, with a tin lid with rubber band attached. A single entrance hole for the ants was punched in the center of the lid. To aid the ants in reaching the sirup, a piece of sponge was put into each jar. Scrap or waste sponges entirely suitable for this use may be purchased at wholesale drug stores for about 25 cents per pound.

Upon beginning to forage at the poison, the ants would be traced to their nest and the location and size of the colony recorded, after which it would be watched and the effect of the poison noted. A definite amount of sirup, usually 4 or 8 ounces, was placed in each jar, every time, and the amounts taken by the ants thus learned.

In poisoning tests on imprisoned ants each colony was confined to a low table supporting a three-celled Janet type plaster of Paris formicary, furnished with vent holes covered with bronze gauze. The ants were allowed to roam at will on top of the formicary and the 4-inch margin between the sides of the formicary and the edge of the table. (See Pl. IV.) To prevent ants from leaving the tables, the latter were placed in shallow galvanized-iron pans about 8 inches wider and longer than the table tops, containing a lubricating oil costing from 15 to 25 cents per gallon. The advantages of this oil were the extreme slowness with which it evaporates, its lack of an odor which might disturb the ants, and its nondrying property. Fresh sirup, cockroaches or other meat, and water were always at

EXPERIMENTAL ORANGE GROVE AT OLLIE, LA., AFTER TREATMENT.

Note the poor shape and small top of the trees resulting from neglected pruning and too close planting. The black spots on the crown of the second and fourth trees are wounds caused by the "sore shin" disease. (Original.)

INTERIOR OF FORMICARIUM.

Type of formicary used in ant poisoning experiments, and method of preventing the escape of ants by resting tables in shallow pans of lubricating oil. (Original.)

hand on the table, in addition to the poison, in order to approximate field conditions as nearly as possible. With this apparatus and method of feeding, ant colonies have been kept in a state of health for nearly two years. In some cases, where the ants are confined for prolonged periods without flesh food, they feed upon their own eggs and young.

Summary of Results of Poisoning Tests.

In conducting tests on nonimprisoned ants, difficulty was experienced in determining the effect of the poison upon the ant colony. Desertion of the nest may mean that the ants have been destroyed, that the poison has merely impelled them to move, that they have moved from need of better quarters, or that they have discovered more abundant and suitable food elsewhere. The colony may move slowly from the immediate neighborhood of the poison, but its scouts continue to hang about the latter indefinitely. It may remain where it is and follow the original trail near the poison without visiting it. Slow migration may occur, giving the impression that the colony is being destroyed, when such is not the case. From 26 to 298 days were required to bring out the results. If the poison dosage is too strong, the ants will leave it before much harm befalls them; if so weak as to assure continuous feeding, its action is extremely slow. The amounts of poisoned sirup consumed by the ants in field tests varied from as low as 0.04 ounce per day over a period of 189 days to as high as 1.2 ounces per day for 296 days. Dead worker ants were found in or near the poison jars only in the case of three of the poisons, viz, strychnine, potassium cyanid, and arsenic. Large numbers of dead ants occurred often only at the jars containing potassium cyanid.

The poisons selected for a final testing upon imprisoned colonies were strychnine, potassium cyanid, arsenic trioxid, lead arsenate, mercuric and mercurous chlorid, tartar emetic, sodium arsenite, chloral hydrate, and belladonna. The first symptoms of poisoning shown by the imprisoned colonies are a strong desire on the part of the workers for water and assiduous cleansing of the body, particularly the jaws. An ant will commonly regurgitate a dose of poison, and a sister worker will cleanse her distended jaws with great thoroughness, repeatedly going over them with the mandibles and tongue. The next effect upon the colony is generally the death of some of the young, followed by a slackening, and finally a cessation of oviposition. The young then die rapidly, followed by workers, until all of both phases are dead. The queens then begin to do their own foraging, and finally succumb to the poison, at times not until several days after the demise of the last worker.

The poisons which came through both tests with the best record were:

(1) Chloral hydrate, 3 gm., to sirup, 120 gm.
(2) Sodium arsenite, 0.143 to 0.287 gm., to sirup, 120 gm.
(3) Arsenic trioxid, 0.125 to 0.250 gm., to sirup, 120 gm.
(4) Lead arsenate, 1.0 gm., to sirup, 120 gm.
(5) Tartar emetic, 0.525 gm., to sirup 120 gm.

By far the most rapid and successful of all was the chloral hydrate mixture.

Poisoning Ants in the Orange Groves.

Two experiments were conducted in an attempt to destroy the ants in orange groves by means of poisoning. One of these, in which the trees were not banded and weeds were allowed to flourish during the experiment, failed to have any appreciable effect upon the ants.

In the other one a plat of 237 orange trees was first completely isolated from the rest of the orchard by means of barrier ditches. All weeds and trash were then removed from the plat, and the trees all banded with an adhesive mixture, thus limiting the food supply for ants within the plat to the poison and a comparatively few rotting oranges, dead insects, and fiddler crabs. The ground in the plat was almost covered with a mass of ants, there being 250 "very large," "large," and "small" colonies, or more than one for every tree. The ants took the poison intermittently, attendance being abundant at certain jars at one time, at others the next, and attendance at the poison was no doubt greater than it would otherwise have been because of the scarcity of food.

The result of the poisoning and tree banding together was to reduce the ants after about four months to 2 "large" and 17 "very small" colonies. On ordinary inspection and comparison with the adjoining plat one would say that there were no ants left in the treated plat. The poison, in itself, was not a marked success, however, as cutting off the food supply had caused fully 75 per cent of the ants to migrate, as shown by the speed with which the first large disappearance of ants took place, and the frequent occurrence of thousands of dead ants on the water in the ditches.

USE OF TREE-BANDING MIXTURES.

It seems doubtful whether adhesive and other repellent mixtures to be applied to the trunks of the trees will ever be used extensively as ant barriers in Louisiana orange groves. Such barriers do not reduce the ant population and can not be considered as a positive means of control. When used on a large scale bands of this sort need more or less frequent inspection and renewal or respreading, and the cost of maintenance would not be justified under present conditions by the increased crop returns.

In Los Angeles County, Cal., it appears that the citrus mealybug could be completely controlled in many cases merely by excluding the ants from the trees. Should that condition remain indefinitely, banding the trees would probably be as cheap a method of checking the mealybug as any other. At all events tree-banding mixtures will always have a use in protecting yard and ornamental trees, beehives, etc., from the ants. They may be used also to advantage in some cases in connection with poisoning and trapping the ants.

In an endeavor to discover an ant barrier of this nature which would be impervious to changes in the weather, and which would only require infrequent renewal or respreading, more than 20 mixtures were tested upon orange, fig, and other trees. Lack of space prevents including detailed results of the individual experiments, and only the general conclusions already published elsewhere[1] will be stated.

Adhesive Mixtures.

The most effective material of the adhesive type tested was made after the following formula:

Flowers of sulphur, part by weight	1
Commercial tree adhesive, parts by weight	6

All the lumps in the sulphur should be broken and the two ingredients thoroughly stirred together with a wooden paddle. The sulphur not only greatly prolongs the softness of the material, but appears to have a sufficiently repellent effect upon the ants to prevent them from bridging the bands with bits of trash or their own bodies. This mixture will remain effective in rainy, foggy, or exceptionally dry weather for from 3 to 5 months. If directly exposed for long periods to the sun, however, the surface becomes hard enough for ants to pass, and the bands should, therefore, be applied where the shade of the tree will protect them. This mixture must not be applied directly to the bark of trees, as it will be to some extent absorbed and may in time cause injury. It should be applied to tire tape or other waterproof material which has first been wrapped about the trunk.

Repellent Mercuric Shellac.

It is well known that corrosive sublimate has a strongly repellent effect upon the ants, and is the active ingredient in most, if not all, of the "ant tapes" found on the market, as well as of those watery solutions to be applied to household furniture with a paint brush.

[1] Horton, J. R. Some weather-proof bands for use against ants. *In* Mo. Bul. Cal. St. Comm. Hort., v. 5, p. 419–421. 1916.

It seemed desirable to give this chemical a thorough trial in the field, but it was necessary to devise a means of protecting the mercuric salt from rain. The ant tapes and liquids on the market were useless for outdoor work, because their value was quickly destroyed by moisture.

In original experiments performed by the writer it was found that the corrosive sublimate could be made impervious to water by dissolving this salt in an alcoholic solution of shellac. A considerable experimentation, in which both methyl and ethyl alcohol and various strengths of the mercury were used, resulted in the following formula, which was most satisfactory:

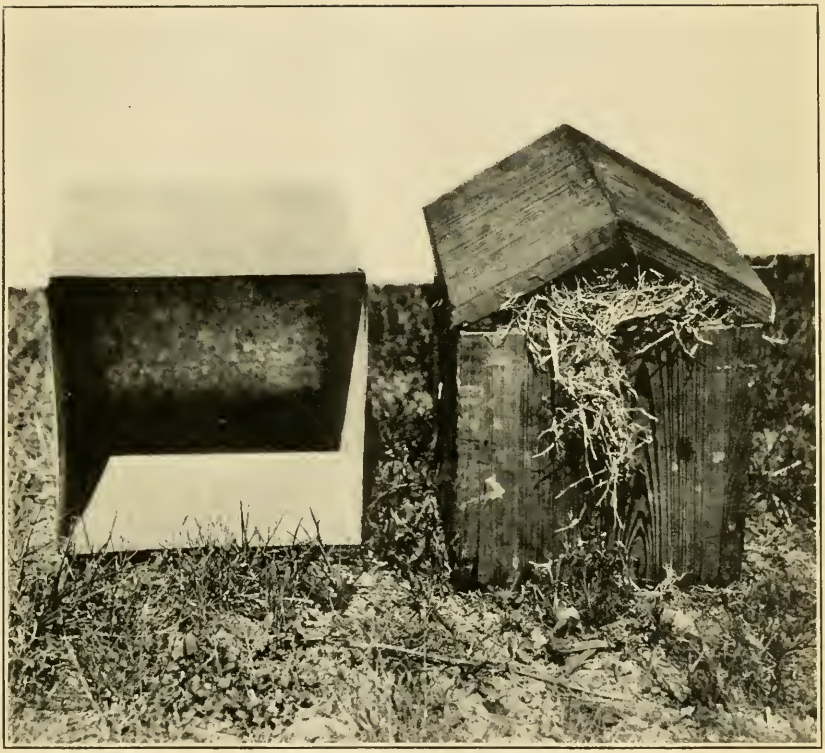
Corrosive sublimate	gm	20
Ethyl alcohol	c. c	60
Shellac	gm	31

The corrosive sublimate is first dissolved in the alcohol, then the shellac added, and the mixture shaken until all is dissolved.

In the few tests made with this mixture in the field it proved effective against the ants for about two months under the most trying conditions. It is less effective, however, than the adhesive mixture previously described, and too expensive for use on a large scale. It must never be applied directly to trees, as it will quickly kill the bark clear through and ultimately destroy the tree. It may be used by first applying thickly to strips of cloth, or soaking the latter in the solution, and then allowing them to dry out thoroughly. This method is, however, too tedious and expensive for practical use.

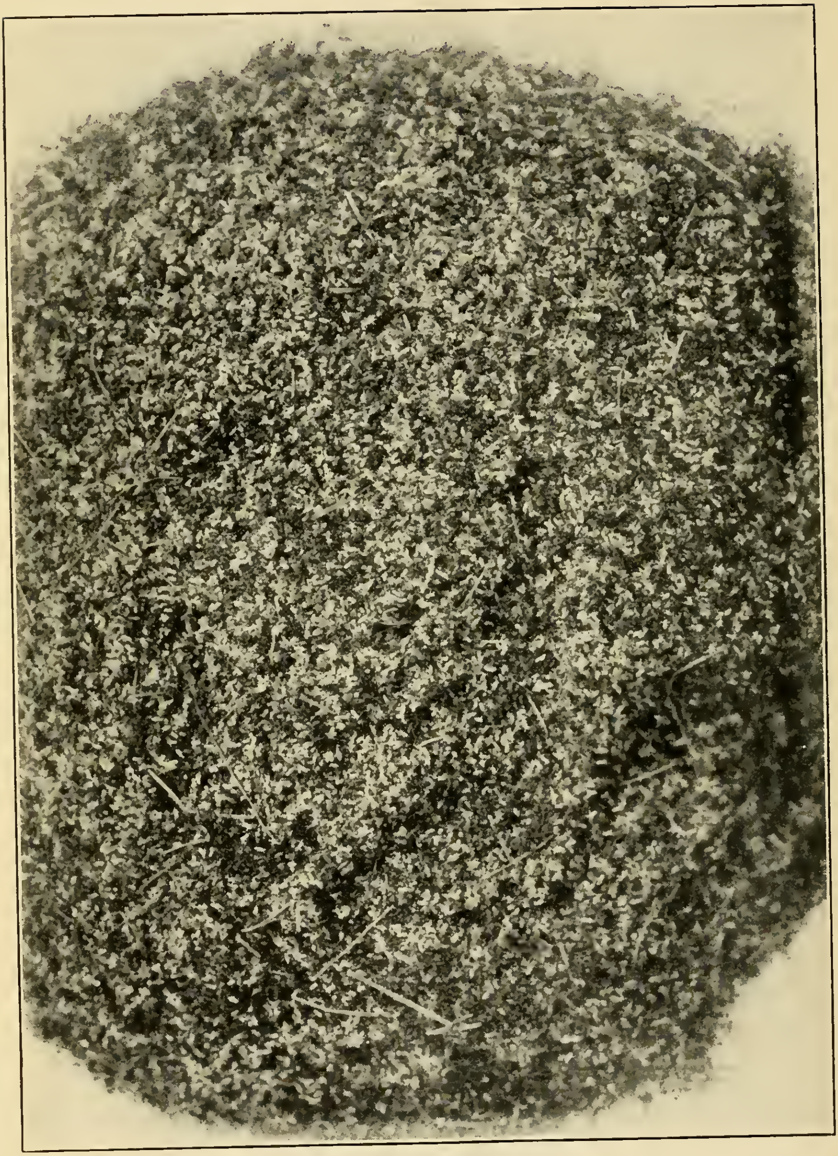
Shellac solution of corrosive sublimate, made after the foregoing formula and painted in bands from 6 to 8 inches wide on the legs of tables, refrigerators, etc., where food is kept, ordinarily will keep the ants away for a year or more. The banding material will not long retain its strength when applied to metal surfaces, such as stove legs and galvanized-iron garbage pails.

There is considerable danger attendant upon the careless use of corrosive sublimate, but if the precaution is taken not to get it into a cut or abrasion, or into the mouth or eyes while mixing, there is nothing to fear from it. It is much safer to handle in the form of a shellac solution than in that of an ant tape, being applied with a paint brush and not requiring any direct handling whatever. Once the "paint" has become dry there is no chance for the corrosive sublimate to shake loose and get into food. In making ant tape, on the contrary, there is danger of splashing the solution into the face or of getting it into a slight cut on the hands in soaking and drying the cloth strips, and when these are applied the loose poison in the fibers of the cloth is a constant source of danger to young children and domestic pets.



TRAPPING THE ARGENTINE ANT.

Ant trap nest and fumigating cover used in destroying the Argentine ant in the orange groves of Louisiana. (Original.)



TRAPPING THE ARGENTINE ANT.

Mass of dead ants killed in one of the traps nests at Happy Jack, La. About one-third natural size. (Original.)

EFFECT OF CORROSIVE SUBLIMATE.

A poisonous emanation appears to be given off by the mercuric shellac band which is very injurious to the ants, as one example of the behavior of ants which have crossed it will illustrate. An ant attempting to cross one of these bands suddenly stopped when part way across and began to stroke the antennæ with the first pair of legs. It remained on the band about 1½ minutes, turning slowly about, stroking the antennæ, and drawing the legs between the mandibles. It then slowly retraced its steps off the band and moved aimlessly about for a time, often getting in the way of other ants. Soon one of these stopped and took hold of one of its antennæ. This made it active long enough to disengage itself, when it again became sluggish and wandered aimlessly. This continued as long as it was watched—about 10 minutes. Other ants, some of which were themselves sick, were trying to drag their dizzy fellows to a shelter. Most of the sick ants finally became very sluggish and many of them fell from the tree.

TRAPPING THE ARGENTINE ANT IN LOUISIANA.

By far the best and the only practical means of destroying the Argentine ant in the orange groves of Louisiana is by trapping. The discovery that the ants would collect in large numbers in boxes of decaying vegetation in winter was first made by Messrs. Newell and Barber, who described a method of destroying them based on this fact.[1] The method of trapping about to be described differs in several important respects, however, from that recommended by these gentlemen. It is based mainly upon the fact that a very slight rain at any season of the year will cause the ant colonies to come out of the ground, where most of them nest, and seek dry, sheltered places.

Effect of Rains Upon the Ants.

The favorite rainy-weather nesting places of the ants are under loose boards, piles of lumber, boxes, logs, sacks, and pieces of cloth, piles of bricks, piles of dead weeds, under and in the sides of buildings, etc. They also preferably seek high ground, and, other conditions being equal, the largest colonies will be found on the ditch banks and the high ground at the base of the trees. Just as foraging workers often complete a partial natural shelter found upon a tree or elsewhere by making walls of bits of trash, the ants often build elaborate structures of soil particles and trash under the loose boards and other shelters found on or near the ground.

The idea of using the traps about to be described was first suggested by the behavior of the ant colonies in an orange orchard in

[1] Op. cit., p. 95–96.

which a poisoning experiment was being conducted. As the jars used would be partly filled with water every time it rained, a shelter was made for each of them out of two ends of an orange box nailed together in the shape of a gable. Soon after these covers had been laid, every one was found to harbor an ant colony which crowded it to its fullest capacity. Protection from the rain alone not satisfying the ants, they shut out the light and drafts by completely filling in the space between the jar and the top and ends of the cover with particles of soil. Each nest was no doubt ideal from the ants' point of view. Each was honeycombed with galleries of all shapes and sizes, ramifying in every direction. Any desired degree of moisture could probably be had in these galleries, those nearest the top being driest, and those directly on the surface of the ground most humid. The occupants would only need to move to underground quarters should prolonged dry weather occur. Each of these "ant castles," as they might be called, was perfectly protected from rain by a good pine roof. On removing the roof and looking into the galleries, thousands of eggs, young, and queens were revealed. Many solid masses of young and eggs as large as a hen's egg could be collected in these shelters. It was very evident that the ants could be much more rapidly destroyed when gathered together in this manner than by the tedious and unsatisfactory method of feeding them poison.

Protection from rain and drafts, good drainage, and darkness being the principal nesting requisites of the ants, it appeared that these requirements could best be met by a box with a roof. It was also found that ants could be induced to mass more thoroughly in numerous comparatively small colonies than in a few extremely large ones. A small covered box-trap was, therefore, given a trial, 15 of them being used in the first test. This was so satisfactory that it was followed by a large-scale experiment in which over 400 traps were used.

Description of Ant Traps and Fumigating Covers.

The first traps (see Pl. V) were made of $\frac{7}{8}$-inch cypress; but sap pine proved to be just as good and was cheaper. Each trap consisted of the following 9 pieces: Two sides, 12 by 12 inches; 2 sides, 10 by 12 inches; 1 bottom, 10 by 10 inches; 2 top pieces, 8 by 12 inches, and 2 pieces of triangular molding 12 inches long. First the smaller sides and bottom are fastened together with rosined nails or screws to prevent warping, then the larger sides added. The top pieces are fastened together in the form of a gable, with a tight joint, this roof being set loosely on top of the box. The pieces of molding are nailed across the inner side of the roof where it touches the top of the trap to hold it in place.

Covers to keep the gas in while fumigating are made of 28-gauge galvanized iron, each consisting of one piece 38 inches by $13\frac{1}{4}$ inches, bent into two right angles, forming two sides and the top, and two pieces 13¼ by 13¼ inches, forming the other two sides. The edges of the latter two pieces are folded inwardly over those of the first piece and hammered tightly together. Covers with soldered, instead of hammered, seams are preferable, however, unless the latter are very well made. The completed cover should measure 12½ by 12½ by 12½ inches inside, leaving a margin of ¼ inch to turn down all around the outside to reinforce the open edge.

Results of Ant-Trapping Experiment.

The experiment, the results of which are about to be briefly stated, was conducted in a block of approximately 19 acres[1] of bearing orange trees completely overrun with ants, located at Happy Jack, La. The traps, numbering 415 in all, or about 22 per acre, were set April 21–22, 1914. A trap was placed on a slight elevation at the outer edge of the spread of every second tree each way, or one trap to each four trees. Tests of various kinds of filler had shown previously that the best for summer was dry grass and weeds; for winter, equal parts of decaying manure and dry grass and weeds. From the time of setting the traps until the first rain, about 56 days, the ants were nesting almost wholly at from 8 inches to 1½ feet in the ground. Even after such a period of prolonged drought, however, a rain of about 0.2 inch, occurring June 18, 1914, was sufficient to drive them into the traps in large numbers.

Tests of different strengths of carbon disulphid and strong ammonia water as fumigants proved that 12 ounces per trap of the ammonia was satisfactory. The carbon disulphid, however, proved satisfactory at as little as 2 fluid ounces per trap, allowing the traps to fumigate for 1 hour.

The first fumigation was started June 23, at which time it was necessary to fumigate 334 of the traps, only those which contained large and complete colonies being disturbed. The second, third, and fourth fumigations were started July 21, August 26, and September 28, respectively, completing the summer's killing. A solid mass of ants, in all stages, nearly as large as a man's hat, was killed in each trap each time. The workers and even the queens were so numerous that it was entirely out of the question to separate and count them in any large number of the traps (see Pl. VI). The queens, however, were counted each time in one or two traps with an average killing, and in this way it was estimated that 1,161,323 queens were killed in these first four or summer fumigations, 600,000 in the first two, 295,895 in the third, and 265,428 in the fourth. All of the traps were

[1] All references to the acre are to the "square acre," not the "acre front."

full and fumigated the second and third times, and 404 of them the fourth time. The next five fumigations were started November 12, and December 4, 1914, and January 7, February 25, and June 7, 1915, the number of traps fumigated being 409, 403, 405, 305, and 21 at each respective fumigation. The number of queens killed in the last five fumigations was 34,765, 32,240, 55,080, 19,215, and 4,599, respectively.

Before undertaking the work, an agreement had been made between the officers of the Bureau of Entomology and the orange grove company by which that company was, among other things, to maintain open barrier ditches[1] around the treated block, and keep that block of the orchard in a state of clean cultivation at its own expense throughout the course of the experiment. Succeeding events, however, prevented the company, through no fault of its officers, from carrying out its part of the agreement. The result was that the ditches were not maintained, and weeds and trash remained in the orchard at all times; hence, many ants migrated into the block, often being traced directly to the traps, and other nesting places besides the traps were numerous. The persistent habit of the queen ants of forming small offshoot colonies along the worker's trails is at once the principal means of spread and a great safeguard to the species. In the interval from the second to fifth fumigations, from 41 to 46 trails of ants were found migrating into the orchards from the direction of the levee alone, at every examination. Many ants from outside the orchard were, therefore, killed in the traps, and the duration of the work was unnecessarily prolonged thereby. The record of ants killed at the various fumigations is given in Table VIII.

TABLE VIII.—*Results of ant-trapping experiment in an orange grove. Louisiana, 1914–15.*

Fumigation No.	Date of beginning.	Number of traps necessary to fumigate.	Estimated number of queen ants killed.	Fumigation No.	Date of beginning.	Number of traps necessary to fumigate.	Estimated number of queen ants killed
1	June 23, 1914	334	600,000 (1 and 2)	7	Jan. 7, 1915	405	55,080
2	July 21, 1914	415		8	Feb. 25, 1915	305	19,215
3	Aug. 26, 1914	415	295,895	9	June 7, 1915	21	4,599
4	Sept. 28, 1914	404	265,428				
5	Nov. 12, 1914	409	34,765	Total			1,307,222
6	Dec. 4, 1914	403	32,240				

[1] It should be noted that a ditch of this sort already occurred along each side of the orchard from front to back, being constantly necessary to drain off the surface water. It was only necessary to clean the weeds out of these ditches and deepen them a little, and excavate a short ditch across the front of the place. The ants were prevented from coming in at the rear by the marsh.

After the eighth fumigation, February 27, 1915, there was very decided reduction in the number of ants in the orchard, and the foreman of the place remarked that the ants were getting very scarce in the block. Only straggling workers occurred in a few of the traps from this time until the next fumigation, June 7. On March 25 examination of 30 orange trees revealed only one scout ant, and it was reported that there were no more ants about. A ranch hand said he had uncovered only three nests in plowing the entire block, while in a neighboring orchard (which had been treated for ants by the flooding method for three years or longer) he had raised so many he could not keep track of them. On the same date the ants were extremely numerous in the orange trees in an adjoining grove.

A further examination on April 16 showed ants to be present on only 1 in 40 trees, and then not numerous enough to form trails. *There were no ants at the blossoms or at the numerous aphids on the trees.* Some large umbrella trees, which usually had from six to eight large trails, were absolutely free from ants. In the house it was no longer necessary to isolate food supplies, beds, etc., from the ants, from which there was not the slightest further annoyance, as stated by both the foreman and his wife. In the upper portion of the same property, about 90 rows from the experimental block, on the contrary, the ants were running in heavy trails up all the trees and were numerous in the blossoms and at aphids.

After the February fumigation another was not warranted for about three and one-half months, or until June 7, when 21 of the traps contained sufficiently large colonies to seem to warrant their destruction. The killing of queens had been reduced from nearly 300,000 in each of the first three or four fumigations to less than 5,000, and, of course, all the other stages had been comparably reduced. The experiment was a complete success, for it reduced the ants to negligible numbers.

The following rough but not widely erroneous estimates will give an idea of the populousness of the ants in this orchard: The total estimated number of queens killed, as reference to Table VII will show, was 1,307,222. The workers and young must be estimated by volume. In the first four fumigations every trap fumigated contained fully one-half gallon of ants in all stages, and in each of the succeeding five nearly a quart. The total number of traps fumigated in the first four operations was 1,568; therefore 784 gallons, or about 15½ barrels, of ants were destroyed. In the remaining five fumigations there were 1,543 traps; therefore about 385 gallons, or about 7½ barrels, of ants were destroyed. The bulk of the ants destroyed in this work, therefore, would be almost great enough to fill twenty-three 50-gallon barrels.

Method and Cost of Fumigating Ant Traps.

It is recommended that not less than 25 traps per acre of 100 trees be used in ant trapping in the orange groves. There should also be 12 covers for each 100 traps. A trap should be placed near every other tree each way. For example, one near each of the first, third, and fifth trees in the first row, then similarly in the third, fifth, and seventh rows, etc. The traps should be located just under the outer spread of the trees, where they will not be in the way of the cultivator or so close to the tree that the latter will be injured by the fumigant. The distance from the trunk should be about 4 feet. They should be placed upon slight, level elevations made by throwing up and smoothing off a few shovelfuls of dirt.

The ants will be destroyed much faster if every part of the orchard, including ditch banks and the tree hills, is kept free from weeds, loose boards, boxes, sacks, etc. It is, of course, not recommended to plow and cultivate during the winter months, but the orchard should be kept clean during the summer. In winter the traps should be filled with damp but not wet stable manure and dry weeds, the manure occupying the lower half of the box. In summer the manure, which is used principally for its heat, may be omitted. It is important to keep the lids on the traps at all times, as they keep out the rain, a very essential condition, darken the nest, and in winter help to retain its warmth.

When the trap is full of ants and ready to fumigate the lid is thrown off, 2 fluid ounces of carbon disulphid poured in, and the cover quickly slipped on, the edges being banked with dirt to aid in retaining the gas. One man can do the work where the number of traps is small. Where the number of traps is larger they can be fumigated most efficiently by a crew of three men, one of whom measures and pours the liquid while the others remove the covers from fumigated traps, place them over those to be fumigated, and bank them with earth. A shovelful of soil tamped down at each side is sufficient. The traps must be allowed to fumigate for an hour. A crew of three men working continuously can handle 48 covers, removing them from one lot of traps and resetting them over the next in from 50 minutes to an hour. Two ounces of carbon disulphid will kill every ant in the trap and ants, worms, and sowbugs for 3 inches in the ground beneath. While the same trap filler may be used indefinitely, it and the traps should be given a thorough airing after each fumigation.

The figures here given on the cost of installing and operating the traps are based entirely upon the foregoing experiment conducted by the Bureau of Entomology. The cost of the traps, made of C-grade sap pine, all parts cut to fit, knocked down, was $0.23 each, to which must be added an additional $0.08 for transportation and setting up, making a net cost of $0.31 each. The covers were made and delivered for $0.75 each. On this basis the first cost of traps and covers per acre would be about as follows:

25 traps, at $0.31 each	$7.75
3 covers, at $0.75 each	2.25
Net cost of traps and covers per acre	10.00

A crew of three have in practice fumigated 400 traps in 1½ eight-hour days, their services, at the rate of $1.25 per day each, costing $5.62. The carbon disulphid at that time cost $10.75 per hundred pounds. On this basis the cost of fumigating per acre of 100 trees per time would be about as follows:

Cost of labor fumigating 25 traps, at $0.014	$0.35
Cost of fumigant, 25 traps, at $0.013	.325
Net cost of fumigation per acre	.675

SUMMARY AND CONCLUSIONS.

Most of the orange groves of southern Louisiana, with the exception of well-tended groves and seedling orchards, have been declining in the last seven or eight years. As a rule, maximum productiveness is reached at from 7 to 10 years of age, after which it diminishes, the actual crop loss up to 1914 being approximately 37 per cent of the known possible production. The principal cause of this decline of trees and loss of crop, which has been largely blamed upon the Argentine ant, is cultural neglect.

The part played by the ant in causing this condition has been exaggerated. The only direct injury done by the ant is to destroy a negligible number of orange blossoms. The ants do not attend the armored scales of citrus or secure honeydew from them, nor do they disseminate the living scales. They do, however, disturb the predatory enemies of these scales, preventing the destruction of as large a proportion of them as would otherwise occur. Nevertheless, the natural enemies of the armored scales do not prevent heavy infestation even in orchards free from ants. The ant can not prevent the control of the armored scales in Louisiana by spraying nor will it increase the cost of spraying. Destruction of the ants will not control these scales, and they must be controlled if orange growing in that State is to be made profitable.

Under present conditions the Argentine ant does not cause exceptionally severe infestations in the orange groves of Louisiana, even of those soft scales to which it is most favorable. The mealybugs have not been of importance as an orange pest in ant-invaded orchards during the years 1913 to 1915, partly due to the effectiveness of natural enemies, especially certain internal parasites, partly to overcrowding of the trees by armored scales and white flies, and partly because of the poor physical condition of the trees.

In Los Angeles County, Cal., where the trees are kept free from other scales and vigorously growing, the mealybugs increase tremendously as a result of ant attendance. Ordinarily they are kept under complete control, where the ants do not occur, by their predatory enemies. In orchards where fumigation has been neglected and the trees become overcrowded with the black scale, the mealybug does not benefit so much from ant attendance, and infestation is much milder.

The fluted scale has never been found in the orange groves proper of Louisiana, and the part played by the Argentine ant in causing the outbreak of this scale at New Orleans in 1916 is not known. The occurrence of this outbreak, closely following the 1915 hurricane, suggests the probability that the insect was largely spread by this means. The fluted scale is unable, under present conditions, to thrive on the orange trees of southern California even under the heaviest ant attendance, apparently being held in check principally by the Australian lady-beetle (*Novius cardinalis* Muls.), the green lacewings, and the dipterous larva *Cryptochaetum monophlebi* Skuse.

While the black scale occurs in New Orleans under constant attendance by the Argentine ant, the ant has failed to bring it into prominence there, and not a single infestation or even a single specimen has been discovered in any of the orange groves of Louisiana. In California the black scale infestations often become very severe after a single season during which fumigation has been neglected. In two years' time the insect is capable of increasing from almost none at all to such extreme numbers as to occupy every suitable feeding spot on the trees which it infests. Attendance by the ant for a single season does not noticeably increase the infestation of the black scale in California, where it reaches a maximum whether the ant is present or not. The natural enemies of this scale are not numerous and effective enough to control it.

While exceptionally large numbers of the soft brown scale occur on certain host plants or parts of such plants under ant attendance in Louisiana, the natural enemies of this scale, especially the internal parasites, continue to hold it to insignificant numbers in the orange groves under present conditions. In Riverside County, Cal., this scale appears to have increased considerably in certain ant-infested orchards, but is generally controlled along with other scales by fumigation. In Los Angeles County both the soft brown and the citricola scales are scarce in ant-invaded as well as other orchards. The soft brown scale, however, is undoubtedly more numerous on camphor and bottle trees (*Sterculia diversifolia*) and some other plants in sections of Pasadena where the ants occur than in sections where they do not.

There is reason to believe that the Argentine ant may be an active agent in the spread of diseases through its habit of visiting various parts of the tree, and particularly freshly made wounds, for the purpose of feeding. It appears to introduce gummosis and wood-rotting fungi in this way more rapidly than could otherwise be the case. It may act as a conveyor of diseases of bacterial origin, such as the citrus canker, by carrying the causal organisms about on its legs and body.

The control of the Argentine ant in Louisiana by the trapping method described in preceding pages is entirely practicable at a moderate cost. If ants are deterred by barrier ditches from entering the grove rapidly, five or six fumigations about a month apart should so reduce the worst infestations that annoyance from ants will cease. Thereafter fumigation of a few of the traps once in every three to six months will suffice to prevent further molestation. The estimated cost of reducing the ants from most extreme numbers to the few remaining where there is effective control would be about $6.03 per acre[1] for labor and fumigant, or not to exceed $16.03, including the first cost of traps and covers. It is believed that large sections of territory where the annual rainfall is heavy could be effectively and economically freed from ants by this method if all the members of the community would cooperate in the undertaking. Although the labor of ant destruction might be somewhat prolonged in cities because of the numerous buildings and other suitable nesting places, this method, it is believed, might be advantageously adapted to city use.

Destruction of the ants in Louisiana orange groves will not effectively control the armored scales, or the white flies and the rust mite, and would not pay for itself in actual crop increase. Regardless of the ants many run-down orange groves in Louisiana can be so improved by one season's thorough spraying and cultural treatment as almost to double their production. The success of certain orchards in southern Louisiana demonstrates that oranges can be profitably grown there if the trees are carefully selected and planted and the best-known cultural practices and methods of insect control followed. The growing of citrus is a business which is increasingly requiring thoroughgoing business methods, and this applies in Louisiana as elsewhere.

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[1] The term acre as used in southern Louisiana means an acre along the river front by 40 acres deep, and should not be confused with the present use of the term, signifying 160 square rods.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 671

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER. June 21, 1918

THE DIAGNOSIS OF BEE DISEASES BY LABORATORY METHODS.

By ARTHUR H. McCRAY,
Apicultural Assistant,
and
G. F. WHITE,
Expert Engaged in the Investigation of Bee Diseases.

CONTENTS.

INTRODUCTION.

Already some of the States have established laboratories for the diagnosis and investigation of the diseases of bees. The number of State laboratories where a rapid and accurate diagnosis of suspected material can be made will no doubt increase in the future in proportion as State laws for bee-disease inspection and control are instituted and perfected. Inspectors realize that there will be always some suspected brood and many conditions among adult bees which can not be diagnosed in the field, but which will require laboratory methods for diagnosis. In addition to the demands made by inspectors for the examination of suspected material, there will be numerous independent requests from beekeepers.

During the past several years the writers have examined a large number of specimens of suspected brood and bees sent to the Bureau of Entomology, and have developed and perfected methods and technique in the diagnosis of the known diseases of bees which, it is believed, will prove valuable to others. It is the aim of this paper to present these methods of diagnosis for the benefit of those who may engage in similar work.

For the understanding and application of the methods herein outlined, a preliminary training in general bacteriology, supplemented by a special knowledge of the pathogenic bacteria and the methods pursued in the diagnosis of diseases in general, is essential. As efficiency depends largely upon a knowledge of pathology, too much emphasis can not be given to it. With such general and special training as a basis, and with a knowledge of the bee diseases, the acquisition of the special methods necessary for a laboratory diagnosis of them becomes a comparatively simple matter.

One of the authors (White) began his investigations on the diseases of bees in 1902, and from this date to 1909 examined and diagnosed about 500 samples of suspected material and during the period developed the laboratory methods as given in the present paper. Since 1909 the senior author (McCray) has carried on the work of diagnosing the samples received by the Bureau of Entomology and up to the present time has examined and diagnosed about 5,000 of them.

LABORATORY METHODS.

OBTAINING THE SAMPLES.

For a satisfactory diagnosis of suspected brood the material at hand should be adequate. The size of the comb containing the affected larvæ should be ample. A piece about 5 inches square is suitable, provided it contains a sufficient number of larvæ. All samples, no matter how far sent or how long in transit, should be inclosed in wooden boxes to prevent crushing during transportation. Pasteboard boxes are apt to allow the sample to be crushed, while samples inclosed in tin boxes are often covered with a rich fungous growth when received. Both the crushing of the sample and the fungous growth obscure the gross features which form an important part of the examination. The sample should not be wrapped in cloth or paper, as this will tend to retain moisture and further encourage fungous growth. If thin paper is used, it frequently adheres so closely that its complete removal is difficult. The sample should contain no honey, as a small amount of it in a comb is sometimes sufficient to cause an unsightly mass, owing to leakage through the package in transit. As complete a history as can be obtained should accompany each suspected specimen as an aid to diagnosis. The Bureau of Entomology for several years past has sent out a printed question card with blank spaces for answers by the beekeeper sending the suspected brood. Some of the more important of these questions are as follows:

1. Is there any bee disease in your neighborhood?
2. If so, what disease?
3. Have you brought colonies from a distance? If so, give source.

4. Have you fed honey from other sources than your own apiary? Give source if known.
5. Is the diseased brood mostly capped or is it mostly uncapped?
6. What is the color of the larvæ (grubs) soon after death?
7. Later, what is the color of the decaying larvæ?
8. Are the dead larval remains ropy?
9. Do you notice any disagreeable odor in the hive?
10. Does there seem to be an unusual number of queenless colonies in the apiary?
11. What disease do you suspect?
12. Give location of the apiary from which sample was taken by town (or township) and county.

While a diagnosis sometimes can be made from larvæ which have been removed from their cells, and sent without the comb, such material is not satisfactory. It is far better to examine the infected larvæ in the comb in which they die. The diagnosis of bee diseases should not be based upon the examination of honey alone.

EXAMINATION OF THE SAMPLES.

In diagnosis both gross and microscopic examinations are made of the suspected material.

GROSS EXAMINATION.

The following points are to be taken into consideration: Character of the caps; regularity of the brood; proportion of affected brood; position of diseased larvæ within the cell; age, color, consistency, and odor of the affected brood; and kind of larvæ affected, whether queen, drone, or worker brood. These factors will be taken up in detail as each brood disease is considered separately.

In the gross examination of the comb it should be held in such a manner that a good lighting of the interior of the cells is secured. This is especially important in examining for scales. The best method of examining suspected brood is to hold the comb in a vertical position and about level with the eyes; then, by gradually inclining the top of the comb toward the observer, a point is reached at which the greatest amount of light is thrown upon the floor of the cells. This brings out the scales with great prominence and permits of their close scrutiny within the cells. In examining the affected brood for consistency and adherence to the cell walls in the scale stage, a small pair of curved forceps is convenient.

The gross examination of the adult bees will be considered under Nosema disease.

In routine diagnostic work unstained water mounts have been found very satisfactory in searching for spores, and stained preparations are made for the vegetative forms. Carbol fuchsin is a suitable stain to use.

MICROSCOPIC EXAMINATION.

The number of larvæ or pupæ to be examined in a given sample depends upon various factors. If the case is a typical one, one larva or pupa dead of a disease usually is sufficient. If, on the other hand, the gross appearance is not so definite and the microscopic picture from the first dead remains examined is unsatisfactory, others must be studied. While much might be written concerning the microscopic appearance of smears from larvæ or pupæ affected with the various brood diseases, as compared each with the others and with smears from healthy brood, such elaborate descriptions are not deemed advisable in this paper. Only the more salient features of the microscopic picture will be given for each disease considered, as it is believed that such descriptions will best serve those for whose benefit the paper is prepared.

It will be understood that when the authors write of the recognition of certain organisms by microscopic examination, as, for example, that of *Bacillus pluton* or *Bacillus alvei*, either in stained smears made from tissue or in stained smears made from agar plates, they refer to the recognition of the organism under observation only in a general way, meaning rather that the microscopic picture suggests the organism. The identification of the organism is complete, naturally, only after a consideration of its cultural characteristics also.

CULTURES.

In culturing the affected brood agar as ordinarily prepared in the laboratory is used in making plates. Those larvæ or pupæ are selected which upon microscopic examination have shown evidence of disease. Of course as many additional ones may be cultured as desired. The cultures are incubated for different periods of time, as will be noted in the discussion of the diseases.

Dead, not living, larvæ are examined.—In the laboratory examination of diseased bee brood, the affected larvæ are always received dead, therefore nothing will be said relative to symptoms and appearance of affected living larvæ.

DISEASES TO BE DIAGNOSED.

EUROPEAN FOULBROOD.

European foulbrood is an infectious disease of the brood of bees caused by *Bacillus pluton* (White, 1912).

GROSS CHARACTERS.

(*a*) *The caps and regularity of the brood.*—Larvæ that die of European foulbrood do so usually before they reach the age at which brood is capped. Brood dead of the disease is therefore usually found in uncapped cells. When the larvæ die after capping the caps usually are entire, but may be punctured. The caps may be slightly sunken, but usually are not. Owing to the fact that such a small percentage of the affected brood becomes sealed, a comb of brood affected with European foulbrood with its few sealed cells and large amount of young uncapped brood presents a distinctive appearance (Pl. I, fig. 1) and shows a marked contrast to the solid areas of brood of uniform age in healthy combs.

(*b*) *Proportion of affected brood.*—European foulbrood usually has made rather extensive ravages by the time the beekeeper detects it; hence in many samples received for diagnosis a very large proportion of the larvæ in the comb are affected. Toward autumn, however, it is not unusual to receive samples containing a small number of affected larvæ.

(*c*) *Position of larvæ within the cell.*—The usual position for larvæ affected with European foulbrood is that of lying curled at the bottom of the cell. Other affected larvæ lie extended in the cell, but these are few in number.

(*d*) *Age of the dead larvæ.*—In most of the specimens received for diagnosis by far the larger proportion of the affected larvæ are young, lying curled at the bottom of the cell as just stated. Besides this comparatively young brood, older larvæ, including a few sealed ones, may be found affected.

(*e*) *Color.*—A change in color is one of the first abnormalities noted in brood dead of European foulbrood. Yellow or gray and combinations of these two colors are among the first to be noted. Later the yellow and gray gradually deepen, until quite a dark brown is attained. Larvæ dead of this disease often present a peculiar appearance, as though they were melting away under the influence of heat. The transverse tracheal branches stand out prominently. This melting appearance of the larvæ, the yellow, gray, and brown coloration, prominent tracheal branches, and large amount of uncapped affected brood are characteristics not easily confused, in the majority of cases, with those of other diseased conditions of the brood.

(*f*) *Consistency.*—Larvæ dead of European foulbrood are comparatively friable. However, larvæ which are somewhat viscid usually may be found. Perhaps slimy, rather than viscid, expresses better the consistency of some of these larvæ.

(*g*) *Odor.*—A slight, inoffensive odor is frequently to be noted in European foulbrood. The yeastlike odor which has been described is not constant in brood affected with European foulbrood. A similar odor may be detected in samples other than those which contain European foulbrood.

(*h*) *Kind of brood affected.*—Sometimes samples are received which contain only affected drone-brood. Most cases, however, consist only of worker-brood. Queen larvæ also may be attacked.

(*i*) *Scales.*—Scales are formed by the drying of the affected larvæ, and from the foregoing description of the dead brood some conception may be gained as to their form and appearance. Scales of European foulbrood, like most of the affected larvæ, are small and lie at the bottom of the cell, from which they can be separated with ease. The color of the scale is in general yellow, gray, or brown, and the cross markings formed by the transverse tracheal branches usually are still in evidence. This is the usual type of scale found in European foulbrood. Occasionally there will be received, however, a sample containing only a few scales, or perhaps a single scale, in marked contrast to the scale just described. These scales are always few in number in a given comb area, are usually dark brown in color, are less easily removed than the small ones, and are not brittle but rubberlike in consistency.

MICROSCOPIC FINDINGS.

The appearance of *Bacillus pluton*, the etiological factor in European foulbrood, in stained preparations usually is sufficiently characteristic to render its microscopic identification comparatively certain. Besides *Bacillus pluton*, the following secondary invaders may be found: *Bacillus alvei*, *Streptococcus apis*, *Bacillus vulgatus*, *Bacillus mesentericus*, *Bacillus orpheus*, and *Bacterium eurydice*. Without careful observation *Bacillus pluton* and *Streptococcus apis* might be confused. Upon careful examination it is found that *Bacillus pluton* presents considerable variation in size and morphology in the individual organisms. Some of them occur in the form of cocci, yet the general picture is that of an organism with more or less pointed ends. Thin smears should be made in order to obtain details of morphology.

It is important to have a true conception of the microscopic appearance of *Bacillus pluton*. The essential facts are the typical morphology and the manner of grouping of the individual organisms. The general shape of the group is often more or less circular, although numerous groups of more or less irregular form may be observed. Groups of varying shapes and sizes will be noted as successive fields are brought into view. It is the presence of these groups, containing a sufficient number of organisms with the pointed ends described, that serves to differentiate *Bacillus pluton* from *Streptococcus apis*. *Streptococcus apis* usually occurs in forms which are sufficiently coccuslike to lead to little or no hesitancy in differentiating it from *Bacillus pluton*. Forms which are sufficiently pointed to resemble *B. pluton* do occur, however, and if only a few are present in a field the differentiation of these species is not possible. By making a sufficient number of smears from a sufficient number of larvæ, forms in abundance typical of either *B. pluton* or *Strep. apis* usually can be found. In stained smears of *Strep. apis* the organisms are found to be spread out over the whole field with no tendency to grouping as in the case of *B. pluton.* Sometimes in examining European foulbrood larvæ the microscopic picture shows practically nothing but *B. pluton.* More often, however, *Strep. apis*, *B. alvei*, and other rod forms are found. Some larvæ will disclose *B. alvei* alone, others *Strep. apis* alone, and still others, these two organisms without *B. pluton.* Continued search is sometimes necessary before larvæ are found revealing *B. pluton*, either alone or with one or more of the secondary invaders just mentioned. The authors have found *Bacillus pluton* in the small yellow, gray, and brown scales as well as in the soft melting larvæ. They are not prepared, however, to state the length of time that the organism persists in the dried state. Mention has been made of larger scales of rubberlike consistency which occur only occasionally and in small numbers in a given comb. Such scales always yield microscopically *Bacillus alvei* in abundance, and usually this organism alone. The microscopic appearance of *B. alvei* in the spore stage is rather characteristic, the spores practically always showing vestiges of the rods clinging to them. This aids in differentiating it from *B. vulgatus* and *B. mesentericus. Bacillus orpheus* may be recognized microscopically in the spore stage by the position of the spore in the rod, it being eccentrically placed. *Bacterium eurydice* is a small, slender organism which does not form spores.

CULTURES.

At the present writing no medium suitable for growing *Bacillus pluton* has been devised, hence agar plates made from European foulbrood larvæ show only the secondary invaders—*B. alvei*, *Strep. apis*, *B. vulgatus*, *B. mesentericus*, and *B. orpheus. Bacillus alvei* is encountered very frequently and is always secured on culturing larvæ in which the microscopic examination has revealed the presence of the organism. *Streptococcus apis* occurs occasionally. *Bacillus vulgatus* and *B. mesentericus* frequently are met, but usually in small numbers only. *Bacillus orpheus* in large numbers is occasionally encountered. *Bacterium eurydice*, as a rule, does not appear in the cultures. *Bacillus alvei* is the only organism occurring with any marked degree of frequency and in any great numbers on agar plates made from affected larvæ of any of the known infectious brood diseases of bees. Rarely do cultures from larvæ dead from any cause other than European foulbrood show the presence of this species.

The appearance of *B. alvei* on agar plates is rather characteristic. The colonies usually occur in abundance, often being innumerable.

When a few colonies are present there is seen, under low magnification, a granular center for each colony surrounded by numerous smaller but similar growths. There is little chance for error in the identification of *B. alvei*, assuming that the gross characters of the suspected material cultured had suggested European foulbrood and that the microscopic examination of the material had suggested the organism.

Cultures should be incubated until the second day in making a diagnosis of suspected European foulbrood material, since spores of *B. alvei* are not produced in abundance until that time. Two days, then, is the minimum time in which a report can be rendered on this disease. *B. vulgatus*, *B. mesentericus*, and *B. orpheus* may be recognized, when present, by their morphology and cultural characteristics (McCray, 1917).

AMERICAN FOULBROOD.

American foulbrood is an infectious disease of the brood of bees caused by *Bacillus larvae* (White, 1907).

GROSS CHARACTERS.

(*a*) *The caps and regularity of the brood.*—A large amount of the affected brood is capped, and many of the caps may be sunken and many perforated. The coloration, the sunken and perforated caps, and the irregularity produced by the capped and uncapped cells present quite a characteristic appearance (Pl. I, fig. 2).

(*b*) *Proportion of affected brood.*—The proportion of affected to healthy brood in American foulbrood is, as a rule, high, although specimens secured early in the attack may show a considerable proportion of unaffected brood.

(*c*) *Position of the larvæ within the cell.*—Inasmuch as most of the larvæ in American foulbrood die after the time of capping, the position of the larvæ is that of extension along the floor of the cell. But the dead larvæ quickly lose their form and symmetry, so that a dark, shapeless mass soon occupies the lower portion and bottom of the cell.

(*d*) *Age of the affected larvæ.*—The usual age at which the larvæ are found dead of American foulbrood is just after the time of sealing. This fact is of importance in considering the size of the scale and its position within the cell. Rarely is young unsealed brood found affected in this disease.

(*e*) *Color.*—Most of the dead larvæ when received for diagnosis will be of a dark chocolate color. Only rarely are larvæ of the lighter shades of brown seen. The late stages of decay are very dark brown.

(*f*) *Consistency.*—The consistency of the affected larvæ is characteristic and pathognomonic. The larvæ are strikingly viscid, so

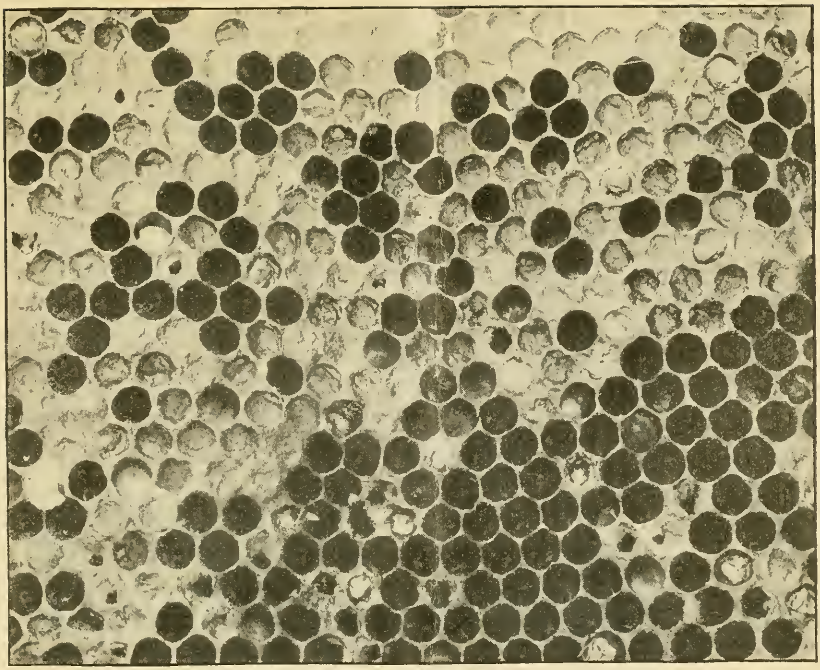

FIG 1.—COMB CONTAINING LARVÆ DEAD OF EUROPEAN FOULBROOD.
About natural size. (Original.)

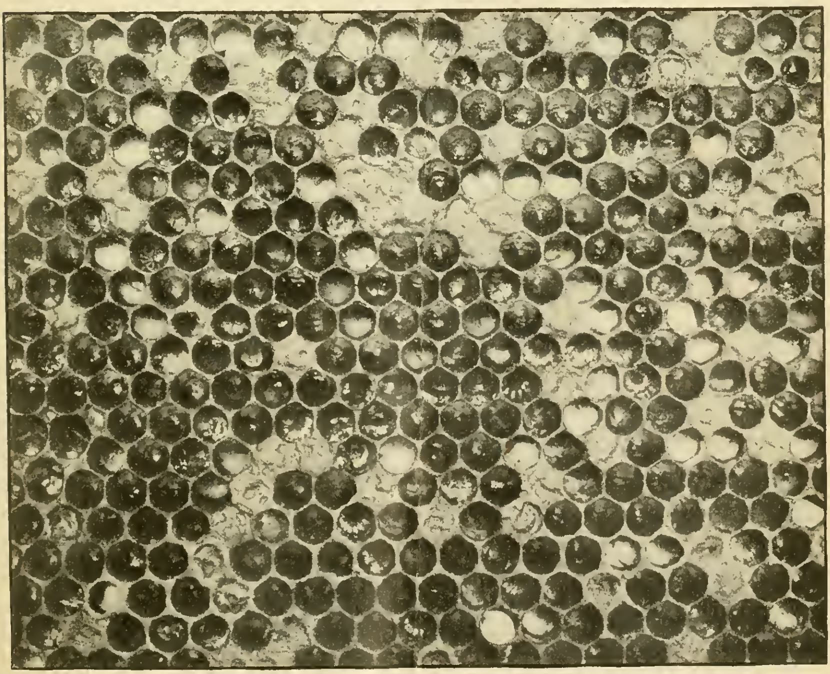

FIG. 2.—COMB CONTAINING LARVÆ DEAD OF AMERICAN FOULBROOD.
About natural size. (Original.)

EUROPEAN AND AMERICAN FOULBROOD.

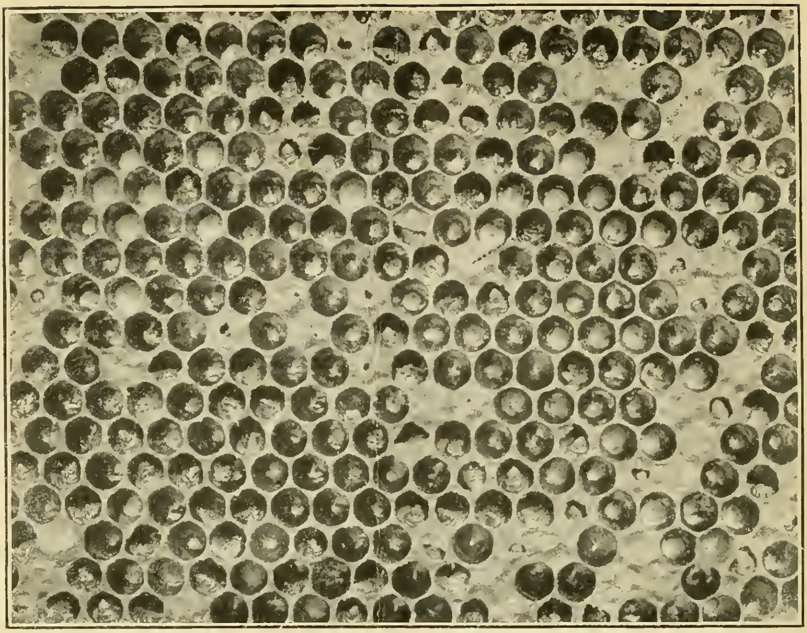

FIG. 1.—COMB CONTAINING LARVÆ DEAD OF SACBROOD.
Natural size. (White.)

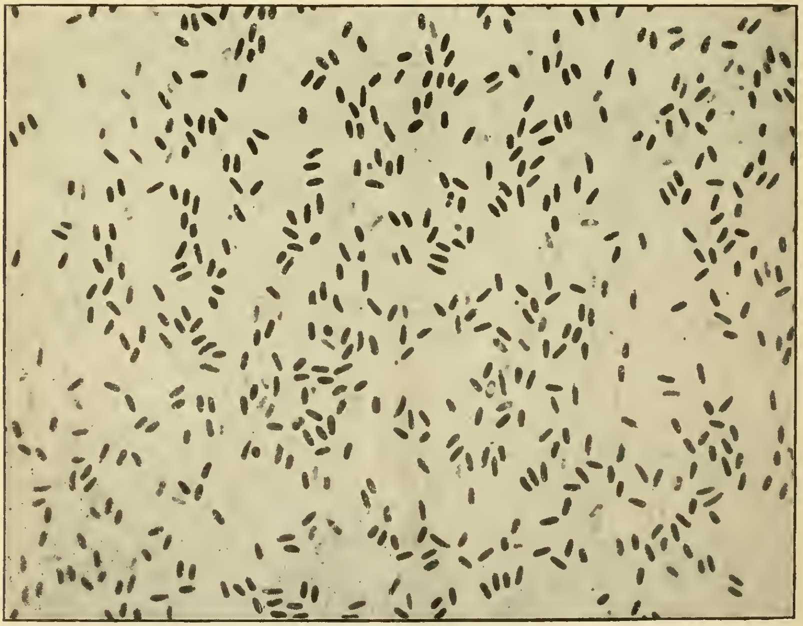

FIG. 2.—STAINED SMEAR PREPARATION SHOWING SPORES OF NOSEMA APIS.
Highly magnified. (Original.)

SACBROOD AND NOSEMA SPORES.

that on thrusting the forceps into the brown larval remains and withdrawing them a portion of the decaying mass adheres and is drawn out, often to a distance of 3 or 4 inches. The viscidity is often referred to by the term "ropiness" in beekeeping literature. In the rare instances in which young uncapped affected larvæ are encountered the ropiness is less pronounced.

(*g*) *Odor.*—The odor is characteristic and may be described as unpleasant. Often it is feeble or absent altogether, probably having disappeared after the removal of the diseased brood from the hive. Affected brood-comb will absorb other odors if given the opportunity, thus masking the original characteristic odor. Such disappearance and masking of the odor has been observed where specimens of diseased brood in combs from various sources had been thrown together and allowed to lie about preparatory to being destroyed (McCray, 1916).

(*h*) *Kind of brood.*—It is affected worker-brood that is most often encountered in American foulbrood samples, although drone-brood is sometimes affected.

(*i*) *Scales.*—The scales of American foulbrood are distinctive and are characteristic of the disease. If they are present in sufficient numbers the disease can be diagnosed from the gross appearance alone. The lower cell walls can be easily illumined by tilting the upper portion of the comb toward the observer, as previously described. The scales appear extended along the lower cell wall, are quite dark in color, and adhere closely to the floor and base of the cell. Sometimes they adhere so closely as to break when an attempt is made to remove them from the cell. Often a semblance of the form of the pupæ is evident in the dried-down mass forming the scale. Some of the mouth parts of the pupæ sometimes protrude sufficiently to adhere to the roof of the cell.

MICROSCOPIC FINDINGS.

In considering the microscopic appearance of stained smears from infected brood in this disease, there usually is only *Bacillus larvae* in the spore form to engage the attention of the observer. In some instances, however, samples containing the disease in its earlier stages are received and then *Bacillus larvae* in the rod or vegetative form may be encountered. Such a sample usually is more difficult to diagnose. To receive a sample in which some older larvæ containing spores of *Bacillus larvae* can not be found, however, is a very rare occurrence.

In a stained smear made from an infected larva and mounted in water, the microscopic picture is rather characteristic. The most striking feature of the mount is the large number of spores adhering to the cover glass, floating with the current, or dancing free in the water medium. Many of the spores stain slightly about the periphery, which aids somewhat in the observation. Good results may be obtained from an unstained water mount. The vegetative forms of *Bacillus larvae*, when they are present, are observed to be slender rods, which tend to occur in chains.

CULTURES.

In culturing affected larvæ it is the absence of growth on the agar plates that is important in the diagnosis of American foulbrood. This is because the spores of *Bacillus larvae* will not germinate and grow on the ordinary media of the laboratory, and other growth is absent because there are seldom secondary invaders present. Occasionally there will be a spreading growth of *B. vulgatus*, or *B. mesentericus*, and very rarely of *B. alvei*. On quite rare occasions a considerable number of colonies of *B. vulgatus* or *B. mesentericus* have been found. As both of these species form spores, as a rule, within 24 hours, their differentiation from *B. alvei* usually can be made in this way. A report on a sample of American foulbrood, therefore, nearly always can be made within a day.

SACBROOD.

Sacbrood is an infectious brood disease of bees caused by a filterable virus (White, 1913 and 1917).

GROSS CHARACTERS.

(*a*) *Character of caps and regularity of the brood.*—Larvæ usually die after capping in this disease, some of the dead brood being uncapped by the bees later. Occasionally the caps are punctured. An area of comb affected with sacbrood therefore presents an irregularity. So far as the age of the affected larvæ themselves is concerned, there is considerable uniformity owing to the fact that death in this disease occurs after sealing during the two-day period of rest just preceding pupation. The affected brood, however, is interspersed among healthy brood of varying age, which adds to the irregular appearance of the affected comb (Pl. II, fig. 1).

(*b*) *Proportion of affected brood.*—As a rule there is not a large proportion of affected brood in a given comb area. Often there will be an affected larva only here and there.

(*c*) *Position within the cell.*—The position of the affected larvæ is that of extension lengthwise along the floor of the cell, against which the dorsal portion of the larva lies. The head is turned upward, toward the roof of the cell.

(*d*) *Age.*—The brood dies after it has been sealed.

(*e*) *Color.*—Usually by the time brood is received for diagnosis the color of the affected larvæ is brown or quite dark—often almost black. If the brood is in the earlier stages of decay, however, the color may be light yellow, light gray, or light brown. The lighter shades soon deepen to the darker ones.

(*f*) *Consistency.*—The consistency is characteristic. The cuticular portion of the body wall of an affected larva is decidedly resistant so that the larva may be grasped with forceps and removed from the cell intact. After removal from the cell the larva has the appearance of a small closed sac. When the sac is ruptured the contents will be seen to be watery. Suspended in the waterlike fluid will be noted numerous fine brown granules.

(*g*) *Odor.*—There is no distinctive odor to sacbrood combs.

(*h*) *Kind of brood.*—The greatest ravages occur in the worker-brood. Affected drone-brood may be encountered.

(*i*) *Scales.*—The scales when dried down are quite black and the surface appears somewhat roughened. They separate readily from the cell wall and may be lifted out intact by means of forceps.

MICROSCOPIC FINDINGS.

The striking feature of the microscopic examination is the absence of microorganisms. Rarely a few rods may be observed. A large amount of detritus is always in evidence, consisting of the brown granular material seen on gross examination after rupturing the body wall of the larva. These granules are in a large part the result of the disintegration of the fat body of the larva.

CULTURES.

As might be expected from the microscopic examination, agar plates inoculated with infected material are practically always negative as to bacterial growth. Even the presence of organisms of the *vulgatus* group is rare. No other growth occurs unless from chance contamination.

OTHER ABNORMAL CONDITIONS OF THE BROOD.

There are noninfectious abnormal conditions of the brood of bees which have been confused with one or more of the infectious diseases. Among the more important of these may be mentioned chilled brood, starved brood, overheated brood, drone-brood resulting from laying workers, and brood dying after removal from the hive. The names given to most of the foregoing conditions are sufficient to indicate in a general way the probable cause of death. These conditions are less likely to be confused with American foulbrood than with either one of the other two infectious brood diseases of bees. The specimens that resemble European foulbrood in the gross consist of soft, easily ruptured, gray, yellow, and light-brown larvæ. The irregularity of the brood, the age, the color, and sometimes the scales bear a striking resemblance to many cases of the disease.

On microscopical examination of the affected larvæ the smear often discloses microorganisms, yet they lack the definite, clear-cut, positive picture desired in the diagnosis of the disease. If, on culturing, the agar plates are free from *Bacillus alvei* the specimen is usually considered negative.

Occasionally specimens are received resembling sacbrood that tend to cause confusion. The head in some of these has a tendency to turn upward, resembling sacbrood, but unless there is present the tough body wall and watery granular contents, a diagnosis of sacbrood should not be made. A resemblance to the disease is sometimes noted after the brood dries down to form a scale, dark in color and separating readily from the cell wall. The microscopic examination and the cultures are often negative as in sacbrood. In such cases, when there are only a few affected larvæ, it is impossible to make a diagnosis. Samples of comb containing only pollen without brood or scales have been received for diagnosis. Such specimens are always unsatisfactory and insufficient for diagnosis.

TABLE 1.—*Differential features in the diagnosis of the brood diseases of bees by laboratory methods.*

	European foulbrood.	American foulbrood.	Sacbrood.
General appearance of brood.	Brood irregular. Large amount of affected brood unsealed.	Very irregular; affected brood sealed, sunken and perforated caps present.	Brood less irregular, perforated caps present, dark sunken caps not so pronounced as in American foulbrood.
Proportion of affected brood.	Varying number of young larvæ affected, usually many.	Usually a large amount of brood affected.	Small amount of brood affected.
Position within cell	Usually curled at bottom. Larvæ soft, with melting appearance.	Extension along lower cell wall. Larvæ soon become a shapeless mass.	Extension along lower cell wall. Head turned upward. Normal form maintained.
Age of the larvæ	Usually die before capping	Usually die after capping	Almost invariably die after capping.
Coloration	Larvæ yellow, gray, and brown.	Usually dark chocolate	Soon become dark brown to almost black.
Odor	Slight, inoffensive	Usually strong characteristic odor. More or less offensive.	None.
Consistency	Soft, rather friable	Viscid, can be "roped" out a distance of 3 or 4 inches.	Contents watery and granular. Larvæ can be removed from cell without rupturing body wall.
Kind of brood affected	Often considerable amount of drone-brood as well as worker-brood.	Any considerable amount of drone-brood less likely to be seen.	Greatest ravages among worker-brood.
Scales	Usually small and lie at bottom of cell. Yellow, gray, or brown in color. Sometimes a few larger, brown, rubberlike scales. All scales separate readily from cell wall.	Extension along lower cell wall dark brown in color. Surfaces somewhat smooth. Separate from cell with difficulty.	Extension along lower cell wall. Dark in color, often black. Somewhat roughened appearance. Separate readily from cell wall.
Microscopic findings	*Bacillus pluton* always. *Bacillus alvei* usually. *Streptococcus apis* sometimes. *Bacillus orpheus*, *Bacterium eurydice*, *Bacillus vulgatus*, and *Bacillus mesentericus*, occasionally.	Usually only *Bacillus larvae*. Occasionally *Bacillus vulgatus* and *Bacillus mesentericus*.	Negative as a rule.
Cultures	Any of the above organisms except *Bacillus pluton*.	Frequently negative. Never *Bacillus larvae* on common media.	Nearly always wholly negative.

NOSEMA DISEASE.

Nosema disease is an infectious disease of adult bees. It is the only adult disease which at the present time can be diagnosed by laboratory methods (White, 1918). Sixty years ago Dönhoff (1857) observed an infectious condition among adult bees in which, upon examining the stomach of affected bees, small oval bodies were found. This work had been practically forgotten until Zander (1909) reported some interesting findings in a disorder of adult bees. He found that the stomach wall of bees taken from colonies suffering from what he called "malignant dysentery" contained a protozoan parasite. To this parasite he gave the name *Nosema apis*.

In England (Graham-Smith, Fantham, Porter, Bullamore, and Malden, 1912) Nosema infection in bees has been associated with a disorder referred to as the Isle of Wight bee disease. Recent investigations in Scotland (Anderson and Rennie, 1916) have lead to a somewhat different view. As *Nosema apis* occurs in the group Microsporidia the name "microsporidiosis" has been given to the disease (Fantham and Porter, 1912).

Nosema disease is widely distributed. It occurs in Germany, Australia, Switzerland, and England at least. The junior author (White, 1914) has found the parasite *Nosema apis* in samples of bees from a large number of the States of the United States and from Canada. The disease weakens and even kills colonies and is therefore one of interest to beekeepers. The exact losses from it are not known, but in America they are less than has been attributed to it in some other countries.

OBTAINING THE BEES.

Either dead or living bees are suitable for examination. Dead bees may be dry and still be suitable material. Living bees for examination can be sent very satisfactorily in mailing cages such as are used by queen breeders; dead ones may be sent in any convenient way. A complete history of the colony and apiary as to disease should accompany the bees.

GROSS CHARACTERS.

The presence of various symptoms has been mentioned as being of importance in the diagnosis of Nosema infection. Among these are noted the spotting of the hive with feces, abdominal distention, the presence of shiny bees devoid of hair, and the activity of the bees, either in the cages or when free. These are of questionable value. It is upon the presence or absence of Nosema spores that the diagnosis is based. Bees otherwise apparently healthy may, upon examination of the stomach, show the presence of spores of *Nosema apis* in large numbers.

MICROSCOPIC FINDINGS.

The bees if alive may be killed easily by crushing the thorax between the jaws of a pair of dissecting forceps. Then the thorax is grasped by the thumb and finger of one hand, the tip of the abdomen is grasped with a pair of forceps held in the other, and by gentle traction the ventriculus (stomach) and hind gut usually come away entirely and may be teased apart for examination, or the whole gut may be crushed under a cover glass and examined. In making a diagnosis at least 10 bees should be examined. Spores of *Nosema apis* if present are easily recognized, being oval, highly refractile bodies (Pl. II, fig. 2). Usually they occur in large numbers crowding the field. They stain with difficulty, and for diagnostic purposes water mounts unstained are satisfactory. The young forms of the parasite when present are quite difficult of detection, and should not be depended upon in the diagnosis.

Occasionally protozoa other than *Nosema apis* have been encountered in the examination of adult bees. These have no relation to Nosema disease, however, and may be disregarded in its diagnosis.

LITERATURE.

Much has already been written on bee diseases. The journals on beekeeping contain numerous articles pertaining to them. Bulletin No. 98 of the Bureau of Entomology briefly reviews a number of papers, published prior to 1912, dealing with the causes of these diseases. The papers reviewed and the publications cited, together with the papers in the following list and the references which they contain, comprise a fairly comprehensive résumé of all the literature detailing work done on these diseases.

With regard to further papers to appear soon, it is announced that studies have been made on American foulbrood and European foulbrood similar to those on sacbrood (White, 1917) and Nosema disease (White, 1918) and that the results are now being prepared for publication.

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L. O. HOWARD, Chief

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THE SOUTHERN GREEN PLANT-BUG.

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Entomological Assistant, Truck-Crop Insect Investigations.

CONTENTS.

INTRODUCTION.

In the extreme southern portion of the United States, particularly in those States bordering the Gulf of Mexico, a large pentatomid bug, *Nezara viridula* L., is a serious pest on cultivated plants. Important vegetable and truck crops are subject to injury and it is as an enemy of such crops that the species is considered in this article. The investigations upon which the article is based have been carried on principally at Baton Rouge, La.[1]

Nezara viridula is here given the name of "the Southern green plant-bug." The word "Southern" is proposed to distinguish the species from the closely related *Nezara hilaris* Say. While the latter is also a pest on cultivated plants, and approaches *viridula* in color, its range extends farther north in the United States than does that of *viridula*.

NATURE OF DAMAGE.

Both adults and nymphs feed by inserting their beaks into the plant tissue and extracting the plant juices, minute spots marking the points where the beak has punctured. The growing shoots of plants, and especially developing fruit, are preferred as feeding

[1] The writer wishes to acknowledge the cooperation, in this investigation, of Messrs. C. E. Smith and J. L. E. Lauderdale, while members of the Bureau of Entomology. The drawings of figures 4, 5, 9, 12, and 13 and the photographs (figs. 1-3 and 6-8) have been prepared by Mr. W. M. Dovener of the Bureau of Entomology.

places. Attacked shoots usually wither and are either retarded in their growth or, in cases of severe infestation, die. Such damage has been noted on Irish potato and sweet potato.

In the case of immature fruit the tissue around the point where the beak has been inserted does not develop normally and these points sometimes become centers of callous growth. The growth of developing fruit is retarded when injured in this manner and the fruit often withers and drops from the plant. Injured tomatoes, although small and distorted, sometimes assume a yellow color.

During 1917 injury by the nymphs to tomatoes and beans was demonstrated by confining nymphs with tomato fruits and growing beans. In the case of tomato a number of small green fruits

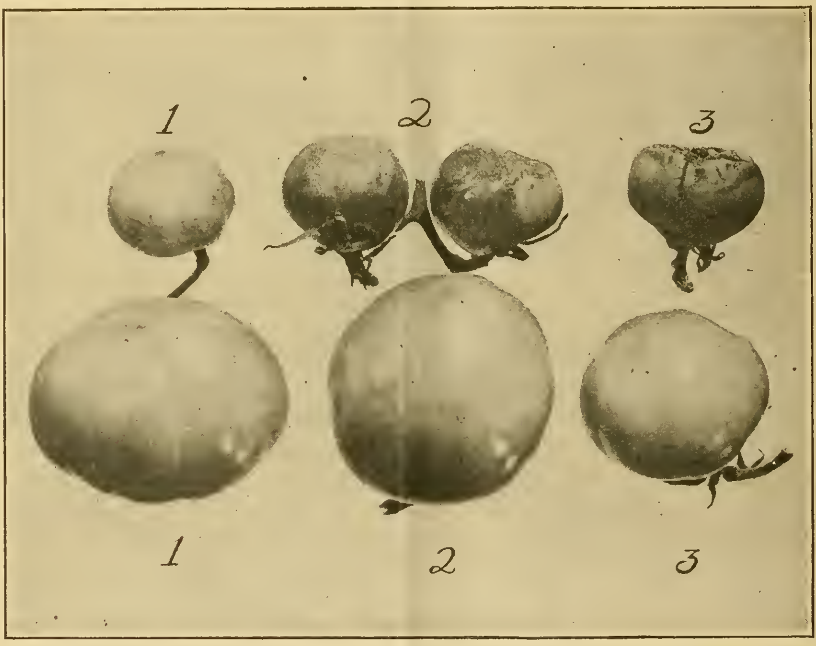

FIG. 1.—Injury to tomato fruit by nymphs of the Southern green plant-bug (*Nezara viridula*): Injured fruit above, normal fruit below. Developing fruit was covered with cheesecloth sacks in which nymphs were confined. Fruit bearing same number was approximately same size when inclosed in sacks.

growing in the field were closely covered with cheesecloth. In some of these covers nymphs were placed while other fruit was left to serve as checks. Examination later showed that those fruits with which nymphs had been confined had not developed to the same extent as did the check fruit. In some cases the fruits upon which nymphs had fed withered later and dropped from the stem. (See fig. 1.)

Beans growing in flowerpots were placed under covers. Nymphs were confined with some, while other plants were used as checks. No fruit developed on those plants upon which nymphs were allowed to feed. While the amount of fruit that developed on the check plants was not as great as it would have been under natural field conditions, the effect of the feeding of the nymphs was apparent when plants receiving the two treatments were compared. (See fig. 2.)

During 1916 an unusual type of injury to cauliflower was reported from Breaux Bridge in St. Martin Parish and from Terrebonne Parish, La. This was apparently due to the feeding of both adults and nymphs of the Southern green plant-bug. They were numerous

FIG. 2.—Injury to beans by nymphs of Southern green plant-bug. Beans growing in flowerpots were placed under wire cages. No pods developed on plants at right, with which nymphs were confined.

at and about the point where the leaf stems are attached to the main stalk of the plant. The stems became discolored and the leaves dropped prematurely.

DESCRIPTION OF STAGES.

THE ADULT.

The adult (fig. 3) when viewed from above has the characteristic form of the family Pentatomidæ, which may be described as shield-shaped. The dorsal surface of the body is slightly, and the ventral surface strongly, convex.

In living specimens the body as well as parts of the appendages are usually light green, the dorsal surface being somewhat darker than is the ventral surface. Exceptions to this may be found in the case of adults collected during the cooler months of the year. Such individuals are darker in color, perhaps because of the lower temperatures to which they are subjected, the light green in certain individuals being replaced by purple. Mounted specimens are usually dull green.

FIG. 3.—Southern green plant-bug (*Nezara viridula*): Adult. Enlarged about 4 diameters.

There is considerable variation in size, the average female being somewhat larger than is the average male. The sexes are differentiated by the appearance of the last abdominal segment, especially by the presence of a notch in the margin at the posterior end of the abdomen of the male (fig. 4.). This notch is not present on the female (fig. 5). A technical description follows.

Subovate, dorsal surface slightly convex, ventral surface strongly so. Color usually green, sometimes tinged with purple. Head somewhat prolonged, angular, tylus equalling cheeks. Eyes very dark red or black. ocelli appearing as tiny beads of amber. Antenna five-jointed; in comparative length the order is as follows: First, second, fifth, third, and fourth, the fourth being the longest. In green specimens the distal end of third antennal segment, and at least the distal half of fourth and fifth, is dark, of a red or brown color. Labrum dark red or brown, a dark line extending from the end of the labrum to dark tip of beak. Sides of pronotum nearly rectilinear. Three or five white points at base of scutellum along edge of pronotum. Black dot at each basal angle of scutellum. Distal end of tibia, and the tarsi, brownish. Small black dots along sides of abdomen at posterior tip of each segment. In purplish specimens coloration not so apparent. When wings are folded, entire surface of body, except membranous portion of wings, roughened by numerous punctures, especially dense on dorsal surface. Osteolar canal or orifice short, rather broad, truncated at apex, and not extending more than half way to lateral margin of metapleura.

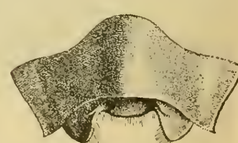

FIG. 4.—Southern green plant-bug: Ventral view of tip of abdomen of male. Greatly enlarged.

FIG 5.—Southern green plant-bug: Ventral view of tip of abdomen of female. Greatly enlarged.

From center of base of head to tip of abdomen 10 males average 12.1 mm., ranging from 11 to 13.5 mm. Average width at shoulders 7.85 mm., ranging from 7 to 8.5 mm. Average length of 10 females 13.15 mm., ranging from 12 to 15.5 mm. Average width at shoulders 8.3 mm., ranging from 7.5 to 9.5 mm. Average length of head about 2 mm.

COMPARISON WITH OTHER SPECIES OF NEZARA.

Four species, namely, *viridula* L., *pennsylvanica* DeG., *hilaris* Say, and *marginata* P. B., usually have been considered as belonging to the genus Nezara.[1] Whether considered of sufficient importance to be a generic character, or only a specific one, the difference in the shape of the orifice (osteolar canal) is the most satisfactory character for separating *viridula* from the other species. In *viridula* (fig. 6) the orifice is short, rather broad, truncated at the apex, and does not extend more than half way to the lateral margin of the metapleura. In the other three species (see fig. 7) it is long and curved, becoming gradually evanescent, and extends almost to the posterior lateral angle of the mesopleura.[2]

FIG. 6.—*Nezara viridula:* Portion of ventral surface of mesothorax and metathorax, showing the orifice or osteolar canal. Coxæ of legs of second and third pairs at right. Greatly enlarged.

THE EGG.

The egg (figs. 8 and 9) is cylindrical, rounded at the lower end and flattened on top. On the top are the short, club-shaped chorial processes arranged in a circle and attached to the egg between the cap and the outer edge by their smaller ends. Their distal ends are bent toward the center of the cap. The writer has found the number of chorial processes on an egg to range from 28 to 32. Whitmarsh (13),[3] in his description of the stages of *Nezara hilaris*, states that there are as many as 65 of these processes on the egg of that species.

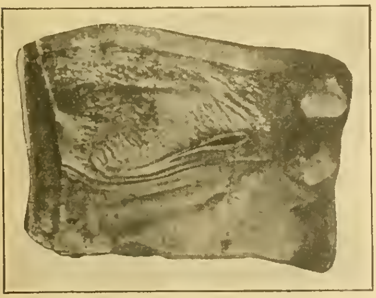

FIG. 7.—*Nezara hilaris:* Portion of ventral surface of mesothorax and metathorax, showing the orifice or osteolar canal. Coxæ of legs of second and third pairs at right. Greatly enlarged.

The surface of the egg is roughened, with traces of hexagonal markings. A number of eggs that the writer has measured gave an average height of 1.24 mm. and an average diameter of 0.85 mm.

[1] Some writers include *viridula* only under this genus, placing the other three species under the genus Acrosternum of Fieber.

[2] Some authorities mention other characters by which *viridula* may be distinguished, but the writer, finding some of these inconstant, considers it advisable to mention only the difference in the shape of the orifice.

[3] Numbers in parentheses refer to "Literature cited," p. 26.

When first deposited, eggs that have been kept under observation were of a cream color. Later they became salmon color and just before hatching the crimson markings of the inclosed nymphs were visible through the shell, a somewhat triangular area on the head being especially conspicuous.

NYMPH STAGES.

There is a marked variation in the coloration of different nymphs in the same period of growth and individuals vary considerably in coloration from day to day. The writer has observed a marked difference in coloration of different individuals after the third and fourth molts, as indicated by Morrill (7) in his figures of nymphs in the fifth instar. There are found in the fourth and fifth instars both light and dark nymphs, as well as others of intermediate coloration. In the case of numerous individuals that have been under observation it has been found that in the fourth instar the percentage of nymphs of the light and dark types—if such they may be called—is about the same. Nymphs in the fifth instar belong for the most part to the light type.

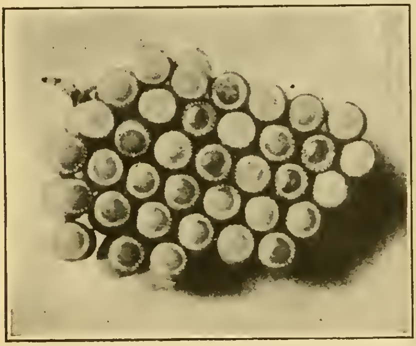

FIG. 8.—Southern green plant-bug: Egg-cluster, viewed from above. Enlarged about 6 diameters.

In the following descriptions the color notes should not be considered as having too great significance. Up to and including the third instar these notes refer, in so far as coloration is concerned, to normal or average nymphs, during the summer months. For the nymphs in the fourth and fifth instars two forms are described. One represents the darkest and the other the lightest form that the writer has found.

While the writer has not had the opportunity of examining the nymph stages of *Nezara hilaris*, the species with which *viridula* is most likely to be confused in the United States, it is evident from Whitmarsh's (13) descriptions and figures, especially with regard to the coloration and markings on the dorsal surface of the adbomen, that the nymphs of *hilaris* and *viridula* are quite distinct. In *viridula* the number and arrangement of the light-colored spots on the dorsal surface of the abdomen of nymphs in the second to fifth instars, inclusive, are very constant (although some of them are not apparent in the fifth instar, as they are covered by the wing pads), and serve to distinguish the nymphs from those of *hilaris*, in which these spots are not present. (Figs. 10 and 11.)

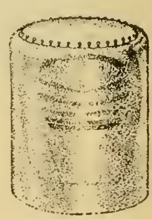

FIG. 9.—Egg of Southern green plant-bug, lateral view, showing embryo within. Highly magnified.

Dorsally the surface of the head and thorax of all stages is roughened by punctures and wrinkles. The surface of the abdomen is smoother, the punctures and wrinkles present being largely confined to areas around the glands and along the sides. Short setæ are scattered over the surface of the body and appendages. The margins

FIG. 10.—Southern green plant-bug (*Nezara viridula*): Nymph, fifth instar; light and dark types Enlarged about 4 diameters. (Morrill.)

of the thorax, which in the instars succeeding the first are serrated, are most prominent in the third and fourth instars.

Immediately after molting the abdomen of the nymph is quite flat dorso-ventrally but it gradually becomes thicker, until just before the new molt it is turgid and glistening. The nymph increases

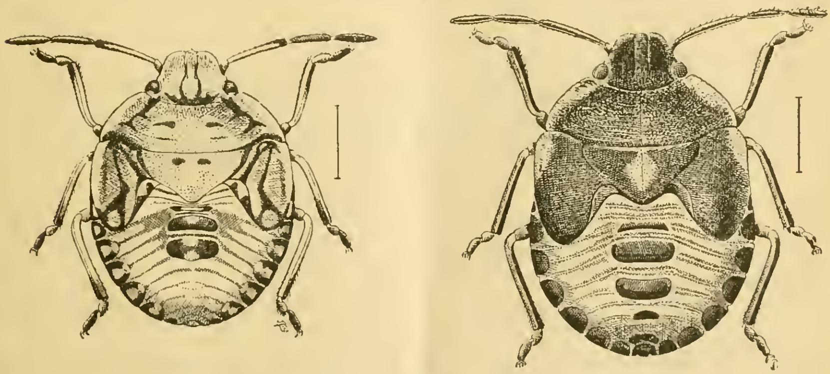

FIG. 11.—The green plant-bug (*Nezara hilaris*): Nymph, fifth instar; light and dark types. Enlarged about 4 diameters. (Morrill.)

in size from the beginning to the end of any instar and the length and width is also increased through molting.

Especially in the last two instars there is considerable variation in the size of different individuals in either stage even just after or before molting. This, of course, would be expected from the variation in size of the adults.

In molting the skin splits down the median line of the thorax and at the juncture of the head and thorax on the dorsal surface. Through this opening the nymph gradually works its way, leaving the entire covering of the body behind.

FIRST-STAGE NYMPH.

Ovate, strongly convex above, less so below. Body and appendages with short, scattered setæ. Antennæ, beak, and legs long and stout. Antenna four-jointed; first joint shortest, second and third of about equal length, fourth longest, largest at middle and approaching point at tip.[1] Four-jointed beak reaching beyond base of abdomen. Eyes prominent. Claws simple, two in number, each with pulvillus. Divisions of body and segments of thorax, and to less extent segments of abdomen, marked by indentations along edge.

As the nymphs issue from the eggs they are colored as follows: Eyes and a triangular area on top of head, one edge extending from lower point of one eye to lower point of other eye, crimson; remainder of head yellowish white. Thorax and abdomen golden yellow except for traces of transverse crimson lines which, between thorax and abdomen, form a transverse band. Antennæ, beak, and legs without color, nearly transparent.

Until the time of the first molt, when the nymphs attain a length of about 1.6 mm. and a width of 1.1 mm., they become gradually darker.

The following notes refer to their coloration just before molting:

Dorsal surface.

Head: Eyes deep red. Triangular area on head crimson or brown. At least area at base light yellow. Rest of head sometimes brown or in part yellow.

Thorax: Central portion of prothorax and mesothorax light yellow, the sides and rear of this area sometimes tinged with red. Sides of prothorax and mesothorax reddish brown or brown, with yellow sometimes present along edge. Metathorax reddish brown or brown.

Abdomen: Usually darker than head and thorax. For the most part dark brown, sometimes almost black. White spot on either side near base. Three glands, the anterior one being much narrower than the other two, reddish brown with cream-colored spot behind and to either side of last two. Somewhat semicircular, usually yellowish spot on either side of each segment, its straight edge along edge.

Ventral surface.

Head: Light yellow tinged with red. Antennæ light yellow with last segment somewhat dusky at tip and with crimson areas on joints near and at junctures. Beak light yellow with dusky tip.

Thorax: Light yellow tinged with red. Legs of same color with last segment of tarsi somewhat dusky.

Abdomen: Darker than head and thorax, having dusky tinge, especially a band down either side extending from edge about half way to median line, containing along the edge yellow semicircular spots corresponding to those found on dorsal surface.

Sometimes the whole under surface is dusky and the coloration not as distinct as above indicated.

SECOND-STAGE NYMPH.

Shape and relative length of segments of antennæ and beak much as in first stage Sometimes almost entirely black after molting.

The following color notes refer to mature individuals:

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[1] See Table I, giving lengths of antennal segments, p. 11.

Dorsal surface.

Head: Black.

Thorax: Black except for four yellow spots usually present, one near entire outer edge of prothorax and two, similarly located, on mesothorax.

Abdomen: Dark reddish. Tubercles black. Minute light spots sometimes present on median line. When present one is usually found between first and second and one between second and third tubercles. Four light areas, usually white, across base to form what approaches a band. Row of five light dots on either side of median line, the first and second very small and close together. Row of six light spots along either side of abdomen, the posterior one smallest and sometimes not apparent. All light spots are either white or light yellow, those over the central portion of the abdomen being usually yellow. Row of eight black semicircular spots along either edge of abdomen, one on a segment, their straight edges on line where dorsal and ventral surfaces of abdomen meet. Tip of abdomen black.

Ventral surface.

Head: Black. Antennæ and beak black, except for red areas between second and third and third and fourth antennal joints.

Thorax: Black except for yellow spots that may be present on prothorax and mesothorax, corresponding to those on dorsal surface, and reddish area between coxæ. Legs black.

Abdomen Reddish with row of five black spots extending from tip up median line and row of black spots along edge, corresponding to those on dorsal surface. Tip black.

About to molt they measure approximately 3 mm. in length and 2 mm. in width, being widest across the abdomen.

THIRD-STAGE NYMPH.

Shape, coloration, and general appearance same as in second instar, though black may sometimes be replaced by olive green.

When mature it measures about 3.6 mm. in length and 2.6 mm. in width across the abdomen.

FOURTH-STAGE NYMPH.

Shape as in preceding stages. The second segment of the antenna now longest. In this instar occur what may be termed light and dark forms as well as individuals of intermediate coloration. The light and dark forms are described below. When mature the nymph measures approximately 6.2 mm. in length and 4.7 mm. in width.

Light form, dorsal surface.

Head: Pale green with black border and black line on either side of tylus where it joins jugum. These lines extend to middle of base of head where they join small black area. Eyes black.

Thorax: Pale green with few scattered black dots and other black markings. Sides bordered with black and with orange-colored area near edge of prothorax and one of same color near edge of mesothorax.

Abdomen: Darker green than head and thorax. Darkest around glands, last two of which are salmon colored. Four white areas along base of abdomen nearly joined to form what approaches a band across base. Two small white dots on median line, one between first and second and one between second and third glands. Row of five white dots on either side of median line, diverging anteriorly and converging posteriorly. Row of six white dots, the posterior one much smaller than others, along either side of abdomen just inside connexivum. On connexivum six black-bordered, salmon-colored dots.

Ventral surface.

Head: Pale green with yellowish tinge anteriorly. Sides and front bordered with black. First joint of antenna for most part light green, others fuscous. Labrum fuscous, the rest of base of beak light green. Last two segments of beak fuscous.

Thorax: Pale green with few scattered black dots and lines. Sides bordered with black and with orange-colored area just inside border. Femora light green. Tibiæ and tarsi dusky to fuscous.

Abdomen: Pale yellowish green. Sides and posterior end bordered with black, with salmon-tinged band just inside border. Spiracles black.

Dark form, dorsal surface.

Head: Dark brown, nearly black, sometimes with jugum yellow.

Thorax: Dark brown, nearly black, except for yellow area near edge of prothorax and one near edge of mesothorax.

Abdomen: Dark brown, nearly black. Last two segments lighter than others White markings as in light form. Color of glands same as rest of ground color. Salmon-colored areas along connexivum absent.

Ventral surface.

Head: Greenish black. Beak and antennæ of same color.

Thorax: Greenish black except for yellowish areas near edge of prothorax and mesothorax and light, whitish band down median line under beak. Legs greenish black.

Abdomen: Light yellow tinged with red and with greenish-black border at sides and posterior end. Row of five greenish black spots along median line. Spiracles black.

FIFTH-STAGE NYMPH.

Shape much as in preceding stages, but development of wing pads now quite pronounced and basal portion of abdomen in part covered by them. Length, when mature, about 10 mm., width about 7 mm.

Light form, dorsal surface.

Head: Pale green with black border and a black area at base on either side of median line. Eyes for most part black.

Thorax and wing-pads: Pale green with black border on sides and with few scattered black dots and other black markings. A narrow orange-colored band just inside black border, more pronounced on prothorax.

Abdomen: Pale yellowish green with black area about rose-colored glands. Yellowish-white, rounded spots located as follows: Two small ones on median line, one between first and second and one between second and third glands; row of five on either side, just outside median line, the third and fourth largest; row of five on either side near connexivum, the first sometimes covered by wing-pads. On connexivum, at either side of each segment, a rose-colored, black-bordered, somewhat semicircular area, its less curved border outward. Near posterior end of abdomen these areas not well defined.

Ventral surface.

Much as in light form of fourth-stage nymph except that band just inside black border of abdomen is rose colored.

Dark form, dorsal surface.

Head: Juga chrome orange with black border on outside edge. Rest of head and eyes dark brown, nearly black.

Thorax: For most part dark brown, nearly black. Black-bordered, orange-colored areas, one near both outside edges of prothorax and one near outside edge of both primary wing-pads. Yellowish area along inside edge of both primary wing-pads.

Abdomen: Dark brown, almost black.[1] At base a yellowish-white area on either side of median line. Other yellowish-white spots and rose-colored areas on connexivum as in light form.

Ventral surface.

Head: Olive green with black markings. Beak and antennæ olive green to black, lightest near base.

Thorax: Olive green with black markings except for chrome-orange areas near edge of prothorax and mesothorax. Legs olive green near base, becoming gradually darker to black tarsi.

Abdomen: Light yellow tinged with red and with black-bordered, rose-colored areas on connexivum corresponding to those on dorsal surface. Row of four greenish-black spots along median line. Spiracles black.

COMPARATIVE LENGTHS OF ANTENNAL SEGMENTS OF NYMPHS AND ADULT.

While the measurements given in the following table are taken from single individuals only, they indicate the comparative lengths of the segments in any one stage. It will be noted that the antenna of the nymph is made up of four segments while that of the adult is composed of five. In this connection it may be stated that the writer has seen an abnormal adult with one antenna composed of four segments and the other of five.

Up to and including the third instar the fourth segment of the antenna is longest. In the fourth and fifth instars the second segment is longest, while in the case of the adult the last three segments are of about equal length, any one being longer than either the first or the second segment.

TABLE I.—*Lengths of segments of antennæ of nymphs and adults of Nezara viridula.*

Stage.	First segment.	Second segment.	Third segment.	Fourth segment.	Fifth. segment.
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*
First-instar nymph	0.14	0.19	0.18	0.37	....
Second-instar nymph	.15	.40	.33	.53	....
Third-instar nymph	.18	.60	.50	.67	....
Fourth-instar nymph	.29	1.17	.88	1.07	....
Fifth-instar nymph	.44	1.71	1.22	1.27	....
Adult	.53	1.07	1.66	1.76	1.56

DISTRIBUTION.

Bueno (9) states that *Nezara viridula* is recorded "from the whole of Europe except the extreme north, Asia, Africa, Malaysia, Australia, New Zealand, South America, at least in the north, Central America, and enters into the United States at the south, being found in Texas and Florida." Specimens have been seen from Cuba, Porto Rico, and St. Croix (U. S. Virgin Islands) in the Lesser Antilles.

[1] In individuals of this form examined by the writer the general color of the dorsal surface of the abdomen is much darker than Morrill's (7) figure would indicate.

In the United States (fig. 12) its range covers the extreme southern portion, although at times it occurs outside this area. In the files of the Bureau of Entomology there are records of its injurious occurrence in South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas. This would indicate that the species is most numerous in the southern portion of the Cotton Belt.

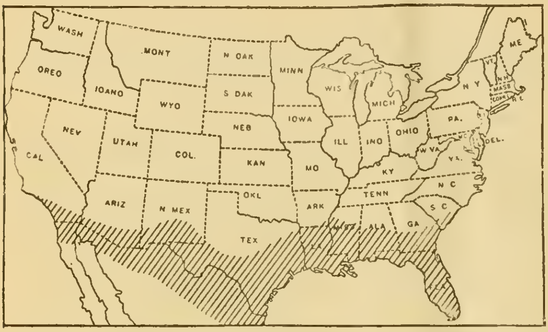

Fig. 12.—Map showing distribution of the Southern green plant-bug in the United States. Shaded areas indicates probable distribution.

From what has been observed in regard to the distribution of this species, it is evident that it is of foreign origin and, like many others of our principal pests, was introduced into this country many years ago. It is also obvious that it would be impossible even to hazard a conjecture as to the source from which it obtained a foothold in the southern United States.

REVIEW OF LITERATURE.

The species was first described as *Cimex viridulus* by Linnaeus (1) in 1758 from specimens from India and, according to Banks (6), it has been described since then under several other names by various authors. Van Duzee (5), Banks (6), and Barber (10) have mentioned areas and localities where it occurs and Van Duzee (5) and Parshley (11) have given characters by which it can be separated from closely related species.

Short notes regarding *Nezara viridula* were published in Insect Life in 1889 (2) and 1893 (3, 4). The notes published in 1893 relate to specimens sent to Washington by correspondents in Plaquemines Parish, La., and Altoona, Fla.

In 1910 Morrill (7) included a short account of the species in Bulletin 86 of the Bureau of Entomology. He mentioned the species as occurring on cotton, potato, and turnip, in Florida, Louisiana, and Texas, and gave figures of the light and dark types of nymphs in the fifth instar.

In 1912 Bueno (9) recorded the finding of the species in a greenhouse in Brooklyn, N. Y., and stated that he believed it to have been introduced from Europe or Florida, though he saw no reason why it could not establish itself in the latitude of Brooklyn inasmuch as it occurred in Germany and Russia. A short description was included and a number of food plants listed.

Froggatt (12), in 1916, recorded it as injuring tomato, French bean, and potato in New South Wales, and stated that it had appeared in the neighborhood of Sydney about five years previous to that date.

It was mentioned by Watson (14), in 1917, as an enemy of various crops in Florida, being treated especially as an enemy of truck and garden crops. Hand collecting was referred to as a satisfactory method of control to be practiced in the garden.

UNPUBLISHED RECORDS.

Among the records in the files of the Truck-Crop Insect Investigations, Bureau of Entomology, there are several notes referring to injury by the southern green plant-bug. Specimens were taken at the time the notes were made and these have been seen by the writer.

Mr. W. R. Beattie collected specimens at Mount Pleasant, S. C., on September 23, 1907, from tomato and stated that "in numerous instances" he "found as many as 5 to 20 working on a single fruit." On October 24 of the same year Mr. H. M. Russell reported severe injury to kumquats and Satsuma oranges in a grove of 1,000 trees at St. Leo, Fla., the insects apparently having migrated to the grove from neighboring cowpeas after these had died. The owner of the grove estimated that because of the injury he had lost all of his Satsuma fruit and 250 boxes of kumquats. The inside of the injured fruit was dry and pithy.

In a note from Brownsville, Tex., dated May 25, 1909, Messrs. D. K. McMillan and H. O. Marsh stated that these bugs were "very abundant during the fall and early winter on eggplant, tomato, okra, cabbage, and corn."

On October 20, 1917, Mr. M. H. Carter, of Troy, Ala., sent adults taken from cowpeas and wrote, "they have caused thousands of dollars damage in south Alabama this year by destroying the field-pea crop."

Mr. H. K. Laramore wrote on November 15, 1917, sending specimens collected at Jacksonville, Tex., on turnip and rutabaga, that the species was very common, doing "a great deal of damage to crucifers especially" and "I am told it is out of the question for them to attempt to raise late cowpeas in Cherokee County."

In the office records are included also other notes which, though unaccompanied by specimens, probably refer to this species. During November, 1911, the American Sumatra Tobacco Co., of Quincy, Fla., wrote regarding injury that "the loss attributable to them can be counted into thousands of dollars." In the case of tobacco it was stated that "wherever they sting a leaf it wilts the same and the leaf becomes absolutely worthless." Injury to velvet beans was also referred to.

Writing from Winnfield, La., on December 8, 1914, Mr. C. P. Seab stated that "it is this bug which attacks the lima and string bean as well as the cowpea. The farmers tell me it is almost impossible to have any kind of beans or peas on account of this bug."

February 2, 1917, Mr. John A. Creel wrote from Clapton, Ala., regarding "green bugs" that "attack peas of all varieties, velvet beans, peanuts, sugar cane, squash, okra, butter beans, etc.," and stated that "they attack any kind of grain or vegetable when in the green stage. The vegetable or grain will, after being punctured, become hard and dry, and good for nothing."

FOOD PLANTS.

Other writers have recorded *Nezara viridula* as feeding on beans, cotton, cowpea, *Gynandropsis pentaphylla*, hackberry, okra, maize, mulberry, orange, peas, pepper, potato, rice, sugar cane, sunflower, sweet potato, tomato, and turnip. We have taken it on a number of these plants and, in addition, on Brussels sprouts, cauliflower, collards, eggplant, globe artichoke, mustard, and radish.

While little damage is recorded to some of the plants mentioned and while it probably does not breed on all of them, it is a quite general feeder. Watson (14) states that it "attacks nearly all garden plants." Among vegetables the writer has found that serious injury is usually to tomato, bean, Irish potato, sweet potato, and okra. In the late fall and early winter the various stages are often abundant on mustard and turnip. They have also been observed congregated on the remaining green portions of okra plants after frost. It appears that legumes are favored as food plants. Farmers sometimes complain that the bugs greatly decrease the yield of seed of cowpeas by injuring the developing pods. Other writers mention the species as a pest on cotton and orange, and the records in the Bureau of Entomology, mentioned above, indicate that it feeds also on cabbage, corn, peanut, squash, tobacco, and velvet bean.

SEASONAL HISTORY AND HABITS.

HABITS OF THE ADULT.

The adults from the last generation of nymphs, some of which may be found feeding at Baton Rouge until late fall and early winter, often congregated on mustard and turnip, usually seek hibernating quarters. Rosenfeld (8) lists them among the insects taken from Spanish moss in Louisiana during December and January. Mr. O. W. Rosewall, professor of entomology at the Louisiana State University, has informed the writer that he has taken adults during the winter months under logs on batture land of the Mississippi River near Baton Rouge. A few, however, may be found in the field during mild periods of weather throughout the winter. The overwintered adults mate in the spring and the writer has found eggs in the field at Baton Rouge as early as April 13. They have also been taken as late as November 8.

In feeding the adults prefer, as do the nymphs, the growing shoots or developing fruit of their host plants. They are active and capable of strong flight. Morrill (7) has recorded their capture at night and mentions the fact that when an electric light was turned on at night in a room where adults were confined they became restless. This was verified by observations at Baton Rouge.

When handled the adults give off a disagreeable odor. On this account they are sometimes spoken of as "stink-bugs."

COPULATION.

As has been noted by Whitmarsh (13) in the case of *Nezara hilaris*, the male and female of *viridula* usually remain in copulation for a considerable period of time, firmly attached to one another by the tips of their abdomens and with their heads facing in opposite directions. Copulation is also repeated at intervals, as the results of observations on reared individuals given in Table II will show.

OVIPOSITION.

The eggs are placed close together in clusters which, when viewed from above, have much the appearance of pieces of capped honeycomb (fig. 8). Individual eggs are attached to one another, and the cluster to the surface upon which it rests, by an adhesive substance given off by the female at the time of oviposition. In the field the female prefers the underside of a leaf as a location for the egg mass. Egg clusters deposited outside of confinement and examined by the writer have with one exception been made up of from 60 to 116 eggs. A cluster taken on November 3 contained only 36 eggs. Rearing records also indicate that the females sometimes deposit their eggs in smaller clusters, but in such instances this may have been due to their having been disturbed while ovipositing.

RECORDS OF REARED ADULTS IN CONFINEMENT.

Several adults, reared from nymphs, were kept under observation in the insectary until their death, especially with the idea of obtaining data on the period of time elapsing between the time the females emerged from the last nymphal skin and the time of egg laying, the number of eggs laid, copulation, and length of life of males and females. These individuals were confined in jelly glasses containing moist sand, a male and a female being placed in each tumbler. Green tomatoes were used as food and the contents of the tumblers examined daily. Table II includes notes made on some of the pairs.

Several females never laid eggs. One of these issued on July 22 and lived until October 30, part of the time in company with a male. No eggs were found in the ovaries at death. On the other hand, some females that laid eggs had well-formed eggs in the ovaries at death. Seventy-seven eggs were found in the ovaries of the female of Pair L after three clusters, containing 240 eggs in all, had been deposited.

While one female deposited a cluster of eggs 19 days after becoming adult, the average length of this period was nearly four weeks.

TABLE II.—*Length of life, dates of mating and egg laying, and number of eggs deposited by reared adults of Nezara viridula.*[1]

Pair.	Female issued.	Male issued.	Mated.	Male dead.	Female dead.	Eggs deposited.	Number of eggs.	Eggs deposited.	Number of eggs.	Eggs deposited.	Number of eggs.	Total number of eggs deposited.
A	July 13	July 14	July 31; Aug. 12, 15	Aug. 18	Aug. 21	Aug. 12	69	Aug. 20	62			131
B	July 16	July 20	Aug. 10, 11	Aug. 17	Aug. 22	Aug. 8	62	Aug. 14	76			138
C	July 11	July 21	Aug. 6, 9	Aug. 19	Aug. 24	Aug. 20	55					75
D	July 20	July 21	July 31; Aug. 1, 2, 3, 5, 13, 14, 16, 17	Aug. 27	Aug. 26	Aug. 13	52	Aug. 14	9			61
E	July 18	July 19	July 31; Aug. 2, 23, 24	Sept. 11	Sept. 3	Aug. 23	26	Aug. 27	4	Sept. 1	12	42
F	July 28	July 28		Aug. 6	Sept. 17	Aug. 20	59					59
G	Aug. 2	Aug. 2	Aug. 12, 28	Sept. 23	Sept. 1	Aug. 26	10	Aug. 27	65			75
H	July 25	July 25	Aug. 4, 6, 7, 13, 20	Aug. 22	Oct. 1	Aug. 13	70	Aug. 24	35			105
I	Aug. 14	Aug. 14	Sept. 1, 2	Sept. 30	Oct. 13	Sept. 18	78					78
J	Aug. 14	Aug. 14	Aug. 30; Sept. 9, 21, 24, 25	Nov. 2	Nov. 2	Sept. 9	79	Sept. 19	72	Sept. 30	69	220
K	Aug. 14	Aug. 14	Aug. 30; Sept. 6, 10, 18	Nov. 3	Sept. 20	Sept. 6	65	Sept. 10	23	Sept. 18	59	147
L	Aug. 13	Aug. 13	Aug. 27, 28, 30; Sept. 5, 7, 8, 9, 10, 11, 18	Sept. 24	Nov. 18	Sept. 5	87	Sept. 18	83	Oct. 18	70	240

[1] Temperatures to which individuals were exposed shown in figure 13.

PERIOD OF INCUBATION OF EGGS.

Table III gives data on eggs that were laid by females in the insectary, in which place the eggs were also kept until they hatched. Jars containing the adults and eggs were examined each morning and the date on which eggs were noted is taken to be the date on which they were deposited. In a like manner the date when nymphs were found is taken as the date of hatching.

The eggs composing any one cluster usually hatched at approximately the same time. An exception to this occurred in the case of a cluster of eggs deposited on October 16. Nymphs issued from some of these on October 29, when the thermograph reached a maximum of 87° F. at noon. At 2 p. m.[1] a "norther" caused a sudden drop in temperature, the thermograph registering 34° F. the next morning. No more nymphs were observed to issue on October 30 or 31 when the maximum temperatures were 53° and 63° F., respectively, but on November 1, when the maximum temperature was 70° F., other eggs hatched.

The temperatures to which the different egg clusters were exposed apparently governed to some extent the period of incubation, the period being longer for the lower temperatures.

TABLE III—*Incubation periods of egg clusters of Nezara viridula.*[1]

Deposited.	Hatched.	Days.	Deposited.	Hatched.	Days.	Deposited.	Hatched.	Days.
July 22	July 28	6	Aug. 18	Aug. 23	5	Sept. 4	Sept. 9	5
July 22	July 28	6	Aug. 20	Aug. 26	6	Sept. 5	Sept. 10	5
July 30	Aug. 4	5	Aug. 20	Aug. 26	6	Sept. 6	Sept. 12	6
Aug. 9	Aug. 14	5	Aug. 22	Aug. 28	6	Sept. 6	Sept. 12	6
Aug. 13	Aug. 18	5	Aug. 22	Aug. 28	6	Sept. 6	Sept. 11	5
Aug. 13	Aug. 18	5	Aug. 24	Aug. 30	6	Sept. 18	Sept. 25	7
Aug. 14	Aug. 19	5	Aug. 25	Aug. 31	6	Sept. 27	Oct. 6	9
Aug. 14	Aug. 19	5	Aug. 26	Aug. 31	5	Oct. 16	Oct. 29	13
Aug. 15	Aug. 20	5	Sept. 2	Sept. 7	5	Oct. 18	Nov. 9	22

[1] For temperatures to which eggs were exposed see figure 13.

HABITS OF THE NYMPHS.

The nymph issues from the egg through a circular opening at the top which it makes by removing the cap or lid. The brownish T-shaped egg-burster, by means of which the cap is removed, is usually left in the eggshell when the nymph emerges.

During the first instar the nymphs ordinarily cluster together, often on the eggshells, and apparently do no feeding. After the first molt they begin to search for food and soon become scattered. Subsequent to the first molt, and especially during the later instars, the nymphs are active and when disturbed they often seek protection by moving to places out of the disturber's range of vision. They are found usually upon those portions of the plant on which they prefer to feed—the growing shoots and more especially the developing fruit.

[1] All references to "clock time" refer to Standard Time.

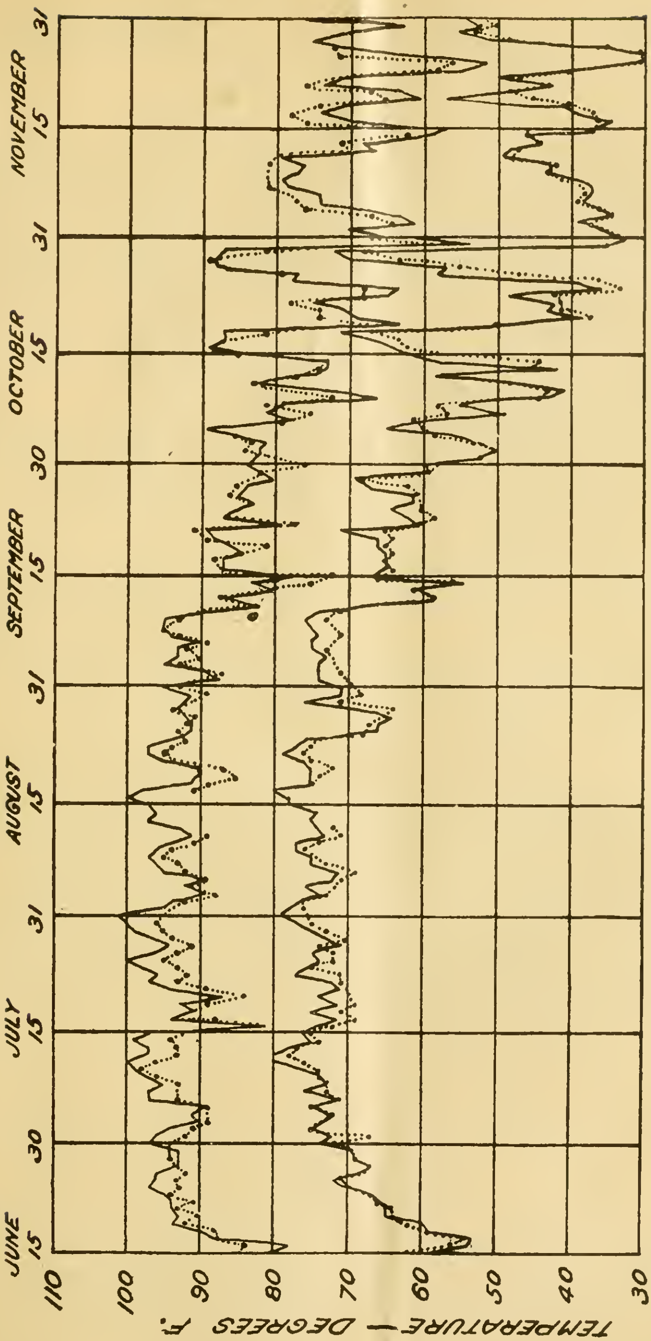

FIG. 13.—Showing temperatures at Baton Rouge, La., during the time when life-history studies of the Southern green plant-bug were conducted. Unbroken line indicates temperature in insectary where studies were conducted. Broken line indicates temperatures for Baton Rouge as given by the United States Weather Bureau.

When handled the nymphs give off a disagreeable odor. This odor is scarcely perceptible in the case of nymphs in the first instar but increases in strength in the succeeding stages.

PERIODS OF NYMPHAL STAGES.

Tables IV and V are introduced to show the minimum number of days spent by nymphs from different egg clusters in the five instars. Table IV refers to nymphs kept in the office and Table V to nymphs kept in the insectary. The nymphs issuing from a single egg cluster were kept together in a cloth-covered jar containing moist sand. Green tomatoes were used as food and proved very satisfactory. Fresh ones were placed in the jars at frequent intervals in order that the food supply might approximate that in the field.

The jars were examined daily, and the dates given for the different lots are those on which the first individual from a certain egg cluster issued from the egg or from a subsequent nymphal instar. It is assumed, therefore, that the first individual to issue from an egg cluster was the first to become adult.

Individuals from any one egg cluster spent about the same amount of time in either of the first two nymphal instars, but during the later instars the periods became less constant. Temperature conditions apparently had an important bearing over this. For instance, during a period of warm weather in the fall a few nymphs in a certain instar would molt; then the temperature would suddenly fall and several days of cool weather follow, no other nymphs molting until this period had elapsed. Periods of several days, therefore, sometimes occurred between the time when the first and last adults appeared. In the fall these periods were sometimes prolonged to 30 days.

The periods spent by the nymphs of different egg clusters in the succeeding instars were apparently influenced by the prevailing temperatures; low temperatures lengthening the periods. This can be seen by comparing the dates given in Table V with the insectary temperatures shown in figure 13.

TABLE IV.—*Minimum length of instars of Nezara viridula based on records of first individuals.*[1]

Lot.	Hatched.	Second instar.	Third instar.	Fourth instar.	Fifth instar.	Adult.
A	July 2	July 5	July 10	July 20	July 26	Aug. 2
B	July 4	July 7	July 13	July 19	July 29	Aug. 8
	Number of days to complete instar.					
A		3	5	10	6	7
B		3	6	6	10	10

[1] Average of maximum temperatures to which nymphs were exposed, 89° F.; average of minimum temperatures, 80° F.

TABLE V.—*Minimum length of instars of Nezara viridula based on records for first individuals.*[1]

Period spent in first instar.	Days.	Period spent in second instar.	Days.	Period spent in third instar.	Days.	Period spent in fourth instar.	Days.	Period spent in fifth instar.	Days.
June 18-22	4	June 22-26	4	June 26 to July 4.	8	July 4-12	8	July 22-31	9
Aug. 14-17	3	Aug. 22-29	7	July 7-13	6	July 12-22	10	Aug. 3-10	7
Aug. 18-22	4	Aug. 22-26	4	July 7-12	5	July 13-22	9	Aug. 5-12	7
Aug. 19-22	3	Aug. 22-28	6	July 24-30	6	July 26 to Aug. 3.	8	Sept. 7-20	13
Do	3	Aug. 23-29	6	Aug. 26 to Sept. 1.	6	July 30 to Aug. 5.	6	Sept. 11-26	15
Aug. 20-23	3	Aug. 27 to Sept. 2.	6	Aug. 28 to Sept. 4.	7	Sept. 1-7	6	Sept. 23 to Oct. 6.	13
Aug. 23-27	4	Aug. 31 to Sept. 7.	7	Sept. 8-16	8	Sept. 4-11	7	Sept. 24 to Oct. 17.	23
Aug. 28-31	3	Sept. 3-8	5	do	8	Sept. 16-22	6	Sept. 25 to Oct. 18.	23
Do	3	do	5	do	8	Sept. 16-23	7	Oct. 6-29	23
Aug. 30 to Sept 3.	4	Sept. 4-8	4	Sept. 19-27	8	Sept. 16-25	9	Oct. 6-28	22
Aug. 31 to Sept. 3.	3	Sept. 10-19	9	Sept. 20-28	8	Sept. 27 to Oct. 6.	9	Oct. 8-29	21
Aug. 31 to Sept. 4.	4	Sept. 13-20	7	do	8	Sept. 28 to Oct. 8.	10	Oct. 9-28	19
Sept. 7-10	3	Sept. 14-20	6	Sept. 25 to Oct. 5.	10	Sept. 28 to Oct. 9.	11		
Sept. 9-13	4	Sept. 17-25	8			Oct. 5-18	13		
Sept. 10-14	4	Oct. 17-29	12						
Sept. 12-17	5	Oct. 18 to Nov. 10.	23						
Oct. 6-15	9								
Oct. 11-17	6								
Oct. 14-18	4								

[1] For temperatures to which nymphs were exposed see figure 13.

NUMBER OF GENERATIONS ANNUALLY.

As has been stated, eggs have been taken in the field at Baton Rouge as early as April 13, and as late as November 8, while nymphs in the fifth instar were observed December 23. Life-history studies were conducted in an insectary where both the maximum and minimum temperatures are slightly higher than those given by the Weather Bureau of the United States Department of Agriculture for Baton Rouge (fig. 13). Under these conditions it would appear that, while the egg and nymphal stages may be passed in about a month, during the summer months, adults usually do not begin egg-laying until nearly four weeks after molting the last nymphal skin. Field and insectary observations indicate that four generations develop annually in the field at Baton Rouge.

NATURAL ENEMIES.

In spite of the disagreeable odor of the species of the genus, the Bureau of Biological Survey has recorded finding specimens of Nezara in the stomachs of certain birds, but it appears to have been always *hilaris* that was found. *N. viridula* is probably also eaten.

Morrill (7) and Whitmarsh (13) mention the fact that the eggs of *hilaris* are parasitized by a species of Trissolcus, and it would thus appear that the eggs of *viridula* would also be attacked by this parasite, although many egg clusters of *viridula* collected in the field failed to show any evidence of parasitism.

A PARASITE.

Trichopoda pennipes Fab.—Morrill (7) mentions the presence of the egg of a tachinid fly on a nymph in the fifth instar collected at Quincy, Fla., among a lot of 39 specimens in stages susceptible to parasitism by tachinids. The writer has found tachinid eggs common on adults taken at Baton Rouge, and in all cases where the flies have been reared they have proved to be adults of *Trichopoda pennipes* (fig. 14), which is known to attack a number of the larger Hemiptera. Upon completing their growth the larvæ left the bodies of their hosts and transformed to puparia in the soil. The puparium is cylindrical in shape with rounded ends. It measures about 7 mm. in length and 3.5 mm. in width and when fully colored is dull reddish black.

FIG. 14.—*Trichopoda pennipes*, a tachnid fly parasitic on the Southern green plant-bug: Adult. Enlarged about 3 diameters. (Chittenden.)

Of 73 adults collected on mustard December 6, 1915, 13 males and 5 females, or nearly 25 per cent, bore tachinid eggs. Most of the adults had only one egg upon them, but one had two, two three, and one four. Of the 26 eggs on all adults, 4 were on the dorsal surface and 20 on the ventral surface, while 2 were on the eyes. Four eggs were found on the head, 10 on the prothorax, 3 on the mesothorax, 2 on the metathorax, 5 on the abdomen, and 2 on the wing covers. An egg has also been observed on the femora of one of the fore legs.

The surface of the egg that is quite firmly attached to the host is usually flat. The opposite surface is strongly convex and is ellipsoidal in outline. The entire surface of the egg is glistening and is marked by minute hexagonal reticulations. The egg measures about 0.54 mm. in length and 0.35 mm. in width. Its color varies from white to gray, apparently being white when first deposited.

PREDACIOUS ENEMIES.

Podisus maculiventris Say.—A single instance of this common pentatomid bug preying upon *Nezara viridula* was noted in the field at Baton Rouge during December, 1914. This individual had a nymph in the fifth instar impaled on its beak.

Euthyrhynchus floridanus L.—Among the notes in the Bureau of Entomology files made by the late H. M. Russell, mention is made of two predacious enemies observed by him in Florida during 1907.

Specimens of *Nezara viridula* accompanied the notes. At Dade City, on November 11, an adult of the pentatomid bug *Euthyrhynchus floridanus* was found with its rostrum thrust into a mature individual.

Bicytes quadrifasciata Say.—Mr. S. A. Rohwer of the Bureau of Entomology states that a bembecid wasp which Mr. Russell collected at St. Leo, Fla., October 22, 1907, belongs to this species. The specimen was taken while in flight with an adult of *Nezara viridula* grasped in its mandibles.

CLIMATE AS A CONTROL FACTOR.

Whitmarsh (13) considers climate an important factor in the natural control of the related *Nezara hilaris* in Ohio. Cold winters, or periods of cold weather following unusually warm weather during the winter months, killed many individuals of that insect. Observations made in connection with *Nezara viridula* in the Gulf States indicate that sudden drops in temperature during the winter months kill many individuals in the field. In Florida Mr. H. M. Russell found, on December 5, 1907, "a few dead adults after the freeze" of the preceding night. Writing from Brownsville, Tex., on May 25, 1909, Messrs. D. K. McMillan and H. O. Marsh stated that the "species has been conspicuously absent for several months, though very abundant during the fall and early winter * * *" and added "It may be that the two freezes of January 15 and early February may have had some influence."

The writer has found that in the insectary at Baton Rouge individuals, especially in the nymphal stages, are sometimes killed by low temperatures during the winter months.

METHODS OF ARTIFICIAL CONTROL.

It is well known that the pentatomid bugs and other large plant-bugs are quite resistant to contact insecticides, and the experiments indicate that it is difficult to control the southern green plant-bug by using insecticides of this type.

SPRAYING WITH NICOTINE SULPHATE.

Individuals in various nymphal instars, as well as adults, have been drenched with dilutions of nicotine sulphate which contained 40 per cent of nicotine by weight in combination with yellow laundry soap at the rate of 2 pounds to 50 gallons of water. These individuals were then kept under observation in the insectary and the effects of the different mixtures upon them noted. A dilution of 1 part nicotine sulphate to 300 parts of water killed all nymphs, but even in the proportion of 1 to 100 the nicotine had little effect on the adults. A dilution of 1 to 600 was not effective against nymphs in the third, fourth, and fifth instars. On the day following the treatment over 50 per cent were active, and even in the case of nymphs in the third instar at least 50 per cent survived.

SPRAYING WITH KEROSENE EMULSION.

Experiments with strong mixtures of kerosene-soap emulsion also gave unsatisfactory results. One part of stock solution, made up of kerosene and yellow laundry soap, to two parts of water did not kill all nymphs that were drenched with it. Undiluted kerosene, as would be expected, quickly killed individuals in both the nymphal and adult stages.

In the experiments it was noted that nymphs which, immediately after being drenched with a contact insecticide, apparently showed signs of approaching death, recovered later.

HAND PICKING.

Hand picking can be done profitably where valuable vegetable crops are being attacked. The bugs may be collected in a receptacle containing a little water coated with a film of kerosene, or some other collecting device may be used. Where the bugs occur on other than low-growing plants the receptacle may be a pan or wide-mouthed dish and the bugs may be brushed or knocked from the plants into it. Collecting can be done best in the early morning, or during cool weather, when the bugs are sluggish. In addition to collecting and destroying the adults and nymphs, the destruction of egg clusters is recommended.

In order to secure a maximum reduction in the amount of damage done to the plants, hand picking not only should be carefully done, but should be put into practice when the attack begins.

USE OF TRAP CROPS.

The adults are attracted to mustard and turnips during the fall, as indicated by the collections referred to below. These were made from a few plants in a garden at Baton Rouge where serious injury by the species is seldom noted. About 15 minutes a day were spent in the work, all collections being made from the same plants. It would appear that after the first collection the succeeding adults were individuals that came to the plants from the time of one collection to the next, it being unlikely that many adults escaped at the time each collection was made.

On October 24, 47 adults were collected; on October 25, 81; on October 28, 79; and on October 31, 42. In addition to the foregoing 249 adults, 148 nymphs were collected.

The fact that nymphs and adults are often very abundant in the late fall on turnip and mustard suggests that a few of these plants, or others on which the southern green plant-bug is found to congregate, might be grown as trap crops in sections where serious injury occurs. The bugs might be hand picked or killed by spraying with a strong contact insectide or by using a gasoline torch. Even if it were found necessary, in order to kill the nymphs and adults economically, to use measures that would injure the plants, the operation might prove profitable in areas where serious damage occurs. Where the plants have not been grown especially as trap crops the destruction of the nymphs and adults when they congregate in large numbers would assist materially in reducing their destructiveness.

SUMMARY OF CONTROL MEASURES.

It would seem that spraying with a contact insecticide is not practical, unless employed in connection with trap crops where injury to the plants by the insecticide is not of importance. While it is possible to use mixtures strong enough to kill even the adults, the injurious effects of the insecticide upon the plants, as well as their present cost, would have to be considered.

The writer is inclined to agree with Watson (14) that hand picking is the most satisfactory control measure where valuable vegetable crops are seriously attacked, but for less valuable crops it is questionable whether this could be profitably done.

The fact that the adults congregate on turnip and mustard late in the fall in Louisiana suggests that a few of these, or other plants upon which they congregate, might be grown to serve as a trap crop.

GENERAL SUMMARY.

A pentatomid bug, *Nezara viridula* L., here given the common name of the southern green plant-bug, causes severe injury to cultivated crops in the southern portion of the Cotton Belt of the United States. Among the vegetable and truck crops injured are tomato, beans, Irish potato, sweet potato, okra, mustard, and turnip.

The species is widely distributed over the world and attacks a great variety of plants.

The adults and nymphs cause injury by inserting their beaks into the plant tissue and extracting the juices. Young growing shoots and developing fruit are most seriously injured.

Life-history studies have been carried on at Baton Rouge, La., in an insectary where the average maximum and minimum temperatures are slightly higher than those given by the United States Weather Bureau for the same locality. One female began egg-laying 19 days after becoming adult, although the average length of this period for the several females under observation was about four weeks. The number of eggs deposited by different females varied greatly. Some laid no eggs, while one deposited 240 and had 77 well-developed eggs in the ovaries at death. The eggs are placed in clusters, and in the field they have been found always on the underside of leaves. These clusters were made up of from 36 to 116 eggs.

In the insectary the minimum period necessary for the incubation of the eggs was 5 days. For the five nymphal stages the minimum periods were 3, 4, 5, 6, and 7 days, respectively, a total of 30 days for the egg and nymphal stages. The temperatures to which the eggs and nymphs were exposed apparently had a bearing on the length of the period of any stage. Development was more rapid during the summer than during the fall.

Eggs have been found in the field at Baton Rouge as early as April 13 and as late as November 8. It is probable that in this latitude four generations may develop in a year. Adults are found hibernating during the winter months, but they also occur on plants in the field during mild periods of weather during this season.

Four enemies have been observed, the tachinid fly *Trichopoda pennipes* Fab. apparently being the most important.

As a method of control the collection and destruction of eggs, nymphs, and adults is recommended where valuable vegetable crops are attacked. Adults congregate on turnip and mustard during the fall and a few of these plants, or others on which they congregate, might be grown as trap crops in sections where serious injury by the species occurs. The adults may be collected from these plants and destroyed.

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(12) Froggatt, W. W.

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First appeared on tomato plants in the neighborhood of Sydney some five years previously. Increased in numbers during last two years and has become a pest of the fruits and foliage of tomato, the foliage and young pods of French beans, and potato plants. Short account of distribution, injury, and stages. Suggests hand picking and use of "oil spray or tobacco and soap wash" against nymphs, as methods of control. Original figures of egg, first, second, and fifth instar nymphs, and adult.

(13) Whitmarsh, R. D.

1917. The green soldier bug, Nezara hilaris Say. Ohio Agr. Exp. Sta. Bul. 310, p. 517-552, 15 figs. [+1].

An extended, well-illustrated account concerning the related *Nezara hilaris* Say, based principally on observations in Ohio. Information regarding food plants, life history, habits, parasite, and climate as a control measure. Description of stages and an account of character and extent of injury to peaches, as a pest of which it is considered. In introduction (p. 519) statement that this "or more probably a closely related species, *Nezara viridula*," has been reported as an enemy of peaches in Florida.

(14) Watson, J. R.

1917. Florida truck and garden insects. Univ. of Fla. Agr. Exp. Sta. Bul. 134, p. 34-127, fig. 10-66.

Pages 83-84: General account under name of "pumpkin bug." Attacks nearly all garden plants, especially legumes and particularly cowpea. Several generations a year, adults hibernating in fall and coming out early in spring. Control difficult. Young may be killed by kerosene emulsion or strong soap solutions but adults only at strengths that would injure plants. Hand collecting, in morning or on cold, rainy day, practical in garden or in particularly valuable patch of cowpeas. In ordinary field of cowpeas planting plenty of seed and keeping plants growing vigorously recommended. Mentioned elsewhere in bulletin as injurious to beans, okra, peas, pepper, Irish potato, sunflower, and tomato.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 703

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

WASHINGTON, D. C. November 20, 1918

MISCELLANEOUS TRUCK-CROP INSECTS IN LOUISIANA.

I.—INSECTS INJURIOUS TO THE GLOBE ARTICHOKE IN LOUISIANA.

By Thos. H. Jones,

Entomological Assistant, Truck-Crop Insect Investigations.

INTRODUCTION.

Insect injury to the globe or burr artichoke (*Cynara scolymus*) apparently has received little attention from American economic entomologists. While the artichoke has not as yet attained the rank of an important food plant in the United States, the demand for the edible heads is increasing in the markets. The crop is grown in Louisiana, and since the fall of 1914, when the writer was assigned for work on truck-crop insects, in cooperation with the Louisiana Experiment Stations, many growers have complained of insect injury to the plants.

The most serious damage to the globe artichoke in Louisiana is caused by two species of plant-lice, or aphids, *Myzus braggii* Gillette and *Aphis rumicis* Linnaeus, both usually occurring in the same field and being most numerous during the late winter and in the spring.

INJURY CAUSED BY THE ARTICHOKE APHIS, MYZUS BRAGGII.

The artichoke aphis is the most common and, generally speaking, the most injurious insect enemy of the globe artichoke in Louisiana. It occurs in great abundance on the under sides of the leaves and its green color harmonizes with that of the leaf. In cases of severe infestation its presence brings about a condition such as that described in the following letter sent in by a correspondent in Rapides Parish: "Please let me know what to do for burr artichoke plants attacked by a dark smut which attracts large flies and bees. I had

58681°—18—Bull. 703——1

the same disease attack my plants last year about the same time. Most of the plants recovered, but seem to have lost vitality and did not bear fruit as early or as plentifully as in former years." The presence of the "dark smut," the flies, and the bees referred to is accounted for by the "honeydew" from the aphids, and in fields where the Argentine ant (*Iridomyrmex humilis* Mayr) is present, this obnoxious pest attends the aphids. Besides this complaint from Rapides Parish, there are also at hand records of *Myzus braggii* injuring globe artichoke in East Baton Rouge, Ascension, Iberville, Terrebonne, and Plaquemines Parishes.[1]

Myzus braggii also infests the yellow thistle (*Cirsium horridulum*) which is a common weed in Louisiana. (See Pl. I, fig. 1.) This plant is closely related, botanically, to the globe artichoke, so that the presence of the same species of insects on the two plants is to be expected. Prof. C. P. Gillette, who described *Myzus braggii*[2] from Colorado in 1908, and who has determined material sent to him from Louisiana, states that at Fort Collins, Colo., it is found on Canada thistle (*Cirsium arvense*) during the latter part of the summer and early fall, and that "the winter hosts are the Russian olive, *Hippohaes rhamnoides*, and *Shepherdia arvensis*."[3]

ENEMIES OF THE ARTICHOKE APHIS.

While no internal parasite has been found attacking this aphis, a number of predacious insect enemies have been observed. These include the larvæ of the syrphid flies *Allograpta obliqua* Say and *Syrphus americanus* Weidemann, the larvæ and adults of the coccinellid or ladybird beetles *Scymnus puncticollis* LeConte, *Scymnus terminatus* Say, *Hippodamia convergens* Guérin, and *Cycloneda sanguinea* Linnaeus, as well as the larvæ of a chrysopid and a hemerobiid, both undetermined. The coccinellid beetle *Megilla maculata* DeGeer and the predacious bug *Triphleps insidiosus* Say have been taken on globe artichoke infested with *Myzus braggii* and probably feed upon this aphis. The aphid is attacked by a fungus, which Dr. A. T. Speare, Bureau of Entomology, has determined as *Entomophthora fresenii* Nowakowski. At Baton Rouge *Scymnus puncticollis* appears to be its most efficient enemy.

INJURY CAUSED BY THE BEAN APHIS, APHIS RUMICIS.

While not as common on globe artichoke in Louisiana as *Myzus braggii*, this aphis is more difficult to control by spraying than is the latter species, largely because of the fact that infested leaves

[1] Dr. F. H. Chittenden states that he has collected the species on globe artichoke at Washington, D. C.

[2] GILLETTE, C. P. NEW SPECIES OF COLORADO APHIDIDAE, WITH NOTES UPON THEIR LIFE HABITS. *In* Can. Ent., v. 40, no. 1, p. 17–20, pl. 1. 1908.

[3] GILLETTE, C. P. CONFUSION OF RHOPALOSIPHUM HIPPOHAES KOCH, AND MYZUS BRAGGII GILLETTE. *In* Jour. Econ. Ent., v. 8, no. 3, p. 375–379, pl. 17, 18. 1915.

become distorted in such a manner that the aphids can be reached only with difficulty with a contact insecticide. (See Pl. II, figs. 1 and 2.)

CONTROL OF THE APHIDS ATTACKING ARTICHOKE.

During 1917 *Myzus braggii* and *Aphis rumicis* were controlled satisfactorily at Baton Rouge by spraying with 1 part, by weight, of nicotine solution (containing 40 per cent of nicotine as sulphate) to 1,000 parts of water, with laundry soap (standard, noncaustic type) added at the rate of 1 pound to 25 gallons of water. (See Pl. I, fig. 2, and Pl. III.) Because the plants in some rows in the field where the experiments were conducted were never sprayed, these plants served as a constant source of infestation for the sprayed plants, especially those near the untreated plants. The Argentine ant apparently was responsible in part for the spread of the aphids. More frequent sprayings were necessary, therefore, than would have been the case had all the plants in the field been sprayed. The plants were sprayed seven times, January 31, March 2, March 14, March 29, April 19, April 26, and May 26, respectively. The material was applied with a compressed-air sprayer holding about 3 gallons. The first picking of edible heads from the sprayed and unsprayed rows was made on May 11 and at frequent intervals thereafter until June 29. From 65 plants in the sprayed rows 310 heads or burrs were obtained and from 39 plants in the unsprayed rows 39 heads, an average of nearly 5 heads from each sprayed plant and an average of 1 from each unsprayed plant. The difference in growth made by the sprayed and unsprayed plants was very noticeable and if the weather had not been dry there is little doubt that the increase in the crop from the sprayed plants would have been still greater than that from the unsprayed plants.

It is especially advisable to begin spraying globe artichokes when the aphids first appear on the plants, which is usually when they are small. One reason for this is that after *Aphis rumicis* has become abundant the leaves are so badly distorted as a result of feeding that it is very difficult to reach them with the spray. Another reason for timely spraying is that if delayed until the aphids have reached their maximum abundance, much of the injury for which they are responsible already has been done, and as the period of maximum abundance under such conditions often comes when the plants have developed a heavy growth of leaves, a larger amount of spray material and more time for its application are required than when the spraying is done early. Some growers who spray for the control of the aphids, but who do not begin until the plants are large and heavily infested, find it advisable first to cut off and destroy the older and badly distorted leaves.

It is interesting to note that a company which grows each year from 10 to 15 acres of globe artichokes in Plaquemines Parish, Louisiana, has found that the aphids can be killed successfully by a nicotine-sulphate spray. Mr. E. P. Barrios, county agent of the parish, at whose suggestion the spraying was begun, has furnished the writer with the following information regarding the methods followed. The spray mixture, which is applied with knapsack sprayers equipped with angled nozzles, is made up as follows:

Tobacco extract containing 40 per cent nicotine as sulphate__ounces__	8
Fish-oil soap__pounds__	3
Water __gallons__	50

This mixture contains 1 part of nicotine sulphate to 800 parts of water. As an additional aid in controlling the aphids, the method of planting followed makes it possible to utilize the same ground for artichokes during successive years. The young shoots are transplanted each fall in rows between the rows of old plants. Since the old rows are placed 8 feet apart there is ample space between rows to make this practical. When the young sets have taken root the old plants are plowed under and, as they are well covered with dirt, the aphids present on them are killed. The aphids on the young plants now may be more readily controlled by spraying, because of the smaller amount of foliage they present.

It is possible that aphids on globe artichokes could be economically killed by fumigation, especially when only a few are grown, and for this purpose nicotine paper might be utilized, a cover to confine the fumes being placed over each plant as it is fumigated.

OTHER INSECTS ATTACKING THE GLOBE ARTICHOKE IN LOUISIANA.

The banded leaf-footed plant-bug, *Leptoglossus phyllopus* Linnaeus, feeds on the globe artichoke. Its normal food plant, as has been noted by Chittenden,[1] is the yellow thistle, *Carduus spinosissimus* (=*Cirsium horridulum*). The adults and nymphs are often numerous upon both plants, the adults being especially common on the thistle during late winter and early spring.

Larvæ of the corn earworm (*Chloridea obsoleta* Fabricius) have been found boring into the edible heads, and a plant-bug, *Thyreocoris pulicarius* Germar, has been observed clustered upon them. Nymphs of *Nezara viridula* Linneaus have been found on the heads, and a scarabaeid beetle, *Euphoria sepulchralis* Fabricius, has been captured under conditions indicating that it was injuring them.

[1] CHITTENDEN, F. H. SOME INSECTS INJURIOUS TO GARDEN AND ORCHARD CROPS. U. S. Dept. Agr. Bur. Ent. Bul. 19, n. s., 1899. See p. 47.

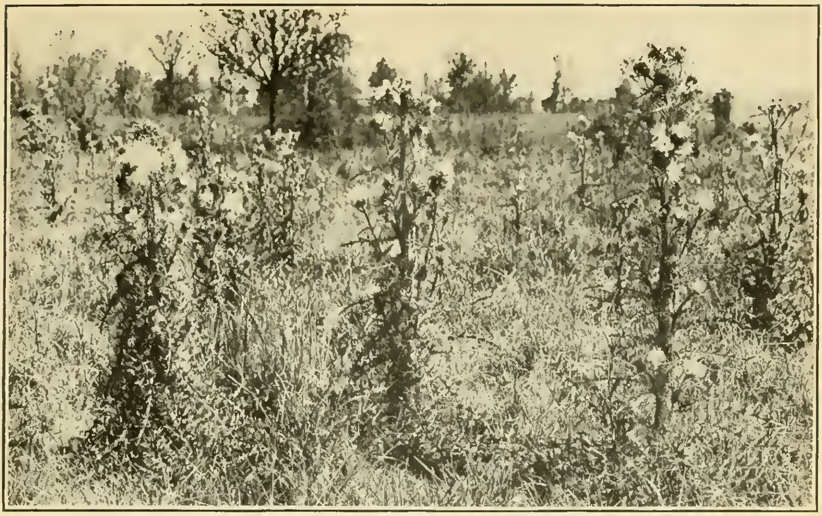

FIG. 1.—YELLOW THISTLE (CIRSIUM HORRIDULUM), A COMMON WEED IN UNCULTIVATED FIELDS IN LOUISIANA.

It is closely related to the globe artichoke, and some of the aphids which attack the latter feed on the thistle.

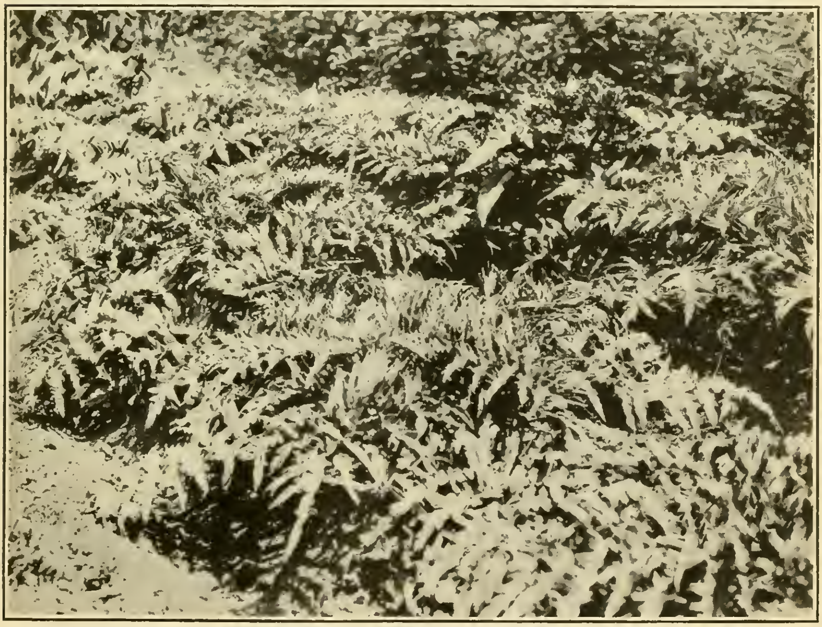

FIG. 2.—GLOBE ARTICHOKES ON WHICH APHIDS, MYZUS BRAGGII, HAVE BEEN CONTROLLED BY SPRAYING.

WILD AND CULTIVATED FOOD PLANTS OF MYZUS BRAGGII.

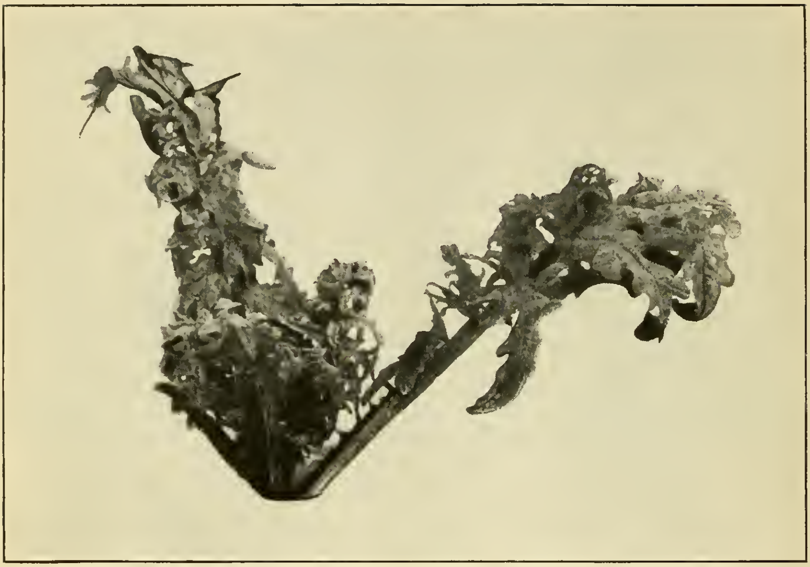

FIG. 1.—YOUNG PLANT INJURED BY THE BEAN APHIS (APHIS RUMICIS).

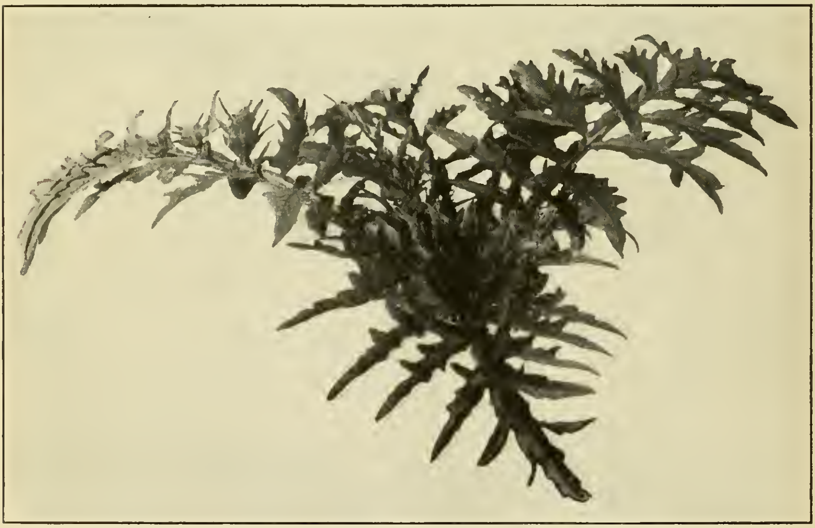

FIG. 2.—HEALTHY YOUNG PLANT, SHOWING BENEFITS OF SPRAYING.

THE GLOBE ARTICHOKE AND APHIDS.

SPRAYED AND UNSPRAYED ROWS OF GLOBE ARTICHOKE.

The aphids *Myzus braggii* and *Aphis rumicis* have been controlled in the row at left by spraying with nicotine sulphate. The plants in the row at right have not been sprayed.

Cutworms, the predominating species apparently being *Feltia annexa* Treitschke and *Agrotis ypsilon* Rottemburg, cause some injury, especially during the cooler months of the year when only the smaller developing leaves are present on the plants.

Larvæ of two agromyzid flies, *Agromyza platyptera* Thomson var. *jucunda* Van der Wulp, and *Agromyza* sp.,[1] have been found mining in the leaves and the membracid *Entylia sinuata* Fabricius breeds on them. The leaves are also fed upon to some extent by various other insects, among them the larva of the cabbage looper (*Autographa brassicae* Riley) and the adult of the southern corn rootworm (*Diabrotica duodecimpunctata* Olivier).

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[1] Determined by F. R. Cole. In 1914 Mr. I. J. Condit found larvæ of *Phytomyza* (*Napomyza*) *lateralis* Fallén working as leaf miners on globe artichokes at Berkeley, Cal. The reared adults were determined by Mr. Frederick Knab, Bureau of Entomology.

II.—THE GRANULATED CUTWORM,[1] AN IMPORTANT ENEMY OF VEGETABLE CROPS IN LOUISIANA.

By Thos. H. Jones,

Entomological Assistant, Truck-Crop Insect Investigations.

INTRODUCTION.

Cutworms periodically cause serious damage to vegetable crops in Louisiana and adjacent territory and it is seldom that they do not occur, at least in small numbers, in land planted to such crops. Complaints of injury are often made by people who have small gardens as well as by those who make the growing of truck crops their livelihood.

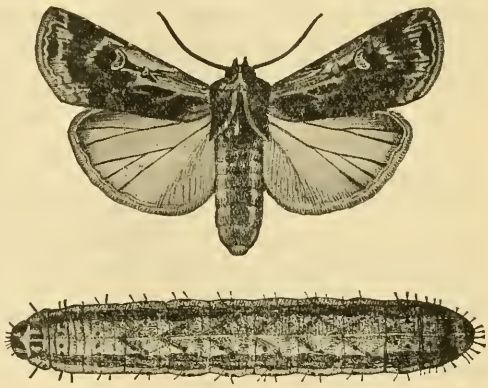

Fig. 1.—The granulated cutworm: Moth above, larva below. Somewhat enlarged. (Chittenden.)

Observations made in the State from 1914 to 1917, inclusive, indicate that the granulated cutworm (*Feltia annexa* Treitschke) (fig. 1) is the principal species attacking vegetables.[2]

Of 1,431 cutworms, representing collections made from about injured plants at Baton Rouge during the months of April, June, July, August, October, November, and December, of 1915, 1916, and 1917, 1,345, practically 94 per cent, were identified as *Feltia annexa*. The proportion of this species, in one collection, was as low as 76 per cent, but at other times it exceeded 90 per cent. The remainder of the collections noted was composed of 47 larvæ of *Agrotis ypsilon* Rottemburg (3.2 per cent), 35 larvæ of *Feltia malefida* Guenée (2.5 per cent), and 4 larvæ of undetermined species.

[1] *Feltia annexa* Treitschke.

[2] Messrs. C. E Smith, J. L. E. Lauderdale, and M. R. Smith, who were stationed at Baton Rouge, La., for the Bureau of Entomology during this period, rendered valuable assistance in the investigations upon which this paper is based.

NATURE OF DAMAGE.

As is true with other cutworms, the most serious damage done by the granulated cutworm is due to its habit of cutting off small plants near the surface of the ground. Two other types of injury have been noted. Where the plant is too large to be severed near the surface the larva ascends the plant and feeds on the foliage. (See Pl. IV, A, B.) Since feeding is done at night the cause of the damage often is not known to the grower. Irish potatoes, beets, and Brussels sprouts have been observed that were defoliated in this way, examination revealing numerous larvæ secreted in the soil beneath.

The other type of injury is to the fruit of certain plants, principally when it rests on the ground. The fruit of tomato and eggplant, if so located, is sometimes bored into and made unsalable. (Pl. IV, C.)

DESCRIPTION OF STAGES.

THE MOTH.

The moth (fig. 1) is one of the somber-colored species of the family Noctuidae. The fore-wings are covered above with brown, gray, and black scales, among which a few white ones are often present. These scales are so arranged that portions of the wings are brown or gray, or a mixture of the two colors, with black markings. The fore-wings of certain individuals may in general be darker or lighter than those of others of the same sex, but those of the female usually are darker than those of the male. The hind wings are white, more or less dusky along the margins and veins. The antennæ of the male are pectinate, those of the female not pectinate. Ten mounted males averaged 37 mm. in width from tip to tip of the fore-wings, the width ranging from 31 to 40 mm. Ten females averaged 40.4 mm., the widths ranging from 37 to 43 mm. The following is the description by Hampson:[1]

♂ [Male]. Head and thorax red-brown slightly mixed with fuscous; tegulae with slight black medial line; legs black and brown; abdomen pale red-brown, the ventral surface whitish. Fore wing pale red-brown, with some fuscous suffusion below base of cell and on costal area before apex; an indistinct double, waved, black subbasal line from costa to vein 1; the antemedial line double, very strongly dentate outwards below costa, in cell and above inner margin, and angled outwards in submedian fold; the claviform defined by black, narrow and elongate; the orbicular and reniform small, defined by black, the former oblique elliptical, open above, and with a black streak in the cell between it and the reniform; the postmedial line indistinct, strongly dentate, bent outwards below costa, and oblique below vein 4; the subterminal line represented by a series of pale and fuscous dentate marks; the veins of terminal area streaked with black, and with a terminal series of black points. Hind wing semihyaline white, the costa and cilia at apex slightly tinged with brown.

♀ [Female]. Fore wing suffused with fuscous, leaving the costal area to end of cell and the terminal area brown.

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[1] Hampson, George F. Catalogue of the Noctuidae in the Collection of the British Museum. *In* Catalogue of the Lepidoptera Phalaenae in the British Museum, v. 4, p. 354–355. London, 1903.

THE EGG.

The egg approaches a hemisphere in shape, the smooth lower surface being at most only slightly convex. About 38 small ridges or ribs originate at the base and converge toward the apex, to which not all of them persist. Crossing between these ribs are numerous smaller ones. A minute "button" is present at the apex. The egg when first laid is yellowish white, becoming darker before hatching. The diameters of 15 eggs gave an average of 0.64 mm., ranging from 0.60 to 0.69 mm.

THE LARVA.

The following description of the larva, by Dr. H. G. Dyar, is taken from Hampson:[1]

Head 3.5 millim., pale brown, pale reticulate, vertical band dark brown, strongly angled at top of clypeus, which is brown filled. Cervical shield well cornified, shining brown, cut by a pale dorsal line and traces of a subdorsal one. Dorsal space broadly pale, faintly brown, clouded on the centres of the segments, heaviest next the obscure, pale, dorsal line. Skin rather thin, smooth. Lateral space brown with faint pale subdorsal and lateral lines. Substigmatal band broad, distinctly but not brightly or very uniformly white-pigmented, the subvertical area becoming translucent. Tubercles dark brown, rather large and distinctly cornified; anal plate brown.

THE PUPA.

Riley has already given a very good description of the pupa and the following is taken in part from his notes:[2]

General color brown ochre, the surface smooth and glistening, except for impressions. In specimens from which the adult is about to issue the color becomes of a darker brown, the eyes black. Head small, with front slightly prolonged. Posterior lateral angle of prothorax with a dark brown transverse swelling, which closes the first spiracle. Abdomen with dorsal surface of segments 4–7 anteriorly with a transverse, rounded, darker brown ridge, marked with quite a number of very coarse and deep impressions. On segments 5–7 these ridges encircle the segments, though on the ventral surface they are not dark brown and the impressions are not as prominent. Stigmata black. Tip of last segment dark brown, ending in two stout teeth, each terminating in a very fine spine, which is curved downward. Each side, just before the tip, is a small blackish tubercle, and, dorsally, a little in front of this is a short spine.

Ten pupæ averaged 18.6 mm. in length and 5.9 mm. in lateral width across the third abdominal segment, ranging in length from 17 to 20.5 mm., and in width from 5 to 6 mm.

FOOD PLANTS.

The larvæ are very general feeders and probably attack practically all vegetable crops. We have found them injuring bean, beet,

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[1] Op. cit., p. 355.

[2] RILEY, C. V. THE GRANULATED CUTWORM (LARVA OF AGROTIS ANNEXA TREITSCHKE). *In* Report of the Entomologist, Ann. Rpt. U. S. Commr. Agr. f. 1884, p. 291, 292, Pl. II, fig. 1. 1885.

Brussels sprouts, cabbage, cauliflower, eggplant, Irish potato, pepper, tomato, and turnip.

LIFE HISTORY AND HABITS.

HABITS OF THE MOTH.

In the insectary the moths remain inactive during the day. In the field their activities probably take place at night, the moths secreting themselves during the day in places that are at most only poorly lighted. Specimens either have been collected in the field or have issued in a well-ventilated insectary during all months of the year except April and June.

OVIPOSITION.

No eggs have been collected in the field. In the insectary they were deposited at night singly over objects to which the moths had access, with the flattened side of the egg adhering to the surface upon which it rested. Riley has stated that moths which he had under observation scattered their eggs irregularly and singly on grass, though he considered this habit exceptional and probably abnormal, as a result of confinement.

NUMBER OF EGGS DEPOSITED.

During 1917 females were confined in the insectary and records kept of the number of eggs deposited by each. They were fed sweetened water and, once egg-laying had begun, eggs usually were deposited every night during the period of oviposition. The number of eggs deposited by different moths, the number of well-developed eggs in the ovaries at death, and the number of eggs deposited daily by a single moth, varied greatly. The highest number deposited during a single night was 307. During December eggs were deposited on a night when the thermograph registered as low as 19° F. The confinement of males with females apparently had no bearing on the number of eggs deposited. Males kept alone and with females lived as long as did the females. Table I gives data concerning the female moths.

TABLE I.—*Egg-laying records of Feltia annexa, Baton Rouge, La., 1917.*

Female moth issued.	First eggs laid.	Last eggs laid.	Moth died.	Total number eggs laid.	Number of eggs in ovaries at death.	Total number of eggs.
1917	1917	1917	1917			
Sept. 10	Sept. 12	Sept. 20	Sept. 20	812	0	812
Nov. 19[1]	Nov. 22	Dec. 9	Dec. 11	878	385	1,263
Nov. 22	Nov. 29	Dec. 6	Dec. 14	47	392	439
Nov. 17	Nov. 20	Dec. 8	Dec. 15	1,106	268	1,374
Nov. 11	Nov. 18	Dec. 8	Dec. 17	361	420	781
Dec. 4			Dec. 18	0	311	311
Nov. 30	Dec. 2	Dec. 8	Dec. 19	5	433	438
Dec. 2	Dec. 4	Dec. 26	Dec. 27	883	0	883
Nov. 29[1]	Dec. 3	Dec. 26	Dec. 30	1,060	79	1,139
Nov. 7	Dec. 22	Dec. 29	Dec. 30	142	360	502

[1] Confined with male.

HABITS OF THE LARVA.

The larvæ feed at night, and during the day usually are found in the soil near the plants upon which they have fed the previous night. At Baton Rouge larvæ have been taken in the field during all months except March, May, and September, and it is believed that they may be found throughout the year. There are apparently five and possibly six generations a year in this locality, and these so overlap that, at certain times, all stages are present in the field simultaneously.

There has been considerable variation in the number of times larvæ have molted in confinement. Some were observed to have 5, some 6, and others 7 larval instars. Larvæ from the same lot of eggs varied in this respect, though usually there was a variation of only one instar. Generally the individuals that spent the longest time in the larva stage underwent the least number of molts.

LENGTH OF EGG, LARVA, AND PUPA STAGES.

The length of time spent in the egg, larva, and pupa stages is governed apparently by the temperatures to which these stages are exposed. Table II, collated from notes, gives data on eggs, larvæ, and pupæ under observation at different seasons of the year in the insectary at Baton Rouge. The minimum period for the egg, larva, and pupa stages combined was as low as 38 days during July and August, while a period of 54 days was spent in the egg stage alone during December, 1917, and January, 1918. At this time temperatures below 30° F. were several times recorded on a near-by thermograph and during this period 8° F. and 11° F. were registered. These low temperatures prevailed during a period of weather unusually cool for Baton Rouge and were apparently the cause of the failure of many of the eggs to hatch. Some larvæ that issued on January 6 also were killed, apparently by these temperatures, although others survived.

TABLE II.—*Lengths of egg, larva, and pupa stages of Feltia annexa, Baton Rouge, La., 1917.*

Eggs deposited.	Eggs hatched.	Number days in egg stage.	Larvæ issued.	Larvæ pupated.	Number larvæ under observation.
July 14, 1917	July 18, 1917	4	July 18, 1917	Aug. 10–14, 1917[1]	12
Aug. 25, 1916	Aug. 31, 1916	6	Aug. 31, 1916	Sept. 24–Oct. 6, 1916	19
Oct. 22, 1916	Nov. 3, 1916	12	Nov. 10, 1915	Jan. 13–29, 1916	11
Dec. 6, 1917	Jan. 29, 1918	54	Mar. 13, 1917	Apr. 25–30, 1917	19

Number days in larva stage.	Larvæ pupated.	Adults emerged.	Number pupæ under observation.	Number days in pupa stage.
23–27	Aug. 10–14, 1917[1]	Aug. 21–26, 1917	12	11–14
24–36	Sept. 24–Oct. 6, 1916	Oct. 12–26, 1916	19	18–20
64–80	Jan. 13–29, 1916	Mar. 6–20, 1916	11	45–53
43–48	Apr. 25–30, 1917	May 12–20, 1917	19	19–21

[1] Larvæ stopped feeding and entered soil Aug. 8–12 and it is assumed that they pupated two days later.

ENEMIES.

A tachina fly, *Linnaemyia comta* Fall., identified by W. R. Walton, and an ichneumon fly, *Enicospilus purgatus* Say, identified by A. B. Gahan, have been reared from larvæ collected at Baton Rouge. A sarcophagid fly, determined by J. M. Aldrich as *Sarcophaga helicis* Townsend, issued from a rearing jar containing larvæ of *Feltia annexa* and may have been parasitic on them. Dead larvæ, invested with fungus, have been found also in rearing cages. The fungus has been identified by Dr. A. T. Speare as *Entomophthora virescens* Thaxter.

METHODS OF CONTROL.

Experiments indicate that, of the four methods of control following, only the use of poisoned baits and the treatment of attacked plants with arsenicals will prove satisfactory. The latter method is especially applicable when large plants are being injured and in certain instances, especially where severe injury to foliage is being done, both methods might be used simultaneously to advantage.

HAND PICKING.

One control measure is suggested by the fact that larvæ are found during the day in soil about plants on which they have fed during the previous night. This method is sometimes followed in Louisiana. Vegetable fields, usually fields where transplanting has been recently done, are examined and when cutworm injury is noted, search for the larva is made in the soil about the base of the damaged plant. If the larva is discovered it is killed. This work can be done best in the early morning. Later in the day wilting of the severed part of the plant makes it more difficult to locate the injury, and the larva may move from the injured plant or bury itself deeper in the soil as the day advances.

This method of control, even if practiced for several days and carefully done, is expensive and by no means satisfactory. It is impossible to discover all the larvæ in a field by following such a method and the plan furthermore rests on the unsatisfactory basis that some injury must be done before the larva is killed. If larvæ are abundant, a large number of young plants are often cut off during the first night after they have been set out.

BARRIERS AROUND PLANTS.

Experiments made in cages and in the field indicate that in setti
out plants injury may be reduced, to a certain degree, by wra
the stems with newspaper or oiled paper, or placing c
wrapping paper or metal about them. Such practices do no

THE GRANULATED CUTWORM.

A.—Plant of Brussels sprouts injured by larvæ in the field. B.—Injury to beet foliage by larvæ in the field. C.—Tomato fruit injured by larvæ. D.—Cabbage plants showing value of tin cans in preventing injury by larvæ.

THE GRANULATED CUTWORM.

Showing value of spraying in controlling the larvæ. The same number of cabbage plants were in each box at the time equal numbers of larvæ were confined in each. The photographs were taken 23 days later. A.—Sprayed plants. B.—Unsprayed plants.

prevent injury and besides the expense of placing these barriers around the plants, their presence may retard the growth of the plants. In the experiments larvæ sometimes ascended the barriers, either when the stems were wrapped with the material or when the barrier was at some little distance from the stem. If food plants, unprotected by barriers, are present there is less damage to the protected plants than is the case when only protected plants can be reached. This is shown in Plate IV, A, B, D. The plants protected by the cans, containers such as canned goods are sold in, with the tops and bottoms removed, show no injury, while the unprotected plants have been seriously fed upon.

POISONED BAITS.

Satisfactory results have been obtained in destroying the larvæ in cages and in the field with poisoned bran mash. A mixture made up in the following proportions has given good results:

Bran	pounds	10
Molasses	quart	1
Paris green	pound	½
Water	quarts	7

Juice and finely chopped rind and pulp of 2 oranges.

In cages where young cabbage plants were growing larvæ were observed to feed upon this poisoned mash after it had been scattered thinly over the soil. No damage to the plants was noted and larvæ were dead on the following day. Of 202 larvæ collected from the soil 88 per cent were dead within three days after the mixture had been scattered over a field of Brussels sprouts that were being injured. A portion of the remainder apparently were not killed because they had completed their growth and stopped feeding before the poisoned mash was put out.

A mixture of 20 pounds of bran, 2 pounds of powdered arsenate of lead, ½ gallon of molasses, and about 14 quarts of water has also given good results in killing larvæ in the field.

When the larvæ are found to occur in abundance in a field at plowing time and this field is to be immediately planted, it would seem advisable to apply poisoned baits before the field is planted rather than to wait until the crop shows injury.

TREATING PLANTS WITH ARSENICALS.

When the larvæ are feeding upon the leaves of plants it is possible to reduce their numbers by applying arsenicals to the foliage. This method is especially applicable in the case of plants that have reached a considerable size, and under certain conditions the arsenical may at the same time prevent injury by other leaf-eating insects. Plate V shows two boxes of cabbage plants. The plants in one box were sprayed with powdered arsenate of lead at the rate of 2 pounds to 50 gallons of water, with 2 pounds of yellow laundry soap added. The plants in the other box were left untreated. Larvæ were then confined in both boxes. The appearance of the sprayed plants 23 days later is shown in Plate V, A, and that of the unsprayed plants in Plate V, B. The larvæ in the box containing the foliage to which poison was applied fed but little before being killed, while those in the other box continued to feed until their larval growth was completed.

III.—EXPERIMENTS IN CONTROLLING THE TOMATO FRUITWORM WITH ARSENICALS.

By Thos. H. Jones,

Entomological Assistant, Truck-Crop Insect Investigations.

Spraying and dusting experiments for the control of the tomato fruitworm (*Chloridea obsoleta* Fabricius) were conducted during 1916 and 1917 at the Louisiana Experiment Station, Baton Rouge, La. This work was carried on in cooperation with Dr. C. W. Edgerton, plant pathologist of the station, who was especially interested in the fungicidal value of some of the materials used.

In 1916 a spring and a fall crop of tomatoes were used in the experiments. In the case of the fall crop a heavy frost occurred before much fruit had matured. The next day all fruit was gathered and weighings and counts made. In 1917 only a spring crop was used in the experiments.

The sprays were applied by means of small compressed-air sprayers of about 2½ gallons capacity. The materials were carefully applied. On the spring crop of 1916 about 10 gallons of spray were used on an average in spraying eight times a row of 54 plants, set 2 feet apart in the row. On the fall crop of 1916 approximately 4⅔ gallons were used in spraying the same number of plants seven times. For spraying the same number of plants five times in the spring of 1917 about 7 gallons were used.

The dusting was done with a dust gun. In dusting the spring crop of 1916 approximately 17 ounces of undiluted powdered arsenate of lead were used in making eight applications to an average row of 54 plants, set 2 feet apart in the rows. In dusting the same number of plants of the spring crop of 1917 five times, approximately 12½ ounces were used. For the dusting a specially prepared, light, finely powdered arsenate of lead was used, as was also used in spraying the spring crop of 1916.

In Tables I–III "wormy" refers to fruit that was apparently injured by the larva of *Chloridea obsoleta*. Without doubt the injury to a small percentage of this fruit was due to other causes, principally the hornworms, *Phlegethontius* spp. and larvæ of the granulated cutworm *Feltia annexa* Treitschke.

TABLE I.—*Tomatoes set out in field Apr. 11, 1916. Applications of sprays and dusts made Apr. 25, May 5, May 15, May 24, June 2, June 12, June 22, July 3, and July 13. No. 3 not sprayed after May 24. No. 4 not sprayed after June 12. Nos. 5, 6, and 7 not sprayed, and No. 9 not dusted, after July 3. Harvesting began June 14, ended Aug. 3.*

EARLIANA VARIETY.

No.	Material used.	Number of applications.	Total weight tomatoes.	Weight wormy.	Per cent weight wormy.	Total number tomatoes.	Number wormy.	Per cent wormy
			Pounds.	*Pounds.*				
1	Check	....	266.7	73.1	27.4	1,413	436	30.8
2	Bordeaux mixture, 4-4-50	9	297.5	61.0	20.5	1,718	357	20.7
3	Commercial powdered arsenate of lead, 1½ pounds to 50 gallons 4-4-50 Bordeaux mixture	4	216.9	49.8	22.9	1,441	368	25.5
4	Same as No. 3	6	359.4	63.4	17.6	1,862	344	17.9
5	....do	8	262.5	29.2	11.1	1,415	177	12.5
6	Commercial Bordeaux and arsenate of lead mixture, 1 pound to 6 gallons water	8	229.1	24.8	10.8	1,392	157	11.2
7	Commercial powdered arsenate of lead, 1½ pounds to 50 gallons water	8	238.2	23.2	9.7	1,385	145	10.4
8	Dusted with 9 parts powdered sulphur and 1 part commercial powdered arsenate of lead, by weight.	9	303.1	30.2	9.9	1,786	170	9.5
9	Dusted with commercial powdered arsenate of lead, undiluted	8	348.4	21.1	6.0	1,468	105	7.1

GLOBE VARIETY.

No.	Material used.	Number of applications.	Total weight tomatoes.	Weight wormy.	Per cent weight wormy.	Total number tomatoes.	Number wormy.	Per cent wormy
1	Check	....	203.8	36.8	18.1	1,180	211	17.8
2	Bordeaux mixture, 4-4-50	9	236.8	23.8	10.0	1,252	126	10.0
3	Commercial powdered arsenate of lead, 1½ pounds to 50 gallons 4-4-50 Bordeaux mixture	4	190.6	13.0	6.8	1,120	86	7.7
5	Same as No. 3	8	221.4	11.6	5.2	1,073	51	4.7
6	Commercial Bordeaux and arsenate of lead mixture, 1 pound to 6 gallons water	8	317.5	19.2	6.0	1,468	92	6.2
7	Commercial powdered arsenate of lead, 1½ pounds to 50 gallons water	8	254.2	16.8	6.6	1,318	74	5.6
8	Dusted with 9 parts powdered sulphur and 1 part commercial powdered arsenate of lead, by weight.	9	275.2	16.8	6.1	1,331	75	5.6
9	Dusted with commercial powdered arsenate of lead, undiluted	8	249.6	10.9	4.3	1,474	46	3.1

TABLE II.—*Tomatoes set out in field Aug. 14 and 15, 1916. Applications of sprays made Sept. 2, Sept. 12, Sept. 22, Oct. 2, Oct. 12, Oct. 23, and Nov. 2. Harvesting began Oct. 24, ended Nov. 15.*

EARLIANA VARIETY.

No.	Material used.	Number of applications.	Total weight tomatoes.	Weight wormy.	Per cent weight wormy.	Total number tomatoes.	Number wormy.	Per cent wormy.
			Pounds.	*Pounds.*				
1	Check	....	41.2	9.3	22.5	588	113	19.2
2	Bordeaux mixture, 4-4-50	7	100.1	27.8	27.7	849	241	28.3
3	Commercial powdered arsenate of lead, 3 pounds to 50 gallons 4-4-50 Bordeaux mixture	7	109.5	16.9	15.4	1,012	144	14.2
4	Commercial powdered arsenite of zinc, 3 pounds to 50 gallons water.	7	113.9	19.3	16.9	1,122	188	16.7
5	Commercial Bordeaux and arsenate of lead mixture, 1 pound to 6 gallons water	7	108.7	15.5	14.2	1,147	139	12.1
6	Commercial powdered arsenate of lead, 3 pounds to 50 gallons water.	7	80.5	11.3	14.0	880	112	12.7

TABLE II.—*Tomatoes set out in field Aug. 14 and 15, 1916*—Continued.

HYBRID VARIETY.[1]

No.	Material used.	Number of applications.	Total weight tomatoes.	Weight wormy.	Per cent weight wormy	Total number tomatoes.	Number wormy.	Per cent wormy.
1	Check	....	69.2	9.3	13.4	694	93	13.4
2	Bordeaux mixture, 4-4-50	7	66.9	13.3	19.8	546	94	17.2
3	Commercial powdered arsenate of lead, 3 pounds to 50 gallons 4-4-50 Bordeaux mixture	7	82.3	11.1	13.4	724	73	10.0
4	Commercial powdered arsenite of zinc, 3 pounds to 50 gallons water.	7	107.3	12.7	11.8	852	88	10.3
5	Commercial Bordeaux and arsenate of lead mixture, 1 pound to 6 gallons water	7	95.9	11.3	11.7	856	78	9.1
6	Commercial powdered arsenate of lead, 3 pounds to 50 gallons water.	7	57.7	3.8	6.5	597	33	5.5

[1] Hybrid selected by Dr. Edgerton, the parents being the Earliana and a wilt-resistant hybrid.

TABLE III.—*Tomatoes set out in field Apr. 4 and 6, 1917. Applications of sprays and dust made May 3, May 12, May 22, June 1, and June 12. Harvesting began June 11, ended Aug. 11.*

EARLIANA VARIETY.

No.	Material used.	Number of applications.	Total weight tomatoes.	Weight wormy.	Per cent weight wormy	Total number tomatoes.	Number wormy.	Per cent wormy.
			Pounds.	*Pounds.*				
1	Check	....	247.1	47.9	19.3	1,747	398	22.7
2	Bordeaux mixture, 4-4-50	5	216.7	41.5	19.1	1,682	370	21.9
3	Commercial powdered arsenate of lead, 3 pounds to 50 gallons water	5	303.1	37.4	12.3	2,102	362	17.2
4	Commercial Bordeaux and arsenate of lead mixture, 1 pound to 6 gallons water	5	261.8	31.8	12.1	1,850	317	17.1
5	Commercial powdered arsenate of lead, 3 pounds to 50 gallons 4-4-50 Bordeaux mixture	5	297.0	38.8	13.0	1,929	313	16.2
6	Commercial powdered arsenite of zinc, 3 pounds to 50 gallons water.	5	265.5	27.8	10.4	1,856	270	14.5
7	Commercial powdered arsenate of calcium, 3 pounds to 50 gallons water	5	298.2	31.8	10.6	1,936	270	13.9

GLOBE VARIETY.

No.	Material used.	Number of applications.	Total weight tomatoes.	Weight wormy.	Per cent weight wormy	Total number tomatoes.	Number wormy.	Per cent wormy.
1	Check	....	211.7	24.2	11.4	1,473	207	14.0
2	Commercial powdered arsenate of calcium, 3 pounds to 50 gallons water	5	248.5	28.0	11.2	1,695	247	14.5
3	Bordeaux mixture, 4-4-50	5	194.8	22.5	11.5	1,240	175	14.1
4	Commercial powdered arsenite of zinc, 3 pounds to 50 gallons water.	5	227.5	22.1	9.7	1,597	200	12.5
5	Commercial powdered arsenate of lead, 3 pounds to 50 gallons 4-4-50 Bordeaux mixture	5	186.6	21.0	11.2	1,219	150	12.3
6	Commercial powdered arsenate of lead, 3 pounds to 50 gallons water.	5	247.4	20.7	8.3	1,701	180	10.5
7	Commercial Bordeaux and arsenate of lead mixture, 1 pound to 6 gallons water	5	205.1	19.5	9.5	1,570	159	10.1

THIRTEEN VARIETIES.

No.	Material used.	Number of applications.	Total weight tomatoes.	Weight wormy.	Per cent weight wormy	Total number tomatoes.	Number wormy.	Per cent wormy.
1	Check	....	228.0	43.2	18.9	1,438	335	23.2
2	Dusted with commercial powdered arsenate of lead, undiluted	5	159.3	11.9	7.4	1,199	124	10.3

The results of the two years' work show considerable variation. None of the treatments can be considered to have reduced the injury profitably. Arsenate of lead, applied undiluted as a dust, gave the best results. It was to be expected that the sprays and dusts used on the spring crop of 1916 would show better results than those used on the spring crop of 1917, as in 1916 their application was continued longer after harvesting began. On the fall crop of 1916, however, where harvesting was completed 13 days after the last spraying, the spraying apparently had little or no effect in some instances in reducing injury. In this connection it should be stated, however, that the plants used as checks produced but a small amount of fruit, partly because they were badly injured by Phlegethontius larvæ when small. Comparisons of results from sprayed and check plants may, therefore, not be indicative of the true value of the sprays.

It is to be noted that the Earliana variety of tomato showed a higher percentage of injured fruit than did either the Globe or the hybrid.

The diagrams (figs. 2–5) show the number of tomatoes produced each week by Earliana and Globe plants set out in the springs of 1916 and 1917, part of these being sprayed with arsenate of lead and the others serving as a check. The percentage of the number of fruit showing injury is also given. The diagrams show that the Earliana produced the greater portion of its crop sooner than did the Globe and that in 1916 both varieties produced their crops within a shorter period of time than in 1917, there being a pronounced "second crop" during 1917.

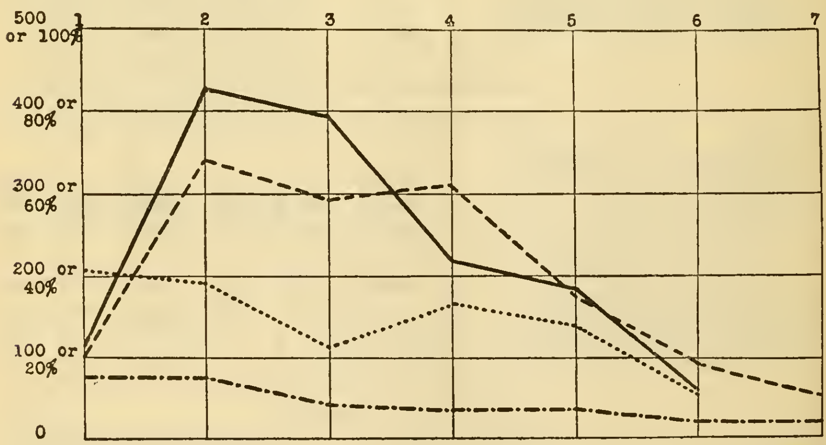

FIG. 2.—Diagram, prepared from weekly totals during harvesting season, showing number of tomatoes of the Earliana variety and percentage apparently injured by the tomato fruitworm in 1916. Spaces between horizontal lines represent 100 in case of total number of tomatoes, and 20 in case of percentage wormy. Vertical lines represent weeks. The solid line represents the total number of tomatoes from the unsprayed check; the dotted line, the percentage of check wormy; the line of dashes, the total number of tomatoes from plants sprayed with arsenate of lead; the line of dots and dashes, the percentage of sprayed tomatoes wormy.

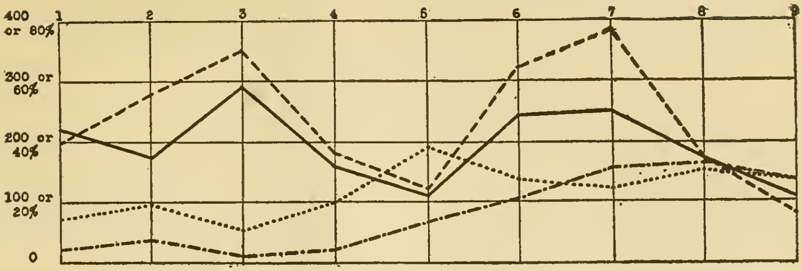

FIG. 3.—Diagram, prepared from weekly totals during harvesting season, showing number of tomatoes of the Earliana variety and percentage apparently injured by the tomato fruitworm in 1917. Spaces between horizontal lines represent 100 in case of total number of tomatoes, and 20 in case of percentage wormy. Vertical lines represent weeks. The solid line represents the total number of tomatoes from the unsprayed check; the dotted line, the percentage of check wormy; the line of dashes, the total number of tomatoes from plants sprayed with arsenate of lead; the line of dots and dashes, the percentage of sprayed tomatoes wormy.

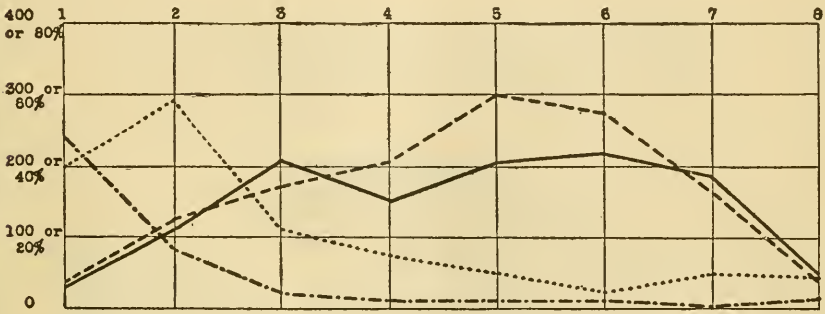

FIG. 4.—Diagram, prepared from weekly totals during harvesting season, showing number of tomatoes of the Globe variety and percentage apparently injured by the tomato fruitworm in 1916. Spaces between horizontal lines represent 100 in case of total number of tomatoes, and 20 in case of percentage wormy. Vertical lines represent weeks. The solid line represents the total number of tomatoes from the unsprayed check; the dotted line, the percentage of check wormy; the line of dashes, the total number of tomatoes from plants sprayed with arsenate of lead; the line of dots and dashes, the percentage of sprayed tomatoes wormy.

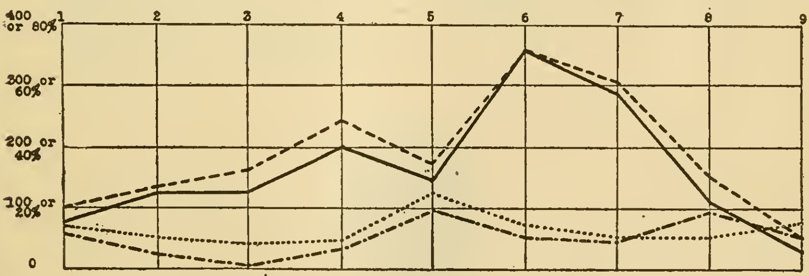

FIG. 5.—Diagram, prepared from weekly totals during harvesting season, showing number of tomatoes of the Globe variety and percentage apparently injured by the tomato fruitworm in 1917. Spaces between horizontal lines represent 100 in case of total number of tomatoes, and 20 in case of percentage wormy. Vertical lines represent weeks. The solid line represents the total number of tomatoes from the unsprayed check; the dotted line, the percentage of check wormy; the line of dashes, the total number of tomatoes from plants sprayed with arsenate of lead; the line of dots and dashes, the percentage of sprayed tomatoes wormy.

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BULLETIN No. 707

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER August 26, 1918

RESULTS OF EXPERIMENTS WITH MISCELLANEOUS SUBSTANCES AGAINST BEDBUGS, COCKROACHES, CLOTHES MOTHS, AND CARPET BEETLES

By

E. W. SCOTT, Entomologist, Enforcement Insecticide Act
and W. S. ABBOTT and J. E. DUDLEY, Jr., Scientific
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CONTENTS.

INTRODUCTION.

In connection with the enforcement of the insecticide act of 1910, numerous substances entering into the composition of proprietary insecticides have been tested against many different insects, resulting in the accumulation of a large amount of data relative to the efficacy of such substances. This work is conducted at the Insecticide Board's Testing Laboratory, located at Vienna, Va., and directed by Dr. A. L. Quaintance, of the Bureau of Entomology.

This paper, the first of several to be published on the results of such tests, presents data on the efficacy of various substances, used alone and in combination, against bedbugs, cockroaches, clothes moths, and carpet beetles.

BEDBUGS.

METHODS OF TESTING.

The tests of various materials, in many cases of previously undetermined insecticidal value, against the bedbug (*Cimex lectularius* L.), are of two general types, (1) jar tests and (2) room tests. In the former 20 bedbugs were confined in a pint jar with paper scraps or excelsior to furnish hiding-places, and thoroughly dusted or sprayed with the material to be tested, after which the jars were covered with cheesecloth. At least two of these jars were used in each test. Records were taken at the end of 24 hours, and as often thereafter as was considered necessary. With each series of tests two similar jars, each containing 20 bedbugs and paper scraps or excelsior, were used as a check. If the mortality in these checks ran above 35 per cent the whole series was discarded, except in those cases where the mortality in the treated jars was 10 per cent or less. No food was furnished in any of these tests, but it should be noted that in many cases the experiments were continued for two weeks with a mortality of less than 10 per cent in the checks.

This method of testing, although admittedly very severe on the bugs, and not simulating natural conditions, was used primarily to ascertain whether the given insecticide material would kill the insects and was not intended to determine its exact value under practical conditions.

Experiments on a practical scale were made by thoroughly dusting badly infested rooms or beds with the material to be tested. In these experiments the room or bed was examined only once, usually four or seven days after treatment.

KILLING EFFECTS OF LIQUIDS AGAINST BEDBUGS.

HYDROCARBON OILS.

Twenty-seven different hydrocarbon-oil preparations, composed largely of oils of the nature of kerosene and gasoline mixed with varying amounts of nitrobenzene, phenols, essential oils, etc., were tested. All of these were found to be very effective, most of them killing 100 per cent of the treated insects within 24 hours.

As remedies against bedbugs, the oil sprays possess one very great advantage over other insecticides—their power of penetration. With powders and most liquids it is very difficult, if not impossible, to reach the bugs, which are generally hidden during the day in cracks and holes in the beds, behind wall paper and moldings, or in the bedding itself, and in these places they are readily reached by the heavier oils. These sprays possess the added advantage of destroying the eggs whenever they come in contact with them, and here, also, their powers of penetration greatly increase their practical effectiveness.

The preparations composed largely of oils of the nature of gasoline were found, in jar tests, to be as effective as the kerosene sprays, but because of very rapid evaporation they are not as valuable under practical conditions as are those composed of a heavier oil, and it has been found that gasoline, at least under certain conditions, is not effective against bedbug eggs. (See p. 7.)

COAL-TAR CREOSOTE EMULSIONS.

Numerous tests with coal-tar creosote emulsions indicate roughly that the effectiveness of this class of materials depends on two factors: (1) The dilution, and (2) the amount of water present in the original emulsion. When used undiluted, these emulsions killed from 95 to 100 per cent in 24 hours, but when diluted 1 to 30 or more, in no case were all of the insects killed, although many of the tests were continued for seven days.

MERCURIC CHLORID.

Table I gives the results of tests with mercuric chlorid against bedbugs.

TABLE I.—*Results of tests with mercuric chlorid used as spray against bedbugs confined in jars.*

Test No.	Per cent mercuric chlorid.	Other ingredients.	Number used.	Duration of test.	Per cent dead.	Untreated, per cent dead.
				Days.		
1	0.23	Water	40	4	10	10
2	.50	do	80	8	39	15
3	1.00	do	120	4–8	20–53	7.5
4	1.09	Alcohol	120	5	70	30
5	1.35	Alum, salt, water	65	12	75–100	23
6	2.00	Water	80	8	58	15
7	4.00	do	80	8	77	0
8	5.72	Water, alcohol, phenol 1.44 per cent	40	6	45–95	13
9	6.00	Water	40	1	100	35

Table I shows that mercuric chlorid, even in a 2 per cent solution, is somewhat effective, and that a 6 per cent solution killed 100 per cent of the treated bugs within 24 hours.

As mercuric chlorid is a very violent poison, its use ordinarily would be attended with considerable danger, but in solution a small amount can be used effectively without serious danger of accidental poisoning. In solution it also can be more thoroughly applied and forced into cracks and holes, so that, on drying, it leaves a thin film of poison which will remain to kill any bugs not hit by the spray.

EXPERIMENTS WITH POWDERS AND OTHER MATERIALS.

PYRETHRUM.[1]

Tests with 28 different samples of pyrethrum have been made and all samples were found to be very effective against bedbugs in jar tests.

These tests also show that there is no practical difference in effectiveness between powder made from the buds, half-open flowers, half-closed flowers, and closed flowers, or between the cultivated and wild flowers. Tests made during 1912 with powders made from 1908, 1909, and 1910 crops of flowers showed no practical difference in their efficiency, which indicates that pyrethrum does not deteriorate materially in four years.

The actual effect of pyrethrum on bedbugs is to render the insects inactive almost at once, and, although slight movements of the legs and antennæ may continue for several days, the insects do not recover.

Under the conditions of jar tests five samples, consisting wholly or largely of pyrethrum stems, were found to be of comparatively little value. In the one-room test made with powdered stems they appeared to be absolutely ineffective. In this test a grossly infested bed was thoroughly dusted, and four days after treatment careful search failed to locate a single dead bug, either in the bed or on the floor. Many living bugs were found in cracks where the powder was still plainly visible, and some were seen crawling about with their backs still covered with it.

TOBACCO POWDERS.

A number of tests were made with tobacco powders against bedbugs dusted in jars, and it was found that powders containing as high as 3.41 per cent, 3.73 per cent, and 5.26 per cent nicotine did not kill all of the treated insects in 12 days.

HELLEBORE.

Not one of the seven different lots of hellebore tested was of value against bedbugs.

This would appear to indicate that hellebore is of no value as a contact insecticide, and this conclusion is greatly strengthened by the fact that it was found to be ineffective against 12 different species of other sucking insects.

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[1] A powder made by grinding to an impalpable powder the flower heads of a chrysanthemum, *Pyrethrum cinerariaefolium* and *P. roseum*. The manufactured product has been sold also as "buhach," Persian insect powder, and Dalmatian insect powder.

POWDERED MIXTURES CONTAINING MORE THAN ONE ACTIVE INGREDIENT.

A number of jar tests have been made with 20 miscellaneous powders containing small amounts of nicotine, naphthalene, pyrethrum, and various oils as active ingredients. These powders were more or less effective, depending on the amount of the active ingredients present.

MISCELLANEOUS MATERIALS.

The following materials were found to be more or less effective against bedbugs, killing from 80 to 100 per cent in jar tests:

Miscellaneous materials more or less effective against bedbugs.

Material.	Form of preparation.	Killed.
		Per cent.
Acetic acid	50 per cent solution	100
Ammonia water	Undiluted	80
Coal-tar oil, chlorinated	....do	100
Cottonseed oil	10 per cent mixture	93
Glycerol	Undiluted	100
Kerosene	10 per cent mixture	100
Linseed oil	....do	94
Nicotine (40 per cent, as sulphate)	1–32	80–90
Do	1–64	80–95
Pine needles, oil of	10 per cent mixture	100
Sabadilla seeds	Dust	100
Turpentine, crude wood	Undiluted	100
Mercuric chlorid	Dust	100

These data show little of interest, except the efficiency of sabadilla seeds (*Sabadilla officinalis* Brandt). These seeds or extracts are largely used in remedies for vermin on the human body, especially in the hair, but their use against bedbugs is rather unusual. In five tests they proved to be very effective, killing from 95 to 100 per cent in 48 hours.

Mercuric chlorid, used as a dust, killed all of the treated insects, but this material is too poisonous for general use in houses.

The following is a list of various materials which were found to be ineffective against bedbugs. The method of testing is indicated in parentheses.

Materials found ineffective against bedbugs.

- Allspice (jar).
- Alum (jar).
- Angelica root (jar and room).
- Arsenious acid (jar).
- Borax (jar).
- Boracic acid (jar).
- Chamomile flowers (jar).
- Colocynth pulp (jar).
- Eucalyptus leaves (jar and room).
- Formaldehyde (room, 8.87 per cent solution, sprayed twice, 1 part to 14 parts water).
- Lead acetate (jar).
- Paris green (jar).
- Pepper, red (jar).
- Quassia chips (jar and room).
- Sodium bicarbonate (jar).
- Sodium fluorid (jar and room).

The principal fact of interest in these data is that such violent stomach poisons as arsenious oxid and Paris green were found to be ineffective, as were also the milder sodium fluorid, lead acetate, borax, and boracic acid. These results show conclusively that bedbugs can be controlled only by an insecticide which acts directly on the body, and that none of the materials with which the insect comes in contact is taken into the stomach.

Although, in a few cases, these materials appeared to have some slight effect on the insects, the number killed was so small that they would be of no value under practical conditions.

PHOSPHORUS PASTES.

Two tests were made with pastes formed of sugar, water, and starchy material, and containing, in one case, 1.91 per cent and, in the other, 2.21 per cent of phosphorus. The first test was made in a room badly infested with bedbugs, and the paste was liberally smeared in the corners of the bedstead and in the cracks around the baseboards and moldings. Observations were made several days after treatment, and it was then evident that this material was of no value. Hundreds of living bugs were present, and the only dead ones seen were a very few that had become entangled in the paste and stuck fast.

In the second test the paste was smeared on pieces of paper and placed in a box containing 50 bedbugs. One week later examination showed that 90 per cent of the insects were still living and active.

FUMIGATION AGAINST BEDBUGS.

Results obtained in a limited number of tests made with sulphur as a fumigant show that it will kill bedbugs, and indicate that the necessary amount for effective use is at least 1 pound to 1,000 cubic feet of room space.

Not only is sulphur fumigation effective against the bedbugs themselves, but it has been found by several workers to kill the eggs also, which makes it a very satisfactory method of fighting this insect. This effectiveness against the eggs is of particular importance, since they are often deposited in inaccessible cracks and holes, or behind wall paper, where it is very difficult, or even impossible, to reach them with a dust or spray.

The following materials were found to be ineffective as fumigants against bedbugs when used at the rate indicated:

Paradichlorobenzene (8.5 pounds to 1,000 cubic feet).
Paraformaldehyde (2.25 pounds to 1,000 cubic feet).
Charcoal (1.64 pounds to 1,000 cubic feet).

TESTS AGAINST BEDBUG EGGS.

The eggs used in these experiments had been deposited on pieces of paper or cloth. These were thoroughly sprayed or dusted with the materials to be tested and then placed in jars covered with cheesecloth. Kerosene oil was the only material used which was found to be completely effective, not one of the eggs sprayed with this material hatching. The fact that the eggs sprayed with gasoline apparently hatched in a perfectly normal manner indicates that this material, although effective against bedbugs, vaporizes so rapidly that it does not penetrate the eggshell and reach the embryo, and that the evaporation is so complete that not enough oil remains, at the end of six days, to kill the newly hatched insects.

Mercuric chlorid, either as a dust or in a 1.35 per cent spray, appeared to have no effect on the eggs, as the young bugs emerged at approximately the same time as those from the untreated eggs. Where this material was applied as a dust, enough was present to kill all of the insects as soon as they had left the eggs, but the amount left by the 1.35 per cent solution apparently was not great enough to kill them.

SUMMARY.

1. The hydrocarbon oil sprays were found to be very effective against bedbugs, killing, in most cases, 100 per cent within 48 hours.

2. Coal-tar creosote emulsions were effective, when used undiluted, but their effectiveness fell very rapidly when they were diluted.

3. Mercuric chlorid, as a dust and in a 6 per cent water solution, was found to kill 100 per cent of the treated insects.

4. Pyrethrum was found to be very effective against bedbugs, while pyrethrum stems were of little or no practical value.

5. Tobacco powders, containing as high as 5.26 per cent of nicotine, were found to be of little or no value.

6. Hellebore was found to be absolutely ineffective against bedbugs.

7. Twenty miscellaneous powdered mixtures containing more than one active ingredient were tested and found to be more or less effective, depending on the amount of the active ingredients present.

8. Acetic acid, ammonia water, coal-tar oil (chlorinated), cottonseed oil, glycerol, kerosene, linseed oil, nicotine, oil of pine needles,—sabadilla seeds, turpentine and mercuric chlorid were found to be effective.

9. Twenty miscellaneous materials were found to be ineffective.

10. Sulphur fumigation, at the rate of 0.97 pound to 1,000 cubic feet of room space, was found to kill 100 per cent of the treated insects.

11. Three miscellaneous fumigants were found to be ineffective.

12. Phosphorus pastes proved to be of no value against bedbugs.

13. Kerosene was found to be effective, and gasoline and mercuric chlorid ineffective, against bedbug eggs.

COCKROACHES.

METHODS OF TESTING.

Two methods were employed in testing various materials against the common roach (*Blattella germanica* L.): (1) Badly infested rooms or kitchens were dusted or sprayed, and (2) cages were dusted or sprayed. The latter tests were made in wooden cages 11½ inches long, 9½ inches wide, and 2¾ inches deep, with top and bottom made of fine-mesh screen wire. For each test the entire interior of two or more of these cages was thoroughly dusted or sprayed with the substance to be tested. Twenty roaches, together with a small amount of bread for food and a few paper scraps to furnish hiding-places, were then added. At least two untreated cages, each containing 20 roaches with food and paper scraps, were used as a check with each set of tests. If the check showed a mortality of more than 20 per cent at the close of any series of tests, the experiment was discarded. However, it was rarely necessary to discard tests on this account, since the mortality of roaches confined in cages is almost negligible. Records were taken at the end of 24 hours, and as often afterwards as was considered necessary. The tests generally were closed at the end of one week, but in some cases observations were continued for longer periods.

It is considered that this method of testing, i. e., dusting or spraying the cage before inclosing the roaches, approximates the conditions that are met with in treating rooms, where only a very small proportion of the insects can actually be hit with a spray or powder, and therefore it is assumed that the real value of a given substance is determined by the number killed through coming in contact with it after it has been applied, rather than by the number killed through direct application. These cage tests, of course, are open to the objection that they are much more severe on the roaches than are the conditions which obtained in the room tests, since every part of the cage can be thoroughly treated, while many parts of a room will not be thoroughly sprayed or powdered, and many of the insects may not come in contact with the substance applied.

A limited number of fumigation tests were made in rooms or boxes. For the purpose of closely comparing the rapidity of the killing properties of two or more powders, tests were made by dipping the insects into the powder and placing them in empty vials where the effect of the substance could be noted.

ACTION OF MATERIALS ON ROACHES.

Upon careful study of the habits of roaches it has been found that these insects frequently cleanse their legs and antennæ. When any dirt or powder comes in contact with the appendages, these are at once drawn through the mouth parts of the insects and in this way cleaned. As a result, a certain amount of any powdered substance applied directly to a roach, or through which it may crawl, is thus taken into the mouth. In this way any poison, whether distasteful or not, finds its way into the stomach. Therefore it is not necessary to mix a stomach poison, in powdered form, with an attractive bait, since the chances are much greater that the poison will reach the stomach of the roach through its habit of cleansing itself than through the eating of the poisoned bait.

True contact poisons, as, for example, mineral-oil sprays, kill by coming in contact with the body. This may result (1) through direct application or (2) by coming in contact with the roach after it has been applied.

Certain substances, such as sodium fluorid, will act both as contact and as stomach poisons.

Substances also may kill through gases given off, as in the fumigation tests.

KILLING EFFECT OF POWDERED SUBSTANCES USED AS DUSTS AGAINST ROACHES.

SODIUM FLUORID.

In Table II are given the results of tests with sodium fluorid in kitchens and lunch rooms.

TABLE II.—*Results of tests with sodium fluorid against roaches in badly infested kitchens, bakeries, lunchrooms, milk-bottle exchanges, etc.*

Test No.	Per cent sodium fluorid.	Other ingredients.	Number used.	Duration of test.	Per cent killed.
1	100		Many	48 hours	100
2	100		do	do	100
3	100		do	do	100
4	100		do	do	100
5	50	Wheat flour, 50 per cent	do	do	100
6	50	do	do	5 days	98
7	50	Ground flint, 50 per cent	do	24 hours	100
8	50	do	do	48 hours	95

As will be noted in Table II, sodium fluorid, when used undiluted in badly infested kitchens and lunchrooms, kills practically every roach within 48 hours, and there is almost no reduction of this efficiency when it is used with equal parts of some inert substance, as flour or ground flint. The substitution of ground flint for wheat flour did not decrease the effectiveness of sodium fluorid, and it is apparent also that the addition of a bait for the purpose of tempting the roach to eat the poison is not necessary. The insects are killed just as quickly through taking the fluorid into the system while cleansing the appendages as though eating poisoned bait.

In addition to the foregoing room tests, many cage tests were made in which sodium fluorid was mixed with lime or some other inert substance in varying proportions, ranging from 1 to 100 per cent. Under these conditions it was found that a mixture containing as low as 18 per cent of sodium fluorid killed all of the insects within 24 hours. Such low percentages as 5, 3, and 1 per cent were effective, but failed to kill 100 per cent, even when the tests were continued for 7 days.

Sodium fluorid proved the most effective of all the materials tested. While it acts primarily as a stomach poison, it may act also as a contact poison to a slight degree.

PYRETHRUM POWDER.

In tests of 22 different samples of pyrethrum powder (powdered flowerheads of *P. cinerariaefolium* and *P. roseum*) all were found to be very effective against roaches treated in cages, and no practical difference in value was found between the powders made from open, half-open, and closed flowers, or between the wild and cultivated flowers. Tests made during the winter of 1912 with pyrethrum powder from the crops of 1908, 1909, and 1910 showed no practical difference in their efficiency, thus indicating that this powder does not deteriorate materially in four years.

Pyrethrum stems, ground, were found to have no insecticidal value, and their addition to pyrethrum powder is certain to reduce its effectiveness.

The general effect of pyrethrum powder on roaches is to paralyze them and render them inactive almost at once, and, although slight movements of the legs and antennæ may continue for as long as 48 hours, a roach that has been thoroughly dusted will not recover.

Pyrethrum powder is not nearly as active against roaches as is sodium fluorid. Sodium fluorid may be diluted greatly and yet kill quickly, whereas pyrethrum powder when mixed with only a small percentage of inert matter kills very slowly. Therefore, in practice, it appears necessary to use unadulterated pyrethrum powder for effective results.

BORAX.

Borax, when used under average room conditions, was found to be partially effective, but can not be relied upon in cases of gross infestation.

Under the severe conditions attending the cage tests borax killed all of the treated roaches in from 4 to 7 days, when the amount of borax was not less than 12 per cent. With 10 per cent of borax or less, all were not killed in 7 days.

Borax as an insecticide acts very slowly, and satisfactory results against roaches, in most cases, can be obtained only when the material is repeatedly and persistently used.

Tests were made also to determine whether borax acts against roaches as a stomach poison or as a contact poison. In two tests bread which had been soaked in a saturated solution of borax was allowed to dry, and was then placed in the regular roach cages in large pieces, no other food being added. In the first of these tests all of the insects were dead at the end of 11 days, and in the other 70 per cent were killed in 16 days. In another test a mixture of 50 per cent borax and 50 per cent corn meal was moistened and allowed to dry in firm cakes, which were placed in the roach cage. In this test 75 per cent were killed in 16 days. In the untreated cages only 5 per cent were dead at the close of the experiment. Since, in these tests, there was very little opportunity for the borax to affect the roaches, except when taken internally with food, it would appear that the action of borax is primarily that of a stomach poison. This view is strengthened by the fact that borax was found to be ineffective against 8 species of sucking insects and effective against 7 species of chewing insects.

TOBACCO POWDERS.

In tests with nine different tobacco powders, in which the nicotine content ranged from 0.025 to 5.26 per cent, it was found that they were of no value against roaches. While nicotine is a stomach poison, it is evident that the roaches did not get enough of the powder, which carries only a small percentage of nicotine, to cause death.

PLASTER OF PARIS AND FLOUR.

Thorough tests were made of the method of killing roaches that has been quoted so often, namely, feeding the roaches a mixture of plaster of Paris and flour and furnishing them water to drink. The supposed effectiveness of this method is based upon the theory that the roach eats the mixture and then drinks the water, the plaster of Paris " setting " in the intestines and killing the roach.

A mixture of 25 per cent plaster of Paris and 75 per cent flour was fed to about 100 roaches on a table surrounded by a trough of water, the water being accessible to the roaches. Observations for nine days showed that none had been killed. This mixture was replaced with a mixture of 50 per cent plaster of Paris and 50 per cent flour, the roaches being allowed to remain on the table. Observations for 30 days showed that none had been killed, and they appeared as lively and healthy as when placed on the table. The presence on the table of innumerable roach droppings in the form of elongated white pellets of hardened plaster of Paris is conclusive evidence that the mixture was freely eaten, but that the plaster of Paris did not " set " until after it had left the intestines.

These tests demonstrate that the " plaster of Paris and flour treatment " is of no value against the common roach or " Croton bug," and would throw grave doubts upon its effectiveness against any other species of roaches.

MISCELLANEOUS POWDERS PARTIALLY EFFECTIVE AGAINST COCKROACHES.

Table III gives the results of tests with miscellaneous powders.

TABLE III.—*Results of tests with miscellaneous materials which were found to be effective against roaches.*

Test No.	Active ingredients.	Inert ingredients.	Kind of test.	Number used.	Duration of test.	Per cent killed.
					Days.	
1	Alum, 100 per cent		Cage	80	7	60–80
2	Arsenious oxid, 8.98 per cent	Sodium oxid and paper.	...do	40	7	60–80
3	Arsenious oxid, 61.01 per cent	Sucrose, 35.28 per cent.	...do	15	7	100
4	Arsenious oxid, 86.93 per cent	Talc, 13.07 per cent	...do	40	4–7	95–100
5	Arsenious oxid, 76.14 per cent, and barium carbonate, 22.89 per cent, mixture.	.....do	...do	15	3	100
6	Barium carbonate, 100 per cent	.....do	...do	40	3	100
7	Barium fluorid, 100 per cent	.....do	...do	40	10–14	100
8	Do	.....do	Room	Many.	14	98–100
9	Boracic acid	.....do	...do	Many.	7	50–60
10	Calcium fluorid, 100 per cent	.....do	Cage	20	7	95
11	Do	.....do	Room	Many.	14	95
12	Copper sulphate, 100 per cent	.....do	Cage	40	8	80–90
13	Hellebore (*Veratrum* sp.), 100 per cent.	.....do	...do	120	7–14	85–100
14	Mercury bichlorid, 1.09 per cent	Ethyl and methyl alcohol.	...do	140	7	30–65
15	Mercury bichlorid, 100 per cent	.....do	...do	20	1	100
16	Mercury bichlorid, 5.72 per cent, and phenol, 1.44 per cent, mixture.	Water	...do	40	8–14	100
17	Paradichlorobenzene, 100 per cent.	.....do	...do	40	2–7	100
[1] 18	Do	.....do	Room	40	2	48
[2] 19	Sabadilla seeds, powdered, 10 per cent.	Corn meal, 90 per cent.	Cage	80	19–34	70–100
20	Sodium silicofluorid, 100 per cent.	.....do	...do	100	5–7	75–100
21	Do	.....do	Room	Many.	14	67

[1] Fumigation. [2] Furnished as food.

All of the materials given in Table III were active in varying degrees, killing from 48 to 100 per cent.

Although it would appear that several of these materials were satisfactorily effective, the fact that in the cage tests, in most cases, they required from 4 to 14 days to kill all of the treated roaches in a given cage, shows that they act too slowly to commend themselves for general use. Barium carbonate and mercuric chlorid are the only materials that would appear to warrant further tests, and there is no indication that they will approach the effectiveness of sodium fluorid.

As only one of these mixtures (test No. 3) contained any substance that might serve as a bait, it is evident that their efficiency must be due to their being taken into the mouth by the roach when the appendages are cleaned. This conclusion is strengthened by the results of dipping tests, where roaches dipped in arsenic trioxid or sodium arsenite died in less than 48 hours.

It should be emphasized that arsenious oxid and mercury bichlorid are far too poisonous to human beings to be generally used as roach remedies under average dwelling conditions.

Hellebore, while poisonous to insects when taken internally, acts so very slowly that it can not be classed as a roach remedy.

In the test of paradichlorobenzene 8½ pounds of this material were exposed for 44 hours at a temperature of about 80° F. in a room the capacity of which was 846.5 cubic feet. The roaches were placed on the floor in two cages, and even this heavy fumigation, with the insects fully exposed, failed to kill 50 per cent.

MISCELLANEOUS POWDERS INEFFECTIVE.

The following list of various powdered materials tested, unadulterated, was found to be ineffective against roaches. Not less than 40 roaches were used in the cage tests, and the experiments were continued for at least a week. The room tests were made in badly infested rooms or kitchens and were generally continued for seven days. The method of testing is indicated in parentheses after the name of the material.

Miscellaneous powders ineffective against cockroaches.

Allspice (cage).
Angelica root (cage).
Anise seed (cage).
Barium sulphate (cage).
Calcium carbonate (cage and room).
Calcium hydroxid (room).
Calcium oxid (cage and room).
Calcium sulphate (cage and room).
Camphor (cage and room).
Cassia (cage).
Chamomile flowers (cage).
Charcoal (room).
Cloves (cage).
Colocynth pulp (cage and room).
Cornstarch (room).
Corn meal (room).
Dolomitic lime (cage).
Eucalyptus leaves (cage).
Ferric oxid (room).
Ferrous oxid (room).
Flint, ground (cage).
Fuller's earth (room).
Gypsum (cage and room).
Lead carbonate (cage and room).
Lime, air-slaked (cage and room).
Magnesium carbonate (room).

Miscellaneous powders ineffective against cockroaches—Continued.

Magnesium oxid (room).
Pepper, cayenne (cage).
Potato starch (room).
Quassia (cage and room).
Road dust (cage and room).
Rosin (cage).
Silica (room).
Sodium bicarbonate (cage and room).
Sodium carbonate (cage and room).
Sulphur, refined (room).
Sulphur sublimated (cage and room).
Wheat flour (room).

EXPERIMENTS WITH LIQUIDS AND PASTES.

KILLING EFFECT OF PHOSPHORUS PASTES.

Ten phosphorus pastes (proprietary), ranging from 0.14 per cent to 2.33 per cent, were tested against roaches in cages, but none of them proved effective. Several of them did kill from 50 to 90 per cent, but since, in most cases, the tests were continued for at least seven days, and in no case were all roaches killed in this time, it can be seen that these pastes, even under the most severe conditions and when no other food was available, were not effective to the extent that would be considered satisfactory.

In addition to the cage tests, two of the pastes were tested in badly infested kitchens, and were still less effective. A few dead roaches were found in the kitchens 24 hours after the application of the pastes, but in no case did it appear that more than 10 per cent had been killed, nor was the infestation greatly reduced. The pastes used in the kitchen tests, however, contained only 1.01 per cent and 1.34 per cent of phosphorus.

Under certain conditions, where all food can be kept from the roaches for several days and the phosphorus paste used liberally, it may give satisfaction. The senior writer observed the use of phosphorus paste against roaches, which, in the absence of other food, fed on certain of the young, tender plants in a greenhouse of the War Department. Two or three roaches were seen eating the paste, and the manager of the greenhouse claimed to get entirely satisfactory results from the use of this substance against this insect. This material, however, can not be relied upon for general use under average conditions

HYDROCARBON OILS.

Numerous hydrocarbon-oil preparations, consisting essentially of oils of the nature of gasoline or kerosene, or some heavier oil, to which, in certain cases, had been added small amounts of nitrobenzene or phenols, were tested against roaches in cages. All of these sprays were found to be effective.

In considering the effectiveness of these oil sprays, due weight must be given to the fact that in cage tests the roaches are placed in the sprayed cages before the oil has dried and that they are obliged to remain on, or near, surfaces that are well wet with the oil. Under room conditions many of the insects are hiding in cracks and crevices, and often escape being hit by the oil at the time of application. If they remain in hiding until the oil has dried, which may be from one to several hours, they escape death, but those venturing out before the oil has dried are killed by contact with it. Owing to the chance that many may escape contact with the oil, such sprays, while effective, are less satisfactory than sodium fluorid.

The addition of nitrobenzene or phenols does not appear to increase the effectiveness of the mineral oil.

COAL-TAR CREOSOTE EMULSIONS.

Tests were made with many coal-tar creosote emulsion preparations, undiluted, and in dilutions ranging from 1 part of the emulsion in 10 parts of water to 1 part of the emulsion in 100 parts of water. When applied undiluted the emulsion killed all of the roaches within 24 hours, but as the dilution was increased the effectiveness decreased rapidly, so that when the dilution was greater than 1 part emulsion to 20 parts of water the material proved only slightly effective, or ineffective.

Both cage and kitchen tests indicate that such emulsions should not be diluted more than 1 part in from 20 to 25 parts of water.

FUMIGATION AGAINST ROACHES.

SULPHUR.

Five tests were made with sulphur as a fumigant, the dosage ranging from 4 ounces to 55 ounces per 1,000 cubic feet. The number of tests was so small that no definite conclusions as to the effective strength are drawn. The tests showed, however, that roaches can be killed by sulphur fumigation, and indicate that the minimum amount of sulphur to be used for 1,000 cubic feet (10′ by 10′ by 10′) is about 9 ounces.

NICOTINE.

Nicotine, when used as a fumigant, was found to be of no value against roaches. A dosage of as much as 8 ounces of tobacco extract (40 per cent nicotine, as sulphate) to 1,000 cubic feet failed to kill them. A much greater strength than this would probably be effective, but the cost would be prohibitive.

SUMMARY.

1. Sodium fluorid was found to be the most rapid killer of roaches of all the substances tested. Only 24 hours were required to kill 100 per cent in cage tests, even when the material was diluted down to

18 per cent content. Practically 100 per cent were killed in treated kitchens by the use of a mixture containing 50 per cent of sodium fluorid.

2. Pyrethrum powder, pure, killed practically all of the roaches within 48 hours in cage tests. Its effectiveness was greatly reduced when slightly diluted.

3. Borax, unadulterated, and in combination with inert matter wherein there was less than 12 per cent borax, required from three to seven days to kill all of the roaches in cage tests, proving it to be very slow. Borax, used alone, was only partially effective in kitchen tests.

4. Phosphorus pastes were partially effective in cage tests and only slightly effective in room tests.

5. The various hydrocarbon-oil sprays, undiluted, killed from 80 to 100 per cent in treated cages.

6. Coal-tar creosote emulsions, undiluted, killed all in cage tests, but their effectiveness fell very rapidly when even slightly diluted with water.

7. Tobacco powders containing as high as 5.26 per cent of nicotine were found to be ineffective in cage tests.

8. The plaster of Paris and flour mixture was ineffective against roaches.

9. Alum, arsenious oxid, barium carbonate, barium fluorid, boracic acid, calcium fluorid, copper sulphate, hellebore, mercury bichlorid, paradichlorobenzene, sabadilla seeds, and sodium silicofluorid were found to be more or less active against roaches.

10. Thirty-eight miscellaneous materials were found to be ineffective.

11. Sulphur fumigation, at the rate of 9 ounces of sulphur to 1,000 cubic feet, was effective.

12. Nicotine fumigation, at the rate of 8 ounces of tobacco extract (40 per cent nicotine, as sulphate) to 1,000 cubic feet, was ineffective.

CLOTHES MOTHS.

SPECIES USED IN EXPERIMENTS.

There are two important species of clothes moths occurring in the United States, the webbing or southern clothes moth (*Tineola biselliella* Hum.) and the case-making clothes moth (*Tinea pellionella* L.). The former species was used exclusively in the experimental work on account of its abundance in Washington, D. C., its larger size, and the fact that it readily leaves its case when disturbed.

METHODS OF TESTING.

Against the adults.—Many cage tests were made against the adults in the laboratory, as follows: Twenty large, well-ventilated cages were maintained, allowing 20 separate tests to be carried on at one time. Each cage was made of tulip, or what is commercially known as "whitewood," which, on account of its almost complete lack of odor and volatile oils, should be unobjectionable to moths. The inside dimensions of the cages were: Length, 3 feet; width, 2⅓ feet; depth, 10 inches. In the top a door, 3 feet by 1½ feet, covered with fine-mesh copper wire, provided means of entrance and ventilation, and at the back and at one side were screened apertures as further means of ventilation.

In each cage at the beginning of a test were placed three whitewood boxes, each 10 by 10 by 8 inches, fitted with sliding covers. A quantity of all-wool flannel, in pieces about 6 by 12 inches, was placed in each box. Flannel in two boxes was treated with the material being tested, while that in the third box was untreated and served as a check. The boxes containing the treated flannel were kept on one side of the cage; the untreated box on the other side, in order to minimize any chance of odors from the treated flannel affecting the untreated. The sliding covers were about three-fourths closed to exclude light and, at the same time, leave ample room for entrance of moths.

Finally, from 10 to 20 adult moths were placed in the large cage, the door quickly fastened, and the whole left in a quiet room. After a week or so more moths were often added to the cage, depending upon the available supply. The cage was fairly light; boxes fairly dark; and, as moths have a decided aversion to light, this condition tended to attract them to the boxes. The tests ran at least a month, sometimes longer, the purpose being to secure a maximum number of eggs hatched into larvæ large enough to be accurately counted. At the time results were recorded the number of dead moths, of living and dead larvæ, and of unhatched eggs was noted. The number of live larvæ found on the treated flannel, compared with the number found on the untreated flannel used as a check, determined the protective[1] value of the substance against moth infestation.

In addition to the cage tests, several room and trunk tests were made against the adults to approach more nearly practical conditions.

Against the larvæ.—The substance being tested was applied to the infested flannel in trunks, boxes, open battery jars, and closed bat-

[1] The word "protective," used in connection with these tests, is a rather broad term and is purposely used as such. At the time of testing the object was to determine whether materials used against moths as "repellents" had any so-called "repellent" effect upon the adult moth. Observations showed that, in the majority of cases where the effective remedies were used, adults were found to have entered boxes containing treated flannel, and often the number of dead ones there present, at the time of examination, equaled the number dead in boxes containing untreated flannel. It would appear, then, that the substances used did not act as repellents, but that moths entered boxes containing treated flannel and were either killed by the fumes or remained there until death occurred from other causes.

tery jars. Two lots of larvæ, treated, and one lot, untreated, made up each test. The usual duration of each test was one week, it being assumed that if the material used did not kill in that time it would be of no practical value.

Against the eggs.—Large pieces of flannel were placed in a jar containing many adult moths, and when the moths had deposited numerous eggs on the flannel it was taken out and cut into pieces in such a manner that each piece contained 10 or more eggs. The material to be tested was thoroughly applied to the pieces of flannel containing the eggs, and the treated flannel was then placed in open jars. An untreated lot, serving as a check, was used in each test. Observations were made at the end of 10 days to 2 weeks.

EXPERIMENTS AGAINST CLOTHES MOTHS.

NAPHTHALENE: EFFECT ON CLOTHES-MOTH ADULTS.

In two cage tests, as described, the flannel in the treated boxes was dusted with naphthalene flakes, and 10 adult moths were liberated in each cage. Examination made four weeks after treatment showed that the flannel in the treated boxes was entirely free from infestation by clothes-moth larvae, whereas the flannel in the untreated boxes was badly infested. Two other cage tests were made, in which naphthalene in the form of cakes or "bricks" was used, with the same result.

A room approximating 1,000 cubic feet was used for a "protective test" with naphthalene on a large scale. Three of the above-described small whitewood boxes containing flannel were placed in opposite corners of the room. About one-half pound of naphthalene flakes was placed in box No. 1; about one-fourth pound of naphthalene flakes in box No. 2; and one-fourth pound of naphthalene balls in box No. 3. Two boxes containing untreated flannel were used as checks. One hundred and forty adult moths were liberated in the room, which was made sufficiently tight to prevent their escape. At the end of 2½ months all of the treated boxes were entirely free from infestation, while the untreated boxes contained many living larvæ.

A duplicate room test was made, one lot of treated flannel being placed in a closet in the room, and the closet door being allowed to remain open. Again, all treated flannel remained free from infestation, while on the untreated flannel 80 live larvæ were counted.

Several trunk tests were made. In the first series flannel, to which was added naphthalene flakes at the rate of one-fourth pound to 5 cubic feet, was placed in a trunk of average size. Forty adult moths were liberated in the trunk, and the lid closed. Examination at the end of eight weeks disclosed no larvæ on the flannel, and all of the adults dead. In an untreated trunk serving as a check, in which the same number of adults were liberated, the flannel was badly eaten by larvæ, and a large number of live larvæ were present. In a duplicate test, in which naphthalene balls were used at about the same rate, the results were identical.

A second series of trunk tests was made, in which three trunks of average size were used, and adult moths were liberated in the trunks from time to time during the course of the experiments. In trunk No. 1 three-fourths pound of naphthalene flakes was scattered over the flannel and over the bottom of the trunk. Ten moths were added every two weeks, from May 7 to July 21, making a total of 70 moths used. Two months later (Sept. 20) examination developed that the flannel was unhurt, and no living adults, no larvæ, or eggs were found. In trunk No. 2 one pound of naphthalene balls was used, and moths were added as in trunk No. 1. The results were the same as obtained with the flake naphthalene. In the check (untreated) trunk the flannel was badly eaten at the close of the experiment, hundreds of live larvæ and 7 live adults being present.

To determine the rapidity with which adults are killed by confined fumes of naphthalene, a third series of trunk tests was conducted. Ten moths were placed in each of three tight trunks containing flannel and in each case a reasonable amount of naphthalene flakes was added. In from two to six days, all of the moths were dead.

NAPHTHALENE: EFFECT ON CLOTHES-MOTH LARVÆ.

Battery jars and trunks were used to test the effect of naphthalene on the larvæ. In the battery-jar tests jars of 216 cubic-inch content were used. From 10 to 20 larvæ, one-half to three-fourths grown, were placed upon a piece of all-wool flannel in each jar, and a liberal amount of naphthalene was applied to the entire piece of flannel. Two lots of larvæ, treated, and one lot, untreated, made up each test. The forms of naphthalene so tested were (1) one test of coarse flakes, (2) four tests of fine flakes, (3) one test of balls, and (4) one test of cake or brick. In each test the jars remained open. At the end of 7 days each of these substances was found to have killed from 85 to 100 per cent of the larvæ, and of the few remaining alive some were inactive. The flannel, in all cases, was undamaged.

In a second series of jar tests 10 half-grown larvæ were placed on flannel in each of five battery jars, which were tightly covered with heavy paper. To the 5 jars naphthalene flakes were added at the rate of 2, 4, 8, 20, and 40 grams, respectively, per cubic foot. At the end of one week the 2 and 4 gram applications had killed 90 per cent, and in every case all larvæ had been killed by the heavier dosages. In the untreated jars, serving as checks, only 5 per cent of the larvæ were dead. From observations on the effect of naphthalene on the larvæ in these jar tests it was concluded that the naphthalene killed much more effectively and rapidly when the fumes were confined by covering the jars.

In trunk tests against larvæ fresh flannel and 25 larvæ, half-grown, were placed in a lantern globe, the two ends of which were covered with cheesecloth. This lantern globe was placed in a trunk of average size, in which naphthalene flakes at the rate of one-fourth pound to 5 cubic feet were sprinkled, and the lid closed. The use of the lantern globe was to prevent the naphthalene from coming in contact with the larvæ, so that any action noted on the larvæ would be from the effects of the fumes. Examination at the end of 32 days showed that all the larvæ were dead. The flannel was found to be very slightly eaten, showing that some of the larger larvæ had, no doubt, survived long enough to feed slightly. A duplicate test was made, in which naphthalene balls were used at about the same rate, with identical results. In an untreated trunk, serving as a check, to which the same number of larvæ had been added, were found many adult moths and more than a hundred larvæ, and the flannel was badly eaten.

The results of these tests indicate that the killing effect of the naphthalene is due principally to the fumes.

A second series of trunk tests was made, using three trunks of average size, in which larvæ were added at intervals during the course of the experiment. In trunk No. 1 three-fourths pound of naphthalene flakes was scattered over the flannel and the bottom of the trunk. Ten larvæ, half to full grown, were added every 2 weeks for 10 weeks, making a total of 50 larvæ used. Two months after the last lot of larvæ was added examination showed that none had pupated, there had been only very slight feeding on the flannel, and all had been killed.

In trunk No. 2 one pound of naphthalene balls was used, and larvæ were added from time to time as in the test with trunk No. 1. The results were the same as those obtained in the use of naphthalene flakes, except that there was no feeding on the flannel, which was due, no doubt, to the fact that a larger quantity of balls than flakes was used.

In the check trunk (trunk No. 3), at the close of the experiment, numerous moths and larvæ were found and the flannel was badly eaten.

NAPHTHALENE: EFFECT ON CLOTHES-MOTH EGGS.

Pieces of flannel about 1 inch square, containing 10 or more clothes-moth eggs, were thoroughly dusted with naphthalene flakes and placed in two open battery jars. Observations made 10 days later showed that none of the eggs had hatched, while in an untreated jar 16 young larvæ and 2 unhatched eggs were found.

In a duplicate test, in which naphthalene balls were placed on the flannel, the results were identical.

From the results of the foregoing experiments it will be seen that naphthalene kills all stages of the clothes moth very effectively.

CAMPHOR.

Effect on clothes-moth adults.—Gum camphor, broken into small pieces, was used at the rate of about 5 ounces to 5 cubic feet, in a trunk containing flannel. Thirty moths were liberated in the trunk, and the lid closed. Examination made 32 days later showed no living adults and no larvæ, and the flannel had not been fed upon. Cage tests with this substance showed a variation in efficacy from 65 to 100 per cent as compared with the untreated flannel.

Effect on larvæ.—Twenty-five half-grown larvæ were placed on clean flannel in a trunk, and gum camphor was added at the rate of about 5 ounces to 5 cubic feet and the lid closed. Thirty-two days after treatment all of the larvæ were found to be dead, and the flannel had been slightly damaged from feeding.

Gum camphor scattered on infested flannel in an open jar killed 60 to 67 per cent of the larvæ in about 7 days.

Effect on eggs.—In two tests in open battery jars gum camphor killed all of the eggs, when sprinkled on pieces of flannel containing 10 or more eggs.

While camphor proved effective in varying degrees against the various stages of the clothes moth, close observations made during the course of the experiments show that it is much less active than the different forms of naphthalene.

RED-CEDAR CHEST.

Effect on clothes-moth adults.—A red-cedar chest of 10 cubic feet capacity was utilized. No record of the date of manufacture of the chest could be obtained. On May 6, 1915, 10 adult moths and a supply of flannel were placed in the chest. Ten more moths were added every two weeks until a total of 70 was reached. Two months after the last moths were added examination showed that all had been killed and that no eggs or larvæ were present.

Two years later (1917) 30 moths and a supply of flannel were added to the same chest. Observations made nine weeks after the experiment was started revealed no living adults, no eggs, and no larvæ. In a trunk, serving as a check, to which the same number of adults were added at the same time, more than 50 live larvæ were counted on the flannel at the close of the experiment.

Effect on larvæ.—The cedar chest above described was used also for a test against larvæ. In 1915 flannel was placed in this chest, and 10 one-half to three-fourths grown larvæ were added every two weeks until a total of 60 was reached. Examination made two months after the last addition of larvæ showed seven live larvæ; 36 larvæ had died and 17 had pupated. Of the 17 pupæ 2 died in the pupa stage and 15 emerged as moths, but died before any eggs were laid. The flannel had been fed upon considerably, but was not badly eaten.

Two years later (1917) this experiment was duplicated by adding 25 one-half to three-fourths grown larvæ at one time and allowing the experiment to run 33 days. The results were almost identical with those of the first experiment.

Effect on eggs.—A small piece of flannel containing many clothes-moth eggs was placed in the cedar chest described above. At the end of 23 days practically all of the eggs had hatched, but all of the resulting larvæ died almost immediately. A duplicate test was made, with identical results. The check flannel placed in a battery jar showed many eggs hatched and all larvæ alive.

The results of the foregoing tests indicate that adult clothes moths and young clothes-moth larvæ are killed when placed in a cedar chest, but that the larvæ one-half to full grown may live for a considerable length of time, and even, in some cases, reach the pupa stage and emerge as moths. It was observed in all tests that very little feeding was done.

RED CEDAR SHAVINGS AND CHIPS.

Effect of red-cedar shavings and chips on clothes-moth adults, larvæ, and eggs.—In cage tests cedar shavings and chips did not entirely prevent the moths from laying eggs on the treated flannel, yet they showed an apparent protective power when the treated flannel was compared with the untreated.

When cedar shavings and chips were thoroughly applied to larvæ more than one-fourth grown, they had no killing effect, but were somewhat effective against very young larvæ. Cedar chips burned in a fumigating box, at the rate of 2½ grams to 13 cubic feet, were not effective against larvæ.

Cedar chips proved ineffective in preventing the hatching of eggs.

Red-cedar leaves were entirely ineffective in killing larvæ and preventing moth infestation. The oil of cedar leaves, however, proved very effective for both purposes.

In addition to the above forms of cedar, very small boxes having an approximate content of 432 cubic inches (¼ cubic foot), made of freshly cut red-cedar lumber, were used for certain tests. Adult moths were killed in from three to four days when confined in these boxes. From 18 to 25 days were required to kill 85 to 90 per cent of the half-grown larvæ when placed in the boxes.

PARADICHLOROBENZENE.

Effect on clothes-moth adults and larvæ.—Paradichlorobenzene killed only 30 per cent of the adult moths and none of the larvæ placed in a room of 846 cubic feet capacity. Eight and one-half pounds of paradichlorobenzene was exposed in 6 dishes for 21 hours, and during this time one-half pound of the material evaporated. A liberal amount of paradichlorobenzene scattered on infested flannel in an open jar killed all of the exposed larvæ in 20 hours.

In boxes, trunks, or closets this substance would, no doubt, be very effective, when used liberally, as indicated by its rapid killing effect against clothes-moth larvæ when confined in a small space; but owing to rapid evaporation its effectiveness would not last nearly as long as that of naphthalene.

PYRETHRUM POWDER.

Effect on clothes-moth larvæ and eggs.—Pyrethrum powder was found to kill 100 per cent of larvæ on infested flannel, even when used in proportions as low as 4 parts of pyrethrum powder to 96 parts of flour.

Two tests were made with pyrethrum powder against clothes-moth eggs. Whether or not the eggs were prevented from hatching has not been determined definitely. If any hatched, however, the resulting larvæ died immediately, since 16 days after treatment no larvæ were found and the flannel was not damaged.

While no test with pyrethrum powder was made against adult clothes moths, it is safe to say that the powder would kill the adults. Clothing thoroughly dusted with pyrethrum powder would be protected from larvæ resulting from any eggs that might be present.

HYDROCARBON OILS AND OIL EMULSIONS.

Effect on clothes-moth adults.—Various oils of the nature of kerosene have proved very effective in preventing infestation of larvæ, resulting from moths liberated in cages, as described on pages 16 and 17. However, flannels treated with oil emulsions at dilutions varying from 1 part of emulsion in 65 parts of water to 1 part of emulsion in 250 parts of water were not protected from infestation. It is necessary to use such emulsions either undiluted or only slightly diluted if satisfactory control is to be expected.

The vapors evolved from kerosene in a closed jar killed adult moths in 2½ hours, the experiment being so arranged that the moths were not in contact with the oil.

Commercial crude carbolic acid, used at the rate of 1 part of the acid to 10 parts of water, proved effective in protecting flannel from moth infestation.

Effect on larvæ.—Experiments with three different oils of the nature of kerosene, and one experiment with gasoline sprayed on pieces of flannel infested with larvæ, resulted in the killing of all larvæ in each case. Oil emulsions proved of little value, when diluted as much as 1 part of the emulsion to 65 parts of water, against larvæ, as well as against adults. Oil emulsions should be used either undiluted or only slightly diluted.

Commercial crude carbolic acid, used at the rate of 1 part of the acid to 10 parts of water, killed 85 per cent of the larvæ on badly infested flannel.

The vapors evolved by kerosene in a closed jar killed larvæ in 4½ hours, the experiment being so arranged that the larvæ were not in contact with the oil.

Effect on eggs.—Two pieces of flannel, each containing 10 or more clothes-moth eggs, were sprayed with gasoline, with the result that all of the eggs were killed. Also, 3 and 5 per cent solutions of commercial crude carbolic acid killed all eggs in similar tests.

SOAP.

Effect on clothes-moth larvæ.—Fish-oil soap, used at the rate of 1 pound of the soap to 12, 25, and 40 gallons of water, killed all of the larvæ when sprayed on infested flannel. Laundry soap in two tests, in which it was used at the rate of 1 pound to 10 gallons of water, killed all of the larvæ.

Effect on eggs.—Laundry soap was sprayed on eggs on flannel, the strengths used being 1 pound of soap to 10, 20, and 40 gallons of water. The strongest solution killed most of the eggs, but the two weaker solutions were entirely ineffective.

The above results with soap indicate that spraying or washing clothing with strong soap solution will free it from larvæ and eggs of the clothes moth.

NICOTINE EXTRACTS AND TOBACCO POWDER.

Effect on clothes-moth adults.—Flannel dusted with powdered tobacco leaves containing 4.56 per cent nicotine remained free from moth infestation in a single cage test, the untreated flannel, under the same conditions, becoming infested with 12 larvæ. Tobacco powders containing 0.4 per cent and 0.8 per cent of nicotine were not effective in preventing infestation in cage tests. Since the average tobacco powder found on the market contains a great deal less than

4 per cent of nicotine, this substance should not be depended upon for protection of clothing against moth attack.

No tests with nicotine extract were made to determine its value in protecting clothing from moth infestation in the presence of adults.

Effect on larvæ.—In Table IV are shown the results of 18 tests with several forms of nicotine in varying dilutions.

TABLE IV.—*Tests of the killing effect of nicotine solutions and tobacco powders against clothes-moth larvæ.*

Test No.	Nicotine, amount and form.	Dilution in water.	Treated.		Untreated.	
			Number of larvæ used.	Per cent dead.	Number of larvæ used.	Per cent dead.
1	13 per cent as extract	1 to 125	20	5	10	20
2	.....do	1 to 125	10	40	10	10
3	12 per cent as extract	1 to 32	20	20	10	20
4	.....do	1 to 32	20	10	10	10
5	.....do	1 to 32	20	5	10	40
6	40 per cent as sulphate	1 to 100	20	[1] 30	10	20
7	.....do	1 to 100	10	....	10	10
8	.....do	1 to 75	20	15	10	20
9	.....do	1 to 75	10	20	10	30
10	.....do	1 to 50	20	30	10	30
11	.....do	1 to 50	10	30	10	20
12	.....do	1 to 25	10	50	10	40
13	.....do	1 to 25	20	55	10	30
14	0.41 per cent in tobacco dust	Undiluted	20	5	10	
15	0.8 per cent in powdered stalks	.....do	20	....	56	6
16	3.14 per cent in powdered plant	.....do	20	....	50	8
17	3.38 per cent in powdered leaves	.....do	20	10	10	
18	4.56 per cent in powdered leaves	.....do	20	20	50	6

[1] Of those dead, 25 per cent probably drowned, as water was found in the jar.

It is seen that every form of nicotine, at the dilutions used, failed to kill an appreciable number of larvæ, and since the greatest strength used was 1 part of tobacco extract (40 per cent nicotine, as sulphate) to 25 parts of water, it is apparent that to kill a higher percentage the preparation would have to be used very slightly diluted or undiluted. This evidently would not be practical on account of the comparative cost and the danger of staining woolens.

Effect on eggs.—A nicotine-water solution (40 per cent nicotine), used at the rates of 1 part of the mixture to 25 and to 50 parts of water, killed all of the eggs on sprayed flannel. When the proportion of water was increased to 75 parts, 2 eggs hatched in one test and none in the other. The two larvæ resulting from the hatched eggs died almost immediately. When a dilution of 1 to 100 was used in 2 tests, one egg hatched in one test and two in the other, the resulting larvæ dying almost immediately. No greater dilutions were used, but the results indicate that when used at a much greater dilution than 1 to 100, the material would not be effective against the eggs. Owing to the expense of such a substance its use would be prohibitive.

MISCELLANEOUS MATERIALS.

Effect on clothes-moth adults.—Lavender flowers, cayenne pepper, and allspice are of no value in preventing moth infestation.

Cloves and oil of lavender were effective in protecting flannel from moth infestation.

Effect on larvæ.—Miscellaneous substances found to be effective against larvæ are as follows:

Alcohol (ethyl), 95 per cent solution used as a spray. Cloves, used as a dust. Sodium fluorid, used as a dust.

Miscellaneous substances found to be ineffective against clothes-moth larvæ are as follows:

Allspice (dusted).
Angelica root (dusted).
Borax (dusted).
Colocynth pulp (dusted).
Eucalyptus leaves (dusted).
Formaldehyde (sprayed 1 to 10).
Hellebore, white (dusted).
Lavender flowers (scattered on).
Lead carbonate (dusted).
Lead oxide (dusted).
Lime [air-slaked] (dusted).
Pyrethrum stems (dusted).
Quassia chips (dusted).
Sodium bicarbonate (dusted).
Sodium carbonate (dusted).

Effect on eggs.—Sulphur, salt, and borax were of no value in preventing hatching of clothes-moth eggs, when thoroughly sprinkled on infested flannel.

Formaldehyde killed the eggs when used undiluted and when diluted with 5 parts of water, but when used at the rate of 1 part to 10 parts of water eggs were not killed.

At 50 and at 70 per cent a solution of ethyl alcohol destroyed the viability of eggs, but at 30 per cent a solution was ineffective.

FUMIGANTS.

Effect on clothes-moth adults and larvæ.—In Table V are recorded the results of fumigation tests with miscellaneous materials.

TABLE V.—*Results of fumigation tests with miscellaneous materials against adults and larvæ of the clothes moth. Tests made in a fumigating house containing 360 cubic feet of space.*

Test No.	Name of material.	Amount.	Method of application.	Number used.		Percentage killed.	
				Adults.	Larvæ.	Adults.	Larvæ.
		Grams.					
1	Charcoal	265	Burned with forced draft		10		0
2	Formaldehyde	65	Evaporated over lamp	10	10	0	0
3	Paraformaldehyde	23	.....do	20	20	0	0
4	.....do	65	.....do	20	20	30	5
5	Sulphur	208	Burned with wick	15	10	100	20
6	.....do	243	Burned in retort		10		100
7	Sulphur and carbon, equal parts	228	.....do	20	20	50	0

As will be noted, sulphur burned in the form of a candle, at the rate of 208 grams to 360 cubic feet, killed all adults in 18 hours. The combination of sulphur and carbon in equal parts, when burned at the rate of 228 grams to 360 cubic feet, killed 50 per cent of the adults in 18 hours. Sulphur fumes killed larvæ in house fumigation when used at the rate of 243 grams to 360 cubic feet, but was ineffective at weaker strengths.

Formaldehyde in solution and in crystalline form (paraformaldehyde) failed to kill a majority of the adults and was of no value against larvæ.

HEAT.

Effect on clothes-moth larvæ.—The effect of heat on larvæ was tested by placing the infested flannel in an incubator. Ten larvæ were used in each case, with the results shown in Table VI.

TABLE VI.—*Effect of heat on clothes-moth larvæ.*

Length of exposure.	Degree of heat.	Result.
Minutes.	*° F.*	
6	128	All killed.
11	120	Do.
31	110	Do.
11	110	30 per cent killed.
31	105	20 per cent killed.

A single test made by exposing a piece of flannel containing many larvæ in the sun for six hours, the developing temperature ranging from 80° F. to 105° F., resulted in the death of all larvæ.

Effect on eggs.—The effect of heat on clothes-moth eggs was tested in the same manner as described above for larvæ, 10 or more eggs being present on each piece of flannel. See Table VII.

TABLE VII.—*Effect of heat on clothes-moth eggs.*

Length of exposure.	Degree of heat.	Result.
Minutes.	*° F.*	
6	128	All killed.
6	125	Do.
11	120	Do.
31	110	Do.
11	110	None killed.
31	105	Do.

A single test made by exposing for six hours a piece of flannel containing many clothes-moth eggs to the sun in the same manner as described for larvæ resulted in the killing of the eggs. The temperature of the flannel during the exposure rose from 80° F. to 105° F.

HOT WATER.

Effect on clothes-moth larvæ and eggs.—Both larvæ and eggs of the clothes moth were killed by dipping infested flannel for 10 seconds in water at a temperature of 140° F. When dipped for the same length of time in water at a temperature of 122° F., however, neither the larvæ nor the eggs were killed.

SUMMARY.

1. Naphthalene was uniformly effective in protecting woolens from clothes-moth infestation and in killing all stages of the insect.
2. Camphor, though more or less effective against all stages of the clothes moth, proved considerably less active than did naphthalene.
3. A red-cedar chest readily killed all adult moths and showed considerable killing effect upon young larvæ. It did not prevent the hatching of eggs, but killed all the resulting larvæ almost immediately.
4. Red-cedar chips and shavings, while not entirely effective in keeping the adult moths from laying eggs on the flannel treated, appeared to protect it from appreciable injury when used liberally. The chips and shavings showed practically no killing effect against eggs, or against the larvæ when over one-fourth grown.
5. Paradichlorobenzene was not effective against adults and larvæ in a room fumigation test of 21 hours duration, but killed larvæ effectively in battery-jar tests.
6. Pyrethrum powder readily killed clothes-moth larvæ.
7. Various mixtures of oils were effective in protecting clothing from infestation, when used undiluted or but slightly diluted, and killed 100 per cent of the larvæ when used undiluted.
8. Laundry soap killed both larvæ and eggs when used in strong solution.
9. Various tobacco extracts containing nicotine and tobacco powders, when used at reasonable strengths, proved of no value against this insect.
10. Lavender flowers, cayenne pepper, and allspice were ineffective and cloves and oil of lavender effective in protecting flannel from moth infestation.
11. Powdered cloves, sodium fluorid, and 95 per cent alcohol, undiluted, killed larvæ.
12. Allspice, angelica root, black pepper, borax, cayenne pepper, colocynth pulp, eucalyptus leaves, formaldehyde, hellebore, lead carbonate, lead oxid, lime, quassia chips, sodium bicarbonate, and sodium carbonate were of no value in killing clothes-moth larvæ.

13. Borax, salt, and sulphur did not kill clothes-moth eggs; 50 per cent and 70 per cent solutions of ethyl alcohol and a 16 per cent solution of formaldehyde killed the eggs.

14. Fumigation with sulphur proved effective in killing both adults and larvæ.

15. Heat killed both larvæ and eggs when they were exposed in an oven for 31 minutes at 110° F., and in less time at higher temperatures.

16. Hot water killed both larvæ and eggs when infested flannel was dipped for 10 seconds in water at a temperature of 140° F.

CARPET BEETLES.

SPECIES USED IN EXPERIMENTS.

There are two well-known species of carpet beetles in the United States, both injurious to woolen fabrics, but, in contrast to the clothes moths, generally attacking the heavier fabrics, such as carpets and blankets. One species is known as the "carpet beetle" or "black carpet beetle" (*Attagenus piceus* Oliv.) and the other as the "carpet beetle" or "buffalo bug" (*Anthrenus scrophulariae* L.). The former species, on account of its greater abundance in Washington, D. C., was used in the experimental work.

METHODS OF TESTING.

The methods used in testing the insecticide materials against the carpet beetle were essentially the same as used in the clothes-moth tests described on pages 16 and 18.

EXPERIMENTS AGAINST CARPET BEETLES.

NAPHTHALENE.

Effect on carpet-beetle adults.—Two cage tests with naphthalene flakes and two with naphthalene balls, 30 adult beetles being used in each test, resulted in complete protection of the treated flannel in all cases, while the untreated flannel was infested with from 5 to 13 living larvæ.

Two trunks containing flannel were used in tests against the adult beetles. In one trunk naphthalene flakes were applied at the rate of one-half pound to 13 cubic feet, and 40 beetles were added; in the other naphthalene balls were applied at the rate of one-half pound to 10 cubic feet, and 30 beetles were added. Four weeks after treatment all of the beetles were dead and no larvæ were present in the trunk treated with naphthalene flakes. No live adults, but 3 live and 2 dead larvæ, were found in the trunk treated with naphthalene balls, 8 weeks after treatment, and the flannel was not damaged. In an untreated trunk there were several live larvæ, and the flannel was slightly damaged at the close of the experiment.

In 5 closed battery-jar tests, in which the adults were tightly confined with a small amount of naphthalene, they were killed in from 2 to 5 days.

Effect on larvæ.—Coarse naphthalene flakes, fine naphthalene flakes, and finely powdered naphthalene, dusted on larvæ infesting flannel, killed 90 to 95 per cent in open-jar tests.

In a closed trunk naphthalene flakes sprinkled on the bottom, at the rate of one-half pound to 13 cubic feet, killed, in 32 days, all of 25 larvæ placed on flannel in a lantern globe, the two ends of which were covered with cheesecloth to prevent the larvæ from coming in direct contact with the naphthalene. The flannel had not been noticeably injured. Naphthalene balls used against larvæ in the same manner, at the rate of one-half pound to 10 cubic feet, gave the same results. The check trunk showed 8 per cent of the larvæ dead and the flannel badly eaten.

These results indicate, as in the case of clothes moths, that the killing effect of naphthalene is due principally to the fumes liberated.

Effect on eggs.—In two open battery-jar tests with naphthalene flakes, applied to small pieces of flannel containing 10 or more eggs each, no eggs were found to have hatched at the end of 11 days. An average of 13 live larvæ was found on the untreated pieces of flannel.

In two similar tests, in which naphthalene balls were used, the results were identical.

Naphthalene was found to be very effective in protecting flannel from infestation by carpet beetles and in killing adults, larvæ, and eggs.

CAMPHOR.

Effect upon carpet-beetle adults.—In a cage test with gum camphor, in which 35 adults were used, no larvæ were found upon the treated flannel at the end of about one month, while 22 live larvæ were found upon the untreated flannel. In a duplicate test, in which 30 adults were used, 1 live and 2 dead larvæ were found at the end of 30 days.

Thirty adult beetles confined in a tight trunk containing one-half pound of camphor to 9 cubic feet were dead at the end of 30 days, and no larvæ were found to be present. In an untreated trunk 10 live larvæ were found at the end of 30 days, and the flannel had been slightly eaten.

Five closed battery-jar tests, in each of which 5 to 10 beetles were tightly confined with flannel treated with a small amount of camphor, resulted in the killing of 80 to 100 per cent in from 4 to 7 days.

Effect on larvæ.—A trunk test against larvæ was made, using camphor at the rate of one-half pound to 9 cubic feet. Twenty-five larvæ on flannel in a lantern globe were added. Observations showed, at the end of one month, that 72 per cent of the larvæ had been killed. In an untreated trunk only 8 per cent were dead in one month.

Camphor sprinkled over larvæ on flannel in open battery jars killed only a small percentage. In tests with the jars sealed, all the larvæ were killed in from 15 to 29 days, but none were killed in seven days. Only 15 per cent died in the untreated jars in 29 days.

Effect on eggs.—In two tests with camphor scattered on flannel containing 10 or more eggs, no larvæ were found to have hatched in 11 days, while an average of 13 live larvæ was found on the untreated pieces of flannel used as a check.

Camphor, although effective against the various stages of the carpet beetle, was not as uniformly efficient as was naphthalene. Since camphor kills more slowly and volatilizes much more rapidly than does naphthalene, its use is not recommended when naphthalene is available.

RED-CEDAR CHEST.

Killing effect on carpet-beetle adults, larvæ, and eggs.—Thirty adults and a large piece of flannel were confined in a red-cedar chest of 10 cubic feet capacity. At the end of 60 days examination showed that all adults were dead and that one live and more than 100 small dead larvæ were present. No noticeable injury had been done to the flannel.

Twenty-five half to full-grown larvæ, placed upon flannel, were confined in the chest for 60 days. At the end of that time none were found dead, and the flannel had been slightly eaten.

Two pieces of flannel, each containing 10 or more eggs, were inclosed in the chest for 23 days. At the end of that time examination showed 14 small dead larvæ on each piece of flannel. The flannel was not damaged. Although the cedar chest failed to kill the eggs, the newly hatched larvæ died almost immediately.

The cedar chest readily killed newly hatched larvæ, but failed to kill adults before eggs were laid and also did not kill one-half to full-grown larvæ. This cedar chest was the same one used in the clothes-moth test.

CEDAR CHIPS.

Effect on carpet-beetle adults.—Cedar chips were employed in three cage tests, about 30 adult beetles being used in each. Examination of the three tests 30 days later showed an average of 10 live larvæ on the treated flannel and an average of 16 live larvæ on the untreated.

Thirty adults, with a large piece of flannel, were inclosed in a trunk, to which had been added cedar chips at the rate of one-half pound to 9 cubic feet. At the end of 8 weeks all the adults were dead and no larvæ were present. The check trunk showed 10 live larvæ and the flannel slightly eaten.

Adults placed in closed battery jars with flannel treated with cedar chips resulted in the killing of 80 to 100 per cent in 7 days.

Effect on larvæ.—Red-cedar chips were placed in a trunk at the rate of one-half pound to 9 cubic feet. Twenty-five half to full-grown larvæ were added and the trunk closed immediately. At the end of 56 days no larvæ were dead, and the flannel was considerably eaten.

Effect on eggs.—Red-cedar chips were used in open battery jars against the eggs. After 9 days larvæ were observed on the flannel, but were not counted.

Apparently red-cedar chips were not very effective against the different stages of the carpet beetle. Clothing would be protected by the use of cedar chips only when used very liberally.

PYRETHRUM POWDER.

Effect on larvæ and eggs.—Pyrethrum powder was used in four tests against larvæ on flannel in open battery jars. An average of 27.5 per cent was killed in about a week.

Two tests were conducted with pyrethrum powder against larvæ on flannel in large-stoppered bottles. Of a total of 20 larvæ used, 90 per cent were killed in about one week. Fifteen per cent of the larvæ on untreated flannel in stoppered bottles died in the same time.

Two pieces of flannel, each containing 10 or more eggs, were placed in battery jars and dusted with the powder. At the end of 26 days no larvæ were found on the treated flannel, although the eggs may have hatched and the young larvæ have been killed almost immediately. An average of 13 live larvæ was found on the untreated pieces of flannel.

Pyrethrum powder proved considerably less effective against carpet-beetle larvæ than against clothes-moth larvæ.

HYDROCARBON OILS AND OIL EMULSIONS.

Effect on carpet-beetle adults, larvæ, and eggs.—A 10 per cent solution of carbolic acid showed moderate protective value against carpet-beetle adults in cage tests, while a 5 per cent solution proved ineffective.

Mineral oils and oil emulsions of the nature of kerosene killed all the larvæ when used undiluted. The oil emulsions proved effective when diluted not more than 1 part to 10 parts of water. Against eggs, in two tests each, a 3, 5, and 10 per cent solution of crude carbolic acid appeared to prevent hatching.

SOAP.

Effect on carpet-beetle larvæ and eggs.—Fish-oil soap, used at the rate of 1 pound to 4 and 8 gallons of water, killed 100 per cent of the larvæ. When used at the rates of 1 pound to 10, 16, and 25 gallons, from 75 to 90 per cent were killed, while weaker solutions proved ineffective. Practically the same results were obtained by the use of laundry soap.

Laundry soap, used at the rate of 1 pound to 10 gallons of water, appeared to kill all carpet-beetle eggs in two tests. When used at the rates of 1 pound to 20 and 40 gallons of water it was not effective against the eggs.

NICOTINE SOLUTIONS AND TOBACCO POWDERS.

Effect on carpet-beetle larvæ.—Table VIII shows the results of tests with nicotine in various forms against the carpet-beetle larvæ.

TABLE VIII.—*Tests of the killing effect of nicotine solutions and tobacco powders upon carpet-beetle larvæ.*

Experiment No.	Nicotine, amount and form.	Dilution in water.	Number of tests.	Treated.		Untreated.
				Total number of larvæ used.	Average per cent dead.	Average per cent dead.
1	40 per cent nicotine as sulphate	1 to 10	2	20	100	6
2	do	1 to 25	2	20	60	6
3	do	1 to 50	2	20	20	6
4	40 per cent nicotine as extract in nicotine-water solution.	1 to 25	2	20	75	....
5	do	1 to 50	4	40	47.5	....
6	do	1 to 100	2	20	5	....
7	12.5 per cent nicotine in nicotine-water solution.	1 to 125	3	30	70	10
8	11.6 per cent nicotine in nicotine-water solution.	1 to 32	8	80	72.5	4
9	4.56 per cent nicotine in tobacco dust	Undiluted	2	20	5	....
10	0.41 per cent nicotine in tobacco dust	do	2	20	5	....

As will be noted, it was necessary to use a tobacco extract (40 per cent nicotine, as sulphate) diluted at the rate of 1 part to 10 parts of water to kill all the larvæ. All weaker dilutions used failed to kill more than 75 per cent. It is therefore apparent that nicotine sprays are not to be recommended for carpet-beetle larvæ.

Powdered tobacco, containing 4.56 per cent of nicotine, which is considerably above the average percentage of nicotine content for such powders, was ineffective against the larvæ when used as a dust.

In addition to the foregoing tests tobacco powder containing 0.85 per cent nicotine was burned in a box at the rate of 6 ounces to 360 cubic feet. None of the 15 larvæ used in this box fumigation were killed in 19 hours. The strength was increased to 26 ounces to 360 cubic feet with the result that 20 per cent of the larvæ were killed.

Effect on eggs.—A solution containing 40 per cent nicotine extract, used at dilutions of 1 part mixture to 25 and 1 to 50, killed nearly all the eggs, while dilutions of 1 to 75 and 1 to 100 were not effective.

It appears from these tests that the various forms of nicotine are of no practical value against carpet beetles.

MISCELLANEOUS SUBSTANCES.

Effect on carpet-beetle adults.—Oil of cedar leaves effectively protected flannel from carpet-beetle infestation in laboratory-cage tests. Lavender flowers were ineffective in such tests. Formaldehyde fumigation (2⅓ ounces to 360 cubic feet) proved ineffective against adults.

Effect on larvæ.—Miscellaneous substances tested against carpet-beetle larvæ and found to be more or less effective are as follows:

Alcohol (ethyl), 50–95 per cent solutions.
Cloves (powdered).
Gasoline (undiluted).
Mercuric chlorid (1 pound to 50 gallons of water).
Sulphur (burned), 8½ ounces to 360 cubic feet.

Miscellaneous substances found to be ineffective against larvæ are as follows:

Alcohol (ethyl) 20 to 40 per cent solutions (sprayed).
Allspice (dust).
Arsenious acid (dust).
Borax (dust).
Formaldehyde (fumigation).
Hellebore (dust).
Lavender flowers (dust).
Lime (dust).
Pepper, black (dust).
Sodium fluorid (dust).
Sulphur (dust).

Effect on eggs.—Solutions of ethyl alcohol at 30, 50, 70, and 100 per cent appeared to prevent the hatching of carpet-beetle eggs. A 20 per cent solution, however, was of no value.

Borax, gasoline, mercuric chlorid (1 pound to 50 gallons of water), and sulphur failed to prevent hatching of eggs.

HEAT.

Effect on carpet-beetle larvæ.—Tests of the effect of heat were conducted by placing 10 larvæ on flannel in an incubator for varying lengths of time. The results are shown in Table IX.

TABLE IX.—*Effect of heat on carpet-beetle larvæ.*

Length of exposure.	Degree of heat.	Results.
Minutes.	*° F.*	*Per cent killed.*
10	128	100
15	125	100
30	120	100
10	120	30
30	110	0
10	110	0
30	105	0

Effect on eggs.—Ten or more eggs on a piece of flannel were placed in an incubator for varying lengths of time. The results are shown in Table X.

TABLE X.—*Effect of heat on carpet-beetle eggs.*

Length of exposure.	Degree of heat.	Result.
Minutes.	*° F.*	*Per cent killed.*
11	130	100
11	128	50
19	125	100
16	125	100
31	120	0
11	120	0
31	110	0
11	110	0
31	105	0

To kill all larvæ, a temperature of 120° F. maintained for 30 minutes was required. Higher temperatures for less time were equally efficient. To prevent all eggs from hatching, it would appear, from these limited tests, that the length of exposure is more important than the temperature. A temperature of 125° F. for 16 minutes killed the eggs, while an exposure of 128° F. for 11 minutes failed to kill all the eggs.

Two pieces of flannel, each containing 10 or more eggs, were placed in the hot sun for three hours. The temperature on the flannel ranged from 109° F. to 120° F. Observations showed that none of the eggs so exposed hatched, while practically all the eggs on the unexposed flannel hatched.

HOT WATER.

Effect on carpet-beetle larvæ and eggs.—Flannel dipped for five seconds in water at a temperature of 140° F. resulted in the killing of both larvæ and eggs, while water at a temperature of 122° F. failed to kill either larvæ or eggs.

SUMMARY.

1. Naphthalene, against carpet beetles, as against clothes moths, proved effective in preventing infestation of clothing and in killing all stages of the insect.

2. Camphor was effective against the various stages of the carpet beetle, but killed much more slowly than did naphthalene.

3. A red-cedar chest killed adults and newly hatched larvæ, but had no effect on larvæ half grown or larger.

4. Red-cedar chips proved only moderately effective against carpet beetles.

5. Pyrethrum powder proved considerably less effective against carpet-beetle larvæ than it did against clothes-moth larvæ.

6. Various mixtures of mineral oils killed carpet-beetle larvæ, when used undiluted or but slightly diluted.

7. Laundry soap killed both larvæ and eggs when used in strong solutions.

8. Nicotine solutions and tobacco powders proved of no practical value against this insect.

9. Oil of cedar leaves was effective, and lavender flowers ineffective, in protecting flannel from carpet-beetle infestation.

10. Ethyl alcohol (50–95 per cent solutions), powdered cloves, gasoline, mecuric chlorid, and fumigation with sulphur (8½ ounces to 360 cubic feet) killed the larvæ effectively.

11. Ethyl alcohol (20 to 40 per cent solutions), allspice, arsenious acid, borax, formaldehyde fumigation, hellebore, lavender flowers, lime, black pepper, sodium fluorid, and sulphur were ineffective against the larvæ.

12. Ethyl alcohol (30, 50, 70, and 100 per cent solutions) killed carpet-beetle eggs, while borax, gasoline, mercuric chlorid, and sulphur failed to kill the eggs.

13. Heat killed the larvæ, when exposed in an incubator for 30 minutes at 120° F. A higher temperature was required to kill the eggs.

14. Hot water killed both larvæ and eggs, when the infested flannel was dipped for five seconds at a temperature of 140° F.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 708

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

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SHUCK PROTECTION FOR EAR CORN.

By C. H. Kyle, *Assistant Physiologist, Office of Corn Investigations.*

CONTENTS.

INTRODUCTION.

Most corn growers fail to realize that by improving the shuck covering on their corn by selection they may reduce the amount of damage done to the grain. Growers generally consider nothing but the ears and kernels when selecting seed. In weevil-infested sections in particular, variation in the damage of ears is frequently observed, but if the matter is considered the cause is usually attributed to variation in the hardness of the grain. Weevils attack corn of all degrees of hardness, and their progress in consuming the hard corn is only slower than that in the soft corn. Some observers have concluded that since weevils are able to eat the hardest corn, they would also cut their way through the most resistant shucks in order to feed upon the grain, if sufficiently urged by hunger. Others have observed that earworms may cut holes through a large percentage of the protecting shucks and that weevils will enter through these holes, and they have concluded from this that shuck covering can not be made a practicable means of protection. Then, too, there is a sentiment on the part of some against a large amount of shuck.

With such a formidable array of misconceptions and real difficulties as these and others, it is not surprising that little or no action

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is being taken in the matter to bring about practical results. This is especially true in view of the fact that very little experimental work has been done to determine the relationship that really exists between shucks and the corn inclosed by them. However, some reassuring observations in this connection have been recorded by W. E. Hinds, entomologist of the Alabama Argicultural Experiment Station.[1] Below are given certain significant quotations:

> The earliest maturing corn—almost regardless of variety—attracts them [weevils] in greatest number and naturally the ears that have exposed tips and loose, open husks are then the first and most heavily attacked. * * * But naturally the corn from the outer edges of the field and the poorly covered ears throughout the field will always contain more weevils than any other equal number of ears. * * * The two most important factors in producing this [weevil infestation] variation [of varieties] are generally comparative rapidity of development to maturity of the grain and the relative length and tightness of the husk covering. * * * From our study of these varieties, we have become convinced that weevil resistance depends first of all upon the length and tightness of the husk covering upon the maturing ear. * * * Long husks can be bred by selection in any variety. * * * Good husk covering and proper storage methods may entirely prevent the necessity for fumigation treatment.

In the following pages are given the results of investigations whose object has been to establish definitely by positive means some of the more important facts regarding the merits of shucks as a means of preventing ear damage.

RELATION OF SHUCK CHARACTERS TO INSECT INFESTATION.

FIELD INVESTIGATIONS.

The field investigations described in this bulletin were conducted during the period from September 27 to October 4, 1915. The experimental corn had been planted on March 22 and 23 at Thomasville, Ga., and was among the first planted in the community that year. At the time the data were collected the moisture in the grain varied with the variety from 12.5 to 15 per cent.

Fourteen native southern varieties were included in the investigations. They were grown in adjacent rows and harvested and studied separately, but for the purposes of this bulletin the results are considered collectively.

The ears were harvested with all of the shucks in place. They were then separated into three classes, termed "poor shucks," "good shucks without wormholes," and "good shucks with wormholes."

Ears were classified as having poor shucks if the shucks failed to extend beyond the tip of the ear or if extending beyond the tip they did not close tightly and seemed to offer opportunity for insects to enter along the passage used by the silks.

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[1] Hinds, W. E. Reducing insect injury to seed corn. Ala. Agr. Exp. Sta. Bul. 176, p. 49–68, 4 pl. 1914.

Ears were classified as having good shucks if the shucks extended beyond the tip of the ear and closed more or less tightly about the silks. Most of the so-called good shucks were not ideal or such as would be the breeder's aim, but were only better than those classed as poor shucks.

If a hole or holes had been cut through a good shuck by a worm, the ear was put in the class of good shucks with wormholes; if no such openings had been made, the ear was classified as good shucks without wormholes. Only such wormholes as were cut through the shucks were considered. It was found, after removing the shucks, that some of the ears in the class good shucks without wormholes had been attacked by worms, too. They had entered through the silk channel and had either left through the same channel or died.

While the shucks were being removed an examination was made for the work of the earworm and for insect infestation, mold, and discoloration. The number of ears infested with insects or damaged by molds and discoloration was thus determined for each class of shuck covering.

At the time the notes were taken the earworms (*Heliothis obsoleta* Fab.) had completed their work. The black weevils (fig. 1) and a group composed of two or more species of small reddish brown beetles (fig. 2) were practically all the insects which infested the ears at that time. In this bulletin the black weevils are therefore termed "weevils" and the small reddish brown beetles are termed "beetles."

In making counts an ear was considered infested when only a single insect was found inside the shuck covering.

Practically without exception ears infested with weevils were also infested with beetles. For this reason the number of ears infested with beetles is the same as the total number of ears infested with insects.

The results of the investigations of the relation of the shuck covering to insect infestation are summarized in Table I.

TABLE I.—*Relation of the shuck covering of corn to insect infestation in the field.*

Kind of shuck covering.	Percentage of ears—		
	In each class of shucks.	Infested with—	
		Weevils.	Beetles.
Poor	48	52	96
Good, with wormholes	28	38	93
Good, without wormholes	25	9	56
Total		38	85

The total number of ears examined was 1,949. Of these, 48 per cent were in poor shucks, 28 per cent in good shucks with wormholes, and 25 per cent in good shucks without wormholes.

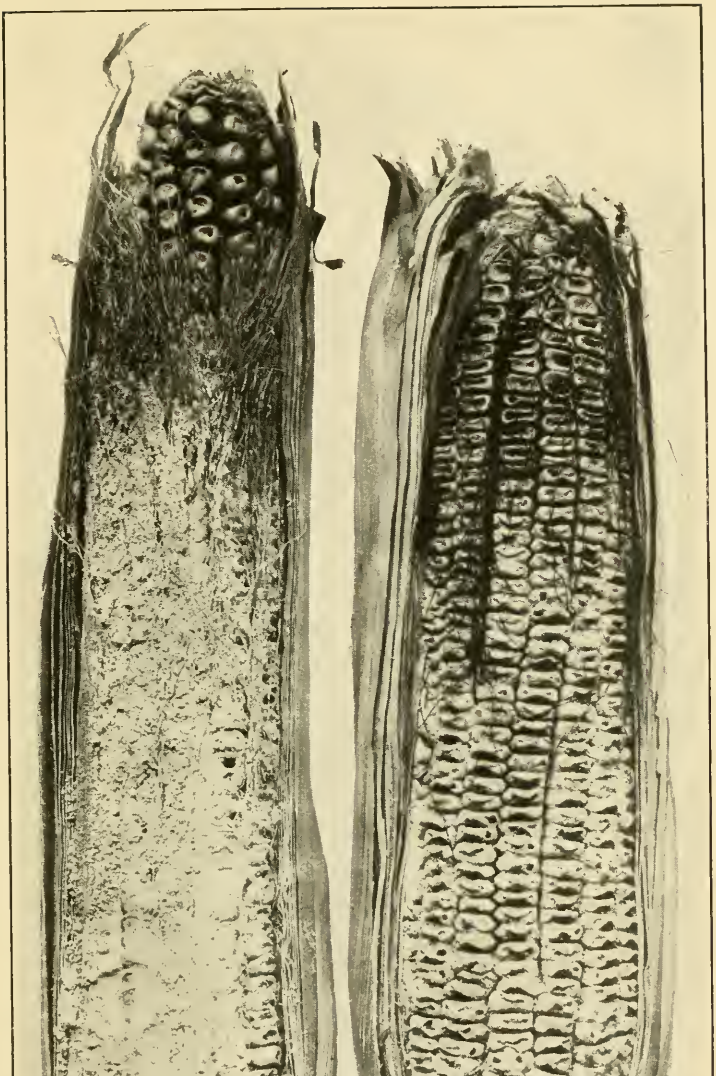
Of the ears in poor shucks, 52 per cent were infested with weevils and 96 per cent with beetles. Of the ears in good shucks with wormholes, 38 per cent were infested with weevils and 93 per cent with beetles. Of the ears in good shucks without wormholes, 9 per cent were infested with weevils and 56 per cent with beetles.

FIG. 1.—Black weevils (*Calandra oryza*), termed "weevils" in this bulletin.

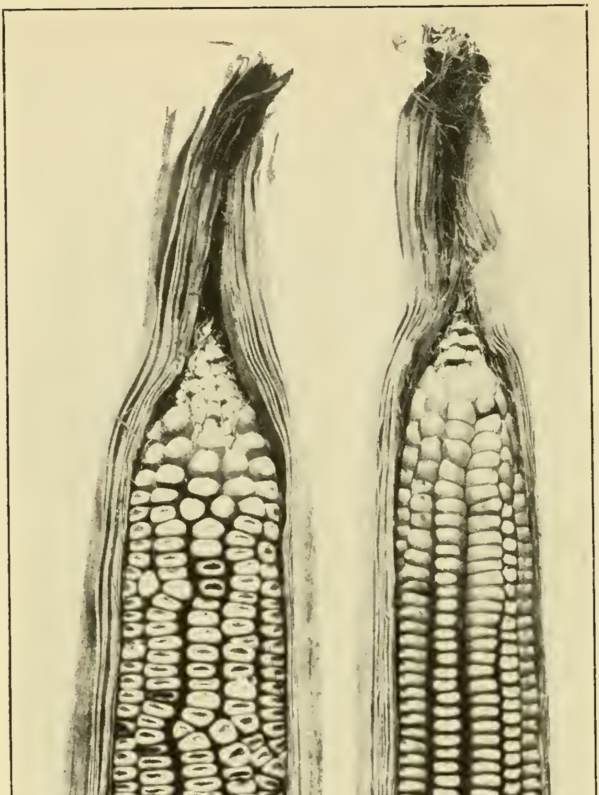
FIG. 2.—Species of small reddish brown insects, termed "beetles" in this bulletin.

A comparison of the classes with different shuck coverings shows 43 per cent more weevil infestation and 40 per cent more beetle infestation in poor shucks than in good shucks without wormholes. The wormholes through what was otherwise good shuck coverings permitted increased infestation amounting to 29 per cent for weevils and 37 per cent for beetles.

Thirty-eight per cent of all the ears examined were infested with weevils and 85 per cent with beetles. From the standpoint of infestation the beetles were the most serious of the two classes of insects; however, close examination failed to discover any damage



EARS OF CORN WITH POOR SHUCK PROTECTION AFTER TEN MONTHS IN FIELD AND STORAGE WHERE WEEVILS WERE VERY ABUNDANT.



EARS OF CORN WITH GOOD SHUCK PROTECTION AFTER TEN MONTHS IN FIELD AND STORAGE WHERE WEEVILS WERE VERY ABUNDANT.

that could be definitely attributed to them. As there was abundant evidence of damage due to the weevils, it was concluded that so far as these two classes of insects were concerned the weevils, though greatly outnumbered by the beetles, had undoubtedly done most of the actual damage to the grain.

STORAGE INVESTIGATIONS.

Representative ears in their shucks were taken from the plat in which the field investigations were made and stored in a tight galvanized-iron bin. In August, 1916, or about 10 months after the corn was first stored, the ears were classified in accordance with the kind of shuck covering found and then carefully examined for insect infestation.

Table II shows the relation of the shuck covering to the percentage of ears infested with weevils and beetles.

TABLE II.—*Relation of the shuck covering of corn to insect infestation after 10 months in storage.*

Kind of shuck covering.	Percentage of ears— Infested with— Weevils.	Percentage of ears— Infested with— Beetles.	Percentage of ears— Not infested.
Poor	97	100	....
Good, with wormholes	55	100	....
Good, without wormholes	4	77	23
Total	66	95	5

A total of 206 ears was examined. Of the ears in poor shucks, 97 per cent were infested with weevils (Pl. I) and 100 per cent with beetles, none being free from infestation. Of the ears in good shucks with wormholes, 55 per cent were infested with weevils and 100 per cent with beetles, while none was free from infestation. Of the ears in good shucks without wormholes, 4 per cent were infested with weevils and 77 per cent with beetles, 23 per cent being free from all infestation (Pl. II).

A comparison of the classes with different shuck coverings showed 93 per cent more weevil infestation and 23 per cent more beetle infestation in poor shucks than in good shucks without wormholes. The wormholes through what was otherwise good shuck coverings permitted increased infestation amounting to 51 per cent for weevils and 23 per cent for beetles.

In this, as in the field investigations, it was found that beetles infested many more ears than the weevils. If they were a factor in damaging ear corn of adapted varieties, the shuck covering would be much less important as a means of protection. Fortunately, this did not appear to be the case, as is shown by the data given in Table III.

TABLE III.—*Relative amount of damage done to corn by weevils and by beetles.*

Infestation.	Total number of ears.	Percentage of—	
		Ears with damaged kernels.	Damaged kernels.
Weevils and beetles together	135	100	60 to 75
Beetles alone	60	5	Trace.

From 60 to 75 per cent of all the kernels on the 135 ears infested with weevils and beetles together were seriously damaged. Of the 60 ears infested with beetles alone, 5 per cent were damaged by something. It is possible that worms or other insects not present at the time of the examination might have been the cause of this damage. At any rate the damage amounted to a mere trace on 11 kernels. It is evident, therefore, that the beetles when alone were of no practical importance in the corn studied. The 11 kernels whose damage is in question were softer than most of those in the varieties used in these studies. If the beetles did this damage, then it is probable that they did so because the comparative softness made it possible. Other investigations have shown that some of the comparatively soft-grain varieties of corn from outside the areas that are badly infested with grain insects may be directly damaged by beetles. This again suggests that kernel density may determine whether direct damage from beetles is possible, and emphasizes the importance of using adapted corn which may involve protective factors that have not yet been clearly recognized. Because of the importance of adapted varieties for practical purposes this publication is confined to the results with such varieties, and since the beetles were not an important damaging factor in this connection, these insects are not further considered here.

The lots of corn considered in Tables I and II were grown in the same plat and harvested at the same time, and were as comparable as it is possible for two lots of ears to be under similar circumstances. As the lot considered in Table I was examined for infestation at harvest time (October, 1915), and the lot considered in Table II was examined for infestation after about 10 months in storage (August, 1916), the differences between the percentages of infestation found at the time of examination should represent the gain in infestation during storage. The percentages of weevil infestation shown in Tables I and II are compared in Table IV.

TABLE IV.—*Relation of the shuck covering of corn to the increase in weevil infestation during storage.*

Kind of shuck covering.	Percentage of ears infested.		Increase or decrease during storage.
	October, 1915.	August, 1916.	
Poor	52	97	45
Good, with wormholes	38	55	17
Good, without wormholes	9	4	− 5

Of the ears in poor shucks, 52 per cent were infested in 1915 and 97 per cent in 1916. The infestation in 1916 was 45 per cent greater than in 1915. Of the ears in good shucks with wormholes, 38 per cent were infested in 1915 and 55 per cent in 1916. The infestation in 1916 was 17 per cent greater than in 1915. Of the ears in good shucks without wormholes, 9 per cent were infested in 1915 and 4 per cent in 1916. The infestation in 1916 was 5 per cent less than in 1915.

It seems a significant fact that during the period of storage the percentage of weevil-infested ears increased decidedly in poor shucks and in good shucks with wormholes, but there was no increase in the percentage of ears infested in good shucks without wormholes. These data, coupled with the fact that no evidence could be found showing that weevils attempt to cut the shucks, indicate that the right kind of shuck covering is an effective barrier to this class of insects.

LABORATORY INVESTIGATIONS.

It is probable that the insects in seeking their food follow the line of least resistence. Under ordinary field and storage conditions they naturally attack the ears with least protection first and successively attack those with greater protection as the demand for food increases. While the investigations discussed on the preceding pages show that the better class of shuck protection successfully resisted insect damage under existing conditions, it is natural to suppose that insects which can eat the hardest kernels (fig. 3) of corn would also cut their way through the protecting shucks if sufficiently urged by hunger. With ordinary field and storage conditions it has always been possible for weevils to find some food, and for this reason it was not necessary to force a way to the corn in the best shucks in order that they might avoid extinction. With complete success in the breeding of ideal shuck coverings this last condition might arise, and it is desirable to know whether the acquired shuck coverings would prevent infestation under such conditions. To determine this point a number of weevils were confined in properly ventilated jars with ears of corn in good shuck coverings, but with no other source of food. The test was begun in August, while the temperature was high and the weevils very active. By the following December all the weevils were dead and dry, none had reached the grain, and no evidence could be found that they had attempted to force their way through the shuck protection to the grain.

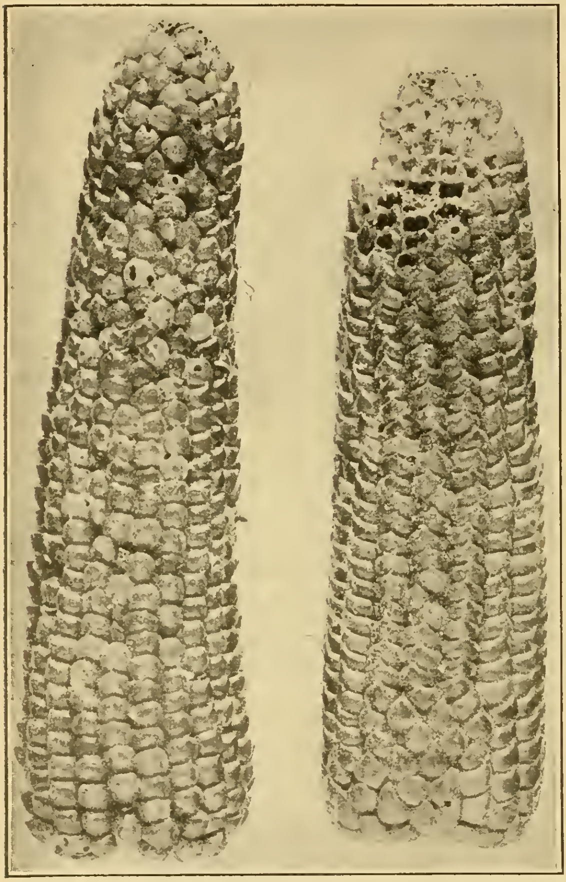


FIG. 3.—White Rice pop corn damaged by weevils. These insects can eat the hardest corn.

As a logical part of this test, some weevils were confined in jars with ears of corn from which the shucks had been removed. This part of the test was identical with the first, with the exception that in this case there was no shuck protection. With four or five exceptions, the weevils were alive at the final examination and had done a very serious amount of damage to all the ears.

This test makes it evident that while it seems that these insects should be quite able to cut through all of the shuck covering that corn may have, they, in fact, will not do so, even though they must starve if they do not.

RESULTS OF INVESTIGATIONS IN 1916.

On October 6, 1916, at Thomasville, Ga., a quantity of corn was selected from a field and examined for ear damage. The variety in this case was one of those used in the 1915 investigations. As may be gathered from the data, it had a wide range of protective adaptation. As the field was located about one-fourth of a mile from places where old infested corn was stored, the opportunity for weevil infestation was very good. The worm damage is believed to have been exceptionally severe.

The ears examined were of three classes. The first class had shucks extending from 4 to 6 inches and the second class from 2 to 3 inches beyond the tips of the ears; the third class had practically no shucks extending beyond the tips of the ears. The relation of shuck covering to infestation as it was found in these classes is shown in Table V.

TABLE V.—*Relation of the shuck covering of corn to insect infestation in 1916.*

Kind of shuck covering.	Number of ears examined.	Percentage of ears—		
		Attacked by worms.	Infested with weevils.	Affected with worm mold.
Extending 4 to 6 inches beyond tips of ears	111	72	9	64
Extending 2 to 3 inches beyond tips of ears	102	87	22	77
Practically no extension	100	96	100	91

Of the 111 ears with shucks extending from 4 to 6 inches beyond the tips of the ears, 72 per cent had been attacked by worms, 9 per cent had been infested by weevils, and 64 per cent had been affected with worm mold. Of the 102 ears with shucks extending from 2 to 3 inches beyond the tips of the ears, 87 per cent had been attacked by worms, 22 per cent had been infested with weevils, and 77 per cent had been affected with worm mold. Of the 100 ears with practically no shuck extension beyond the tips of the ears, 96 per cent had been attacked by worms, 100 per cent had been infested by weevils, and 91 per cent had been affected with worm mold.

In the case of worms, 15 per cent fewer ears were attacked in the 4 to 6 inch extension shucks than in those having 2 to 3 inch extensions, and 24 per cent fewer than where there was practically no extension. There were 13 per cent fewer ears infested with weevils in the 4 to 6 inch than in the 2 to 3 inch extension shucks and 91 per cent fewer than in the shucks having practically no extension, while 13 per cent fewer ears were affected with worm mold in the 4 to 6 inch extension shucks than in the 2 to 3 inch extension shucks, and 27 per cent fewer than in those having practically no extension.

These figures make it clear that length of shuck extension is a controlling factor in the matter of ear damage. In addition, the relationship between the length of shuck extension and the percentage of ears attacked by worms is of special interest because, in connection with the following evidence, it suggests a possible means of overcoming the most serious obstacle in the way of making a perfectly effective shuck protection for practically all of the ears.

SHUCK EXTENSION AS A PREVENTIVE OF WORM DAMAGE.

The foregoing discussion has made it clear that earworms may be responsible (directly and indirectly) for much damage to corn. The fact that earworms can and sometimes do cut holes through a large percentage of the protecting shucks would seem to be an insurmountable barrier to those who would breed for shuck protection against weevils. It has been shown (Table V), however, that the proportion of ears attacked by worms tends to decrease as the shuck extension is increased.

The earworms usually enter the shuck coverings through the silk channels, feeding on the silk as they go, the holes through the shucks being made when they are leaving. If while feeding on the silks and with its hunger not yet satisfied a worm reaches an ear which is sufficiently tender to be attractive, it may feed upon the kernels and cob for a time before cutting out. If, however, during its progress along the silk channel the silks become unpalatable on account of age or the worm reaches maturity, it may abandon its course before reaching the ear. Reasoning along this line, one naturally concludes that the longer the shuck extension or silk channel the more likely it is that worms will leave the shucks before they reach the grain. This conclusion is supported by the data presented in Table VI. The ears examined for this information were a part of those examined to obtain the information given in Table V.

TABLE VI.—*Relation of the length of shuck extension of ears of corn to the worm damage.*

Kind of shuck covering.	Total number of ears examined.	Percentage of ears not eaten because worms cut from silk channels before reaching the grain.
Extending 4 to 6 inches beyond tips of ears	111	14
Extending 2 to 3 inches beyond tips of ears	102	7
Advantage due to the longer shuck extension		7

It may be seen that of the 111 ears with shucks extending from 4 to 6 inches beyond the tips of the ears, 14 per cent had escaped damage because the worms had cut from the silk channels before reaching them. It may also be seen that of the 102 ears with shucks extending from 2 to 3 inches beyond the tips of the ears, 7 per cent had escaped damage because the worms had cut from the silk channels before reaching them.

By comparison it may be seen that the longer shuck extension afforded 7 per cent more protection than the shorter shuck extension.

These investigations, in part at least, show why shuck extension reduces the amount of worm damage. In addition, they suggest the possibility of breeding a shuck extension long enough to be entirely effective against earworms. The extent to which the earworms can be eliminated by the means suggested can only be determined by other investigations.

RELATION OF SHUCK COVERING TO MOLD AND DISCOLORATION.

The relation of shuck covering to the mold and discoloration of corn was studied in the field in connection with the investigations in 1915 of the relation of shuck covering to insect infestation. The affected ears were classed as rotten, discolored, or worm moldy.

Those ears termed "rotten" were extensively affected by molds and would have been rejected by anyone culling to improve the grade of the corn.

Those ears termed "discolored" had some kernels slightly affected by molds, stained by the shucks, checked by small cracks, or they were tarnished as though they had been soaked in water. Most of this discoloration would not have been given serious consideration by the average observer.

The ears termed "worm moldy" were such as were affected by mold that seemed to have been made possible by the attacks of earworms. These ears, because of their large number and the slight damage done, would not have been discarded by the most fastidious in an attempt to improve the grade.

As this corn was examined comparatively early in the fall, a large percentage of the stalks standing erect and the ears not shaded by vines, weeds, or other growth, and as the seasonal conditions for drying the mature ears were favorable, the proportion of damaged corn was much less than may often be seen in the section covered by these investigations.

For these investigations the ears were separated into classes with poor shucks and with good shucks. The class with good shucks includes both those with and without wormholes. In other respects the classification is the same as that for the investigations involving insects. The results of the investigations of the relation of the shuck covering to rotten, discolored, and worm-moldy ears are summarized in Table VII.

TABLE VII.—*Relation of shuck covering to the percentage of ears of corn found to be rotten, discolored, or having worm molds.*

Kind of shuck covering.	Percentage of ears—		
	Rotten.	Discolored.	Worm moldy.
Poor	4	34	58
Good	1	18	40
Total	3	27	50

A total of 1,157 ears was examined. Of the ears in poor shucks, 4 per cent were rotten, 34 per cent were discolored, and 58 per cent were affected with worm mold. Of the ears in good shucks, 1 per cent were rotten, while 18 per cent were discolored and 40 per cent were worm moldy.

A comparison of the classes with different shuck coverings shows that 3 per cent more ears in poor shucks than in good shucks were rotten, 16 per cent more were discolored, and 18 per cent more were affected with worm mold.

GENERAL VALUE OF A GOOD SHUCK COVERING.

Of all the ears of corn produced in the United States each year, comparatively few entirely escape damage. Most of them lose only a few kernels because of earworms or other insects or are more or less reduced in value by molds or discoloration. This damage is usually passed without concern, but when it is considered that a loss of only one kernel per ear amounts to an annual loss for the United States of at least 5,000,000 bushels and that this amount must be multiplied several times to represent the total annual loss, it becomes apparent that these losses are worthy of attention. It seems that by improving the shuck protection ear damage in any section can be considerably reduced, but such protection can be made of the greatest value in sections infested with weevils. Some special advantages of shuck protection in a weevil-infested section are mentioned below.

ADVANTAGES IN THE FIELD.

The relation of the shuck covering to the percentage of damaged kernels is illustrated by the figures presented in Table VIII. These data were obtained on October 6, 1916, from two of the lots of ears considered in Table V.

TABLE VIII.—*Relation of the shuck covering of corn to the percentage of damaged kernels.*

Kind of shuck covering.	Number of ears examined.	Percentage of kernels damaged.			Total.
		By weevils.	By earworms.	By worm mold.	
With practically no extension	100	14	6	[a] 4	20
With an extension of 4 to 6 inches beyond the tips of the ears	111	0	1	[a] 1	1
Advantage in favor of shuck extension		14	5		19

[a] These figures are included in those for worm-eaten kernels.

With practically no shuck extension, 14 per cent of the kernels were damaged by weevils, 6 per cent by worms, and 4 per cent by worm mold. No kernels with shuck extensions of 4 to 6 inches were damaged by weevils, 1 per cent were damaged by worms, and 1 per cent by worm mold. The ears in shucks with practically no extension had a total of 20 per cent of their kernels damaged, while in the ears with shuck extensions only 1 per cent were damaged. It is evident, therefore, that the long shuck extension effected a saving of 19 per cent in the field. This saving could not have been effected by earlier harvesting and fumigation, because the corn was taken from the field as soon as it was sufficiently dry to permit storage.

ADVANTAGES IN STORAGE.

There is some conflict of opinion regarding the matter of storing corn in the shuck. Some believe that corn stored in the shuck is more or less protected from weevils because of the shucks. Others reason that these insects enter the shucks in the field and then, being carried with the ears put in storage, they are able to continue their work of destruction. They further reason that if the shucks were removed in the field many of the insects would be left behind, and to that extent the damage would be lessened. The facts presented on the foregoing pages have shown that the right kind of shuck covering is not entered by weevils, but that poor or defective shucks may be entered. It is evident, therefore, that so far as weevil damage is concerned, the advantage or disadvantage of the method of storing corn in the shuck is determined by the kind of shuck covering on the corn stored. A certain number of ears in all varieties are exposed in the field. To store such ears in their shucks after the grain has become infested is to make conditions most favorable for the insects. To shuck them in the field is to leave a part of the insects behind, but as these ears still contain adults, larvæ, and eggs, destruction will continue, and they will remain a source from which uninfested and exposed corn may become infested.

On the other hand, there are usually some ears in varieties native to weevil-infested sections that because of their effective shuck coverings do not become infested with weevils. To store such ears in their unopened shucks is to afford them continued protection. To shuck such ears is to expose them to the attacks of insects, including the Angoumois grain moth, unless they are protected by other means. The average farmer does not use other effective means of protection, because they involve additional cost and, in the case of fumigation with carbon bisulphid, extra fire risk. Shuck protection involves no additional cost and no extra fire risk. It seems, therefore, that a storage method that utilizes shuck protection will very greatly increase the practice of holding and feeding corn on farms in weevil-infested areas. Such a method is outlined as follows: Grow the best shuck-protected corn, store the shuck-protected ears in their shucks, and feed or sell the unprotected ears as early as possible.

If there is a considerable percentage of unprotected ears, as is always the case at present, and these ears are known to be infested, they should be shucked as early as possible and kept away from uninfested corn. The shucking should be done in such a way that the dislodged insects may be swept together and burned.

ADVANTAGES IN MARKET QUALITY.

The price of corn is governed in part by its commercial grade. In order to improve the grade of corn offered on the market, growers are sometimes advised to cull the damaged ears. It is practicable to cull only such as are extensively damaged. After culling, there may be as much or more damaged corn remaining as was removed, because it is scattered through a large percentage of the ears in the form of discolored and worm-moldy kernels. It has been shown (Table VII) that shuck protection reduces both of these kinds of damage. For this reason it also makes possible a higher grade of corn than can otherwise be secured.

RELATION OF INCREASED SHUCK PROTECTION TO THE COST OF SHUCKING.

There is a noticeable variation in the amount and kind of shucks on corn grown in different sections of the United States. Whenever unshucked corn is subjected to weevil attack, the ears with poor shuck protection are more or less damaged and to that extent are eliminated from the corn to be used for seed. This, then, leaves a higher proportion of the sound corn on ears with good shuck protection. For this reason, the natural tendency, with other circumstances favorable, has been toward the use of seed from ears with good shuck protection. So, as a general rule, varieties native to weevil-infested sections have a heavier and longer shuck than those native to sections without weevils. Notwithstanding the overpowering influence of natural circumstances in weevil-infested sections and its weaker influence in other sections, there has been a general tendency on the part of corn growers toward a lighter and shorter shuck. The chief reason for this preference has been the desire to reduce the amount of hand labor required to shuck the ears.

In some varieties commonly grown in weevil-infested sections, the shuck protection can be greatly improved without producing a greater amount of shuck. This can be done by improving the shape of the present shucks by means of selection, having in view longer and closer fitting coverings. Then, too, improved machinery is now available which may be made to meet any objection to the increased quantity of shuck that is necessary to protect the ears. These machines are known as "shuck shellers" and are now commonly used by the larger grain and feed dealers in the South. Either the shucked or unshucked ears, after having been broken from the stalks, are handled by these machines. In the case of ears in the shucks, the shelled grain, the cobs, and the shucks are separated. The shucks are usually baled and sold for feed, but occasionally mattress and other factories take a part of the output. Some of the companies have received inquiries from paper manufacturers regarding the quantity of shucks they could supply, but up to the present time there has been an insufficient quantity available to justify the paper companies in entering the market for them. Wherever such data could be obtained it was found that the amount obtained from the sale of shucks fully covered the cost of shelling and separation, and there seems to be no chance of an overproduction. It appears, therefore, that increased shuck protection need not increase the present cost of shucking.

THE PRODUCTION OF BETTER SHUCK PROTECTION.

There is abundant evidence to indicate that shuck covering responds to selection. Some of this evidence is summarized as follows: (1) Varieties native to weevil-infested sections usually have a higher percentage of ears in good shucks than do those native to sections where no weevils are found. (2) Varieties native to sections with comparatively few weevils and with poor shuck covering, after having been grown for a number of years in sections very seriously infested with weevils, were found to have as good shuck coverings and as much resistance to weevils as the average native variety. (3) The percentage of ears in good shucks has been increased by systematic selection.

All the known efforts in this line of selection have been of short duration, but they indicate that with similar methods and equal effort progress will be as rapid as that in other lines of selection.

Further investigations are required to determine all the points to be desired in the ideal shuck covering, but it is certain that the portion of the shucks that extends beyond the tips of the ears should be very long and that it should fit tightly about the silks.

The shuck covering can probably be improved in any variety, but some varieties have a greater range of shuck variation than others, and, with other qualities equally good, it would be desirable to start systematic breeding with one of these. Even in those varieties offering the greatest opportunities the ears with ideal shuck extensions are exceptionally rare. With varieties in this low state of selection it will necessarily require several years of the most exacting selection to attain uniform success. The breeder, however, should be encouraged in his efforts by the thought that while he must begin with exceptionally little, the advantage resulting from complete success will be exceptionally pronounced. Certainly the man who has labored to produce higher yields by selection should be attracted by this promising opportunity to save a part of the corn crop. It is usually impossible to prove that the breeder has increased the yielding power of his variety by selection, but the results of selection for better shuck protection are apparent to the eye.

SUMMARY.

The investigations reported upon in this bulletin had for their object the establishment by positive means of some of the most important facts regarding the merits of shucks as a means of preventing damage to ear corn.

Field investigations showed 4 ; per cent more weevil infestation in corn with poor shucks than in that having good shucks without wormholes.

Storage investigations showed 9 ; per cent more weevil infestation in corn with poor shucks than in that with good shucks without wormholes.

Laboratory investigations showed that weevils would starve rather than force their way through good shuck covering.

These investigations showed per cent more rotten, 16 per cent more discolored, and 18 per cent more worm-moldy ears in poor shucks than in good shucks.

The so-called good shucks of these investigations were not ideal, but only better than the so-called poor shucks. The later investigations made it clear that the longer the shuck extension beyond the tips of the ears, the more effective is the protection against causes of damage, including earworms. This suggests the possibility of breeding a shuck extension long enough to be entirely effective against ear damage.

Increased shuck protection need not increase the cost of shucking if proper use is made of shuck-shelling machinery.

These investigations appear to justify the following recommendations:

(1) Breed corn with a very long shuck extension that fits tightly about the silks.

(2) To better protect ear corn in the fields from weevils, earworms, molds, and discoloration, grow the best shuck-protected corn.

(3) To make practicable the more general holding and feeding of corn on farms in the weevil-infested areas, store shuck-protected ears in their shucks and feed or sell the unprotected ears as early as possible.

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UNITED STATES DEPARTMENT OF AGRICULTURE

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Contribution from the Bureau of Entomology
L. O. Howard, Chief
and the Federal Horticultural Board, C. L. Marlatt, Chairman

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THE PINK BOLLWORM[1] WITH SPECIAL REFERENCE TO STEPS TAKEN BY THE DEPARTMENT OF AGRICULTURE TO PREVENT ITS ESTABLISHMENT IN THE UNITED STATES.

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CONTENTS.

HISTORICAL.

In 1842 the superintendent of the Government cotton plantations at Broach, India, sent specimens of a very destructive cotton insect to the distinguished English entomologist, W. W. Saunders. The specimens were described as a new species, *Depressaria* (now *Pectinophora*) *gossypiella*, by Mr. Saunders in a paper presented to the Entomological Society of London on June 6, 1842 (9).[2] This is the first published record concerning the insect which is now attracting so much attention in the principal cotton-producing countries of the world.

For 61 years after the publication of Saunders's description no published statement regarding the pink bollworm was issued. In 1904, however, an article was issued by J. Vosseler (10) regarding the great injury done by the insect in German East Africa. Within

[1] *Pectinophora gossypiella* Saunders; order Lepidoptera, family Gelechiidae.
[2] Numbers in parentheses refer to "Literature cited," p. 27.

the next few years several additional articles dealing with the problem caused by the pest in German East Africa appeared. In 1909 D. T. Fullaway (5) published an account of the pink bollworm and its relation to cotton culture in the Hawaiian Islands, stating that it appeared to have been introduced from India within a very few years.

Only a few more or less technical papers were published from 1909 to 1913. Since the latter date a considerable literature has been built up, consisting largely of papers emanating from Egypt, where the pest has attracted increasing attention.

ORIGINAL HOME.

The original home of the pink bollworm is probably India and possibly Southern Asia generally, and its original host plants were the wild and cultivated cottons of that region. If this natural range of the insect extended to Africa it must have been limited to Central Africa and at least it did not extend to the Nile Valley region where cotton has been an important cultivated crop for a century or more. The occurrence of the insect in Egypt is apparently traced definitely to large shipments of seed cotton or imperfectly ginned cotton from India in 1906–7, and the spread of the insect from the points in the lower Delta near Alexandria, where this cotton was sent for reginning, throughout the Delta, and ultimately throughout Egypt, is so circumstantial as to leave no doubt as to the entry of the insect at that time into Egypt. With the first occurrence of the insect in Egypt it was confused more or less with other insects commonly found in cotton bolls in that country, and this confusion led to a statement by Dudgeon (4) that this insect had probably been in Egypt for many years. The careful investigation of the situation and determination of original points of infestation and spread by expert entomologists in the employ of the British and Egyptian Governments have fully disproved this early surmise and pointed out the circumstantial introduction of the insect into Egypt as noted.

As already noted, the pink bollworm has been recorded as a cotton pest in India since 1842, and the original report made by the Superintendent of the Government Cotton Plantation at Broach, India, is of sufficient importance to be given in full, as follows:

> The inclosed is an insect which was very destructive to the American cotton which was sown here (Broach) on light alluvial soil. The egg is deposited in the germen at the time of flowering, and the larva feeds upon the cotton seed until the pod is about to burst, a little previous to which time it has opened a round hole in the side of the pod for air, and at which to make an exit at its own convenience, dropping on the ground, which it penetrates about an inch, and winds a thin web in which it remains during the aurelia state. Curious enough, the cotton on the black soil was not touched by it. The native cotton is sometimes affected by it.

The significant thing in the paragraph is the statement that the insect was very destructive to the American cotton and that "*native cotton is sometimes affected by it.*" The fact that the American cotton was much more affected than the native varieties is in accord with the general experience with imported plants in relation to native plant pests, and with introduced pests in respect to native plants. The American variety was apparently unresistant in comparison with the native cottons of India which, with little doubt, had been long associated with this pest and which have developed a certain amount of resistance.

The later records of this insect show that it was reported from India on several occasions prior to 1900 or about that period, and those records determined also its occurrence eastward through Burma, Siam, and the Philippines, long prior to what was undoubtedly its original entry into Egypt in 1906–7.

The insect was first noted in Egypt in 1911, and the first severely infested field, one near Alexandria, was noted in the year following (1912). The increase of the damages from this insect in Egypt has been steady since 1912 and this in spite of very laborious and expensive control operations enforced by the Egyptian Government.

The present distribution, therefore, of the pink bollworm is reasonably traceable to spread from Southern Asia in comparatively recent years. The possible exception is German East Africa, and even there the natural explanation of its occurrence is its recent introduction with cotton imported from India, although there is the possibility, already noted, that the natural range of the insect may have included Central Africa and that the African infestation may therefore have come from such native stock.

PRESENT RANGE.

With the exception of two infestations in Texas, which it is hoped will be stamped out, the known range of the pink bollworm is as follows:

East Africa, West Africa, Egypt, Nigeria, Sudan, Zanzibar, India (very generally), Bengal, Ceylon, Burma, Straits Settlements, China, Philippines (Luzon), Hawaii, Brazil, and Mexico. There is also a record from Japan, although this may be erroneous. At any rate it is not confirmed by Prof. Kuwana, government entomologist, according to a statement published by Fullaway (5). The introduction of the pink bollworm into Brazil and Mexico is very recent, and the available records show very clearly how it was accomplished. As these are of special interest at the present time, the particulars will be given.

The information from Brazil comes through Mr. Edward C. Green, superintendent of the Cotton Department of the Ministry of Agriculture, who has published a very full statement on the subject (8). During 1913 Mr. Green made a trip of inspection through the greater portion of the cotton-producing area in Brazil. Special attention was paid to the seed, not only in the fields but in the ginneries, and no infestation was found. In 1916, however, another trip showed that the pink bollworm was present over wide areas in the States of Parahyba, Rio Grande del Norte, and Ceara. It seems that in the years 1911, 1912, and 1913, the Government of Brazil imported nine tons of Egyptian cotton seed. This seed was not fumigated as it was not suspected that any injurious insect was likely to be carried by it. A test for germination showed 89 per cent viable. It is altogether likely that a percentage of the unviable seeds were those attacked by the pink bollworm. All of this seed was sent to agricultural inspectors in various States and by them was distributed further throughout the cotton-growing districts.

There can be no doubt that the general establishment of the pink bollworm in Brazil was due to the importation of the Egyptian seed, and that incalculable losses to the country could have been avoided if proper quarantine precautions had been taken.

In Mexico the pink bollworm was introduced in 1911. During that season two importations of Egyptian seed were made. One consisted of 125 sacks and was planted near Monterey; the other, of 6 tons, and this was planted in the vicinity of San Pedro in the Laguna. From what is known of the abundance of the pink bollworm in Egypt in 1911 it is probable that both shipments of seed were infested and that both of them contributed to the present infestation in Mexico. It is true that cotton culture has not been continued in the vicinity of Monterey, but the crop of Egyptian cotton produced there in 1911 attracted considerable attention and much of the seed was shipped to the Laguna.

The work of determining the spread of the pink bollworm in Mexico was greatly facilitated by the cooperation of the Mexican Government. The Minister de Fomento, Sr. Pastor Rouaix, Sr. José Duvallon, Director de Agricultura, and Prof. Julio Requelme Inda of his department, showed the greatest interest in the matter as soon as the presence of the pink bollworm in Mexico was known. Sr. Duvallon dispatched a special representative, Sr. Alfonso Madariaga, to Northern Mexico, where he spent some months in making examinations in the Laguna. His findings corroborated in every way the discoveries made by Mr. Busck.

Very recently specimens of the pink bollworm have been received from China. They were collected by Mr. H. H. Jobson, who at the present writing (May, 1918) has just returned from China. Mr. Jobson's notes are as follows:

The collection which I have was secured from the seed room of one of the ginneries in Shanghai and from the fields at Tungchow, about 12 hours' ride by boat up the river from Shanghai. The infestation is more or less general throughout China; however, there may be some small areas where it is not present. A majority of the cotton grown within a radius of 100 miles of Shanghai is shipped into that port before being ginned, and from evidences found at the ginning establishments there is no doubt but what all those regions are infested. In fact, the larvæ are so numerous that by going into the seed room of the gins a person may secure any number of them within a very short time, as they may be seen crawling around over the seed and on the walls.

PRESENT DISTRIBUTION IN MEXICO.

As far as absolutely definite evidence shows, the pink bollworm is confined to three localities in Mexico, one of which is the Laguna district, a valley isolated by mountain ranges about 200 miles from the Texas border. The Laguna, in which the bulk of the total Mexican crop is produced, consists of about 1,200 square miles of land. Mr. August Busck, on a trip to Mexico in the early part of 1917, obtained samples of cotton seed from 40 of the estates in that region. Thirty of these samples were found to be infested and later records indicate infestation on ranches from which no insects in the seeds were received. In short it is evident that through the shipment of cotton seed from one part of the Laguna to another and possibly through the flight of the insect, the pink bollworm has become generally established there. Although the distribution of the pest is naturally irregular at the present time, it is certain that it will become uniform in the course of a few years, and that most energetic steps must be taken by the planters to control or eradicate the insect. Other localities known to be infested in Mexico are Allende, about 40 miles south of Eagle Pass, and the Trevino ranch, immediately opposite Del Rio. In both cases the infestations were the result of the receipt of seed from the Laguna.

NATURE AND AMOUNT OF DAMAGE.

The pink bollworm affects cotton production in several ways. In the first place it destroys a certain number of bolls or portions of bolls, in which case the lint produced is short and kinky (fig. 1). The injury, however, does not end with the reduction in the yield of lint. The crop of seed is correspondingly reduced, and what is obtained is of light weight and poor grade. In the crushing of Egyptian seed in England it was found that the oil content was lower than normal by about 20 per cent, and that the oil actually secured was of dark color and comparatively low value. The work of the insect is also of importance in connection with seed for planting. The percentage of germination is naturally low and much larger quantities must be planted to secure a stand.

It is evident from what has been said that the pink bollworm must be of interest to all classes of persons concerned in the cotton trade as well as to those engaged more especially in the cultivation of the crop and the utilization of the seed.

The most accurate information concerning the damage by the pink bollworm is in a recent paper by L. H. Gough (7). This investigator conducted studies in lower and middle Egypt to determine the number of bolls attacked by the pink bollworm. The samples consisted each of 100 green bolls taken at random in fields in various localities. These samples were sent to Cairo where they were given a very careful examination. The total number of bolls examined in

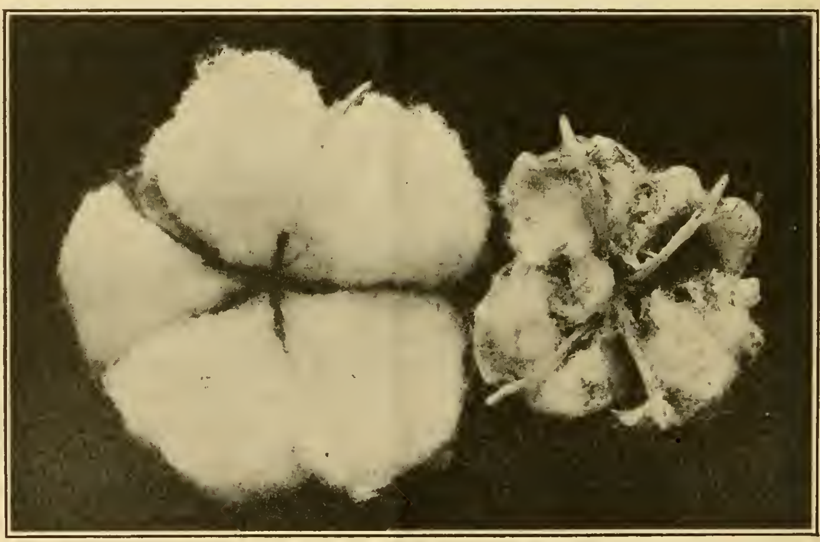

FIG. 1.—At left, normal cotton boll; at right, boll injured by the pink bollworm.

this work was 106,400, and the examinations were continued from July to November. The following are the results of this investigation:

Percentage infested during July, less than 10.
Percentage infested during August, from 10 to 25.
Percentage infested during September, from 25 to 75.
Percentage infested during October, from 75 to 89.

These figures show in a very striking manner the great damage of which the pink bollworm is capable. They may be taken as a fair indication of the injury which would be done in the United States, as the seasonal conditions here are similar to those in Egypt. In short they show that approximately 25 per cent of August bolls and 50 per cent of the September bolls would be destroyed or rendered practically valueless by the insect. They further illustrate the rapid increase of infestation of green bolls with the advance of the season, and indicate the possibility of a high reduction of yield, particularly in all late-maturing cottons where the second and third pickings are of importance. Fortunately for Egypt, one of the principal varieties of cotton grown there, the Sakellarides, matures its crop early and yields most of its cotton with the first picking. In spite of this favorable condition, however, and of expensive control operations enforced by the Government, a very conservative estimate by experts indicates a loss of at least 17 per cent to the Egyptian crop due to this insect. In the Hawaiian Islands the pink bollworm has prevented the development of the cotton industry which at one time showed considerable promise. With relation to German East Africa a statement is made that the pest normally becomes so abundant in two or three years after its introduction in the field as to necessitate abandoning the crop (11).

In Brazil the Minister of Agriculture recently has collected data for an estimate of the damage to the cotton crop caused by the pink bollworm by addressing communications to the governors of the principal cotton-producing states of the Republic. The following is a summary of the results of this investigation:

Losses on account of ravages of pink bollworm in Brazil: Crop of 1917.

Brazilian state.	American currency.
Maranhac	$ 750,000
Piauhy	500,000
Ceara	10,000,000
Rio Grande do Norte	2,500,000
Parahyba	5,925,000
Pernambuco	5,750,000
Alagoas	1,575,000

The loss referred to in the table ran from 30 per cent of the crop in the State of Alagoas to two-thirds of the crop, or 30,000 metric tons, in the State of Ceara.

In Mexico the actual injury caused by the pink bollworm was investigated by the Joint Commission representing the Mexican and American commissions. This commission visited many plantations in the Laguna in 1917. It reported that the loss to the crop of 1917 chargeable to the pink bollworm was not less than 30 per cent. Mr. August Busck, who was a member of the commission, personally estimated losses ranging from 30 to 50 per cent, with individual fields showing even higher losses.

DESCRIPTION AND LIFE HISTORY.

The pink bollworm has four stages, namely, egg, larva, pupa, and adult or moth. The moth (fig. 2) resembles somewhat the common clothes moth of this country. From tip to tip of the extended wings it measures from three-fifths to four-fifths of an inch. It is of a dark-brown color, the forewings ending in a rather sharp point. The hindwings are somewhat broader than the forewings and end in an even sharper point. The eggs are very small objects, somewhat oval, about one-twenty-fifth of an inch long and one-fiftieth of an inch broad. The surface is white and finely wrinkled. The larva (fig. 3) when first hatched is glassy white with light-brown anterior markings. It grows rapidly, and when mature measures nearly a half inch in length. It is cylindrical, white, with the dorsal side strongly colored with pink.

FIG. 2.—The pink bollworm (*Pectinophora gossypiella*): Adult. Much enlarged. (Busck.)

The pupa (fig. 4) is about two-fifths of an inch in length, reddish brown, the posterior end pointed and ending in a hooklike process.

There are several insects found in bolls of cotton in the United States which may be mistaken for the pink bollworm. One of these is the so-called pink cornworm or scavenger bollworm (*Pyroderces rileyi* Walsingham), which frequently is found in decaying bolls, especially those which have been injured by disease. It has not been known to attack healthy bolls. It does not normally make its way into the seed, and this fact will help in distinguishing it from the pink bollworm. Another insect which may be mistaken for the pink bollworm is the common bollworm of cotton (*Chloridea obsoleta* Fabricius). This is the same insect that feeds on corn and is known in some parts of the country as the corn earworm. It bores holes through the carpels of the bolls, feeds for a short time, and then proceeds to another

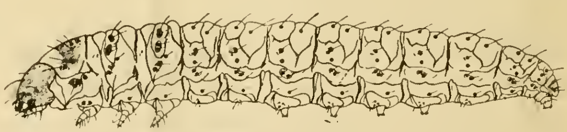

FIG. 3.—The pink bollworm: Outline drawing of larva, showing structure. Much enlarged. (Busck.)

boll. In the early stages it sometimes assumes a somewhat pinkish color. It may be distinguished from the pink bollworm by its habits, especially by the fact that it does not feed altogether in the interior of the bolls and that it is not found within the seeds. When full grown it is much larger than the pink bollworm, measuring about 2 inches in length.

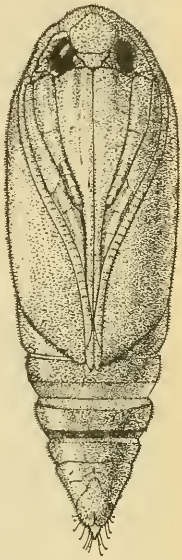

FIG. 4.—The pink bollworm: Pupa. Much enlarged. (Busck.)

The insect most likely to be mistaken for the pink bollworm is the boll weevil. Although the boll weevil is sometimes found in seeds, it generally is found feeding within the interior of the boll. It discolors the fiber considerably, and this causes the interior of the boll to assume a more or less decayed appearance, quite unlike the appearance of bolls infested by the pink bollworm, in which decay generally does not occur. *This so-called cleanliness of the work of the pink bollworm is one of the most useful characteristics in differentiation.*

The accompanying illustrations will assist the reader in deciding whether the work in question is that of the pink bollworm or some other insect found in cotton bolls.

FIG. 5.—Exit holes of pink bollworms in cotton bolls.

Figure 5 shows on the left the appearance of the interior of an injured boll, and on the right the characteristic small circular opening made by the larva for the purpose of allowing the adult to emerge.

Figure 6 shows on the left the characteristic opening made by the ordinary bollworm (*Chloridea obsoleta*). It is of large size and surrounded by a raised margin. The exit holes of the pink bollworm, on the left, are much smaller, more regular, and without raised margins.

Figure 7 shows the appearance of locks of cotton, exhibiting typical injury by the pink bollworm.

Figure 8 shows individual seeds infested by the pink bollworm. In the lower line are the "double seeds." These are frequently

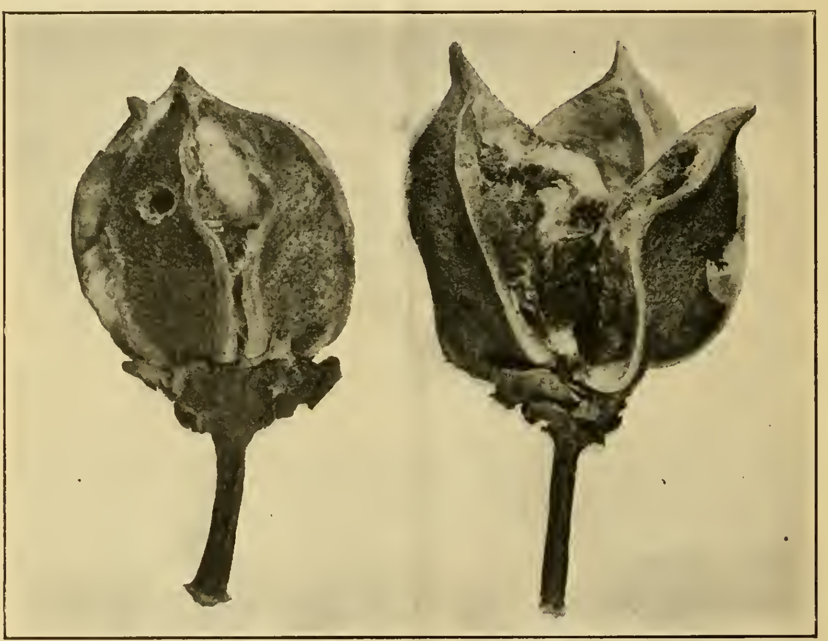

FIG. 6.—Two bolls showing distinction between exit holes of the ordinary bollworm or corn earworm (*Chloridea obsoleta*) and those of the pink bollworm (*Pectinophora gossypiella*). The large hole in the boll to the left was made by the ordinary bollworm and the two small ones in the boll to the right are typical of the pink bollworm.

found as the result of the webbing together of two seeds by larvæ of the later stages in order to obtain more room for pupation.

Figures 9 and 10 illustrate the pink bollworm in a burr and the typical opening made by this insect when it makes its way from one lock to another.

Although these descriptions may help in enabling any one to determine whether the pink bollworm is present in a cotton field, it will always be best to send any specimens to an entomologist without delay for authoritative determination. It is extremely important that any possible infestation by this insect be brought to attention *at the earliest possible date, that prompt eradicative measures may be taken.*

FIG. 7.—Cotton locks showing typical injury by the pink bollworm (*Pectinophora gossypiella*).

Under the authority of the Federal Horticultural Board, Mr. August Busck spent a number of months in the Hawaiian Islands in 1905 studying the life history and habits of the pink bollworm. His

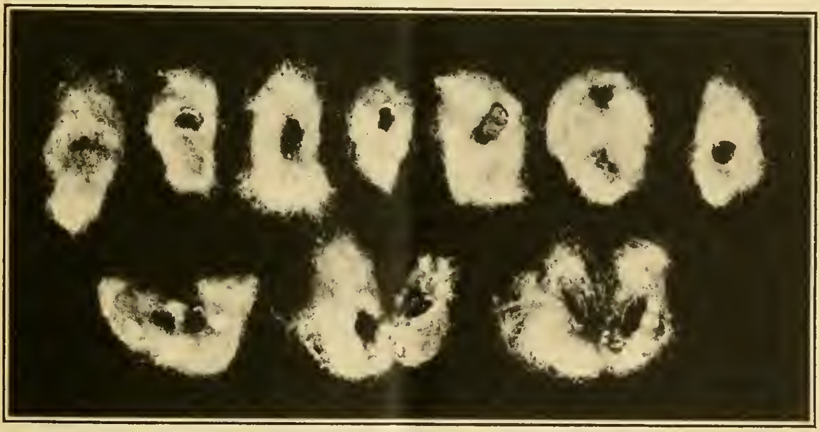

FIG. 8.—Cotton seed containing pink bollworms, opened to show the cells. Both the single and double seeded cells are shown, the double-seeded ones being broken apart.

paper (2) on the subject is by far the most complete of any which has been published. The following statements regarding the life history and habits of the pest are based upon Mr. Busck's paper:

The eggs are laid singly or in small groups on the green bolls or in the flowers. Generally the eggs are to be found near the points of the green bolls in the sutures marking the locks. As many as 4 eggs may be found in this situation and altogether as many as 20 eggs have been found on a single boll. It is estimated that a female will deposit in the neighborhood of 100 eggs. These hatch in from 4 to 12 days.

The larva, immediately on hatching, bores its way into the boll. The infested bolls sometimes become recognizable by a reddish or blackened discoloration which follows attack. Mr. Busck finds, however, that the only conclusive exterior evidence of infestation is the eggshell at the entrance hole or the larva itself within the boll.

FIG. 9.—Pink bollworm on carpel of cotton boll, which shows also typical hole made by worm while traveling from one lock to the next.

The food of the larva is the seed within the boll. It devours one and generally proceeds to the next above. Ordinarily a single larva does not make its way outside of the lock which it first invades, but occasionally the adjoining lock may be entered. It is to be noted that the larva restricts itself to the interior of the boll and never makes its way to the outside for the purpose of reaching another boll. When the larva reaches full growth it often protects itself by webbing two seeds together, the attachment being made to openings brought into contact by the insect. These "double seeds" are characteristic of the work of the insect. Usually they are not destroyed in the process of ginning, and they furnish the best means of determining quickly whether any lot of seeds is infested.

During the summer the larva stage occupies from 20 to 30 days. Later in the season this stage may be more or less indefinitely prolonged. Gough (6), in Egypt, found that larvæ would remain in a quiescent condition for over two years. Mr. Busck caused infested seeds to be placed in small bales of cotton in Honolulu. Examinations made up to 18 months after the time of baling continued to reveal the presence of live larvæ. It is thus evident that the larva stage may be prolonged over at least two growing seasons. It is this feature in the life history of the pest which has facilitated its carriage to many remote quarters of the earth.

After a variable time, as has been indicated, the larva transforms into a pupa or chrysalis. This stage lasts from 10 to 20 days and then the moth emerges. The life of the moth is rather short. Under favorable conditions Mr. Busck succeeded in keeping some specimens alive for 32 days, but under the same conditions the great majority of the insects died in from 14 to 20 days.

The moth is seldom seen in nature. Its habit is to hide during the day under stones or brush. The normal time of flight is from 6.30 to 8 p. m.[1] Although apparently capable of prolonged flight, they prefer to go no farther than the first cotton field. The moth is so quiet in its habits and so easily overlooked that many may occur

FIG. 10.—Typical holes made by pink bollworms through cotton-boll carpels.

unnoticed in the field. In fact Mr. Busck states that frequently he walked through cotton fields in the Hawaiian Islands where the moths had been emerging daily for an indefinite time, and where many thousands must have been present, without seeing a single one.

Statements to the effect that the pink bollworm is attracted to lights have appeared in the literature. Mr. Busck paid particular attention to this point and demonstrated that in Hawaii lights have no attraction whatever for the insect. In fact, the moths were clearly repelled by light. In Egypt experiments have shown some degree of attraction to light but not enough to form the basis for control measures.

[1] Standard time.

The question of the food plants of the pink bollworm is one which has been discussed at considerable length. There are statements in the literature to the effect that the species feeds on pomegranates in Egypt, on milo in Hawaii, and in Egypt and India on teel, okra, and hollyhock. The record relating to pomegranates has been withdrawn by Mr. H. A. Ballou, who has recently published a statement to the effect that it was an error. With reference to milo Dr. D. T. Fullaway has made a statement that the record was from a single specimen from a fallen fruit and that this specimen may well have been a stray larva which crawled into a cracked milo fruit for pupation.

Mr. Busck's observations in the Hawaiian Islands did not reveal any food plants other than species of the genus Gossypium, that is cottons. More recently, however, a statement has been published to the effect that the insect has been reared from a closely related plant belonging to the genus Hibiscadelphus.

The subject of the food plants of the pink bollworm in Mexico and Texas is now receiving very special attention. The extent to which okra, hollyhocks, and various wild malvaceous plants will have to be considered as host plants for the insect in noncotton zones depends upon these investigations, which are being prosecuted thoroughly and with the utmost possible dispatch.

As far as observed, the insect has no preference for cultivated varieties of cotton. The perennial or Caravonica, Chinese, Sea Island, and American Upland varieties growing in Hawaii were attacked to the same extent. Similar observations have been made in Egypt and India.

NATURAL ENEMIES.

The pink bollworm has a number of insect enemies wherever it occurs. In the Hawaiian Islands Busck found at least six species attacking it. Other species have been recorded from Egypt, Brazil. and India.

By far the most important enemy of the pink bollworm is a small mite known as *Pediculoides ventricosus* Newport. This is a common enemy of insects and occurs throughout the world. It seems to have increased to a very considerable extent in Egypt, but it does not appear that it is likely to be sufficiently abundant at any time to serve as an important agency in controlling the pink bollworm. Neither does it appear from the available records that any insect or mite enemies of the pest are likely to be of any practical importance in controlling it.

It is interesting to note that the mite to which reference has been made also attacks human beings. In 1914 large quantities of

Egyptian cotton seed were shipped to London. The laborers employed in handling this seed became affected by a rash of the skin caused by the punctures of the mite. The irritation was severe and resulted in a strike for higher wages. Recently the writer has learned from Mr. E. C. Green that in Brazil, since the establishment of the pink bollworm there, children who play about seed houses soon become affected by a dermatitis which probably is the same as that which has been found to follow the attack of the mite in other parts of the world.

PRECAUTIONS TAKEN TO PREVENT THE INTRODUCTION OF THE PINK BOLLWORM INTO THE UNITED STATES.

Prior to 1913 a considerable number of planters and others interested in the production of long-staple cottons in the United States caused small importations of Egyptian seed to be made. They were planted in many of the southern States, but did not result, for various reasons, in the establishment of the culture of Egyptian cottons. The Department of Agriculture also made special importations. In 1902 a considerable quantity of seed was brought from Egypt and small experimental plantings were made at Pierce and San Antonio, Tex., and at various other points in the Southwest. That the establishment of the pest did not follow any of these importations is due to the recent introduction of the insect into Egypt.

With the approval of the plant quarantine act on August 20, 1912, the Department of Agriculture for the first time obtained authority to regulate the importations of plants and plant products from foreign countries and to take the steps necessary to prevent the introduction of injurious insects and plant diseases by such importations. The pink bollworm was one of the first insects to be considered after the plant quarantine act went into operation. Its foreign status and its menace to American cotton was first brought to the attention of the Federal Horticultural Board in April, 1913, and on May 20 of that year a formal hearing was called at Washington to consider the advisability of prohibiting the importation of cotton seed from all foreign countries. No special opposition was encountered and a quarantine was promulgated on May 28, 1913, to take effect on July 1 of that year. This quarantine forbade the importation into the United States of cotton seed of all species and varieties, and cottonseed hulls from any foreign locality and country excepting the Imperial Valley in the State of Lower California in Mexico. The importation from this region in Mexico was covered by regulations. The importance of this action was shown in May, 1913, by the receipt in Arizona of a shipment of 500 pounds of Egyptian seed which was found to have an infestation by the pink bollworm of about 20 per cent. Thanks to the quarantine law in Arizona and the activity of Dr. A. W. Morrill, the State entomologist, the whole shipment was destroyed by fire.

A little later (Aug. 18, 1913), on the recommendation of the experts of the Bureaus of Entomology and Plant Industry of this department, this quarantine was amended in such manner as to provide, under regulation, for the entry, for milling only, of cotton seed from the States of Nuevo Leon and Tamaulipas, Mexico. A still later amendment permitted the introduction of seed from other of the northern states of Mexico.

The reasons advanced for allowing such entry of Mexican cotton seed were that no insects which were not found in the United States were known to occur there, and that the culture of cotton is more or less continuous with that in the United States. The absence of any cotton pests in the Republic of Mexico which did not occur in the United States at that time had been established by field inspections by several of the entomologists of the department.

To protect the United States from the possible entry of the pink bollworm from the Territory of Hawaii, a domestic quarantine was promulgated June 24, 1913, prohibiting the importation of cotton seed and cottonseed hulls from this territory.

It was thought that the United States was sufficiently safeguarded against the pink bollworm by the quarantines against cotton seed as such, but it soon came to notice that considerable quantities of seed were coming to the United States in bales of lint. A careful examination of picker waste from a large number of bales of Egyptian cotton was made. It was found that considerable numbers of seeds passed around the rollers in the gins and some between the roller and the knife through small openings due to wear. The waste from 37 bales which was examined showed sound seeds, some of them infested, varying from 27 to 600 per bale. The average per bale was 215. The variation in the different bales depended upon the grade of the cotton, the lower grades having many more seeds than the better ones. It was estimated on the basis of the examination of waste from the 37 bales that over 16,000 live larvæ of the pink bollworm were being brought to the United States each year, of which several hundred went to the mills in the cotton belt.

It thus became evident that a quarantine which did not take into consideration the seeds in bales of lint was inadequate. Consequently in May, 1914, a public hearing was held to discuss various means of protection. The different proposals made were that foreign cotton be excluded altogether from the United States; that it be admitted only under a guaranty that all seeds had been eliminated, or that it had been disinfected; that it be allowed to proceed only to mills outside of the cotton belt; and that it be sent to southern cotton mills only after a period of storage of 18 months or more in northern localities. At the public hearing, and subsequently through conferences with members of the cotton trade and representatives of manufacturing associations whose assistance was very valuable to the department, it became evident that there were insuperable obstacles in the way of any of the plans mentioned. It therefore became necessary to make an exhaustive study of the possibility of destroying any infestation which might be found in the bales of lint. The use of cold was found to be impracticable. The use of heat was also impracticable on account of the time necessary to penetrate the highly compressed bales of Egyptian cotton and on account of the increased danger from fires when bales which had been heated were opened in the mills.

About this time Mr. E. R. Sasscer, of the Federal Horticultural Board, and Dr. Lon A. Hawkins, of the Bureau of Plant Industry, had been conducting some experiments in the destruction of insects in various plant products by fumigation in a vacuum. It was found that the killing power of hydrocyanic-acid gas was increased enormously in vacuum and it thus became possible to reach certain classes of insects which heretofore had been uncontrollable. It therefore seemed possible that the vacuum process might be utilized in the fumigation of bales of cotton without necessitating their opening. A small experimental plant was established by the board at Washington and a long and what turned out to be a most interesting series of experiments was begun by Mr. Sasscer.

While this investigation was in progress an order regulating the entry of all imported lint cotton was promulgated by the Secretary of Agriculture April 27, 1915, effective July 1, 1915, and a domestic quarantine regulating the movement of cotton lint from the Territory of Hawaii to the mainland was promulgated June 11, 1915, effective on and after July 1, 1915. Under this order and quarantine, tentative regulations were issued governing and restricting the entry of foreign cotton and also providing for the screening of all rooms or buildings in which foreign cotton was kept and the daily burning of all grades of mill waste in which seeds of such cotton might be found. A corps of inspectors was employed and frequent examinations were made at the mills where foreign cotton was used to insure the faithful following of regulations. In general sympathetic coooperation was obtained. This was especially noticeable in the case of southern mills, the owners and managers of which seemed to realize the danger of introducing the pink bollworm and complied with the orders and regulations of the Federal Horticultural Board in the most hearty and public-spirited manner.

In the experiments with vacuum fumigation of lint cotton conducted by Mr. Sasscer, under the direction and with the advice of the Federal Horticultural Board, tests were made with variations in the dosage of cyanid, the degree of vacuum, the length of exposure, the temperature, and also in the depth of penetration. Steel tubes pointed at one end were provided. These had perforations near the point and were sealed in such a manner as to be perfectly airtight at the other end. Insects were placed within them, and the tubes were then driven into the bales. After the experiment was performed the insects were removed for examination. In this way the exact effect of the fumigation under all varying conditions at different depths within the bales could be determined. At the same time chemical tests were made by the Bureau of Chemistry of this department to run parallel with the tests with insects. These chemical tests confirmed the rapid penetration of the gas.

As the result of a suggestion made following a conference of a committee of cotton manufacturers with the Federal Horticultural Board, the then Office of Markets and Rural Organization of this department conducted a series of manufacturing tests with cotton which had been fumigated with hydrocyanic-acid gas to determine whether the fumigation by this agent would cause any injury to cotton fibers. The results of these tests indicate that such fumigation of cotton did not cause any deterioration of the cotton, either as to percentage of waste, spinning qualities, tensile strength, or bleaching, dyeing, or mercerizing properties of the cotton (3).

In the first series of experiments various insects more or less related to the pink bollworm, but which are native to the United States, were used. After the preliminary work was done and the probable requirements for destroying any insect in the bales of lint were determined, it was decided to add a series of experiments with the pink bollworm itself. For this purpose, under extreme caution to avoid escape, a number of insects were brought from the Hawaiian Islands. The results in all essential respects were similar to those that followed in the case of the insects treated previously.

As the result of all of this work, which taxed the ingenuity of the investigators engaged in it, it was found feasible on a commercial scale to fumigate densely compressed bales of cotton and kill any insect which might be inside.

On March 10, 1916, the fumigation of all bales of foreign cotton arriving at the United States was required as a condition of entry. Advance notice had been given to the importers and others concerned. In spite of considerable difficulties in obtaining materials and in working out mechanical problems, large plants were erected in a remarkably short time and became available for use on the date mentioned. Two of these plants were erected in Boston and one at Oakland, Cal. A little later additional plants were erected at New York City and Newark, N. J., and two plants are now available in Seattle, Wash. These establishments have a capacity sufficient to handle all of the imported cotton without any special delay. The larger plants have a capacity of upward of 1,000 bales per day.

The procedure to be followed in the fumigation of foreign cotton is given in an order of the Federal Horticultural Board (12). The kind of cyanid and sulphuric acid is specified. The rate is 6 ounces of sodium cyanid per 100 cubic feet. The cotton to be fumigated is placed in the fumigating chambers, the doors to these chambers are closed, and the air is exhausted until the vacuum gauge registers 25 inches. At this stage the gas is generated in a retort connected with the large chamber. The valve of the connecting pipe is opened; after the expiration of 15 minutes air is allowed to pass through the generator for 5 minutes for the purpose of removing any gas which may be present. The air valve on the fumigating chamber is then opened and the air allowed to rush in until the gauge registers 5 inches. The cotton then remains in the chamber for 1 hour and 40 minutes, making the total process of fumigation 2 hours. After the completion of the exposure, to remove the gas the pumps are run again and a vacuum of 25 inches established. At this stage the valves are opened and the pumps kept running for some time to complete the washing out of the gas from the bales. The pumps are then stopped and the doors of the chamber opened so that the cotton can be removed and another lot put in.

On December 27, 1915, Mr. R. I. Smith, the inspector of the board at Boston, Mass., called the attention of the board to the fact that a considerable amount of cotton waste was being imported. Some of this waste was found to contain more than twenty times as much seed as a bale of ordinary cotton. On this account the definition of the term "cotton" in the regulations was changed to include all grades of cotton waste except those resulting from processes of manufacture which render it mechanically impossible that seeds may be contained. These are the grades of waste resulting from the carding machines and subsequent processes in the manufacture of cotton. The requirement of fumigation of cotton waste went into effect on February 16, 1916.

On April 11, 1916, the collector of customs at Norfolk, Va., telegraphed the board that some 189 tons of cotton seed from Lagos, West Africa, constituted a portion of the cargo of the British steamship *Appam*, brought to Newport News as a German prize of war. In cooperation with the Office of Markets the board took immediate steps to dispose of this seed, which was found to be infested by the pink bollworm. A provisional sale had been made by the admiralty board to the proprietor of an oil mill in South Carolina. This was set aside as soon as the danger of introducing the pink bollworm was explained. After considering a number of methods of disposing of this seed, it was finally decided to have it treated with sulphuric acid and thus made available as a fertilizer. Through the cooperation of one of the largest manufacturers of fertilizers this was done with the utmost dispatch. The entire lot of 4,000 bags of seed was placed in sulphuric-acid vats within four days from the time the presence of the seed at Newport News became known to the department. As an additional precaution the two holds of the *Appam* which contained the seed were fumigated with a heavy dose of cyanid, and the docks, lighters, and trucks, as well as floors and platforms, were thoroughly cleaned of any scattered seeds.

To guard against the possibility that the pink bollworm had escaped prior to the treatment which has been described, repeated inspections were later made of the cotton fields near Newport News, which are at a distance of about 10 miles. No traces of infestation have been found, and it now seems certain that the establishment of the insect from this seed was prevented.

The chief inspector of the Board in New York City, Mr. Harry B. Shaw, reported in February, 1916, that there appeared to be considerable risk of introduction of the pink bollworm or other cotton insects with old burlaps which had been used for coverings of cotton and to which, as a rule, considerable cotton and occasional cotton seeds remain attached. Such burlaps are imported in large quantities for paper manufacture and other uses, and an investigation which was made of such imports in New York and Boston fully confirmed the risk of the introduction of cotton and cotton seed with such materials. An amendment was therefore added to the rules and regulations governing the importation of cotton into the United States, effective August 1, 1916, providing for the inspection and, where necessary, disinfection of all burlaps or other fabrics offered for import which had been used for covering cotton and to which cotton was adhering.

The possibility of entry of uncrushed seeds containing living pink bollworms or other cotton insects with cottonseed products, such as cake and meal, became evident after careful examination of such imports, and to safeguard their entry an order restricting the admission of cottonseed cake, meal, and all other cottonseed products, except oil, from all foreign countries was promulgated June 23, 1917, and regulations under this order were issued June 29, 1917, effective on and after July 16, 1917.

DISCOVERY IN MEXICO.

Earlier in this bulletin attention has been directed to the fact that when the quarantine against foreign cotton seed was placed in operation the State of Lower California, Mexico, was not included, and that subsequently cotton seed was permitted entry, for milling purposes only, from certain northern States of Mexico. The reason for this was that several of the entomologists of the department had been in northern Mexico and had found no traces of infestation by any insects other than those which are known to occur in the United States. These explorations were made some years ago, however, and it was still thought desirable to have new examinations made on account of the suspicion that the pink bollworm or some other destructive pest might have been introduced in the meantime. Accordingly arrangements were made in 1916 to dispatch an agent to Mexico. Shortly before the time fixed for his departure the activities of the bandits became so great that the trip had to be postponed indefinitely. If it had not been for these circumstances the presence of the pink bollworm in Mexico would have been known some months before it actually came to the attention of the department.

On November 1, 1916, the department received from a planter in the Laguna, who was then residing in Mexico City, a number of specimens of cotton bolls which had been attacked by insects. The sender was under the impression that the insect was the boll weevil which, though introduced in the Laguna on numerous occasions, had never been able to maintain itself on account of climatic conditions. Several of the bolls were found to be infested by the boll weevil, but others showed the presence of the pink bollworm. The determination was first made by Dr. W. D. Pierce and confirmed by Mr. August Busck and other specialists of the Bureau of Entomology.

On November 3, 1916, the situation was considered by the Federal Horticultural Board, and on November 4 an amendment to the regulations extending the quarantine to cotton seed and cotton from Mexico was issued by the department. An investigation was immediately started to determine the extent of the infestation in Mexico and the number of shipments of cotton seed from that country to the United States. It was soon found that a large amount of Mexican cotton seed had been shipped to mills in Texas during the season of 1916. In previous years no Mexican cotton seed had been shipped to the United States, and it was only the disturbed conditions in Mexico and the unprecedented high price of seed in the United States which caused the seed mentioned to be forwarded to the United States.

It was found that a total of 446 carloads of Mexican seed had entered the United States during 1916 prior to November 4. These carloads went to mills at Beaumont, Pearsall, Kaufman, Hearne, San Antonio, Houston, Dallas, Wolfe City, New Braunfels, Grand View, and Alice. The amounts varied from one carload, which went to Wolfe City, to 114 carloads, which went to Beaumont. Ninety-three carloads were shipped to Hearne and 69 to Kaufman, both located in regions where cotton is cultivated on every plantation.

The State authorities in Texas were notified and the Federal Horticultural Board began a campaign to expedite the crushing of the seed and the destruction of any scattered seeds about the premises. The cooperation with the State was through Hon. Fred. Davis, commissioner of agriculture, the entomologist of his department, Mr. E. E. Scholl, and the chief nursery inspector, Mr. E. L. Ayers.

Agents of the Federal department visited the mills which had received the Mexican seed at frequent intervals through the fall and winter. The force was increased by the addition of three men detailed from the Office of Markets of this department. The proprietors of the mills and the State Cottonseed Crushers' Association all assisted very materially in the work, which was done with the utmost possible dispatch and with great thoroughness.

SPECIAL APPROPRIATION FOR THE DEPARTMENT OF AGRICULTURE.

In November, 1916, the department submitted to Congress an estimate for an appropriation of $50,000 to be used, first, in determining the possible presence of the pink bollworm in the vicinity of the mills which received Mexican seed and to stamp out any infestation which might be found; second, to enforce the quarantine against Mexican seed and cotton products which might carry the pink bollworm. This appropriation became available on March 4, 1917.

Under the appropriation the Federal Horticultural Board organized a full field force. It consisted of one set of inspectors to make field examinations to determine whether the pink bollworm could be found, and another to enforce the quarantine regulations at the border ports.

DISCOVERY IN TEXAS.

As the result of the field examinations, to which reference has been made, the first specimen of the pink bollworm in Texas was discovered in Hearne, Tex., on September 10, 1917, by Ivan Schiller, an inspector of the board. This was found in a small field adjoining the oil mill which had received Mexican cotton seed. Later four additonal specimens were found, none of them more than one-fourth of a mile from the mill. On October 5 a specimen was found in a field near the oil mill at Beaumont by inspector H. C. Millender, and on October 25 specimens were taken at Anahuac, in Chambers County, by Mr. H. S. Hensley. The first two of these infestations were undoubtedly due to the Mexican seed which had been shipped to the United States in 1916. The infestation in Chambers County, however, can not be attributed to such shipments. It was found to extend around Galveston Bay from Smiths Point to the vicinity of Texas City. It was heavier near the Bay and diminished regularly toward the interior. After considerable investigation, in which all possible theories have been investigated, the conclusion has been reached that this infestation was probably due to Mexican bales of cotton which were shipped to Galveston in 1915. During this year several thousand bales of cotton from the Laguna in Mexico reached Galveston by way of El Paso. This cotton was on the docks at Galveston at the time of the hurricane of August, 1915. With several thousand bales of Texas cotton it was washed from the docks and distributed around the shore line, in some cases 75 miles away. Many of these bales were broken open by the force of the water. It is well known that Mexican bales contain large numbers of seeds, and cotton plants were found growing along the high water line during the fall of 1915 and the spring of 1916. This theory, while not altogether satisfactory, is considered by Mr. August Busck, who has paid more attention to the study of the pink bollworm than any other entomologist, to be adequate to explain the known situation at the present time around Galveston Bay.

As soon as the presence of the pink bollworm in Texas was discovered the Federal Horticultural Board, in cooperation with the Department of Agriculture of the State of Texas, undertook active measures to eradicate it. The work consisted at first of scouting to determine the limits of infestation, the destruction of any possible infestation remaining in the fields, and the safeguarding by various means of the cotton produced in the infested fields and in neighboring ones during the season of 1917.

Entomologists were obtained from various sources. Twenty-five were engaged in the scouting work in Hearne, and later about 50 in the work in southeastern Texas. As the result of this work it seems practically certain that the infestation in Hearne was limited to the immediate vicinity of the oil mill. In southeastern Texas infestation was found from the vicinity of Beaumont, in Jefferson County, to Arcola, about 7 miles from the Brazos River. The northernmost point infested was in Liberty County, about 18 miles north of the town of Liberty. This area includes all of Chambers, Galveston, and Jefferson Counties, and portions of Liberty, Harris, Brazoria, and Hardin Counties.

The work of removing any possible infestation from the fields consisted of uprooting or chopping down the plants, the collection by hand of all locks or portions of locks which were found on the ground, and the burning of all the accumulated trash with the use of kerosene. In this work 1,624 acres of land in the vicinity of Hearne were cleaned, and 7,170 acres in southeastern Texas. The work was not confined to fields in which infestation was actually found, but included fields at a considerable distance beyond the outermost points found infested. It involved the employment of an average of about 500 laborers for the months of November, December, January, and February, and a portion of March. In many cases the laborers were assembled in camps and housed and provisioned by the department. In other cases, where the work was in the vicinity of towns, it was possible to employ local labor. The safeguarding of cotton products produced in the infested areas in 1917 consisted of the milling of the seed under supervision at certain mills selected because their construction would enable the work to be done with practically no danger of disseminating the pest. The baled cotton, so far as possible, was caused to be exported or shipped directly to northern mills.

COTTON-FREE ZONES.

In 1917 the Legislature of Texas passed an act intended to give authority to prevent the establishment of the pink bollworm in the State. Under this act authority was granted to quarantine the districts in which the insect might be found, and to establish zones in which the planting of cotton might be prohibited. Under this authority on January 21, 1918, the governor of Texas quarantined the Hearne district as well as the territory found infested in southeastern Texas. In the case of Hearne the quarantined area included a territory within a radius of 3 miles from the mill. In the case of southeastern Texas the quarantined area included a safety zone on the outermost points infested approximately 10 miles in width.

On February 25, 1918, following the recommendation of Hon. Fred W. Davis, commissioner of agriculture, the governor of Texas issued a proclamation prohibiting the planting of cotton in the quarantined areas.

The finding of infestation by the pink bollworm in Mexico not far from Del Rio in the spring of 1918 made it necessary to place in operation another section of the Texas pink bollworm act. As a consequence a third noncotton zone was provided to include McKinney, Maverick, and Valverde Counties.

SPECIAL REGULATION AT MEXICAN BORDER.

The risk of direct entry of the pink bollworm from Mexico by flight or by accidental carriage necessitated the provision in the regulations governing the entry from Mexico of cottonseed cake, meal, or other cottonseed products, including oil, that permits for such entry should be issued only for the products named produced in mills located in the Laguna district of Mexico. The object of this proviso with relation to Mexico is to deter the erection of mills near the border of the United States with the consequent risk of escape of insects from seed brought for crushing to such mills near the border.

In this connection it may be noted that active steps toward the control of the pink bollworm have been undertaken in Mexico. A recommendation was made to the Mexican Government by a joint commission, one of the members of which is Mr. August Busck, of the United States Department of Agriculture, that the cultivation of cotton in infested regions be prohibited for a period of three years. It has not been possible up to the present time for the Mexican Government to place this recommendation in operation, but it has issued two decrees looking toward the control of the insect. One of these is a quarantine against the main infested territory with a provision for a safety zone of considerable width. The other provides for the fumigation of all cottonseed produced, whether intended for crushing or planting.

PRESENT WORK OF THE DEPARTMENT OF AGRICULTURE.

To meet the menace of the pink bollworm the activities of the department through the Federal Horticultural Board now include:

(1) The exclusion from the United States of cotton seed from all foreign countries except the Imperial Valley of Lower California, Mexico, and its exclusion also from Hawaii;

(2) Regulating and safeguarding the entry of cottonseed products from all foreign countries and from Hawaii;

(3) Regulation of entry and disinfection of all imported cotton and cotton waste, and also burlaps which have been used as wrappings of foreign cotton, including such material from Hawaii;

(4) Survey, eradication, and control work in Texas in cooperation with the State authorities;

(5) Regulation of rail and other traffic with Mexico;

(6) Determination of distribution in Mexico and cooperation in control measures with the Mexican Government or local Mexican authorities; and

(7) Investigation in Mexico of the life history and habits of the pink bollworm as a basis for control measures.

Detailed information as to these activities and the quarantine and other restricting orders and regulations in relation to cotton and cotton products are given in the monthly numbers of the Service and Regulatory Announcements of the Federal Horticultural Board (13).

In general the work in Texas consists of cooperation with the State of Texas in maintaining the cotton-free zones and safeguarding the products produced therein in 1917, in extensive scouting to determine at the earliest moment the occurrence of the insect in any point in Texas or elsewhere, and in eradicative work.

The work at the Texas border ports consists of the regulation of the traffic from Mexico to prevent the importation, through accident or otherwise, of any Mexican cotton seed. It includes the inspection and disinfection of baggage, the cleaning or disinfection of all freight, express, and other shipments, except those which could not possibly carry infestation, restrictions on the entry of railway cars from Mexico, regulation of the transfer of freight, express, and other shipments, certification of all cars or other carriers of merchandise as a condition of entry into the United States (excepting merchandise or other materials of strictly local origin), and the cleaning of domestic cars as a condition of receiving freight originating in Mexico for movement into the interior of the United States.

The work in Mexico consists of cooperation with the Mexican Government and the planters to stamp out the pink bollworm in that country. The main infestation in the Laguna offers a hopeful opportunity for eradication on account of the loss which the pink bollworm has already shown itself capable of causing, and the fact that the cotton lands are owned by comparatively few persons. The other two infestations in Mexico are on individual ranches where it may be possible to have the planting of cotton abandoned for a series of years beginning with 1919. The work in Mexico also includes an investigation of the life history and habits of the pink bollworm with special reference to means of control.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 730

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPERS December 24, 1918

PAPERS ON DECIDUOUS-FRUIT INSECTS

I. THE GRAPE CURCULIO
II. THE GRAPE ROOT-BORER

By FRED E. BROOKS
Entomologist
Deciduous-Fruit Insect Investigations

III. EXPERIMENTS IN THE CONTROL OF THE ROOT FORM OF THE WOOLLY APPLE APHIS

By B. R. LEACH
Scientific Assistant
Deciduous-Fruit Insect Investigations

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I. THE GRAPE CURCULIO.[1]

By FRED E. BROOKS,

Entomologist, Deciduous-Fruit Insect Investigations.

CONTENTS.

INTRODUCTION.

In many localities in the eastern part of the United States the grape curculio, *Craponius inaequalis* Say (Pl. I, *A—D*), may be classed as the most destructive insect attacking the grape. From some cause or causes which are not entirely clear, the insect is markedly local in its occurrence and within the bounds of its general range appears annually in destructive numbers in some localities whereas it remains practically unknown to grape growers in other districts near by. In places where it is abundant it may be expected to destroy each year from 35 to 100 per cent of fruit on all grapevines that do not receive protection of some kind.

The adult curculio is small and inconspicuous and a grape grower will frequently lose within a short time an entire crop of fruit, that had promised well, without being able to determine the nature of the enemy that caused the loss. He will know only that the grapes while

NOTE.—Acknowledgment is due Mr. C. R. Cutright, who was employed temporarily by the Bureau of Entomology to assist with the present investigation.

[1] *Craponius inaequalis* Say; suborder Rhynchophora, family Curculionidae, tribe Ceutorhynchini, subtribe Coeliodes.

growing became suddenly wormy and were ruined. Fortunately losses from this pest are easily preventable when an intelligent use is made of available means of control. The present bulletin gives an account of an investigation of this species that was carried out principally in a badly infested locality in Central West Virginia during the years 1916 and 1917.

ECONOMIC HISTORY.

This curculio seems first to have been noted as an enemy of the grape in the vicinity of Cincinnati, Ohio, in the year 1853 (2).[1] Walsh (5) states that it ruined fruit at Cobden, Ill., in the period 1863 to 1865 and at Hudson and Marietta, Ohio, from 1863 to 1867, and that in 1867 16 acres of grapes at Big Hill, Ky., were destroyed. He states also (4) that it was destructive at Carbondale, Ill., from 1864 to 1867. In 1890 Riley (15) quotes a correspondent from London, Ky., who said that the grape curculio was doing more damage than all else combined. In 1891 Webster (16) found the insect in Franklin County, Ark., and learned that it had been increasing there for at least 10 years and that it had become almost impossible to obtain crops of fruit without bagging the clusters. Brooks (30) quotes correspondents who showed that in West Virginia it was generally distributed and very destructive to grapes during the years 1899 to 1905.

SYNONYMY.

The grape curculio was first described in 1831 by Say (1) under the name *Ceutorhynchus inaequalis*, from specimens collected in Indiana, where, he states, many beetles were collected in the spring, resting upon a newly constructed fence. Le Conte (8), in his revision of Say's work, placed the species in the genus Coeliodes, but later (11) erected for it the genus Craponius. The synonymy, therefore, is as follows:

Ceutorhynchus inaequalis Say, 1831 (1).
Coeliodes inaequalis (Say) Le Conte, 1869 (8).
Craponius inaequalis (Say) Le Conte, 1876 (11).

COMMON NAMES.

On account of the larva's habit of attacking the seed as well as the pulp of the fruit, the common name "grape-seed weevil" was applied to the species by early writers. At present the common name "grape curculio" is in general use.

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[1] Numbers inclosed in parentheses refer to "Bibliography," p. 16.

DISTRIBUTION.

The grape curculio has been recorded from the New England States (33) to Minnesota (25) and south to Missouri (7) and Florida (33). Within this range there are records of its occurrence in the following States: Arkansas, Florida, Illinois, Indiana, Kentucky, Minnesota, Missouri, New York, North Carolina, Ohio, Pennsylvania, Tennessee, and West Virginia.

FOOD PLANTS.

The adult curculios may be found upon the foliage and the larvæ within the fruit of probably all kinds of wild and cultivated grapes that grow in the localities where the insect is found. There are no records of either the adults or larvæ attacking under natural conditions the leaves or fruit of plants other than the grape. During the present investigation frequent search was made for the feeding marks of the beetles on the foliage of various kinds of plants, but they were not found elsewhere than on grape, nor were the beetles or the larvæ found about any other fruit. Brooks (30) states that beetles in confinement, when deprived of other food, fed on apple and cherry leaves and that one such female deposited an egg in the fruit of Virginia creeper (*Ampelopsis quinquefolia*). This egg hatched but the larva died at the end of two days.

RECENT INJURIES.

During the present investigation the following records were made showing the destructiveness of the curculio at French Creek, W. Va.: On August 14, 1916, several clusters of fruit were picked from an unsprayed Concord grapevine. The clusters bore 163 berries and of these 161 contained curculio stings. At least one-half of the berries had already dropped from the clusters on account of being infested with curculio larvæ. On August 18 of the same year the entire crop of fruit from another unsprayed Concord grapevine was gathered. The vine produced 2,382 fruits and of these 2,274, or 95.47 per cent, showed curculio injury and 108, or 4.53 per cent, were sound. Probably half the grapes originally on the clusters had dropped as a result of infestation, and were not counted.

On August 23, 1917, about 50 grapevines of different varieties growing about farmers' homes in the locality were examined. Counts showed that from 40 to 95 per cent of all unprotected fruit had been ruined by the curculio, the average loss being about 70 per cent.

RESISTANCE OF CERTAIN GRAPES TO CURCULIO ATTACK.

Opportunity was taken to note the extent of curculio injury to about 25 different varieties of cultivated grapes and to three species of wild grapes. The wild species were the fox grape (*Vitis labrusca*), the "pigeon" grape (*V. aestivalis*), and the "frost" grape (*V. cordifolia*). Under similar conditions one variety of cultivated grape will suffer about equally with another. Frequently a discrimination will seem to be shown by the curculio between varieties, since the fruit of one vine may be attacked more extensively than that of another in the same locality. Such discrimination, however, is usually due to the particular locations of the vines rather than to any varietal peculiarities. The fruit of vines trained on the side of a house or of those growing in isolated positions in a field will escape injury to a far greater extent than will that of groups of vines trained on wire, fence, or trellis. Of the wild species the fox grape suffers about equally with the cultivated varieties, the "pigeon" grape to a less extent, and the "frost" grape is very rarely attacked. The immunity from attack of this last species is probably due to its small size and to the fact that it develops much later in the season than do the other species.

THE LIFE CYCLE IN BRIEF.

The beetles appear upon grape foliage in the spring and feed for ten days or two weeks on the upper epidermis and parenchyma of the leaf before beginning to deposit eggs within the young fruit. The larvæ (Pl. I, *H*) from the eggs feed upon the pulp and seeds of the fruit until full grown when they leave their feeding place and pupate within pellet-like earthen cocoons (Pl. I, *J*) located at or just beneath the surface of the ground. In about three weeks the beetles issue from the cocoons and go to the grape foliage, where they feed rather freely on the upper surface of the grape leaves until cool weather in the fall drives them into hibernation.

A few relatively unimportant departures from the foregoing rule are recounted later in this paper.

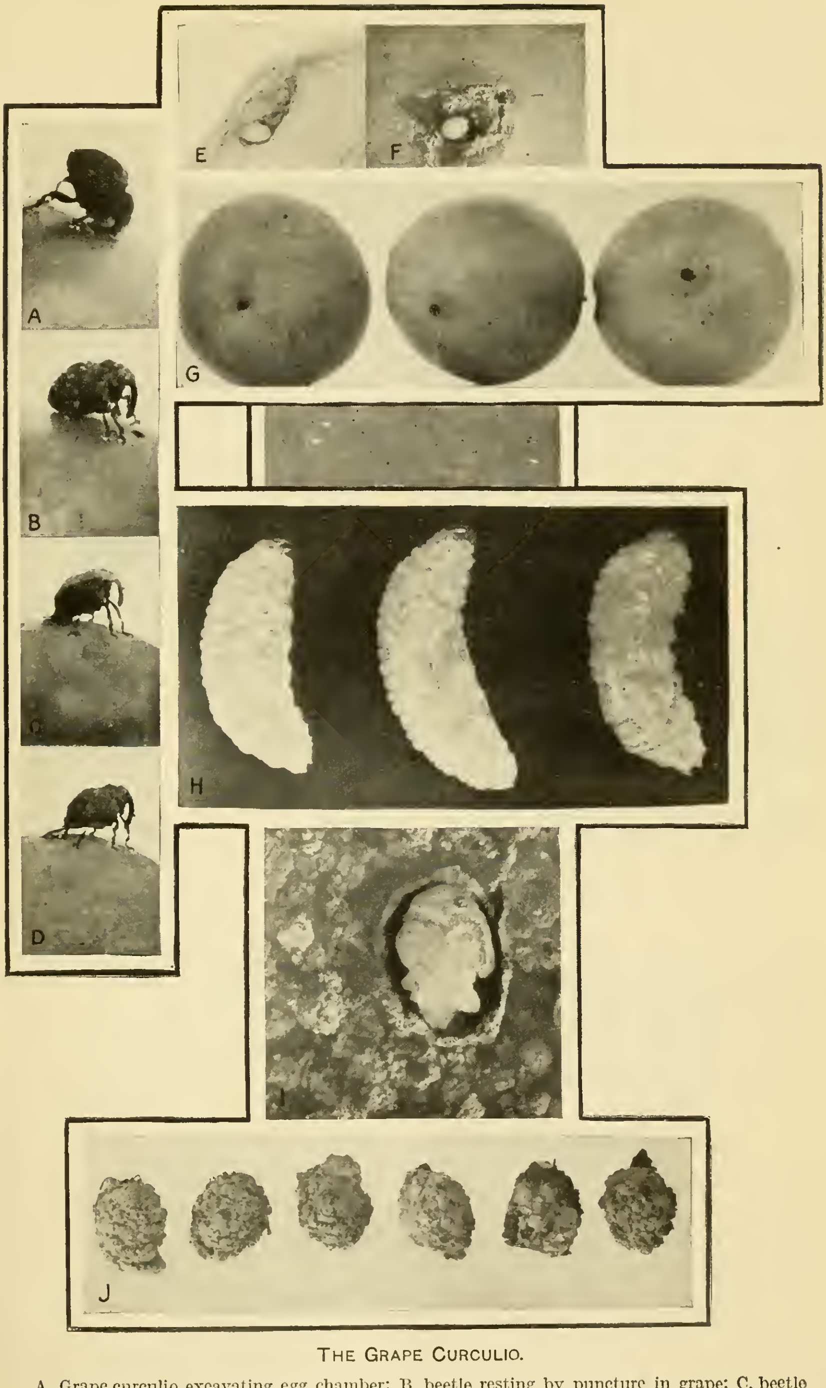
DESCRIPTION.

THE EGG.

The eggs (Pl. I, *E*, *F*) are rather uniformly oblong elliptical in shape. The surface is smooth and opaque, white when first deposited, but turning to yellowish on the second and third days. The average measurement of 10 specimens was 0.46 by 0.71 mm. The egg is attached to the wall of a roomy cavity which the female beetle with her snout excavates from the pulp of the grape through a small hole made in the skin.

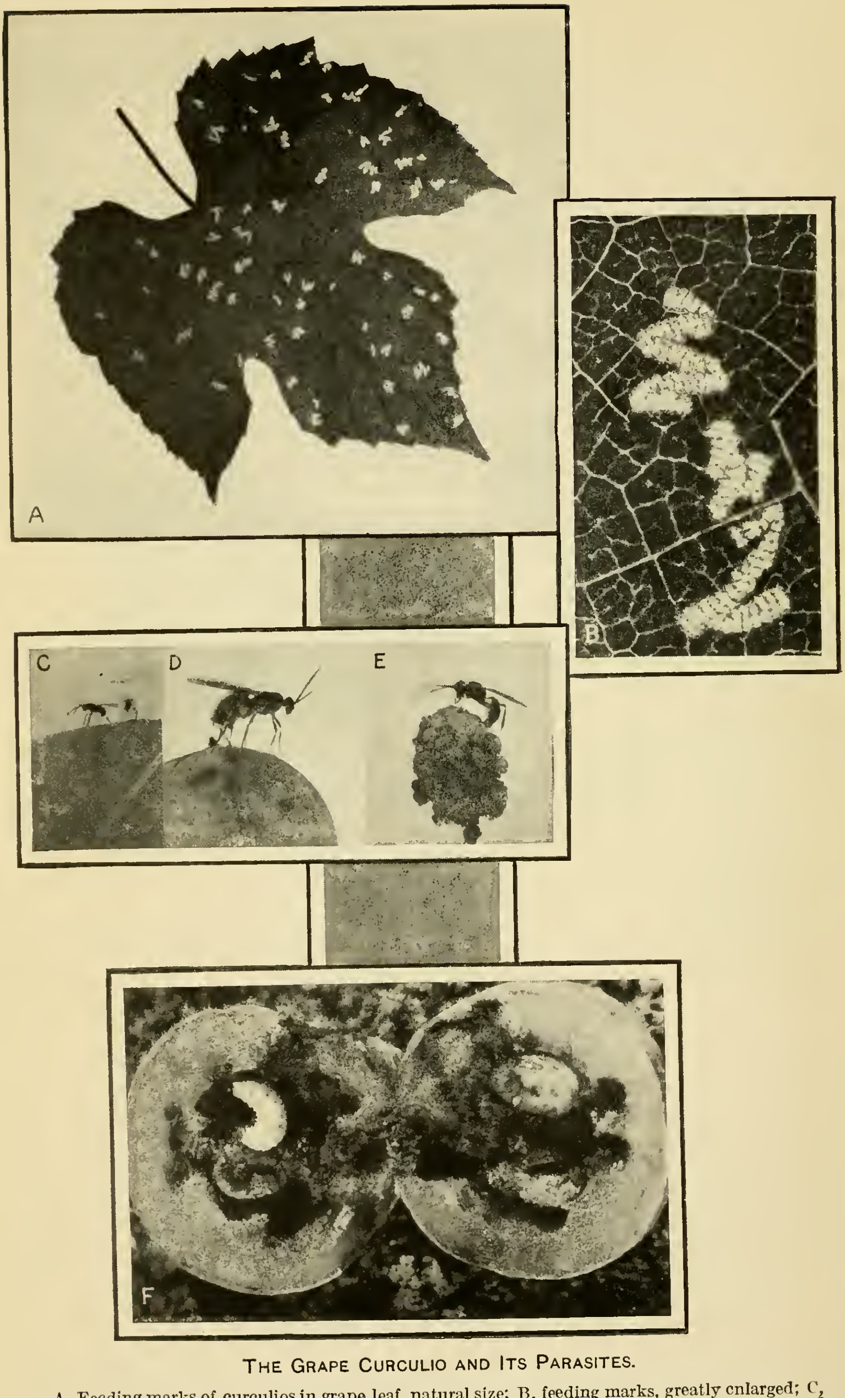
THE LARVA.

The legless, fusiform, curved larva (Pl. I, *H*; Pl. II, *F*) is white with light brown head, the body usually being clouded with the dark-colored contents of the alimentary canal. The average length is 7 mm. and



THE GRAPE CURCULIO.

A, Grape curculio excavating egg chamber; B, beetle resting by puncture in grape; C, beetle ovipositing; D, beetle sealing egg chamber; E and F, curculio eggs in natural position in grape; G, egg punctures in grapes after being sealed; H, larvæ; I, pupa in cocoon in soil; J cocoons. All enlarged. (Original.)



THE GRAPE CURCULIO AND ITS PARASITES.

A, Feeding marks of curculios in grape leaf, natural size; B, feeding marks, greatly enlarged; C, *Anaphoidea conotracheli* in act of ovipositing; D, *Microbracon mellitor* ovipositing in infested grape; E, *Stiboscopus brooksi* ovipositing in curculio cocoon; F, grape cut open to show injury by curculio larva. All enlarged except A. (Original.)

the width, at the widest point, 2 mm. The body is sparsely covered with short, fine hairs.

THE PUPA.

The pupa (Pl. I, *I*) is short, stout, and yellowish white, with the eyes and tip of rostrum reddish and with other dark markings developing as the adult stage is approached. The length is 3 mm. and the width 2 mm. The head and body are sparsely covered with long, stiff hairs. The pupa occupies a small, spherical cocoon formed of grains of earth, the cell having a delicate membranous lining.

THE ADULT.

The beetle (Pl. I, *A–D*) is short, robust, 3 mm. in length by 2.5 mm. in width, the snout being half as long as the body. The color, when fresh from the cocoon, is almost black, fading with age to chocolate brown. The surface is coarsely sculptured with prominent, acute tubercles on the thorax and elytra and the entire body is clothed with minute, whitish, scale-like hairs.

HABITS AND ACTIVITIES OF THE BEETLES.

At about the time Concord grapevines are blooming the grape curculio beetles emerge from hibernation and appear upon the grape leaves. Within the geographical range of the species the date of the first appearance of the beetles on the vines will vary considerably, according to season and locality. In West Virginia the dates of their first observed appearance on the vines are as follows:

Year.	Date.
1904	June 1
1905	May 25
1916	June 14
1917	June 2

Blatchley and Leng (33) record the beetles from central Florida from February 11 to April 13. At first the beetles are somewhat inactive and an individual may remain on a single leaf for a week or more at a time, feeding at intervals on the upper surface and sheltering during unfavorable weather on the underside. Feeding on the exposed part of the foliage is engaged in rather freely from the first appearance of the beetles in the spring until the fruit is ripe, thus rendering the beetles susceptible to arsenical sprays at any time while the fruit is on the vines. Food is also taken in a limited way from the bark of the fruit stems and the females devour the tissues removed in making their egg punctures (Pl. I, *G*) in the fruit. The immature grapes probably never are attacked by the beetles primarily for food, but the ripe fruit is sometimes punctured for this purpose.

The beetles frequently rest on the leaves for long intervals without motion and, even when eating or crawling about, their movements are so slight or so slow as not to attract attention. In appearance a beetle on the vines resembles more closely a small lump of brown earth than any form of animate life. While collecting, the writer has frequently mistaken them for the pellets of excrement dropped by sphinx caterpillars on the grape leaves. When disturbed they do not run or fly directly but leap to a considerable distance and either take wing while in the air or fall to the ground, simulating death. When caught and held closely in the hand they give forth a squeaking note pitched on an exceedingly high key. This note is heard also during sexual attempts of the male.

FEEDING MARKS.

The feeding marks on the leaves (Pl. II, *A*) are situated on the upper surface and extend only through the epidermis and parenchyma. Usually they are in the form of a slightly curved line, averaging about 2 mm. long by 0.5 mm. wide, or of from 2 to 10 such lines, joined at the ends to form acute angles. Under magnification the lines show distinct cross figurations. (Pl. II, *B*) These marks on the leaves usually may serve as the best means of determining the presence of the curculio in any locality, since in badly infested districts, especially in the autumn, the foliage is thickly specked with them. The health of the vine is not impaired to any appreciable extent by even great numbers of the marks, but this feeding habit is otherwise important as furnishing an easy means of control.

Careful measurement of 50 feeding marks showed that the average area covered by each was 3 square millimeters. In order that some idea of the individual feeding capacity of the beetles might be gained, 24 pairs were confined in jars and supplied daily with fresh grape leaves and fruit. Every morning counts were made of the marks on the leaves eaten by each pair. This was continued from July 9 to September 30, a period of 84 days. On the last-named date feeding was discontinued, all the beetles having died or entered hibernation. Table I shows the results of these counts.

TABLE I.—*Number of feeding marks made in grape leaves by 24 pairs of the grape curculio during the period from July 9 to Sept. 30, 1917.*

Pair No.	Number of feeding marks.	Pair No.	Number of feeding marks.
1	1,128	13	1,333
2	1,404	14	1,225
3	431	15	1,180
4	1,076	16	1,127
5	1,084	17	1,139
6	1,292	18	688
7	704	19	1,180
8	1,233	20	1,222
9	1,311	21	1,297
10	874	22	1,201
11	1,164	23	1,549
12	1,413	24	972
		Total	27,227

The records in Table I cover only a portion of the active life of the beetles, and it is certain that the specimens under observation had been feeding on the grape foliage for at least four weeks just prior to July 9, the day of the first record. It is also reasonably certain that at least a part of the beetles had fed for a time during the previous autumn before going into hibernation. On the day of the first record 280 feeding marks were made and the period of greatest feeding activity extended from that date to August 10. This was likewise the period of greatest egg production. On July 30 the beetles made 1,085 feeding marks, which was the maximum number, and on July 31 they deposited 244 eggs, which was also the maximum number. As is shown by Table I, the total number of feeding marks was 27,227, an average of slightly over 567 for each individual. The aggregate leaf surface eaten over by each beetle averaged slightly more than 2½ square inches and the total surface eaten by all the beetles would cover an area nearly four times the size of the printed portion of this page.

RELATIVE FEEDING CAPACITY OF THE SEXES.

During the egg-laying season the food consumed by a female in excavating her egg chambers is considerable, often surpassing daily in weight that of the insect itself. It was thought possible that the amount of fruit pulp eaten in this operation would result, for the time at least, in a decreased amount of leaf feeding by the females and render them less susceptible to arsenical sprays than are the males. Experiments, however, showed that the females do not decrease their leaf feeding during the oviposition period, and that, on the contrary, during days when egg production is heaviest leaf feeding may increase rather than diminish.

For a period of 14 days, from August 8 to August 21, 3 male and 3 female beetles were confined in cages separately and supplied daily with fresh grape leaves and fruit. During the period the males made 251 feeding marks, an average of 83.66 each, while the females made 313 marks, an average of 104.33 each. In addition, the 3 females excavated 125 egg chambers. The individual female which laid the greatest number of eggs made, also, the greatest number of feeding marks, the numbers being 54 eggs and 172 feeding marks. In another experiment, while 5 males were making 1,875 feeding marks an equal number of females under the same conditions made 2,185 feeding marks and excavated 717 egg chambers. It is thus seen that the opportunity for killing the females by poison sprays applied to the foliage during the egg-laying season is at least as good as for killing the males.

EGGS AND OVIPOSITION.

The eggs are placed singly in cavities eaten out of the fruit, the cavities averaging slightly more than 1 mm. deep by 2 mm. wide. (Pl. I, *E*, *F*) The wound is relatively large, and, even in cases where the eggs do not hatch, the hardening of the tissues about the cavity, which take place during the healing process, ruins the fruit for all purposes except that of juice extraction.

In ovipositing the female selects with some care a point, which may be at any place on the surface of the grape, and makes a small opening through the skin with her snout. Without changing her position on the grape she then excavates through the small opening all the pulp within convenient reach of the snout, the completed cavity extending back beneath the body of the beetle. (Pl. I, *A*) All the pulp removed is swallowed, and excrement is voided in small quantities during the operation. When the cavity is finished the beetle turns around, as though on a pivot, and places the tip of the abdomen over the opening in the skin. (Pl. I, *C*) On several occasions as the beetle was in the act of turning, a section of the grape was cut away by the observer so as to expose the lower end of the egg chamber, thus permitting oviposition to be watched from within through a hand lens. This showed, immediately following the appearance of the tip of the abdomen at the opening, a slender ovipositor extended and moved about touching the sides of the chamber. The ovipositor was then withdrawn into the body, but a few seconds later it was suddenly extruded to its full length and pointed rigidly forward, and at this time the movement of the egg could be seen passing down the duct. The tip of the abdomen at the moment was in contact with the wall of the chamber at the point farthest from the opening in the skin, and the egg was ejected and attached at this point (Pl. I, *E*), after which the ovipositor was slowly withdrawn into the body.

After the egg is deposited the beetle ejects a mass of excrement over the opening in the skin (Pl. I, *D*), presses some of the more solid matter of the excrement into the opening with the tip of the abdomen, and then moves away. This excrement soon dries and seals the cavity (Pl. I, *G*). Frequently the female is attended by a male during the preparation of the egg chamber and the work is interrupted by copulation. Table II shows how the time was observed to be divided in six instances where the duration of the different steps was recorded.

TABLE II.—*Time spent in oviposition by the grape curculio.*

Beetle No.	Minutes excavating.	Minutes copulating.	Minutes ovipositing.	Total minutes.
1	7	22	3	32
2	16	0	7	23
3	17	17	3	37
4	18	18	3	39
5	12	13	2	27
6	24	16	2	42
Average	15.6	14.3	3.3	33.3

There are occasional but rare departures from the method of procedure in egg laying as just described. For example, two or three egg chambers were found containing two eggs each, and on one occasion a female was observed to complete her egg chamber and then deposit an egg on the grape near the puncture. She then pushed the egg into the opening with her snout and sealed the chamber in the usual manner. A few eggs were found in excavations in the fruit stems, but the larvæ which hatched from them were not able to subsist on the food at hand.

OBTAINING EGG RECORDS.

For obtaining egg records a large number of beetles were collected from grape foliage early in the season and confined with food in cages. As fast as they could be found mating in the cages they were removed and confined by pairs in glass tumblers. The tumblers were covered with cheesecloth and the beetles provided daily with fresh leaves and fruit. Twenty-four pairs were thus obtained and kept in an open insectary throughout the season. So far as could be determined, by comparing the activities of the beetles in the glasses with those of beetles in the field, egg laying proceeded in the insectary in a normal manner.

Every morning counts were made of the eggs deposited during the preceding 24 hours. Table III shows the result of these counts and is believed to represent with fair accuracy the individual egg-laying capacity of the beetles.

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TABLE III.—*Egg-laying record of 24 female grape curculios.*

Date.	Beetle No.—																								Total.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
July 3	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4
4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
5	1	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	7
6	6	1	0	2	0	3	0	0	1	0	0	0	0	0	3	0	0	0	2	0	3	0	2	0	23
7	4	2	4	2	4	3	1	1	5	0	0	0	3	0	1	0	2	3	3	0	2	1	0	0	41
8	5	4	2	4	3	6	3	4	4	1	3	5	3	0	4	0	7	4	4	3	3	5	5	4	86
9	4	4	3	4	0	5	4	3	4	1	0	0	5	3	5	1	0	5	1	1	3	0	0	5	61
10	5	1	0	7	6	4	0	3	4	2	0	1	2	3	4	2	7	3	3	1	4	2	4	3	71
11	4	4	3	6	3	10	0	2	4	0	0	2	7	4	4	0	5	5	4	4	2	7	1	3	84
12	4	5	3	6	4	6	7	5	5	1	3	5	5	3	0	3	7	4	2	4	4	3	5	3	97
13	8	6	4	7	2	7	6	4	5	2	4	1	4	1	5	3	5	4	5	0	4	4	4	6	101
14	7	5	4	9	4	9	9	7	6	5	4	4	6	6	5	6	6	5	7	6	7	7	4	5	143
15	8	5	3	6	7	10	3	5	6	5	4	5	8	6	5	6	6	6	6	6	4	3	5	4	132
16	9	9	5	6	10	9	6	8	7	4	6	8	7	6	7	5	8	7	6	7	6	8	6	5	165
17	6	7	5	8	5	9	4	6	6	5	4	7	8	5	6	6	8	4	6	6	5	6	5	5	142
18	6	5	4	5	6	9	9	4	4	5	4	8	6	7	5	6	4	6	5	5	3	8	5	3	132
19	7	8	3	8	9	9	9	7	7	7	8	5	9	9	9	9	5	4	4	10	8	6	8	6	174
20	10	5	6	12	11	11	9	9	7	8	4	11	11	8	8	8	5	8	7	6	7	6	8	5	190
21	7	9	6	13	8	11	9	5	6	8	8	9	7	11	8	7	8	8	7	7	6	11	9	5	193
22	10	8	6	8	8	11	10	8	7	9	6	8	10	7	7	9	9	8	9	9	5	5	9	6	192
23	9	9	7	10	10	12	5	8	8	8	6	10	11	8	9	5	9	7	6	10	6	7	10	5	195
24	9	10	5	14	10	12	12	10	10	7	8	10	11	10	11	12	4	10	7	10	6	12	12	7	229
25	9	7	9	10	10	10	7	8	7	9	8	10	11	9	9	9	10	8	9	8	5	8	9	6	205
26	12	10	8	14	12	12	11	9	8	9	7	10	9	9	8	7	9	8	9	11	6	10	11	7	226
27	9	8	8	9	12	12	12	7	8	10	5	10	13	11	10	10	10	8	7	9	5	8	11	4	216
28	8	8	2	12	7	10	7	4	0	4	8	8	5	6	6	6	5	7	6	10	4	5	7	5	150
29	10	8	10	12	11	13	12	10	12	10	4	11	8	12	12	11	11	7	8	12	6	8	13	2	233
30	10	8	6	10	11	8	12	9	8	8	9	10	13	9	8	9	8	12	9	10	7	11	9	10	224
31	12	12	6	16	14	15	10	7	6	8	6	12	12	9	12	13	11	8	8	11	7	11	13	5	244
Aug. 1	9	8	7	14	10	14	12	9	7	4	9	7	14	11	10	11	12	10	10	11	8	12	8	6	233
2	10	9	6	9	11	11	5	5	6	1	7	8	9	5	7	8	6	5	7	8	5	6	11	6	171
3	6	5	4	8	6	6	3	6	4	0	3	6	6	8	4	4	4	4	5	4	5	5	8	4	118
4	6	7	4	8	5	7	4	3	5	0	6	4	6	7	6	1	8	4	7	6	4	6	8	4	126
5	12	8	6	10	10	10	9	8	6	0	6	10	9	8	8	1	9	7	8	7	7	12	8	1	180
6	8	7	5	12	8	12	8	7	5	0	2	7	8	7	7	0	10	5	4	8	5	8	7	2	152
7	5	7	4	8	9	7	5	2	5	0	8	6	6	5	8	0	6	4	10	6	6	3	8	4	132
8	6	6	5	8	6	8	7	3	5	0	4	7	6	7	3	2	7	6	5	5	4	3	4	3	120
9	7	5	3	8	8	8	6	3	4	0	4	7	7	6	6	1	7	5	6	5	2	7	9	4	128
10	3	4	4	6	4	7	5	4	5	0	1	4	4	4	4	0	4	5	4	4	3	4	4	3	90
11	5	4	2	6	4	6	4	4	4	0	3	6	5	5	4	1	3	3	4	6	2	4	4	2	91
12	4	5	5	9	9	6	1	1	5	0	3	7	7	8	2	4	8	7	3	6	3	8	3	7	121
13	4	3	4	9	4	8	7	2	2	0	2	5	6	3	2	0	6	6	4	6	3	6	2	4	98
14	2	7	3	8	5	8	7	1	1	0	2	8	6	6	0	1	6	4	4	5	4	6	1	2	97
15	3	3	3	8	2	6	3	1	3	0	2	5	3	5	1	0	4	4	4	6	2	7	0	2	77
16	0	5	2	6	3	10	3	3	6	0	0	7	5	6	0	2	5	5	0	4	0	6	0	1	79
17	2	4	4	8	4	5	3	2	5	0	1	5	3	7	0	0	4	6	6	3	2	6	0	2	82
18	0	1	2	3	2	2	1	0	0	0	0	2	3	2	0	0	0	4	1	5	1	5	0	0	34
19	0	3	2	2	2	4	1	1	4	0	0	4	2	4	1	0	2	4	1	2	0	9	0	2	50
20	0	0	2	3	0	1	1	2	3	0	2	0	2	2	0	0	1	4	2	4	0	9	0	0	38
21	0	0	0	3	2	2	0	1	1	0	0	0	1	2	0	0	0	4	3	2	0	5	0	0	26
22	1	0	1	0	0	0	0	1	0	0	0	0	1	3	0	0	0	5	0	2	0	5	0	0	19
23	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	4	1	2	0	7	0	1	18
24	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	2	0	3	0	0	9
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	4
26	0	0	0	1	0	0	0	1	0	0	0	0	0	2	0	0	0	2	0	0	0	1	0	0	7
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	3
28	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	1	0	0	1	0	0	1	7
29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	1	0	5
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Sept. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	295	269	202	378	301	386	274	223	245	141	185	286	313	285	248	191	282	283	249	285	196	321	262	180	6,280

As indicated in Table III, the total number of eggs laid by the 24 females was 6,280. The minimum number laid by an individual was 141 and the maximum number 386, the average for the 24 beetles being 261.66.[1] The first eggs were deposited on July 3 and the last on September 5, oviposition by all the beetles covering a period of 65 days. The greatest number of eggs laid by a female in a single day was 16, and this record was made in only one instance. Another beetle laid 15 eggs in a day and there were six cases in which 14 eggs were laid in a day. The period of greatest egg production was from July 13 to August 12, 81.9 per cent of the eggs being deposited between these dates. The maximum number of eggs for one day was 244; these were produced on July 31.

ACTIVITY OF THE BEETLES AT NIGHT.

During the progress of the investigation it became apparent that the beetles were ovipositing and feeding on the leaves to some extent during the night, and, to obtain data on this point, 5 pairs of beetles were confined in cages in the insectary on July 19 and kept under observation until August 3, a period of 14 days. The beetles were provided with fresh grapes and leaves three times daily, at 5 a. m.,[2] 12 m., and 7 p. m., the duration of the forenoon period being 7 hours, that of the afternoon period 7 hours, and that of the night period 10 hours. Each time the grapes and leaves were changed in the cages counts were made of the eggs and leaf-feeding marks produced during the period just ended. The counts showed a total of 455 eggs produced by the 5 females for the entire period. Of this number 85 were deposited during the forenoon period, 148 during the afternoon period, and 222 during the night period. The average was 16.6 eggs for each of the 14 hours of daylight and 22.2 eggs for each of the 10 hours of darkness. Feeding on the leaves was more active by day than by night. The 10 beetles during the daylight periods made 1,072 feeding marks, or an average of 78 for each of the 14 hours of daylight, and 376 during the night period, or an average of 37.6 for each of the 10 hours of darkness.

TIME REQUIRED FOR EGGS TO HATCH.

About 50 eggs deposited on July 17 hatched on July 23 and an equal number deposited on July 21 hatched on July 27, the period of incubation in both cases being 6 days. Differences in temperature probably would produce a variation of a day or two in the length of this period.

All the eggs of a female that had been separated from males for 33 days were found to be fertile, although in nature copulation continues at frequent intervals until the end of the egg-laying season.

[1] It is interesting to note that the average number of eggs laid by 30 females from which a record was obtained in 1905 (30) was 257.46, a difference per individual for the two lots of beetles of only 4.2 eggs.

[2] All references to clock time refer to "Standard time."

ACTIVITIES OF THE LARVÆ.

The young larvæ begin to feed on the grape berry before they are free from the eggshell and within a few minutes after emergence from the shell burrow out of sight within the pulp. On the second or third day they attack the seed and on the fourth day practically all the larvæ are located within the seed cavity of the grape berry. Later they leave the seed cavity and continue to feed on the pulp, soon converting the interior of the grape into a discolored mixture of pulp and excrement. (Pl. II, *E*)

Larvæ reached full growth and issued from the grapes in from 13 to 25 days after the deposition of the eggs. Table IV shows the number that appeared on each day.

TABLE IV.—*Number of days elapsing from deposition of eggs by the grape curculio to issuance of larvæ from the grapes.*

Number of days in grape	13	14	15	16	17	18	19	20	21	22	23	24	25
Number of larvæ issuing	2	5	51	71	29	37	17	10	11	7	1	3	3

According to Table IV, allowing 6 days for the eggs to hatch, the larvæ remain in the grapes from 7 to 19 days, the average time being from 10 to 12 days.

The larvæ squeeze through small holes which they make in the skin of the grape berry and seek at once for places in which to pupate. Most of the larvæ leave the grapes during the morning hours, although a few continue to appear during the afternoon. On August 4, 1917, 57 larvæ dropped from a basket of infested grapes suspended in the vineyard over a container. At the end of every hour the larvæ in the container were collected and counted. The results are shown in Table V.

TABLE V.—*Time of day in which larvæ of the grape curculio leave grape berries.*

[Standard time.]

	A. M.								P. M.		P. M. to A. M.
Hours of day	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–1	1–2	2–4
Number of larvæ	0	2	7	17	13	5	2	5	5	1	0

Table V indicates that more than one-half of the larvæ leave the grapes to pupate between the hours of 7 and 9 in the morning. Most of the cocoons are constructed on the surface of the ground except in cases where the larvæ follow cracks or other openings into the soil. They are frequently placed under fallen leaves or other small objects and are sometimes attached to straws or stones lying on the surface of the ground.

THE PUPA PERIOD.

Small lots of larvæ which had just issued from grapes were placed in jars containing earth on August 1 and 2, 1917. From these larvæ 46 beetles developed, of which 37 emerged on the eighteenth day and 9 on the nineteenth day. This and other observations indicate that in the warmer part of the summer the beetles issue, on an average, about 18 days after the construction of the cocoon. The larvæ that leave the grapes late in August and in September pupate and remain within the cocoon until the spring following, when they issue as beetles at about the time the wintering beetles are emerging from hibernation.

THE BEETLES IN THE FALL.

The young beetles that appear late in summer spend all the remaining warm days of the season on the grape foliage. They feed rather freely and can be distinguished very readily from the old beetles which are still on the vines by their fresher appearance and darker color. Many of the beetles that appear from hibernation or from wintering pupæ in the spring live through the entire season and enter hibernation again in the fall. Of the lot of 48 beetles kept in glass tumblers for the purpose of obtaining egg records throughout the summer of 1917, 36 were still alive on October 4. At that time the 36 beetles were placed in a large jar containing dry, decayed wood and soon thereafter they hid away in the wood fragments and became dormant. There is considerable mortality among the beetles soon after they appear upon the vines in the spring, and the probability is that most of the beetles that die at that time are the individuals that have survived two winters.

NATURAL ENEMIES.

PREDACIOUS FORMS.

At the time the grape curculio larvæ leave the grapes and crawl over the ground in search of suitable places to pupate, they fall an easy prey to ants and other enemies. In the summer of 1917 a small red ant, determined by Wheeler as *Solenopsis molesta* Say, was observed in great numbers feeding on larvæ beneath infested grapevines. Another ant, determined by Wheeler as *Aphaenogaster fulva* Roger, subspecies *aquia* Buckley, variety *picea* Emery, was present in less numbers and was observed attacking the larvæ. A small ground-dwelling spider, as yet undetermined, was seen to pounce upon a curculio larva and was caught as it hurried with its load beneath a stone. The larva of a rove beetle, *Philonthus brunneus* Gravenhorst, and the following species of ants are recorded as attacking the curculio larva: *Camponotus pennsylvanicus* De

Geer, *Myrmica punctiventris* Roger, *Lasius americanus* Emery, *Cremastogaster lineolata* Say, and *Solenopsis debilis* Mayr.

PARASITES.

In August, 1916, it was found that many of the curculio eggs were being destroyed by a minute hymenopterous parasite, determined by Girault as *Anaphoidea conotracheli* Girault Pl. (II, *C*), a well-known egg parasite of the plum curculio, *Conotrachelus nenuphar* Herbst. This parasite is about half a millimeter in length and is barely visible to the naked eye. The legs and bases of antennæ are light brown and the rest of the body is black. In 1917 this parasite was again abundant and was observed frequently ovipositing in the curculio egg punctures in grapes. When a fresh puncture was made by the grape curculio several of these egg parasites would collect about it and could be seen through a lens, thrusting their ovipositors through the skin of the grape into the curculio eggs in the egg chamber. Males usually were present and copulation would take place while the females were struggling with one another for a desired position over the egg chamber. Adult parasites issued in from 10 to 13 days after their eggs had been deposited within the eggs of the grape curculio. When the mature parasites leave the host eggs they sometimes enter the pulp of the grape and mine through it to the surface, making a threadlike burrow half an inch or more in length. The exit hole of the parasite in the skin of the grape is usually near to the original puncture of the curculio.

In determining the extent of parasitization by this species, about 50 curculio beetles were confined on July 24, 1917, in a wire-screen cage over a live branch of grapevine bearing 8 bunches of sound fruit. Two days later the cage and curculios were removed and the punctured grapes left exposed for six days to the attacks of the egg parasites. A later examination showed that 134 curculio eggs had been deposited in the grapes and of these 53, or 39.5 per cent, had been parasitized. The oviposition period of the curculio is sufficiently long for the development of four or five successive generations of the parasite. This may account for an apparently constant increase in the percentage of parasitized curculio eggs as the season advances.

Another parasite, *Microbracon mellitor* Say (Pl. II, *D*) was observed frequently ovipositing in infested grapes on the vine and on the ground. The larva of this species attacks the larva of the curculio externally and devours it, after which it constructs within the grape a small, dirty-white cocoon from which the adult parasite escapes within a few days. A third hymenopterous parasite, *Stiboscopus brooksi* Ashm. (Pl. II, *E*), attacks the curculio while within the cocoon. This parasite is about 4 mm. in length, the ovipositor being one-third as long as the body. The head and thorax are shining black, the abdomen brown, the tips of antennæ dark brown, and the bases of antennæ and the legs light brown. It runs rapidly over the ground under infested grapevines, frequently crawling beneath fallen leaves and into openings in the ground in search of curculio cocoons. When one is found the parasite manifests much excitement and runs about over the cocoon, with both antennæ and ovipositor applied to the surface, in search of a vulnerable point of attack. When such a point is located the ovipositor is thrust viciously to its full length within the cocoon, after which the insect remains quiet for a few seconds while the egg is being deposited. The parasitic larva destroys the curculio within the cocoon and issues as an adult within a short time. Both this species and *Microbracon mellitor* were abundant in the locality where the present investigation was carried out. A single specimen of still another parasite, which has been determined by Mr. R. A. Cushman as *Triaspis curculionis* Fitch, was reared from the grape curculio in 1917.

METHODS OF CONTROL.

SPRAYING.

The long period during which the curculio beetles feed freely on the upper surface of the grape leaves renders them peculiarly susceptible to arsenical sprays. In several cases practically complete freedom from attack was obtained by applying two sprays of lead arsenate at a strength of 3 pounds of the paste to 50 gallons of water, the first just after the blossoms had dropped and the second three or four weeks later. In August, 1917, a count of several thousand fruits of different varieties of grape from sprayed vines showed that only a little more than 1 per cent of the fruit was infested, while on unsprayed vines in the same locality from 75 to 90 per cent of the fruit was punctured.

On July 26 a Concord grapevine was sprayed with lead arsenate at a strength of 3–50. As soon as the spray was dry a branch of the vine bearing leaves and several bunches of sound fruit was inclosed in a wire-screen cage in which 50 male and female curculio beetles had been placed. Four days later, when the cage was removed, all the beetles were dead. The grapes which had been in the cage contained 8 eggs and there were about 50 feeding marks on the leaves, indicating that the death of the beetles resulted from a small amount of feeding. At about the same time another grapevine was sprayed with a tobacco extract containing 40 per cent of nicotine as sulphate at the rate of 1 pint to 800 gallons of water, and a fruiting branch inclosed with 40 beetles. At the end of 4 days 38 of the beetles were still alive in the cage, 119 eggs had been deposited in the fruit, and 1,136 feeding marks had been made on the leaves.

It is possible to destroy the beetles by spraying with arsenicals at any time during the growing season of the fruit, or in the fall after the fruit has been gathered. Preferably, however, a spray should be applied in the spring soon after the blossoms have dropped and another three or four weeks later. This is the season when other grape insect pests and fungous diseases are to be dealt with and the sprays can be prepared and applied for combined results. As has been pointed out, the beetles are feeding on the foliage for 10 days or more before oviposition begins and practically all may be killed by spraying before any injury is done to the fruit.

BAGGING.

Inclosing the clusters of fruit when about one-fourth grown in 1-pound or 2-pound paper bags affords complete protection against the curculio. The ordinary paper bags kept by grocers are sufficient for this purpose. The bags should be slipped over the clusters and the mouth pinned or otherwise fastened securely around the stem. The bags usually remain intact until the fruit is ready for gathering, and the grapes within ripen perfectly. This method of protecting the fruit, however, is much slower and more expensive than is spraying, and for protecting the fruit from the curculio the results are very little, if any, better than would be obtained by spraying.

OTHER METHODS OF CONTROL.

Cultivation of the soil under infested grapevines destroys the curculios to some extent by breaking up the cocoons and exposing the pupæ, or by burying the cocoons so deeply in the soil that the beetles on emerging from the cocoons are unable to work their way to the surface.

A measure of benefit also may be obtained by gathering and destroying the punctured fruit and by collecting the beetles by jarring them from the vines in the early morning or on cloudy days upon sheets spread on the ground beneath the vines.

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II. THE GRAPE ROOT-BORER.[1]

By Fred E. Brooks, *Entomologist, Deciduous-Fruit Insect Investigations.*

CONTENTS.

INTRODUCTION.

The studies of the grape root-borer (*Memythrus polistiformis* Harris) described herein were conducted principally at French Creek, W. Va., during the summers of 1916 and 1917. Conditions there were favorable for the investigation, since the insect occurred abundantly and over a hundred badly infested grapevines were at the entire disposal of the investigator. Wild grapes of the species *Vitis labrusca, V. cordifolia,* and *V. aestivalis* abounded also in the locality, affording an opportunity for observations as to native host plants.

The grape root-borer in all its stages is peculiarly inconspicuous, and there is a possibility that the species is a more widespread and serious enemy of grapes than has been commonly supposed. The eggs (Pl. III, *E*) are small and dark-colored and are so placed by the female moth that they escape notice, the larvæ (Pl. III, *A, B*) feed exclusively on the roots and throw no castings to the surface of the ground, pupation takes place within the soil, and the adults (Pl. III, *C, D*) so closely resemble wasps of the genus Polistes that the casual observer does not distinguish between them and true wasps. Grapevines are rarely killed outright by the borers, but, on becoming infested, usually linger for years, making meager annual growth and bearing reduced crops of fruit (Pl. V). There is a probability that many vineyards suffer seriously from this insect while persons in charge of the vines remain unaware of the true cause of the trouble.

Note.—The author wishes to acknowledge the assistance of Mr. C. R. Cutright, field assistant in the Bureau of Entomology, in conducting the investigation described herein.

[1] *Memythrus polistiformis* Harris; order Lepidoptera, family Aegeriidae.

ECONOMIC HISTORY.

The grape root-borer is a native of the eastern part of the United States, and doubtless bred originally in the several species of wild grapes indigenous to that region. It was first described in 1854 by Harris (1, 2),[1] who recorded injury by the species in North Carolina. In 1867 Walsh (3) wrote of the species at some length and reported injury in Kentucky, Missouri, North Carolina, and Ohio. He quotes a correspondent who said he had noted injury by the root-borer in Missouri for 20 years. Riley (4), in 1871, mentioned the destructiveness of the species in Kentucky and recorded capturing the moths in Missouri. In 1873 Glover (5) reported, on the authority of a correspondent, that 5,000 vines, representing 107 varieties imported from Paris and planted at Albemarle, N. C., were lost as a result of attacks by this borer. Lugger (6) states that a single moth of this species was seen flying about a wild grapevine in Minnesota in 1898. Holland (7), in 1903, mentioned the range of the moth as extending as far north as Vermont. Brooks (8), in 1907, wrote of serious injury by the species in central West Virginia.

GEOGRAPHICAL DISTRIBUTION.

The grape root-borer has been recorded as occurring in the States of Kentucky, Minnesota, Missouri, North Carolina, Ohio, West Virginia, and Vermont. It very probably will be found in other States, where the inconspicuousness of the insect and its work have resulted so far in its being overlooked.

FOOD PLANTS.

Grapevines, so far as known, are the only plants attacked by this insect. Apparently all the common cultivated varieties of the eastern part of the country suffer about equally in this respect. Vines of the fox grape, *Vitis labrusca*, growing in a vineyard, were found to be attacked almost as extensively as Concord and other cultivated sorts, although vines of the same species growing in woods were not injured seriously. Vines of *V. cordifolia* and *V. aestivalis* were not observed to be attacked. The Scuppernong, a variety of the Southern fox grape, *Vitis rotundifolia*, is said by a correspondent of Glover (5) to have withstood attacks.

RECENT INJURIES.

During the past 10 years the writer frequently has observed serious injury by the grape root-borer in a few sections of West Virginia. Vines have been seen in other localities which had every appearance of being infested, but, since the borers can be found only by digging

[1] Numbers in parentheses refer to "Literature cited," p. 28.

to the vine roots, no examination was made and positive evidence of their presence is lacking. A number of old vines are known that have been infested constantly for at least 10 years. In cases where these vines have been pruned, cultivated, and fertilized a strong annual growth of wood is still made and the crops of fruit are satisfactory. Infested vines when neglected, however, in all cases observed have practically ceased growing and died by degrees over a period of several years.

NATURE OF INJURY.

Injury to grapevines by the root-borer is due exclusively to the burrows made by the larvæ in the roots (Pl. III, *A*, *B*), and is usually in the nature of severe root-pruning. The newly hatched larvæ enter the ground in the vicinity of grapevines and penetrate the soil in search of roots, attacking them wherever found. Usually roots smaller in diameter than an ordinary lead pencil are not made a place of permanent attack. Those half an inch in thickness, and often those that are larger, are girdled or eaten entirely off, only a stump of live root being left to help sustain the vine. Frequently all the main roots of a vine will be severed at varying distances from the root center. In such cases the remaining root stumps hasten to send out branch roots, the vigor and extent of growth of the branches depending largely upon the cultural care the vine is receiving at the time.

DESCRIPTION.

THE EGG.

(Pl. III, *E*.)

The egg is 1.1 mm. long by 0.7 mm. wide, chocolate brown, oblong ovate, and flattened; one end is slightly truncate, and a broad furrow extends longitudinally on one side. The surface, except in the furrow, is finely and distinctly reticulate.

Eggs hatch in from 18 to 23 days.

THE LARVA.

(Pl. III, *A*, *B*.)

When first hatched the larva is dingy brown and about 2 mm. in length. After the first or second molt the color changes to white. The head is brown and the body is distinctly segmented and covered sparsely with short, stiff hairs. Full-grown specimens are from 35 to 40 mm. in length. The larva stage covers a period of nearly two years.

THE PUPA AND COCOON.

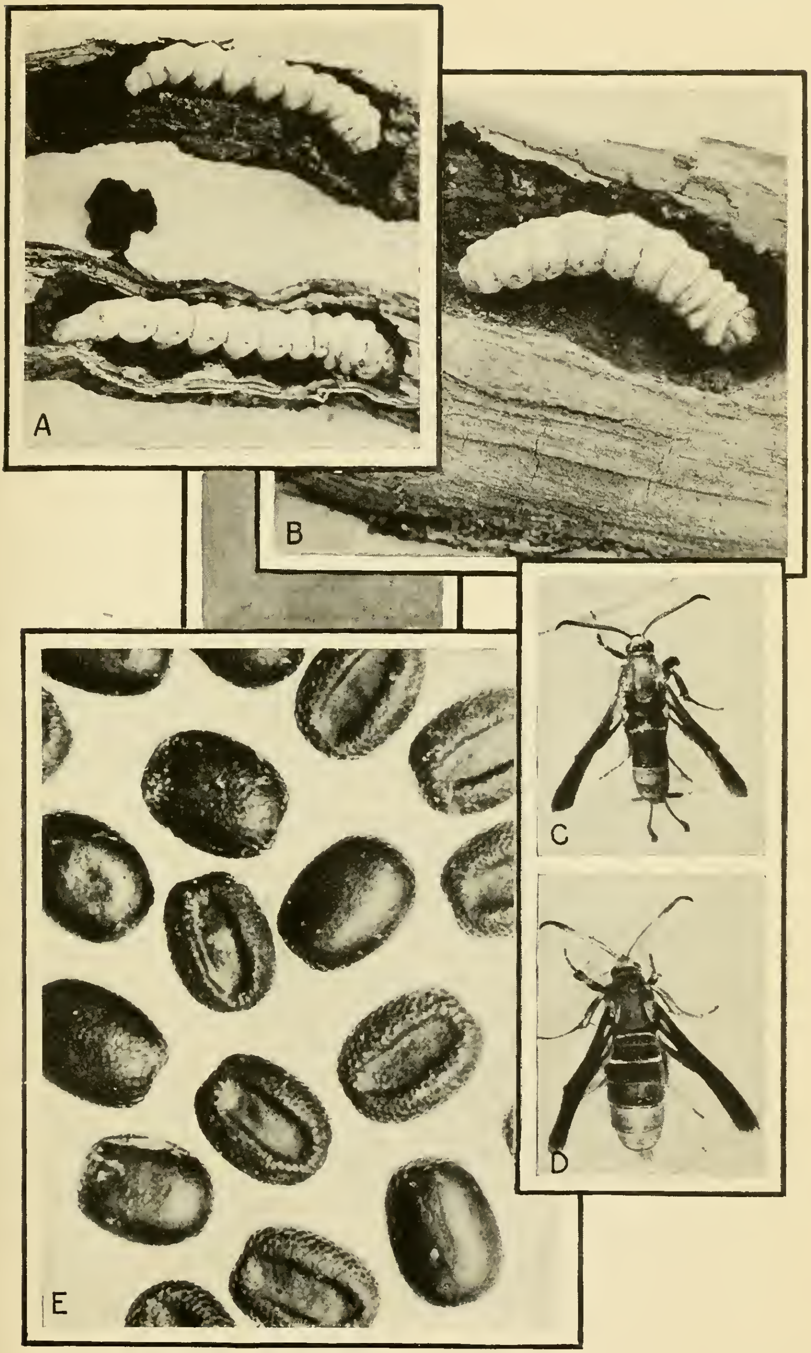
(Pl. IV, *A*, *B*.)

The pupa is dark brown, with bands of a lighter shade encircling the abdomen. Its average length is 20 mm. It occupies a cocoon at the surface of the ground, usually directly over the point in the root where the full-grown larva ceased feeding. The pupa is characteristic of its family, being spindle shaped, the males having 14 and the females 13 rows of strong reflexed dorsal spines, the cremaster consisting in each of 8 stout spines surrounding the anal end. The cocoon is from 20 to 30 mm. in length and stands perpendicularly in the soil with the anterior end just at the surface of the ground. It is composed of frass and grains of earth held together with a parchment-like lining of brown silk. Usually, although not always, more grains of earth than of frass enter into the composition of the outer part of the cocoon. The pupæ and cocoons of the females average longer and stouter than those of the males. When the moth is ready to issue it works half the length of the pupa out of the cocoon and escapes from the pupa case through a slit in the back, leaving the empty case projecting above the ground. (Pl. IV, *B*.) The insect occupies the cocoon for a period of about four weeks.

THE ADULT.

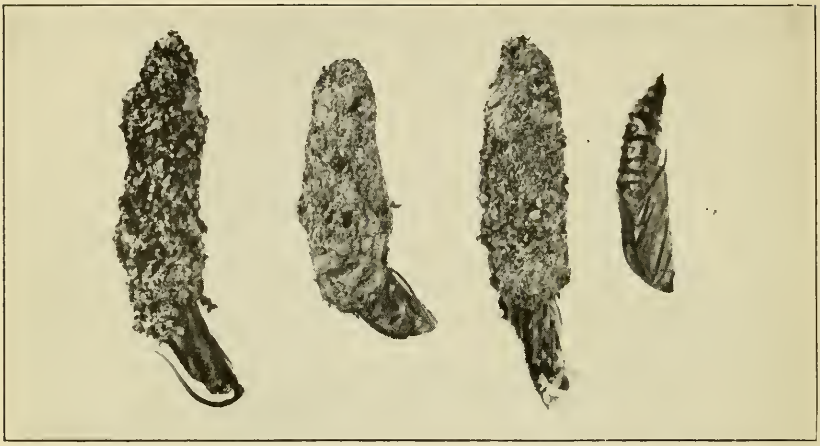
(Pl. III, *C*, *D*.)

The mature insect is a handsome, wasplike moth, the males of which are from 12 to 18 mm. in length, and the females from 18 to 20 mm. The general color of both sexes is dark lustrous brown. The fore wings are brown and the hind wings transparent bordered and veined with brown. The abdomen is encircled at the posterior margins of the second and fourth segments with conspicuous bands of orange and lemon colored scales, the lemon scales predominating in the front band and the orange in the other. There are spots of metallic yellow scales at the base of the wings. The legs are reddish brown. The antennæ of the males are brown, marked with metallic colors and are delicately pectinate; those of the female are brown for a third of the length at the base, the rest metallic purple and bronze. The female has a small orange-colored tuft on each side of the tail and the male has two such tufts on each side, the middle pair being more than twice as long as the others. The scales with which the moths are covered rub off easily and old specimens rarely show all the markings described above.



THE GRAPE ROOT-BORER.

A, B, Larvæ feeding in grape roots (A, natural size; B, enlarged); C, male moth, slightly enlarged; D, female moth, slightly enlarged; E, eggs, greatly enlarged. (Original.)



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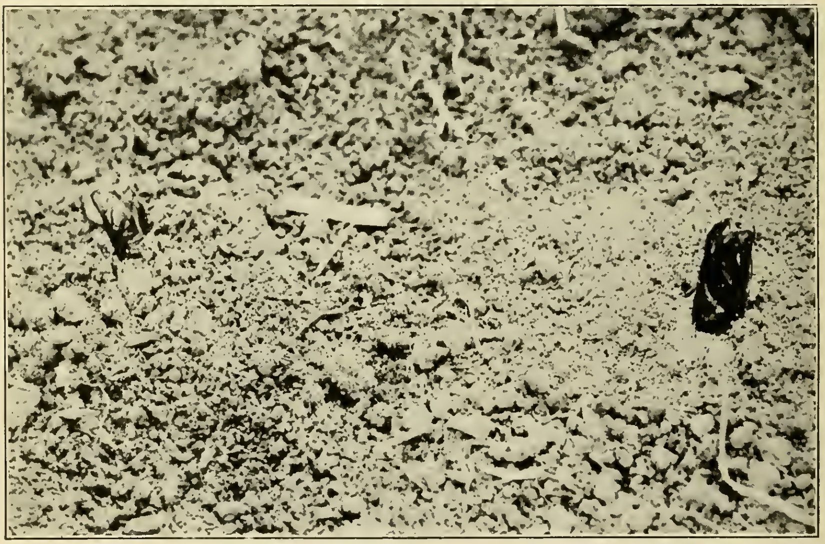

B

THE GRAPE ROOT-BORER.

A, Pupa, cocoons, and empty pupa cases; B, empty pupa cases projecting from ground under grapevine. Slightly enlarged. (Original.)

THE GRAPE ROOT-BORER.

Old grapevine showing small growth and light crop of fruit due to injury. (Original.)

ACTIVITIES OF THE MOTHS.

It has been stated that in North Carolina the moths are on the wing from the middle of June until the middle of September (3) but observations indicate that in West Virginia the period of flight is not so long. Table I shows the dates on which moths were first and last seen in three different years in West Virginia.

TABLE I.—*Period moths of the grape root-borer are on the wing, West Virginia.*

Year.	First seen.	Last seen.	Number of days on wing.	Average number of days.
1907	July 24	Aug. 10	18	
1916	July 20	Aug. 17	29	23.3
1917	July 25	Aug. 17	24	

The records set forth in Table I show that in the locality where the present investigation was made the moths are probably on the wing a little less than 30 days, instead of 90 days, as reported from North Carolina.

The moths issue from the cocoons on bright, warm days, usually about the middle of the forenoon. Of 11 females observed, all left the cocoons between 9 a. m.[1] and 11 a. m. The males after issuing rest for a while on some object near the discarded cocoon and then take flight, but the females are less active and usually remain quietly near the place of emergence several hours to await the coming of the males. Several females that were kept under observation were seen to elevate their genitalia, evidently sending forth a scent to attract males. Almost instantly after this act was begun by the female a swarm of males would appear and copulation would soon take place. Usually the pair would remain connected for 2 or 3 hours, and on the morning following egg laying would begin. In one case observed copulation lasted 2 hours and 45 minutes and in two cases 3 hours and 40 minutes each. Two or three of the females did not attract and receive the males until the morning following their emergence from the cocoons. One group of excited males that gathered around a female contained a single male of the squash-vine borer, *Melittia satyriniformis*. This moth grasped the female and attempted to pair with her after she had united with a male of her own kind.

In ovipositing the females make short flights, alighting on the canes or leaves of grapevines, or, more frequently, on grass, weeds, or straws under or near the vines, and deposit in each place one or more eggs. Sometimes four or five eggs will be placed together and at other times the female will crawl over the surface of a leaf or along a

[1] References to clock time refer to standard time.

grape cane or weed stem, pausing every few inches to deposit an egg. No attempt is made to conceal the eggs, except that the moth occasionally will move along the margin of a leaf and bend her abdomen over the edge, placing eggs on the underside. The eggs are attached very feebly, and the rain or wind soon dislodges them and they fall to the ground before hatching. One female kept in a cage produced 555 eggs and several others more than 400 each. About a week is required by the female in which to deposit her quota of eggs. Females caught in the vineyard while ovipositing and placed in bottles continued to drop eggs with scarcely any intermission resulting from the changed conditions.

As has already been mentioned, there is a close resemblance in the moths to the comb-building wasps of the genus Polistes. The gravid females are somewhat more deliberate in flight than are the wasps, but the males dart about on the wing in a manner that is very wasplike. The males have a habit of resting for long periods in exposed positions about the vines, and when approached or disturbed frequently flutter their wings rapidly, giving off a buzzing sound that still further increases their resemblance to wasps. Rarely the female also will engage in this buzzing performance.

Bottles in which females had been kept in the insectary, and in which they had been seen to elevate their genitalia, were several times taken to the vineyard after the females had been removed. When uncorked, males would appear almost immediately, evidently attracted by the scent, and would even enter the bottles in search of the females.

LARVAL ACTIVITIES.

The larvæ hatch from eggs that at the time are almost invariably scattered over the ground in the vicinity of grapevines. After hatching they at once burrow into the soil and attack the larger grape roots whenever found. It is possible that they subsist on small roots and root fibers while searching for their permanent places of attack, but undoubtedly many of them perish before finding roots to their liking. They enter the roots wherever they come in contact with them, either close to the vine or far out toward the extremities. In one case a larva was found that had penetrated a foot of stiff clay soil and attacked a root at a point 19 feet from the vine.

The ability of the larvæ to penetrate the ground to a considerable distance was shown by placing a large number of hatching eggs on the surface of soil that had been placed to a depth of 9 inches over some sections of grape root in the bottom of a wooden box. Twenty days later the grape roots were removed and the bark found to be filled with young borers. The borers had mined an inch or more in the bark, some of the burrows encircling the roots and others extending parallel with the grain of the wood.

As the larvæ increase in size the burrows become large and irregular in outline, and roots that are half an inch or less in diameter usually are eaten off or injured so severely that the outlying section dies. Very large roots may withstand the combined attacks of several borers without being killed. Such large roots are usually eaten most extensively along the underside.

The larva passes the winter in a roomy chamber at the end of its burrow, the chamber being sometimes, although apparently not always, lined with a very thin web of silk. Feeding is not continued through the winter, but is resumed as soon as the soil becomes warm in the spring.

When full grown the larva makes an open passage from its feeding place upward through the soil to the surface of the ground, where the cocoon is constructed. The larva in some way transports from the root considerable frass for use in making the cocoon. Evidently after the cocoon is begun the larva passes back and forth frequently from the cocoon to the root, probably feeding on the root at intervals and voiding the frass while working at the cocoon. Pupation takes place in June and early July.

NATURAL ENEMIES.

No parasites of this species are known. During the present investigation ants were seen carrying the moth eggs, but what disposition they made of them was not observed. In a previous study of this species (8) the writer found the larva of a firefly beetle (*Photuris pennsylvanica* De Geer) which had broken into a root-borer cocoon and was devouring the pupa. The crested flycatcher (*Myiarchus crinitus*) was observed to catch several moths on the wing.

METHODS OF CONTROL.

This species does not lend itself readily to any of the common insecticidal methods of control; neither is the worming process, so often used against various borers attacking fruit trees, of practical application against this species. The borers feed in the roots over so wide an area that digging for them as a practicable method of destruction is out of the question and even soil fumigants are, for the same reason, of doubtful value.

Thorough cultivation of the soil around the vines during June and July is of some benefit in destroying the larvæ and pupæ in the cocoons. By far the most valuable practice, however, is the application of such cultural methods as would induce in a healthy vine a vigorous and rapid growth. It was found that even badly infested vines, when carefully pruned, sprayed, fertilized, and cultivated, made a normal wood growth and bore satisfactory crops of fruit. The borers, by killing the terminals of so many of the roots, greatly restrict the feeding area of the root system, and it becomes necessary to use fertilizers rather freely within a few feet of the vine, where most of the roots are located. The use of fertilizers and the application of the other cultural methods mentioned become increasingly important as the root injury increases.

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1907. The grape-vine root-borer. West Va. Agr. Exp. Sta. Bul. 110. 3 p., [5] pl.

Account of an investigation of the species in West Virginia.

III. EXPERIMENTS IN THE CONTROL OF THE ROOT FORM OF THE WOOLLY APPLE APHIS.[1]

By B. R. Leach, *Scientific Assistant, Deciduous-Fruit Insect Investigations.*

CONTENTS.

INTRODUCTION.

During the seasons of 1914 and 1915 a series of experiments on the control of the root form of the woolly apple aphis (*Erisoma lanigerum* Hausmann) was conducted in Virginia, the work being based on the results obtained by French investigators in the employment of carbon disulphid and sodium cyanid in solution against the grape phylloxera. The opportunity also was afforded of obtaining data on the use of kerosene emulsion and on the effect of deep planting as preventives of woolly apple aphis injury.

Little work appears to have been done by American entomologists in the employment of carbon disulphid and sodium cyanid in solution as a control for soil-inhabiting insects. The data obtained as a result of the experiments herein reported are presented in the hope that other experimenters will have opportunity to carry out further tests along these lines. Much additional information concerning these treatments is desirable, especially that which may be acquired through experiments carried on under a variety of climatic, crop, and soil conditions.

THE USE OF CARBON DISULPHID IN WATER.

EARLY RECORDS.

The use of carbon disulphid in water was first proposed by Cauvy,[2] of France, in 1875.

It was found that a solution containing from 0.5 to 1.2 per cent of carbon disulphid will kill the grape phylloxera in 24 hours. The

[1] *Eriosoma lanigerum* Hausmann; order Hemiptera, suborder Homoptera, family Aphididae.
[2] Bourcart, E. Insecticides, Fungicides and Weedkillers. p. 74. London, 1913.

advantages claimed for the method are that it is harmless to the vine, even in full vegetation, and that by its use a uniform distribution of the carbon disulphid in the soil is effected. It is stated, however, that the disadvantages of this treatment are the enormous amount of water required and the high labor cost.

No record has been found of the use of this method in the United States.

EXPERIMENTAL WORK WITH THIS METHOD.

Realizing the possible merits of this method of applying carbon disulphid, a series of determinative experiments was carried out during the seasons of 1914 and 1915. The resulting data, herewith presented, include an account of the preliminary work to determine the factors influencing this water treatment and a report of the large-scale operations in the field in which this method was utilized, based on the knowledge acquired in the preliminary experiments. In conclusion, a discussion of the advantages and disadvantages of the treatment is given.

Preliminary Experiments.

PREPARATION OF THE BASIN.

In applying quantities of liquid for the control of soil-inhabiting insects, such as the root form of the woolly apple aphis, it is necessary, in order that the material may be effective, to prepare a basin around the base of the tree for the reception of this liquid in order that it may be spread evenly over the soil surface, and to insure permeation and absorption by the soil.

In preparation for the reception of the carbon-disulphid solution the basin should be made as shallow as possible, to prevent exposure of the roots. If the roots are exposed, the gas in solution is prevented from acting upon the aphids thereon, and the treatment is thereby rendered incomplete. The bottom of the basin should be absolutely level, with the soil heaped up around the edges to confine the liquid to the area undergoing treatment.

In order to simplify the placing of the liquid, strips of galvanized iron, shown in Plates VI and VII, were utilized. These strips were 12 feet in length and 5 inches in width, providing for a circular basin 4 feet in diameter. After leveling the ground about the base of the tree one of the strips of galvanized iron was placed with the ends overlapping 3 or 4 inches (Pl. VI) and the dirt heaped up around the outer edges. This gave a level basin for the reception of the liquid and confined it to the area to be treated.

AMOUNT OF LIQUID REQUIRED IN THE TREATMENT AND THE INFLUENCE OF SOIL TYPE AND SOIL MOISTURE.

The success of this treatment depends on the one essential, that sufficient liquid be used. Experiments carried out for the purpose of obtaining data on this point demonstrated the general efficiency of three-fourths of a gallon of liquid per square foot of soil area treated. This is equivalent to about one and two-tenths inches of water.

This quantity of liquid, in the majority of cases in moist soils, and regardless of the soil type, will penetrate to reach the aphids infesting the roots at the lower levels. This condition is due to the difference in the depth of infestation in the various soil types by the woolly aphis. In general it may be said that the root infestation by this insect occurs at greater depths in light soils—for instance, the shale loams—than is the case in heavy soils, such as the clay loams. On the other hand, a given quantity of liquid will be absorbed to a greater depth by a light soil than by a heavy soil. It may be said, therefore, that a given quantity of liquid will penetrate a given soil in proportion to the depth of the aphis infestation in that soil. For this reason a standard recommendation can be made as to the quantity of liquid required for all soil types.

The treatment may be used in either dry or moist soil, but is less laborious in the latter. If the ground is well drained, the best results are obtained after a heavy rain, when the soil is saturated, since a given quantity of liquid will penetrate deeper in moist soil than in dry soil, thereby resulting in a more thorough control.

When the liquid is applied to dry soil, most of the liquid (when used at the rate of three-fourths gallon per square foot) is taken up and retained by the first few inches of dry top soil. In order to insure the death of the aphids in the lower levels of the soil under these conditions it is necessary to use a much larger amount of liquid per square foot of area treated, with a consequent increase in labor and cost.

THE PREPARATION OF THE LIQUID AND DETERMINATION OF MOST EFFICIENT DOSAGE.

When carbon disulphid is added to water, and the mixture is allowed to settle, the carbon disulphid drops to the bottom of the container and collects in a single large globule. By agitation with a broad paddle the carbon disulphid may be broken up into globules which diffuse to every portion of the liquid. Some of the carbon disulphid goes into solution while the remainder forms a mechanical mixture with the water.

The small amount of carbon disulphid dissolved in water necessary for the success of this method is remarkable. The following experiment will illustrate this point: A one-fourth inch stream of water at 60° F. was led to the bottom of a column of carbon disulphid 18 inches in depth, contained in a glass cylinder, and allowed to diffuse upward through the carbon disulphid, thereby taking up the carbon disulphid in solution. This solution was immediately collected and placed in sealed bottles until used at the rate of three-fourths gallon per square foot for the control of the root form of the woolly apple aphis. This extremely dilute solution, although less than 1 to 1,000, gave perfect control.

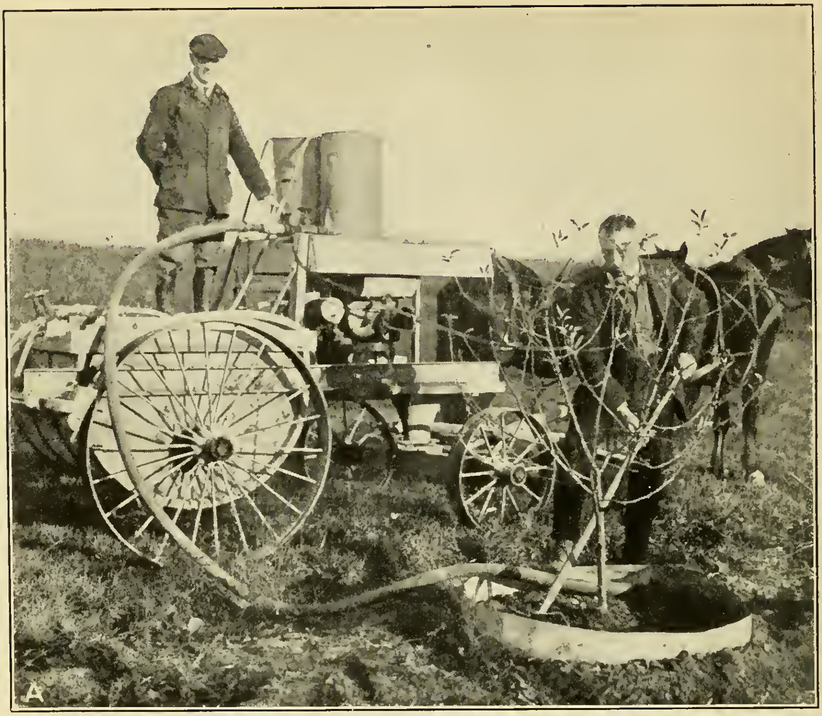
In consideration of the foregoing data, a dosage at the rate of one-half ounce of carbon disulphid to 4 gallons of water was rated as the most efficient, and this was verified subsequently in practice. One-half ounce of carbon disulphid is more than can be dissolved in 4 gallons of water at ordinary temperatures. When the liquid is agitated, the portion of the material not entering into solution forms a mechanical mixture with the water. A margin of safety is thereby secured which insures the success of the treatment. *Under no circumstances is it necessary to employ a stronger dosage than the foregoing.* In fact, when larger doses are used the excess carbon disulphid drops to the bottom of the container, despite agitation, thereby resulting in an uneven strength and consequent danger of injury to the roots.

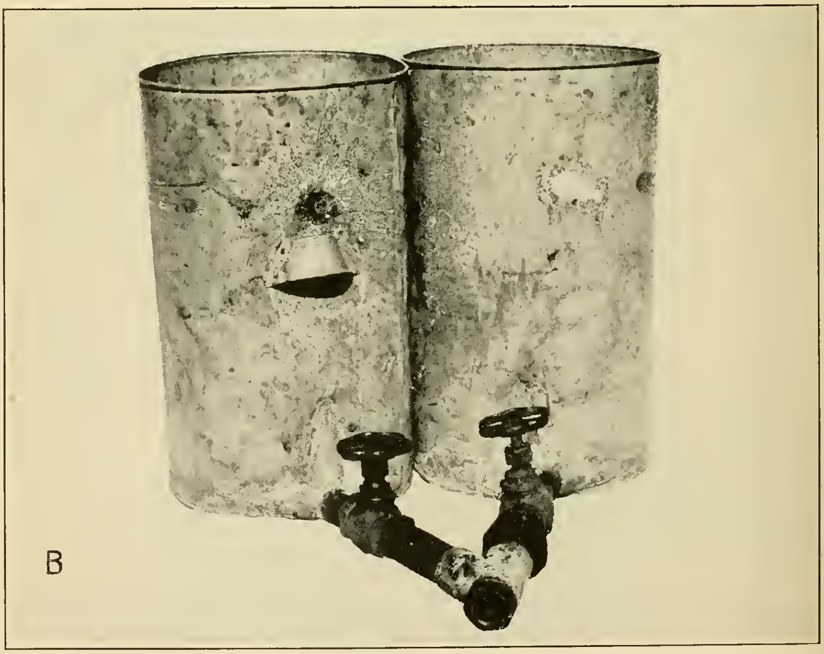
THE DIFFUSION OF THE LIQUID AND CONTAINED GAS IN THE SOIL.

During the course of the work the question arose as to whether the carbon-disulphid gas given off from the water diffused laterally beyond the point in the soil attained by the water itself, and a series of experiments was carried out to determine this point. Figure 1 shows the method employed. The soil treated with the liquid was confined to the circular area 4 feet in diameter within the galvanized-iron strip *D*. The galvanized-iron strip may therefore be taken to represent the line of demarcation between the soil within the strip, directly subjected to the action of the liquid, and the soil outside the strip which remains in its natural state of dryness, except for any possible lateral diffusion at this immediate line of demarcation between the two. At points *A*, *B*, and *C*, respectively, 2, 4, and 6 inches from the strip, screen-wire cylinders containing apple roots infested with the woolly apple aphis were placed in the ground previous to the application of the liquid. When examined 5 days later, the aphids at *A*, *B*, and *C* were alive and breeding. This experiment was carried out in (1) light and (2) heavy soils, both in dry and in moist condition, with the same results. On several occasions the examination of treated trees showed that aphids on the roots located just outside the treated area had escaped, thus corroborating the results of the specific experiments previously outlined. It is apparent, therefore, that the carbon-disulphid gas in the solution does not diffuse laterally through the soil beyond the point reached by the liquid.

CONTROL OF THE ROOT FORM OF THE WOOLLY APPLE APHIS.

A basin for the reception of carbon-disulphid solution, using a strip of galvanized iron. (Original.)





CONTROL OF THE ROOT FORM OF THE WOOLLY APPLE APHIS.

A, The employment of a power-spraying outfit and auxiliary tanks for the application of carbon-disulphid solution in orchard practice; B, the auxiliary tanks. (Original.)

INJURY TO THE TREE.

Apple trees in the first year of growth were treated at the height of the growing season with varying dosages of carbon disulphid in water.[1] One ounce of carbon disulphid to 4 gallons of water caused considerable injury, as evidenced by the drying of the foliage, but did not kill the tree, while 2 ounces to 4 gallons of water killed the tree in three days.[2] Since one-half ounce of carbon disulphid to 4 gallons of water is ample for control there is no necessity for increasing the strength.

In the same way apple trees in their second year of growth were treated with varying dosages of carbon disulphid in water.[1] One ounce carbon disulphid to 4 gallons of water caused no injury, 1½ ounces caused considerable injury, and 2 ounces killed the tree outright in 10 days.[3]

The increased resistance of the older trees is explained by the greater area involved by the root mass, a large part of which was not subjected at all to the fumes of the carbon disulphid.

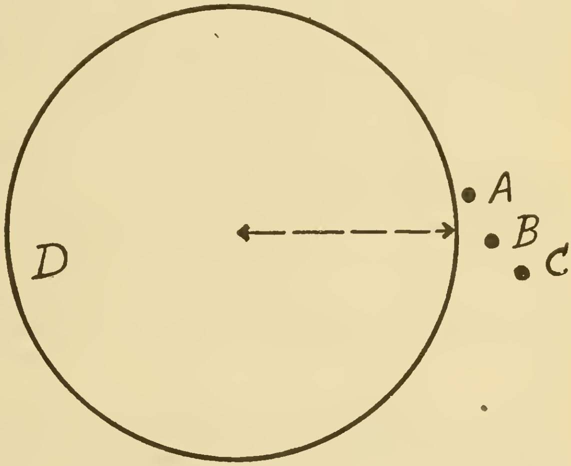


Fig. 1.—Diagram illustrating method of determining the lateral diffusion through the soil of carbon disulphid in water. For explanation see p. 32. (Original.)

During the extended field tests about 500 apple trees of varying ages were treated at the rate of one-half ounce of carbon disulphid to 4 gallons of water and no apparent injury resulted.

Injury to the tree by carbon disulphid in large doses is first indicated by a drying of the foliage. This, however, is merely direct evidence that the small roots and rootlets have been injured, thus cutting off the normal supply of water to the leaves and causing them to turn brown. With medium doses rootlets killed by carbon disulphid are rapidly replaced by the otherwise unimpaired root system. With the dosages of one-half ounce to 4 gallons of water the rootlet injury is negligible, and no killing of the foliage or check in growth will result.

[1] Liquid employed at rate of three-fourths gallon per square foot of soil area treated (p. 31).
[2] Diameter of treated areas in these tests 30 inches.
[3] Diameter of treated areas in these tests 48 inches.

THE BEST TIME OF APPLICATION.

Trees were treated at intervals throughout the season to determine the effect of carbon-disulphid solution when applied at the varying stages of seasonal development. With the possible exception of early spring, when the trees are producing their initial foliage, no noticeable injury was observed. Treatment at this time appeared to delay the process of leafing out. With this treatment it is a question of securing ideal conditions of soil moisture, and not essentially a question of season.

Large-Scale Treatments, Using the Liquid Method.

As a result of the foregoing work experiments involving large numbers of trees were undertaken. These large-scale operations required the employment of a 200-gallon power-spraying outfit and the special galvanized-iron tanks shown in Plate VII. The method of preparing and disposing the solution was as follows:

Having half filled the spray tank with water, the required amount of carbon disulphid, at the rate of one-half fluid ounce to 4 gallons of water, was poured into the tank and the agitation started and continued while the remainder of the water was being run into the tank. The agitation was continued while the outfit was being driven from the source of water supply to the location of the trees to be treated, and by this time the water in the tank was evenly charged with carbon disulphid in solution and in suspension as a mechanical mixture.

The tree basins for the reception of the liquid having been previously prepared, the material was run out through the tanks placed on the top of the engine hood (Pl. VII, *A*) to the basins about the trees. In order to secure accuracy in measuring the liquid, the heights in these tanks representing 4 and 8 gallons were indicated by black circles painted on the inside.

These two auxiliary galvanized-iron tanks (Pl. VII, *B*), having a capacity of 12 gallons each, were connected by a 2-inch Y-pipe to the discharge hose, each of the two arms of the Y-pipe being furnished with a globe valve. The liquid was pumped through a 1-inch hose directly from the 200-gallon tank, and could be directed into either of these two auxiliary tanks at the will of the operator. While one tank was being filled the liquid in the other was being run into a tree basin simply by opening the globe valve belonging to that tank. When empty, the valve was closed and the tank again filled, and during this process the contents of the other tank in turn were emptied into a prepared basin. The process was so regulated that no interruptions were necessary, and 200 gallons of liquid could be disposed of in from 15 to 20 minutes.

A crew of three men was required—a driver, a man to operate the filling and emptying of the tanks, and a man to distribute the water evenly over the surface of the basin.

One tank of 200 gallons was sufficient for the treatment of from 20 to 25 trees, and with a crew of three men it was possible to dispose of one tank an hour, depending on the distance from the water supply.

ADVANTAGES OF THIS METHOD.

The advantages of this method are as follows: When properly agitated every portion of the combination solution and the mechanical mixture contains the same amount of carbon disulphid. When it is poured onto the soil it sinks through the earth, carrying the carbon disulphid to every part of the soil penetrated by the liquid. This results in an even distribution and none of the aphids escape. With this method no portion of the soil receives too much or too little of the fumigant, but just enough to do the work.

DISADVANTAGES OF THIS METHOD.

The greatest disadvantage of this method is the amount of labor in handling the large quantity of water required, the employment of several horses and men being necessary for this purpose.

The difficulty, when ordinary labor is employed, of preparing the basins properly for the reception of the liquid, so as to insure an even distribution of the liquid over the soil area to be treated, is a second disadvantage. On hillsides it is almost impossible to insure the even distribution of the liquid over the surface of the basin.

On some trees, in some soils, the area of infested roots is so extended that treatment of a basin 4 or 5 feet in diameter will not reach all the aphids, and since three-fourths gallon per square foot is required for success, the amount of water necessary for the treatment of an area greater than the foregoing practically limits its use to small trees with restricted root area.

USE OF SODIUM CYANID IN SOLUTION.

EXPERIMENTS ON VINES IN FRENCH VINEYARDS.

Among the substances tried against the phylloxera in France was sodium cyanid in solution. Bourcart [1] records the experiments of Mouillefert as follows:

The stocks were stripped to a depth of about 15 centimeters, with a radius of 30 to 35 centimeters (12 to 14 inches), the soil being rather dry. After pouring on the cyanid solution the soil was replaced at the foot of the stocks and thoroughly packed. The dose varied from 20 to 25 grams per stock, dissolved in 10 liters (2.2 gallons) of water. Wherever the solution had penetrated, the phylloxera and their eggs

[1] BOURCART, E. Insecticides, fungicides, and weedkillers. p. 135. London, 1913.

were dead, but at a depth of 40 to 50 centimeters (16 to 18 inches), as well as between the stocks in a radial direction, even by using five times more water, the result was incomplete.

EXPERIMENTS AT WINCHESTER, VA.

Having prepared the basins as described for the use of carbon disulphid in solution, using 8 gallons of liquid to a 4-foot basin, one tree was treated with the solution at the rate of one-half ounce to 4 gallons of water, and the second tree at the rate of 1 ounce to 4 gallons. The aphids within the treated area were killed.[1]

PREPARATION OF THE SOLUTION.

Sodium cyanid is very soluble in water, and it is therefore not necessary to exercise the same degree of care in preparing the solution as is the case when using carbon disulphid. In the initial experiments outlined above the correct amount of sodium cyanid was weighed out and stirred into the water contained in 2-gallon pails. In the more extended field experiments the material was dissolved in a 200-gallon spray tank and run into the basins through the auxiliary tanks described under the "Use of carbon disulphid in solution."

DOSAGE EMPLOYED.

Experiments were carried out in which from one-fourth to 2 ounces of sodium cyanid to 4 gallons of water were used, and as in the case of carbon disulphid it was found that one-half ounce of sodium cyanid to 4 gallons of water was the most satisfactory.

THE EXTENT OF THE LATERAL AND VERTICAL DIFFUSION OF THE GAS BEYOND THE RANGE ATTAINED BY THE LIQUID.

The particular experiment (p. 32, fig. 1) made to determine whether the fumes of carbon disulphid diffused laterally beyond the range of the liquid was repeated with sodium cyanid. The results were the same in both instances, namely, the fumes of sodium cyanid do not diffuse laterally beyond the point attained by the liquid in its diffusion.

Experiments and observations made during the course of the work confirmed the opinion of Mouillefert, recorded above, that the gas from the dissolved cyanid did not diffuse evenly or produce aphid mortality to the lowest depths attained by the liquid in the case of carbon disulphid.

No difficulty was encountered in killing the aphids at shallow depths when the liquid was used at the rate of three-fourths gallon per square foot of soil area, but the aphids forming the deeper infestation invariably escaped. This was the case even in moist, light soils, where the foregoing quantity of water will penetrate to a considerable depth.

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[1] The aphid infestation on these trees was shallow.

CONTROL OF THE ROOT FORM OF THE WOOLLY APPLE APHIS.

A deeply planted tree with root system exposed; top almost dead. Note the partial success of the roo. system in attaining the upper soil levels. (Original.)

INJURY TO THE TREE.

The trees used in the following experiments were of 1-year growth in the nursery and were planted in the spring, three months prior to the experiments outlined below, which were carried out during the height of the growing season.

4 ounces of sodium cyanid to 4 gallons of water killed the tree in 48 hours. The foliage turned brown and dried.

2 ounces of sodium cyanid to 4 gallons of water killed the tree in 7 days.

1 ounce of sodium cyanid to 4 gallons of water injured the tree, as indicated by the browning of the foliage to some extent, but it did not kill the tree, which resumed growth later in the season.

One-half ounce of sodium cyanid to 4 gallons of water produced no apparent injury nor did it check the growth. Trees treated with this dosage remained normal during the following two years and made a satisfactory growth.[1]

During the following summer, when this block of trees was in its second year of growth, trees other than the ones used in the dosage tests outlined above were treated, with the following results:

4 ounces of sodium cyanid to 4 gallons of water killed the tree in 8 days.

2 ounces of sodium cyanid to 4 gallons of water injured the foliage to some extent but did not kill the tree.

1 ounce of sodium cyanid to 4 gallons of water produced no apparent injury nor was there any check in growth.

One-half ounce of sodium cyanid to 4 gallons of water produced no apparent injury.[2]

It will be observed that the resistance of the apple to sodium cyanid in solution, as in the case of carbon disulphid, depends on the age of the tree. During the extended field tests about 500 apple trees of various ages were treated at the rate of one-half ounce to 4 gallons of water with no apparent injury. In excessive doses the same type of injury occurs as results from the employment of large doses of carbon disulphid.

ADVANTAGES AND DISADVANTAGES OF THE METHOD.

The only advantage possessed by sodium cyanid as compared with carbon disulphid is its ready solubility in water. On the other hand, its uncertainty in producing aphid mortality in the lower soil levels, together with the extremely poisonous nature of the material, precludes its use in practice.

USE OF KEROSENE EMULSION.

PRELIMINARY EXPERIMENTS.

Kerosene emulsion has been recommended repeatedly as a remedy for the root form of the woolly aphis. Experiments were therefore carried out to determine its efficiency and also to determine what takes place when the kerosene emulsion is introduced into the soil.

[1] See footnotes 1 and 2, page 33.

[2] See footnotes 1 and 3, page 33.

For this latter purpose the following apparatus was devised: A series of pinholes was made in the bottom of a pail and the latter then filled with earth, well tamped down, and the soil scooped out slightly and heaped up against the inside of the pail so as to furnish a miniature basin for the reception of the liquid. The soil column thus prepared was approximately 7 inches in depth. Into the basin on the surface of this column was poured 10 per cent kerosene emulsion at the rate of three-fourths gallon to the square foot of soil surface, and a drip pan placed immediately beneath the pail in order to catch the drippings from the soil column. The following conclusions were arrived at as a result of this and several other similar experiments:

A. The first inch of surface soil separates out and retains all the soap in the emulsion, together with some of the kerosene content.

B. The first 4 inches of the soil retains almost all the remainder of the kerosene.

C. The drippings from the soil column 4 inches in depth consist of clear water with a slight trace of kerosene.

FIELD EXPERIMENTS.

Experiments carried out in the field, in which 3-year-old apple trees infested with the woolly aphis were used, corroborated the results obtained in the laboratory. The basins for the reception of the kerosene emulsion were prepared as outlined for the application of carbon disulphid in water, and the material was used at the rate of three-fourths gallon per square foot of soil treated. The majority of the aphids within 8 inches of the surface were killed as a result of the treatment, but those at lower levels escaped. Furthermore, the trees were very severely injured as a result of the application of the emulsion. The following spring, seven months after the treatment, the foliage presented a weak, yellowish appearance, and practically no new growth. The rootlets were badly injured and were not replaced that season by new growth.

The mechanical and unstable character of kerosene emulsion, together with the cost and labor required in preparing the quantity necessary for soil treatment, renders this method of little value.

DEEP PLANTING.

Theories have been advanced from time to time in the literature to the effect that by planting the apple tree deeper in the soil than is normally done the aphis infestation will be prevented. Evidently it is presumed that the aphids will be unable to live at the lower depths in the soil occupied by the root systems of these deeply planted trees. Furthermore, it is taken for granted that the root systems will grow normally at these depths.

The writer fortunately was enabled to make observations and photographs of the effects of deep planting, as carried out by a grower at

Winchester, Va., his object being to prevent the ravages of the woolly aphis. Following this idea he planted 200 trees, the first tier of main roots being 18 to 24 inches below the surface of the ground in a stiff clay soil. The second year after planting some of the trees began to show signs of distress, while others were growing normally. The third year some were dead, others nearly dead, and others growing normally.

An examination of the root systems showed the following conditions:

1. The root growth on the dead trees was poor. The roots had made an unsuccessful attempt to reach the upper layers of the soil. No new tiers of roots had been pushed out at a higher level in the soil.
2. The trees in a subnormal condition had succeded in pushing a few roots up to the top layers of the soil (Pl. VIII).
3. The deeply planted trees which were growing normally had succeeded in pushing the majority of their roots up to the surface layers of the soil.

When trees are planted deeply only a portion of them will succeed in pushing their roots up to the surface layers of the soil. The trees which do not succeed in accomplishing this eventually die. Deep planting is unnatural, injures the tree, and does not prevent aphis infestation.

SUMMARY.

Carbon disulphid, in solution at the rate of one-half ounce to 4 gallons of water and applied at the rate of three-fourths gallon per square foot of soil, will control the root form of the woolly aphis under suitable soil conditions. The liquid is best applied by preparing shallow basins about the tree and should be applied only when the soil is in a moist condition. The solution is best prepared by pouring the carbon disulphid into the water and agitating vigorously. The carbon disulphid thereby breaks up into small globules, some going into solution and the remainder forming a mechanical mixture with the solution. The gas diffuses laterally and vertically only as far as the liquid penetrates and therefore every square foot of infested soil must be subjected to the action of the solution in order to insure complete control. When used at the foregoing rate the carbon disulphid produced no injury to the roots of apple. The treatment may be made at any time during the growing season except during the period of two or three weeks in the spring when the trees are budding out.

In orchard practice the solution is best applied by using a power spraying outfit and two auxiliary tanks.

The advantages of this method are, first, the even diffusion of the liquid and complete aphid mortality in the soil area treated and, second, the safety with which the disulphid can be used. The disadvantages of the method are, first, the huge amounts of water required, with consequent high cost of labor; second, the difficulty, on any but level ground, of preparing basins with level floors, thus insuring the proper distribution of the liquid over the area to be treated; and, third, the wide area of infested roots on older trees, every square foot of which must be treated with the liquid. This last condition precludes the use of carbon disulphid except on small trees with restricted root areas.

Sodium cyanid at the rate of one-half ounce to 4 gallons of water did not kill the woolly aphis in the lower soil depths even when a superabundance of solution per square foot was employed. No injury to apple roots resulted when the material was employed at this strength. The only advantage this material possesses, as compared with carbon disulphid, is its ready solubility in water. On the other hand, its uncertainty in producing aphid mortality in the lower soil levels, together with the extremely poisonous nature of the material, precludes its use in practice.

When kerosene emulsion is applied to the soil it disintegrates into its component parts; the first inch of surface soil retains the soap and some of the kerosene content; the first 4 inches of the soil retains almost all the remainder of the kerosene. Kerosene emulsion, therefore, does not kill the aphids in the lower soil levels and the cost of preparing the quantity necessary for soil treatment renders it of little value. The application of this material to apple roots, in the writer's experience, results in severe injury to the tree.

Deep planting will not prevent woolly aphis infestation and results in the death of many trees so planted, due apparently to the inability of the root systems to function properly under these conditions.

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BULLETIN No. 731

Contribution from the Bureau of Entomology,
L. O. HOWARD, Chief.

Washington, D. C. ▼ July 19, 1918

RECENT EXPERIMENTAL WORK ON POISONING COTTON-BOLL WEEVILS.[1]

By B. R. Coad,

Entomological Assistant, Southern Field-Crop Insect Investigations, Bureau of Entomology.

CONTENTS.

EARLY ATTEMPTS AT POISONING THE WEEVIL.

Practically since the advent of the Mexican cotton-boll weevil innumerable attempts have been made to control this pest by the use of poisons. The results, however, were always discouraging. The best that could be secured apparently was a very slight degree of control which would seldom pay for the expense of treatment. As a result it was generally conceded that the weevil could not be poisoned profitably under cotton-field conditions. This was attributed to the fact that the weevil derived its food from deep punctures which it made into the cotton squares and bolls, thus ingesting very little of the external plant tissues upon which the poison would be found. On account of this feeding habit of the weevil the idea prevailed that the only possible method of poisoning would be one which would so distribute the poison on the plant that small amounts would be eaten during the process of starting the punctures through the external tissues. For this reason all experiments were aimed toward getting a poison which could be driven inside the

[1] In the development of power machinery for applying the poison Mr. Elmer Johnson, of the Bureau of Public Roads, has been of inestimable assistance.

bracts surrounding the cotton square and on to the bud itself. In addition, a considerable portion of the experiments included principally treatments very early in the season before the squares had appeared. At this stage of growth the prime objective was to drive the poison into the terminal bud which forms the tip of the young cotton plant and which is the favorite weevil food before squares are formed. As has been mentioned, however, the results secured from all these attempts to poison the weevil were, generally speaking, very dubious and gave no apparent reason for hope for the successful poisoning of the weevil.

THE WATER-DRINKING HABIT OF THE WEEVIL AND ITS BEARING ON POISONING.

During the seasons of 1913 and 1914 the writer conducted a number of biological investigations on the boll weevil from which an intimation was obtained of the possibility of utilizing certain newly discovered features in an attempt to poison the weevil. It seemed quite obvious that there was no hope of successfully poisoning weevils if full dependence were placed on the amount of poison they would secure in the course of their feeding. These studies, however, demonstrated very clearly the importance of water to the continued existence of the weevil. It was found that under cage conditions they drank water very regularly and it seemed reasonable to assume that under field conditions they would secure this apparently essential moisture by drinking from the rain or dew collected in droplets on the leaves of the cotton plants. With this idea in view, the writer decided to conduct experiments in which the attempt would be made to poison the water which the weevils would drink.

THE POISONING TESTS OF 1915.

The first tests of this nature were instituted in 1915 and have been continued to date by the various agents of the Delta Laboratory of the United States Bureau of Entomology under the direction of the writer. The majority of these tests were located in the vicinity of Tallulah, La., which is in typical delta territory and normally subject to an exceedingly heavy degree of weevil injury due to the great humidity and excessive rains which prevail. For the purpose of these experiments of 1915, triplicate series of plats were surveyed on three different plantations near Tallulah. Each of these series consisted of five plats of about one acre each, as nearly uniform as possible in all conditions affecting their production of cotton. In each case the two end plats were given four, five, and six applications of poison, respectively. It was soon evident that this poisoning was exerting a very decided control on the weevils, as the weevil infestation was considerably reduced in the poisoned plats and these plats continued blooming much later in the season than did the adjoining unpoisoned ones. When the cotton was picked from these plats rather surprising results were secured. Every poisoned plat yielded more than the untreated checks, but the most pronounced feature was the much greater increase in yield with the larger number of poisonings. With four applications a gain of about 15 per cent was secured; with five applications this gain was increased to about 35 per cent, while with six applications it was increased about 70 per cent. In other words, a single extra application over four more than doubled the gain, while two extra applications over four increased the gain between four and five fold. As all applications were started at the same time and the extra treatments consisted simply of a continuation that much later in the season, this seemed to point out very significantly the importance of late-season applications.

POISONING EXPERIMENTS IN 1916.

The results of these experiments were certainly definite and significant, but it was considered possible that they might have been due to some peculiar conditions prevailing during that season and that they could not be duplicated during another year. Consequently the experiments during the season of 1916 were planned largely to check the results secured during 1915, with the important change that provision was made for a wider range in the periods of application. In 1916 the applications in the different experiments extended from the first appearance of the weevils in June until about the 1st of September. On the whole the results in 1916 were just as definite as were those of 1915, and the greater importance of the late-season applications was very plainly demonstrated. In this connection a detailed description of a few of the tests is of interest.

Probably the most spectacular test of the season and the one which aroused the most interest was conducted in a cut of abandoned cotton. Poor drainage and excessive rains during May and June had prevented cultivation of this cut, and on the 25th of July there were no prospects whatever of a crop. The plants were only about 10 inches high and had been so heavily infested by the weevils that there had been no blooms since June. Thus an opportunity was afforded to determine what could be accomplished by poisoning under the most extreme conditions imaginable. An attempt was made to work the cotton out about the 1st of August and a small plat in the center of the cut, only six-tenths of an acre in size, was poisoned. This poisoning was continued during the month of August and surprising results were secured. The weevil infestation decreased rapidly in the poisoned plat and the plants soon started blooming and continued to bloom practically until frost in spite of the fact that all surrounding cotton was very heavily infested with weevils and undoubtedly hundreds, if not thousands, were moving into the poisoned cotton daily. When the cotton matured a remarkable sight was presented. The unpoisoned cotton showed practically no open bolls, while the poisoned plat to the very last row was practically white with open cotton. This is illustrated in figures 1 and 2, which show different views of the dividing line between the poisoned and unpoisoned cotton shortly after the first killing frost. When the cotton was picked it was found that the unpoisoned plats yielded 45 and 65 pounds of seed cotton per acre, respectively, while the poisoned plat yielded about 500 pounds per acre. This, of course, did not constitute a good yield of cotton but was very remarkable in view of the opportunity which this cotton had had to produce a crop.

FIG. 1.—View showing dividing line between poisoned and unpoisoned cotton on Algodon Cut No. 1 October 30, 1916, Tallulah, La. Beginning of additional unpoisoned cotton can be distinguished at upper right-hand corner of view.

This test was particularly interesting because of the severe conditions which prevented the unpoisoned cotton from making any production, because the plants were so small, and because it was possible to poison the last row of the treated plat effectively without allowing the poison to drift on to the adjoining check row. For this reason the line of demarcation between the plats was much more pronounced than usually was possible.

Additional tests during the same season located in better cotton frequently gave larger gains in production per acre, but of course the percentage of gain was not so large. In one case of poisoning during the month of July a gain of about 600 pounds of seed cotton per acre was secured. Figures 3 and 4 show a comparison of the typical picking in the poisoned and check plats, respectively, in this test. In this case the cotton was so luxuriant that the dividing line could not be shown in a single picture, but the two views given in these illustrations were selected by a disinterested planter as being typical of the two plats. Probably the most interesting feature of this test was the fact that there were 22 days of rain during the month when the applications were made. This seemed to indicate that successful results could be secured from poisoning in spite of excessively rainy weather and tended to allay the fear that dry weather would be essential to successful results.

FIG. 2.—Another view showing dividing line between poisoned and unpoisoned cotton on Algodon Cut No. 1, October 30, 1916, Tallulah, La. View looking in opposite direction from that shown in figure 1.

In another case a portion of a cut of new ground practically surrounded by heavy timber was poisoned. This was very heavily infested with weevils, but the poisoned plat yielded about 1,700 pounds of seed cotton per acre as compared with about 900 for the check. The treatments in this case were practically confined to late July.

In all about 15 experiments were conducted during 1916, and the total results showed definitely that it was possible to poison the weevils profitably under certain conditions. Again, the increased value of late-season applications was obvious, for, as a general rule, the early-season applications gave only slight gains with a very doubtful profit whereas the late-season applications all showed pronounced profits.

EXPERIMENTS IN 1917.

EXPERIMENTS AT TALLULAH, LA.

At the beginning of the season of 1917 it was recognized that the experiments to date had merely demonstrated the possibility of poisoning weevils successfully, and that all phases of the economic use of the poison remained still to be worked out. Consequently a very elaborate series of experiments was inaugurated in that season, and about seventy-five tests were started in the neighborhood of Tallulah, each one intended to determine some particular point of importance. These consisted of studies of the comparative efficacy of different poisons, the time of day of application giving the best results,

FIG. 3.—Typical view of opened cotton in poisoned plat on Algodon Cut No. 2, second picking, October 12, 1916, Tallulah, La. For comparison with figure 4.

the most profitable season of application, the proper interval between applications, the requisite amount of poison per acre, and many other similar questions, all of which would have to be answered before definite general advice as to the use of the poison could be given. The early studies had shown that under certain conditions poisoning was profitable, but it was apparent that any change in these conditions might easily result in a much lower gain, if not in an actual loss, and it was essential to determine thoroughly the possibilities and limitations of boll-weevil poisoning before releasing any information for public use. Unfortunately for the experimental work, the season of 1917 in the vicinity of Tallulah was most remarkable for the light degree of weevil damage. This was due to a peculiar combination of seasonal conditions and resulted in an almost complete absence of weevil damage in all of the cotton in which tests had been planned. In other words, the yield of cotton in these cuts was just the same as if no weevils had been present. Of course weevil-control experiments could not be conducted under such conditions and the majority of the Tallulah experiments had to be given up for the season. Nevertheless, a dozen or more cuts were located immediately adjoining timber where a somewhat heavier degree of infestation was experienced, and in these cases the rule prevailed that the heavier the infestation, the greater the gain due to poisoning. These results, of course, fully confirmed those of the preceding two years, but the necessary postponement of many experiments still left many

FIG. 4.—Typical view of opened cotton in check plat on Algodon Cut No. 2, second picking, October 12, 1916, Tallulah, La. For comparison with figure 3.

gaps in the information essential to outlining a general procedure for weevil poisoning.

Figure 5 illustrates something of the results secured in one of the more heavily infested cuts near Tallulah. This photograph was taken to show the difference in the amount of top cotton produced by the poisoned and unpoisoned plats, and shows only the second picking. A considerable gain had already been secured at the first picking, and in the total a gain of something over 50 per cent was secured.

EXPERIMENTS IN ARKANSAS AND MISSISSIPPI.

In addition to the experiments just detailed, a number were conducted in the North Delta, in Chicot County, near Lake Village, Ark., and in Washington County, near Scott, Miss. At both of these points a heavier infestation was produced by different seasonal conditions, and pronounced results were secured from the poison. In every case the experiments were conducted on comparatively small areas, subject to a continual influx of weevils from surrounding untreated cotton, but in spite of this a very definite weevil control resulted from poisoning. The open cotton in every case showed a definite gain to the last row of treatment. The gains per acre ranged from 250 pounds to 1,007 pounds of seed cotton. Views of two of these tests are shown in figures 6, 7, and 8.

It is, of course, impossible to estimate how much larger these gains would have been if entire cuts or entire plantations had been

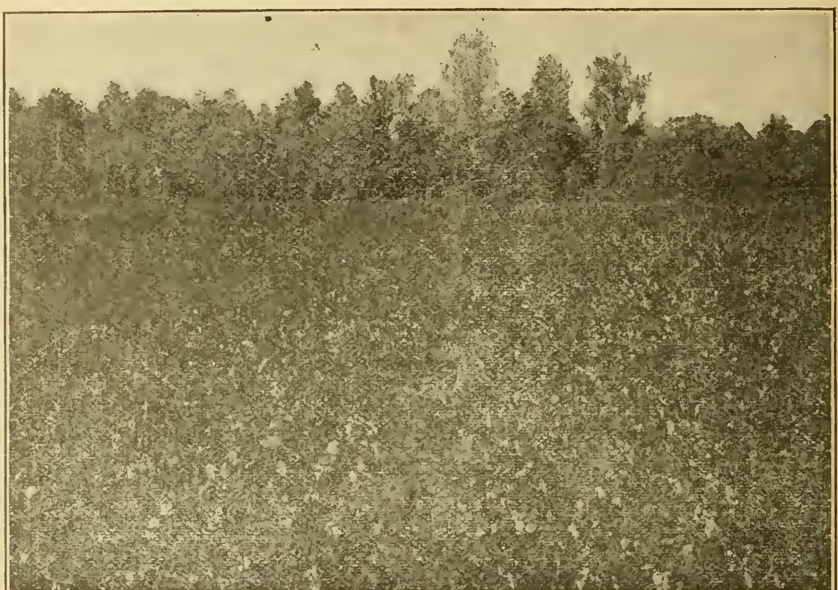

FIG. 5.—View looking across rear end of poisoned cotton on Mound Plantation Cut No. 2, with poisoned cotton on right of view and unpoisoned on left; second picking only, October 23, 1917, Tallulah, La.

treated, and thus the inflow of weevils from unpoisoned cotton prevented, but it is clear that these gains secured on small plats were very conservative. In fact, this was brought out well by one large-scale treatment described below.

A LARGE-SCALE TREATMENT.

About the middle of August the writer was requested to attempt the control of the weevil on a large section of an Arkansas plantation. This cotton was on very fair land, but had not been planted until well along in May. Weather conditions then retarded it greatly and it did not start setting a crop until about the latter part of July. About the middle of August a fair crop of bolls was present, but the plants were large and leafy and the weevils had multiplied so rapidly that one of the heaviest infestations ever witnessed by the writer prevailed. Blooming had practically ceased and the weevils had cleaned up the squares so thoroughly that they were attacking the bolls in enormous numbers and all bolls, even to the largest present, were being riddled with punctures. It seemed probable that on one section no bolls would be left to open. It was, of course, too late to attempt to set a new crop by poisoning, but an effort was made to save the bolls then present on the plants. For this purpose large-scale treatments were continued from August 23 to about September 1, several hundred acres in all being treated. At the beginning of the work a series

FIG. 6.—View along dividing line between poisoned and unpoisoned cotton in Lake Vista Cut No. 2, with poisoned cotton to left of view; second picking only, October 26, 1917, Scott, Miss.

of counts showed that 86 per cent of the squares in the cotton which was to be poisoned had been weevil-punctured. This cotton was given a single poisoning and, about 10 days later, it was found that the weevil infestation in these same cuts had been reduced so that only 36 per cent of the squares were punctured. During the same period the infestation in the adjoining unpoisoned cotton had been increasing steadily. Practically all of the poisoned cuts started blooming again at this time and a number of them reached what is ordinarily termed the "flower-garden" stage of blooming, five to seven blooms per plant on a single day being not at all rare. In starting this treatment it had been anticipated that several applications would be necessary to produce the desired result, but the effect of the single application was so pronounced that it seemed unnecessary to repeat it. The weevils had been so reduced that only 36 per cent of the squares were punctured, and although thousands of weevils were being bred out from the squares on the ground or were coming in from other plantations every day, it was still obvious that the weevils would greatly reduce their attack on the bolls until they had caught up with the squares then present, and that this period would be long enough to allow the bolls to become sufficiently hardened to avoid weevil damage. Owing to the necessity of poisoning considerable areas in this case and to the inability to leave unpoisoned plats as checks, it was of course impossible to determine the exact

FIG. 7.—View down center of check plat, Isola Cut No. 1, on October 26, 1917, showing cotton available for second picking; Scott, Miss. For comparison with figure 8.

benefit derived from the treatment. Rough comparisons, however, based on yields of surrounding cuts, made it obvious that a considerable gain had been secured and it was evident that the poisoning was a very profitable operation.

LABORATORY AND OTHER EXPERIMENTS.

Numerous other field experiments might be detailed to add weight to the results secured, but the ones described have been selected as illustrating the different methods followed and the different conditions experienced, and are surely sufficient to illustrate the effectiveness of the poison. In addition to these field tests a number of laboratory studies were conducted at the same time to check the results in the field. These were conducted under cage conditions and were for the purpose of comparing the effectiveness of different poisons and different methods of poisoning.

IMPORTANCE OF MOISTURE IN POISONING.

One interesting feature of the foregoing tests was the apparent necessity of the presence of moisture if any considerable degree of weevil mortality were to be caused by the poison. It was found that only a very light mortality would result from tests where the plants were kept absolutely dry after poisoning; but as soon as moisture was introduced the mortality increased tremendously. This evi-

FIG. 8.—View down center of poisoned plat, Isola Cut No. 1, on October 26, 1917, showing cotton available for second picking; Scott, Miss. For comparison with figure 7.

dently validated the conclusion that at least a major portion of the success in poisoning was due to ingestion by the weevil while drinking.

RELATIVE EFFECTIVENESS OF DIFFERENT ARSENICALS.

In the course of these experiments quite a number of different poisons were utilized and it was found that nearly all arsenicals were effective to a certain degree but that most of them were not sufficiently effective to be satisfactory. At the outset the ordinary triplumbic form of lead arsenate was utilized. It was found, however, that this was not sufficiently toxic to the weevils to warrant its use and the newer dihydrogen form of lead arsenate proved to be vastly more toxic. This was utilized in practically all of the experiments of 1916, but additional tests demonstrated that a high grade of calcium arsenate was still more effective. This contains a much higher percentage of arsenic pentoxid than any other arsenical utilized and has the great advantage of being much cheaper than lead arsenate. In addition, a number of tests of various mixtures of these arsenicals and dilutions of them with different carriers were conducted. This work is still in the experimental stage and it is difficult to prophesy just what the results will be. It is obvious, however, that either a dihydrogen lead arsenate containing not less than 32 per cent of arsenic pentoxid or a calcium arsenate containing at least 42 per cent of arsenic pentoxid will produce an effective control if utilized properly. It also seems probable that it will

FIG. 9.—Hand dust guns in operation, showing method of use; Tallulah, La., July 15, 1916.

be possible to dilute these considerably with some cheap carrier such as lime, though this has not been definitely determined as yet.

DENSITY OF THE POISON.

Fully as important as the actual composition of the chemical is its physical condition. When the experiments were first started, practically all of these chemicals were prepared only in a density of about 40 cubic inches per pound. It was evident, however, that a much finer powder would afford a greater distribution per pound, and also that a finer powder was apparently more readily taken up by the dew and held in suspension for the weevils. Consequently these poisons were prepared in density ranging from 80 to 160 cubic inches per pound and proved much more effective in that form.

TIME OF APPLICATIONS.

WHEN TO BEGIN POISONING.

The technique of application is obviously much more important than the actual poison utilized, if a poison of satisfactory degree of toxicity be selected. As has been mentioned, very doubtful profits were shown by early-season applications, and the most definite gains resulted from treatments made while the infestation was at its height. This is evidently due to a combination of conditions which need not be discussed in detail here, but which caused an application made at the time the weevils were doing their maximum injury to the crop to be far more effective in their control. This time, of course,

FIG. 10.—Power dusting machine in operation at Tallulah, La., April 26, 1917, showing type of dust fog developed.

varies considerably under different conditions and in different seasons, but is usually the time when the cotton manifestly slackens in blooming, and, while the experiments are not yet completed to the point of outlining definitely just when the most effective season of application will be, it will probably be found to be at about this time.

INTERVAL BETWEEN APPLICATIONS.

The time interval between applications is another important point which must be determined but concerning which comparatively little is known as yet. In most of the tests conducted so far the applications have been repeated at weekly intervals more as a matter of convenience than for any particular reason, but it seems probable that about once a week will constitute an effective application.

TIME OF DAY.

Another question of importance is the time of day for application. It is, of course, well known that much more effective poisoning with dry dust can be conducted while the dew is on the plant, as the poison not only clings to the plant better but has much less tendency to drift away from the cotton. A number of tests have been conducted in an attempt to secure some information on this score but were so hampered by the light infestation of 1917 that definite conclusions are not warranted. It is evident that more effective poisoning usually can be done from about 4 p. m. until about 9 a. m. than at other times, although fairly successful results have been secured from applications made throughout the day. It will probably be found that it is advisable to poison as much as possible during the evening, night, and early morning, and to plan to poison during the day only in case of emergency.

MACHINERY FOR APPLYING THE POISON.

The machinery for the application must, of course, vary according to the requirements of different conditions. A very satisfactory hand gun of the type shown in operation in figure 9 was already on the market and was largely utilized in the experiments described. This gun, however, will cover only about 4 or 5 acres a day, and it was, of course, necessary to develop machinery adapted to larger areas. For this purpose a power machine has been developed somewhat of the type shown in figure 10. These have been increased in efficiency until now nearly 200 acres per day can be covered by a single machine. In addition, efforts are being made to develop an intermediate type of machine which can be sold comparatively cheaply and which will be adapted to the man planting 50 to 100 acres of cotton, and cover 20 to 30 acres per day.

AMOUNT OF POISON PER APPLICATION.

The amount of poison required per application has depended so far more on the requirements of the machinery utilized than on the amount necessary for thoroughly dusting the cotton. As a general rule experimental applications have averaged about 5 pounds per acre, but it is apparent that this amount is excessive, and with further improvement in the machinery it will be possible to accomplish an effective poisoning with a much smaller amount.

NUMBER OF APPLICATIONS.

The number of applications necessary undoubtedly will vary. This must depend entirely on the conditions prevailing within the particular cut under consideration. In most of the experiments conducted so far from three to five applications were made but, as has been shown, the effectiveness of these was considerably reduced by the fact that they were on such small plats. In the only case in which experiments on a very large scale were conducted, the effect of a single application was as pronounced as is ordinarily secured from about three applications on a small plat, due, of course, to the constant migration of weevils into the small plat

COST OF TREATMENT.

The cost of treatment will, of course, vary widely. In the strictly experimental tests conducted so far it has averaged usually about $1 an acre for each application. It must be recognized, however, that it will be possible to reduce this considerably when applications are made on a larger scale, and, with improved machinery, a further reduction will result from the lessened poison requirements. In addition, the probability that it will be possible to utilize carriers and thus further reduce the amount of poison required per acre renders the cost subject to a still greater reduction. It should be remembered, also, that very rarely will it be necessary to poison an entire plantation to control the weevil infestation. The weevils on emerging in the spring will always concentrate near the hibernation quarters in which they spent the preceding winter. They remain rather closely at these points until they have multiplied sufficiently to threaten a shortage in the local food supply. For this reason a great part of the cotton is not seriously infested with weevils until some time after midseason and often not until well along in August. Of course the control measures adopted must depend on conditions on each plantation, but by concentrating on the more heavily infested cuts just before the weevils become sufficiently abundant to start movement to the remainder of the cotton it will be possible not only directly to benefit the cotton treated, but to protect the remainder of the plantation by preventing the weevil migration. In this way the cost of the treatment for a comparatively few acres will be borne by the benefit derived by the entire plantation. In this connection it probably will often prove advisable to give several applications to the more heavily infested cuts and perhaps only a single application to the remainder.

NECESSITY FOR FURTHER EXPERIMENTAL WORK.

In conclusion it should be emphasized that the present bulletin is merely a "progress report" and the writer does not wish to be construed as in any way advising the general use of these poisons for boll-weevil control. There are now too many doubtful points, especially as regards the technique of application; and, as has been shown, the technique of application largely determines the benefits derived. At the present stage of the investigation it is impossible to outline a definite plan of procedure for the poisoning of weevils under all conditions, and much more experimental work will be required before such a plan can be proposed. With the present lack of information on so many important points, any attempt to poison the weevil by the inexperienced may very easily result in actual loss.

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BULLETIN No. 737

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER March 17, 1919

THE TOBACCO BEETLE: AN IMPORTANT PEST IN TOBACCO PRODUCTS

By

G. A. RUNNER
Entomological Assistant

[With Technical Descriptions of Coleopterous larvæ
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CONTENTS

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By G. A. Runner, *Entomological Assistant.*

(With technical descriptions of coleopterous larvæ by Adam G. Böving.)

CONTENTS.

A PEST IN CURED AND MANUFACTURED TOBACCO; ITS COMMON NAMES.

The tobacco beetle or "cigarette beetle," *Lasioderma serricorne* Fabricius, which feeds and lives mainly in dried vegetable products, is by far the most destructive pest with which manufacturers of or dealers in tobacco or tobacco products have to contend. It is present at times in practically all warehouses, cigar and tobacco factories, and retail or wholesale establishments where cured leaf tobacco or manufactured tobacco is handled or stored.

This beetle is now known under several names. "Tobacco beetle," "cigarette beetle," "tobacco bug," "tobacco flea," and "tobacco flea-beetle" are the terms most commonly used in referring to it. The

Note.—The author, Mr. G. A. Runner, was transferred from Southern Field Crop Insect Investigations to Deciduous Fruit Insect Investigations on May 21, 1917.

last two names may have originated from confusion of the species with a field insect, the tobacco flea-beetle, *Epitrix parvula*, which attacks growing tobacco, the holes eaten in the leaf showing in the cured leaf tobacco and somewhat resembling holes made by the true tobacco beetle, *Lasioderma serricorne*. The name "cigarette beetle" has been quite generally used in entomological literature but is not suitable as it conveys the impression that the insect confines its work to cigarettes whereas it is a general feeder upon all cured tobacco products. Throughout this bulletin the name "tobacco beetle," which was used by Mr. E. A. Schwarz in earlier accounts of the insect, is adopted, as the present consideration of the insect refers to its depredations upon all forms of cured and manufactured tobacco.

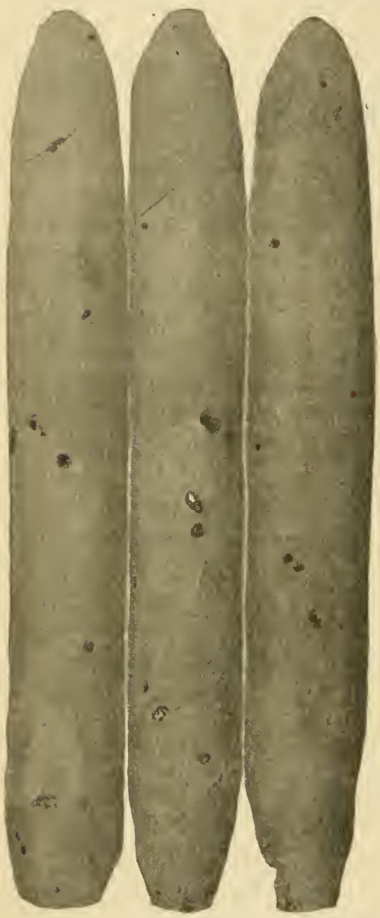


FIG. 1.—Cigars damaged by the tobacco beetle (*Lasioderma serricorne*) showing burrows of larvæ and exit holes of adults.

THE CHARACTER OF ITS INJURY.

The injury caused by the tobacco beetle is very great, owing to its habit of occupying its food substance during all stages of its life. The principal damage is done by the larva or "worm" stage, and with tobacco, as with other food substances, the actual amount consumed usually is of far less importance than is the presence of refuse, excrement, dust, and the dead beetles, which render the manufactured product unsalable.

The insect damages cigars (fig. 1) and pressed tobacco by burrowing small cylindrical tunnels which later become filled with dust and excrement. In cigars the holes may extend from one side to the other, and in some instances the holes or galleries may wind through the filler of the cigar, a large part of the interior being thus destroyed without external evidence of injury to the wrapper. The larvæ often will work between two closely packed cigars, slitting both wrappers lengthwise for some distance, and the pupal cells frequently are constructed between two closely pressed cigars or beneath the band. Injured cigars do not draw well, burn unevenly, and dust is drawn into the

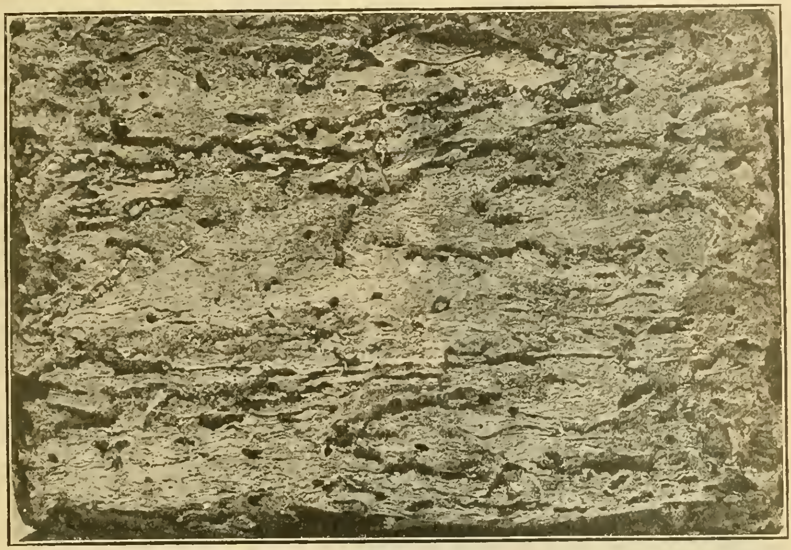


Fig. 2.—Pressed cut smoking tobacco showing burrows of larvæ and exit holes of adults of the tobacco beetle (*Lasioderma serricorne*).

mouth of the smoker. High-grade cigars, in which the more expensive leaf tobacco is used as wrapper or filler, are far more susceptible to injury than are cigars made from heavier, stronger,

Fig. 3.—Chewing tobacco injured by the tobacco beetle (*Lasioderma serricorne*).

and inferior grades. In cigarettes, also, injury is more apt to occur in those made from the sweeter, milder types of leaf, such as is used in the more expensive grades. Fine Turkish tobaccos are especially liable to infestation, holes being bored through the wrappers and frequently through the cork tips. The interior of the cigarette is filled with refuse, and the wrapper becomes soiled and discolored. Smoking (fig. 2) or chewing tobacco becomes badly worm eaten. In pressed kinds, such as plug tobacco and pressed and sliced smoking tobacco, galleries are formed. In pressed plug tobacco (fig. 3) the wrapper is cut and the edges furrowed. Granulated and fine-cut types become mixed with the dust and refuse from feeding and with the dead bodies of adult beetles. Pupal cells occur on the sides of the containers or in the tobacco. Leaf tobacco (fig. 4) is infested in much the same manner as cigars. The larvæ bore holes in every direction through the leaves. Fine wrapper tobacco is often so badly injured that it is worthless. In leaf tobacco used as filler, or in manufactured tobacco or snuff, the damage is confined more to the tobacco actually consumed by the larvæ than is the case with attacks of the insect on the manufactured product.

FIG. 4.—Damage to cigar tobacco by the tobacco beetle (*Lasioderma serricorne*).

CLASSIFICATION AND SYNONYMY.

The family Ptinidae, to which the tobacco beetle belongs, is composed of small insects which rarely exceed one-fourth of an inch in length. The head is usually retracted, the body more or less cylindrical and firm, and the wing covers firm. The species vary greatly in form, and several species belonging to the family have been widely distributed by commerce. Although the family is quite large, comparatively few species are economically important and injurious;

namely, those living in stored products and timber. Among these, besides the tobacco beetle (*Lasioderma serricorne*), may be mentioned the larger tobacco beetle (*Catorama tabaci*) and the drug-store beetle (*Sitodrepa panicea*). The genus Lasioderma of Stephens contains only five known species. The tobacco beetle was first described from America in 1792 by Fabricius (1)[1] under the name *Ptinus serricornis*.

SYNONYMY.

The following synonymy is given by Gemminger and Harold (16):

Lasioderma serricorne Fabricius, Ent. Syst. (1792), v. 1, p. 241; Mulsant, Ann. Soc. Linn. Lyon (1864), v. 12, p. 1, pl. 1, fig. 10; Le Conte, Proc. Acad. Nat. Sci. Phila. (1865), p. 236.

Lasioderma flavescens Dahlbom, Dej. Cat. 3 ed. (1837), p. 129.

Lasioderma testaceum Duftschmidt, Fauna Austr. (1859), Deutchl. Fauna Insecten (1837), v. 11, p. 89, pl. 237, fig. P.

FOOD SUBSTANCES OF THE TOBACCO BEETLE.

The tobacco beetle feeds upon a variety of dried vegetable substances as well as upon a few dried animal substances. Early records describe the insect as feeding upon or living in "dried plants." Its more common food is cured or manufactured tobacco. In drug and grocery stores it is often found infesting such substances as dried roots of various kinds, pressed yeast cakes, and seeds. The writer on one occasion found a collection of dried botanical specimens in a State museum badly injured by the pest. In the course of investigations of the insect it has been reared from and found infesting or feeding upon the following substances: Cured leaf tobacco, manufactured tobacco of various kinds, such as smoking and chewing tobacco, snuff, cigarettes, and cigars; tobacco seed, dried figs, cayenne pepper, ginger, dried dates, powdered orris root, curry powder, starch, pressed yeast cakes, and dried plants of different kinds in botanical collections. When large numbers of the beetles were required at times for experimental work it was found that they could be bred most conveniently in dried yeast cake (fig. 5).

In addition to the food substances already mentioned, the insect has been reported in entomological literature as injuring or infesting opium, red pepper, rice, paprika, stock foods, turmeric, spices, saffron, licorice, bran, belladonna, and pyrethrum powder. Dr. J. B. Smith (59) also mentions injury to cane and rattan work of all kinds, books, and gun wads. Jones (77) reported the insect breeding in raisins in the Philippines. Van Dine (55) states that in the Hawaiian Islands the tobacco beetle is the most common and destructive pest

[1] Numbers in parenthesis refer to "Bibliography," p. 69.

in stored products, and that it infests groceries, drugs, and dried products indiscriminately, but possibly favors manufactured tobacco. He also reports having found the insect very injurious to wall paper and books in Honolulu.

Dried animal substances occasionally are attacked. Dried fish is mentioned as a food substance by Mackie (74), and Van Dine (55) reports the beetle as having been reared from fish guano used as fertilizer. There are also reports of leather goods having been injured. The late F. C. Pratt (53) noted injury by this species to an insect collection in western Texas, about 10 per cent of the specimens in a box of Orthoptera having been damaged.

There are numerous records of the tobacco beetle feeding upon and injuring upholstered furniture. Cook (25) has described injury to

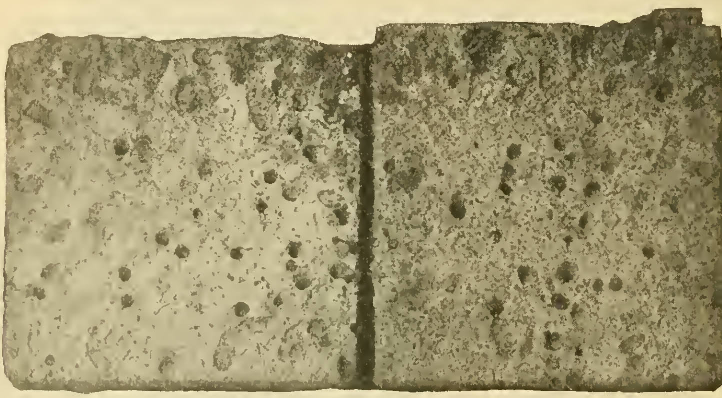


Fig. 5.—Work of the tobacco beetle (*Lasioderma serricorne*) in pressed yeast cake.

furniture, and stated that the work of the insect "made the plush covering look like a sieve." Chittenden (53, 58) has reported the insect as damaging upholstered furniture, rugs, and tapestry in dwelling houses in the District of Columbia, West Virginia, and New Jersey. Osborn (46, 49) has reported infestation of plush upholstered furniture at Columbus, Ohio. Silk as food is mentioned by Osborn (46). Injury to silk and plush hangings in France has been mentioned by Bordage (38).

The occurrence of the beetle in some of the substances given is undoubtedly more or less accidental. Attempts made by the writer to rear the beetle from the egg stage in many of these substances resulted in failure. In many instances the larvæ fed for a time but did not complete their transformation to the adult stage. In controls on these experiments adults were reared from eggs placed in yeast cakes, tobacco seed, or cured tobacco, at the same time and kept under the same conditions.

FOOD HABITS OF BEETLES RELATED TO THE TOBACCO BEETLE.

Beetles belonging to the same family as the tobacco beetle, the Ptinidae, in general usually feed on vegetable matter in an incipient stage of decay or in dried vegetable or animal substances. A few bore into solid wood and others attack living plants.

The larger tobacco beetle (*Catorama tabaci* Guérin) feeds on tobacco and tobacco seed (fig. 6).

The drug-store beetle (*Sitodrepa panicea* Linnaeus) feeds on drug-store supplies such as dried roots and seeds, and sometimes attacks tobacco. Its food habits are very similar to those of the tobacco beetle.

Fig. 6.—Cigar tobacco injured by the larger tobacco beetle (*Catorama tabaci*).

Mezium americanum Laporte occurs in dwellings and breeds in dried animal substances. It is known to infest tobacco seed.

A species of European origin, *Ptinus fur* Linnaeus, now widely distributed by commerce, is said to be often injurious to museum specimens, and has been reported as injuring tobacco.

The following records of food habits of several other species belonging to the same family have been given by Blatchley (71):

Trypopitys sericeus Say. Occurs beneath bark and on old branches of wild cherry and oak.

Caenocara oculata Say. On low vegetation and in puff balls (*Lycoperdon* spp.).

Ptilinus ruficornis Say. Larvæ bore into dead branches of oak and maple.

Some species of Ptinidae bore into decaying timbers of houses. The ticking sound made has given these insects the name of "death-watch" beetle.

LOSSES DUE TO THE TOBACCO BEETLE.

Losses occasioned by the tobacco beetle, either directly or indirectly, occur to some extent in every place where cured or manufactured tobacco is handled. Various statements have been received from manufacturers which show that loss at the factories is very large, but this probably represents only a small part of the loss due to damaged cigars, cigarettes, and manufactured tobacco in the hands of jobbers and retailers. In many factories the loss is estimated to be more than $5,000 a year. An agent of this bureau, on one occasion, in a single factory, was shown 14 barrels of damaged and worm-eaten cigars, part of these having been made from the finer and more expensive grades of Cuban tobacco. The loss from the beetle in this instance was estimated at not less than $7,000, and the damage occurred within a period of only 12 months. At the storerooms of a large jobbing concern in one of the Northern States the writer was shown a lot of smoking and chewing tobacco of various brands said to weigh over one-half ton which was infested and worthless. Part of this tobacco showed injury from mold, but a large part of the damage had been caused by the tobacco beetle. In 1913 a large tobacco firm reported to the Bureau of Entomology that its loss from the beetle amounted to fully $25,000 per annum. The average annual loss in the Philippines per factory for cigars actually destroyed in the factory is said to vary from 6,000 to 13,000 pesos ($3,000 to $6,500) (77). The total money loss in the Philippines from returned cigars which are infested with the beetle has been reported by Mackie (74) to exceed 500,000 pesos ($250,000 U. S. currency) per annum. The actual money loss to the manufacturers from tobacco products returned to the factory represents only a small part of the entire loss caused by the beetle. An enormous loss occurs through damage to hogshead tobacco of certain types, and, as in the case of manufactured or baled tobacco, it is impossible to make even an approximate estimate of the loss. In 1911 Mr. J. Matsumura, inspector of the bureau of monopolies for the Imperial Japanese Government, reported that in a shipment of 60 hogsheads of American tobacco to Japan 50 hogsheads had been so badly damaged by the beetle that the tobacco was almost worthless. In exported hogshead tobacco the lighter types, such as are used in the manufacture of cigarettes, are most susceptible to injury, and a comparatively slight infestation at first may result in a heavy infestation after a long sea voyage through warm or tropical waters. The specially favorable breeding conditions brought about by high temperatures and humidity incidental to long oversea shipments make the beetle unusually destructive to cigars shipped to the United States from the Philippines. A number of dealers have reported serious loss from this source, the infestation spreading to cigars and other classes of manufactured tobacco kept in stock.

Although the tobacco beetle is present and causes more or less loss in all parts of the United States, investigations of the Bureau of Entomology show that damage is greatest in the States bordering on the Gulf of Mexico. One large manufacturer reported that his loss due to infestation of goods, chiefly smoking and chewing tobacco, shipped to the Gulf States had been so great, fully 50 per cent of the manufactured tobacco becoming wormy, that his company had been forced to restrict its activities in that section. To replace this damaged stock made their business in that section unprofitable. The factory was said to be practically uninfested, and few complaints of damage came from other sections of the country where the same class of goods was shipped. In another instance a firm manufacturing high-grade cigars some years ago organized a separate department in which scrap tobacco was worked up into cheaper cigars. At first this department showed an annual profit of about $7,000. The beetle, however, finally became so destructive to this class of goods, and so many shipments were returned to the factory, that this branch of the business was discontinued.

The extent of injury to baled domestic tobacco can not be accurately determined until the tobacco is finally used, and, as with other classes of tobacco, it is difficult or impossible to obtain even an approximate estimate of the total loss.

In wholesale and retail drug stores the insect frequently becomes a serious pest and causes heavy loss by consuming or by making unsalable more expensive products.

DISTRIBUTION AND DISSEMINATION.

Commerce has served to distribute the tobacco beetle widely and it probably now occurs in all countries having a temperate, subtropical, or tropical climate. In warm tobacco-growing countries such as Cuba, Porto Rico, and the Philippines, where the beetles are numerous and breed continuously throughout the year, they are being constantly exported in shipments of cigars or bales of cigar tobacco. Examinations of warehouses in which bales of infested cigar tobacco are stored, at ports of entry in this country, have shown them at times to be heavily infested with the beetle.

There has been a very noticeable increase and spread of the tobacco beetle in tobacco factories in the United States within comparatively recent years. Experienced tobacco dealers and tobacco manufacturers attribute this to the general use of steam in heating factories. The higher and uniform temperatures which are thus maintained make breeding conditions more favorable.

In tobacco factories and buildings in which tobacco products or suitable food substances are stored the insect spreads by crawling or by flight. The adult beetle is capable of flying for a considerable distance. Beetles escaping from cars or ships in which bales or hogsheads of leaf tobacco are shipped find their way to suitable food substances which then in turn become new centers of infestation and dispersion. As the life cycle of the beetle is comparatively short in warm weather, hogsheads of export leaf tobacco, slightly infested when sent out, may become heavily infested *en route* and almost worthless after a long sea voyage, the high temperature and moisture in the hold of a vessel creating ideal conditions for reproduction.

The insect is now so generally disseminated throughout the country that it is a common occurrence to find it in show cases, storage rooms, or humidors in cigar stores. Records of returned shipments at cigar and tobacco factories show that the majority come from retailers in the Southern States and from localities where climatic conditions are especially favorable for the rapid increase of the beetle. In view of this fact it will be seen that the return of damaged goods to the manufacturers does not necessarily mean that the tobacco or cigars were infested when shipped from the factory, the actual source of infestation often being the retail store or distributing point. Even in summer few complaints come from dealers in certain of the Northern States and in Canada. Tobacco infested when shipped from the factory would certainly show damage in such localities if kept even for a short time in warm weather, as experiments made by the writer have shown repeatedly.

Tobacco may become infested also in the hands of the retailer, the beetles coming from other food substances such as yeast cakes in grocery stores, or from vegetable substances used as drugs.

In cigar or tobacco factories the beetles are being constantly introduced in bales or hogsheads of imported leaf tobacco. Cigar manufacturers frequently keep bulk tobacco in bonded warehouses at the port of entry until needed for fabrication. In many instances the bales of tobacco remain in bond for a considerable length of time. A large part of this tobacco comes from Cuba, where the beetle reproduces continuously throughout the year, and infested bales are brought into the warehouses with every shipment.

ORIGIN AND HISTORY.

The original habitat of the tobacco beetle is not definitely known, but probably the insect is native to warm or tropical parts of America. When it was first described from America by Fabricius (1) in 1792 tobacco was not mentioned specifically as food, but the insect was reported as infesting "American dried plants."

The earliest account of injury to tobacco seems to have been that by M. Planche (38), an inspector of tobacco factories, who reported in 1848 that the insect had been found at Paris for the first time in tobacco. It was thought to have been introduced from America. Since 1848 there have been many references to the species in entomological literature as destructive to tobacco and to various dried vegetable substances.

Chevrolat (13), in 1861, stated that the insect attacks cured tobacco, that it is acclimated in all parts of the world, and that in his collection were specimens from both Americas, Algeria, Syria, Germany, and Denmark. Le Conte (15), in 1865, mentioned the beetle as having been carried by commerce over the entire globe, and stated that it lives chiefly, although not exclusively, upon tobacco. Mr. E. A. Schwarz (20), of the Bureau of Entomology, in 1883 stated that it is a well-known pest in many cigar factories in the United States. It seems to have been only within comparatively recent years, however, that the insect has attracted attention as a serious pest in fabricated tobacco. Since the earliest days of the colonies tobacco has been an important crop and one of the main exports of several States. In Colonial times laws regulating the tobacco industry were very exacting and rigidly enforced, and for a long series of years tobacco for export which failed to come up to the legal requirements as to quality and soundness was destroyed. In view of these circumstances it seems strange, if damage to stored tobacco from insects had occurred to any great extent, that the fact was not recorded.

ECONOMIC HISTORY.

From an economic standpoint the history of the species begins with the paper by G. F. Atkinson (21), published in 1885–86. An account of the occurrence, habits, and life history of the insect is given and emergency remedies and means of control are discussed. In 1889 the same investigator published an account of the insect, its life history, remedies, etc., in a report (22) of the South Carolina Agricultural Experiment Station.

Prof. C. V. Riley (31), in 1892, reported the insect as injuring chewing tobacco in Baltimore. He discussed its habit of flight and recommended that windows be closed at night to prevent its entrance. Steaming is given as the best means of killing the larvæ and eggs.

In 1898, in a report upon insect enemies of tobacco, Dr. A. L. Quaintance (40), then State entomologist of Florida, described injury to stored tobacco caused by the beetle, giving an account of habits, food substances, and method of treatment of infested tobacco with carbon disulphid.

Dr. L. O. Howard (42), in 1899, in an article on tobacco insects, gave a general account of the tobacco beetle and other insects injuring stored tobacco, and suggested many practical means of control. Fumigation with carbon disulphid, steam sterilization, and other repressive measures applicable to factory and warehouse conditions were described.

In 1904 Prof. T. B. Symons (51) gave results of experiments in fumigation with hydrocyanic-acid gas and carbon disulphid. Dr. F. H. Chittenden (53), of the Bureau of Entomology, conducted experiments with hydrocyanic-acid gas against the beetle in furniture in 1905.

In 1909 Mr. J. S. Houser (65) reported the beetle extremely destructive in Cuba, and stated that infested tobacco may be fumigated with carbon disulphid or hydrocyanic-acid gas without injury.

The results of experiments with dry cold storage in treating infested tobacco in Brazil were given by Gustav Pook (69) in 1910.

It is stated that the method was in use throughout Brazil and that unusually good results had been obtained.

During the same year (1910) Mr. A. C. Morgan, of the Bureau of Entomology, in an article on insect enemies of tobacco in the United States (70), briefly described methods of treatment with fumigants. It was stated that no method entirely satisfactory had been found for the treatment of baled tobacco. The results of experiments with Röntgen or X rays in the treatment of infested tobacco, conducted by Mr. A. C. Morgan and the writer, were published in 1913 (76).

From Manila, P. I., in 1913, Mr. Charles R. Jones (77) published the most comprehensive article on the tobacco beetle which had yet appeared. The life history and seasonal history of the insect in the Philippines were determined and many practical methods of control tested under cigar-factory conditions. An exhaustive series of tests with hydrocyanic-acid gas showed this fumigant to be effective in treating infested cigars without affecting their quality.

Storage of infested tobacco at low temperatures is recommended by Mr. D. T. Fullaway (79) in a publication of the Hawaii Agricultural Experiment Station in 1914. In 1916 the results of experiments with Röntgen or X rays on different stages of the beetle were published by the writer (86). In 1917 the writer (89) published a general account of the species, its life and habits, and methods of control.

In the historical sketch given only the more important publications relating to the life history of the insect or to the measures employed in its control have been cited. In the bibliography (p. 69–77) reference will be found to most of the papers, relating to the insect, which have been published in permanent form. A synopsis is given of the contents of the more important publications.

DESCRIPTION OF STAGES.

THE EGG.

(Pl. I, fig. 8.)

Egg about 0.45 mm. (0.44–0.46 mm.) long and 0.2 (0.19–0.21 mm.) in diameter; ovoid elliptical, pearly white, becoming more opaque and dull in color just before hatching. Surface smooth, without reticulation or sculpture except a portion at the end from which the larva emerges, which is covered with numerous papillæ.

THE LARVA.[1]

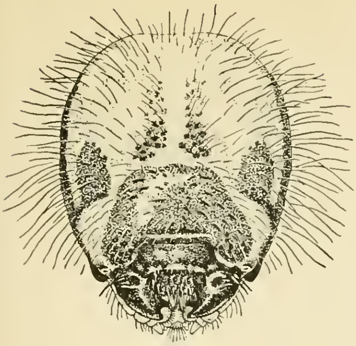
(Pl. I, figs. 1–7.)[2]

GENERAL CHARACTERS.

Ventral side of epicranium not continued behind the posterior end of hypostoma and its tentorial pits; gula transverse, laterally attached to the posterior

[1] In order that the identification in the field may be as accurate as possible it is necessary from time to time to incorporate in an economic bulletin technical descriptions. These descriptions are drawn up after extremely careful study of the anatomy of the larva by a specialist on the group. The following descriptions, kindly prepared by Dr. Adam G. Böving, will be of great assistance in future studies of ptinid larvæ. First is presented a description of the characters common to many ptinid larvæ, then the characteristics of the genus, and finally the specific characters of *Lasioderma serricorne*.

[2] Description of larva (with Pl. I, figs. 2–7) made by Dr. Adam G. Böving.



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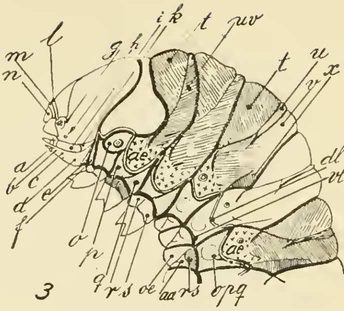

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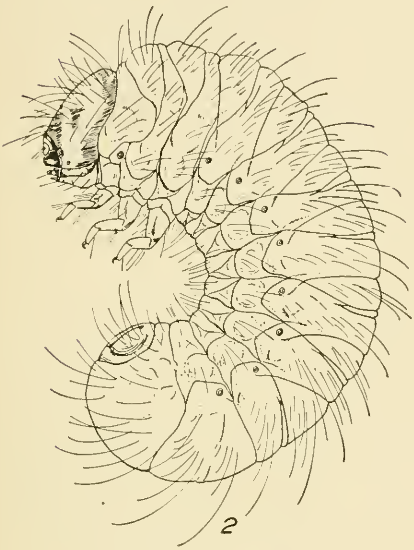

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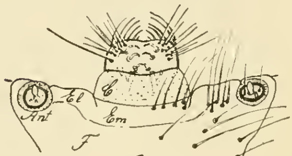

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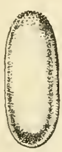

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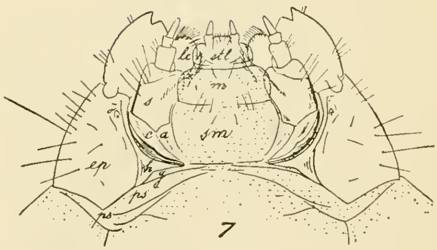

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EGG AND LARVA OF THE TOBACCO BEETLE (LASIODERMA SERRICORNE).

FIG. 1.—Front view of face. FIG. 2.—Side view of larva. FIG. 3.—Thoracic and abdominal areas: *aa*, Parasternum; *a*, labial palp; *ae*, alar area; *b*, stipes labialis; *c*, mentum; *d*, submentum; *dl*, dorso-lateral suture; *e*, gula; *f*, presternite; *g*, antenna; *h*, ocellus; *i*, stipes maxillaris; *k*, cardo; *l*, epistoma; *m*, clypeus; *n*, labrum; *o*, preepipleurum; *oe*, basisternum; *p*, epipleural lobe; *q*, postepipleurum; *r*, prehypopleurum; *s*, posthypopleurum; *t*, prescutum; *u*, scutum; *v*, scutellum; *vl*, ventro-lateral suture; *x*, postscutellum. FIG. 4.—Anterior portions of face (labrum, clypeus, epistoma, and frons): *Ant*, antenna; *c*, clypeus; *el*, epistoma, lateral part; *em*, epistoma, median part; *f*, frons. FIG. 5.—Prothoracic leg. FIG. 6.—Mandible, ventral side. FIG. 7.—Underside of head: *a*, Maxillary articulating skin; *c*, cardo; *ep*, epicranium; *g*, gula; *h*, hypostoma; *lc*, lacinia; *m*, mentum; *o*, ocellus; *ps*, presternum; *sm*, submentum; *stl*, stipes labialis; *x*, process between lacinia and hypopharynx. FIG. 8.—Egg. (Figs. 1 and 8 drawn by Joseph D. Smith; figs. 2–7 drawn by Adam G. Böving.)

margin of the hypostomal triangles, anteriorly adjoining submentum, posteriorly adjoining the presternites; occiput directed obliquely downwards and forwards. Mouthparts hypognathous; labrum and clypeus present; antenna small, situated at the anterior corner of frons, separated from basal skin of mandible by a narrow chitinous bridge; maxillary palp three-jointed, no definite palpiger; submentum and mentum the conspicuous parts of the ventral side of head; maxillary articulating area simple, neither chitinized nor subdivided into two or more separate lobes; stipes labialis with well developed ligula, labial palpigers, and palpi; hypopharyngeal chitinizations not developed. Tentorial bridge broad; hypopharyngeal bracon present. Body curved, wrinkled, fleshy, whitish. Legs developed; with several joints; last joint clawlike; no real claws; prehypopleurum and posthypopleurum indicated but not chitinized. Prothorax with small presternites fused into a narrow, transverse band; no separate prebasisternum; no sternellum; poststernellum well developed; mesothorax and metathorax with well developed epipleural median lobe closely connected with the alar area; spiracle-bearing preepipleurum not reaching the presternum; no definite sternellum; mesothorax with and metathorax without poststernellum. Abdominal segments ten; prescutal area large, protuberant; dorsal parts of scutum and scutellum not developed into ampullatory lobes; epipleurum bulged; parasternum anteriorly limited by a straight line; ninth abdominal segment without cerci or any chitinizations. Spiracles annuliform; mesothoracic spiracle apparently prothoracic, the preepipleurum of mesothorax being pushed forwards; metathoracic spiracle rudimentary; eight abdominal spiracles.

GENERIC CHARACTERS.

In the family Anobiidae (Ptinidae), the genus Lasioderma, belonging to the group Ptinini, is characterized as follows: Head rounded, not deeply sunk into prothorax; epistoma strong, rigid, with median region only slightly concave, and lateral regions subrectangular, projecting, not divided by any depressions; labrum subrectangular, with straight anterior margin and rounded corners; clypeus somewhat broader, subrectangular; one ocellus; antenna two-jointed, with large terminal sensory papilla; mandible with bidentate apex and convex, irregularly serrated cutting edge; no molar part or prostheca; maxillary lacinia single, broad, flat, semiovate, spinose, extending from distal end of stipes; at its base arising from the boundary region between hypopharynx and stipes maxillaris a freely projecting, somewhat shorter, four times narrower, lanceolate, spinose structure; stipes labialis broad and short; mentum somewhat large, transversely subrectangular, separated from the still broader, trapezoidal submentum by a straight, rather faint line; maxillary articulating lobe small; gula very narrow. Legs five-jointed; tarsal joint distinct, falciform, clawlike. Prothorax with tergum outlined like a dumbell, the alar areas being lobate, much larger than the upper tergal part; no chitinous linear impression between alar area and the upper tergal part. Mesothorax and metathorax both with sharply defined prescutum; scuto-scutellar parts fused. The first seven abdominal segments with a large prescutum, a narrow scutal fold, and a large scutellum; the tergal parts of the last three abdominal segments not divided; tergal folds dorsally and laterally granulated, but without transverse series of stout, backwardly curved spinules; tenth abdominal segment well developed, with two large, cushion-like pads on each side of a linear, vertical, anal fissure. Last spiracle no larger than the preceding abdominal spiracles.

SPECIFIC CHARACTERS.

Median region of epistoma with a row of five setæ on each side, lateral regions naked; labrum with about seven straight setæ on the upper surface at each anterior corner, several long, medianly curved setæ along the anterior margin and an oblique row of three, shorter, stouter, hook-shaped setæ on the under surface on either side of and posteriorly approaching the median line; clypeus naked; stipes labialis, mentum, and submentum with long soft setæ; maxillary articulating area not setiferous.

LARVAL INSTARS.

First-instar larva 0.55 to 1.4 mm. long; yellowish white; the digestive tract showing darker; body set sparsely with very long, pale hairs; head 0.12 to 0.16 mm. long. Second-instar larva about 3 mm. long; yellowish white; head 0.22 to 0.24 mm. long. Last-instar larva about 4 mm. long; yellowish white; set entirely with long, silky, yellowish brown hairs; chitinous parts brown; spiracles concolorous with body; head 0.5 to 0.7 mm. long.

THE PUPA.

Pupa (Pl. II, fig. 2) uniformly white when first transformed. Length (average) 3.5 mm. (2.5–3.75 mm.); width about 1.7 mm. (1.1–2 mm.); tips of elytra attaining fourth visible ventral segment of abdomen. Metathoracic legs beneath the elytra not attaining tips of inner wings. Head bent upon thorax and beneath pronotum. Ultimate and penultimate abdominal segments ventrally each with a pair of fleshy lateral protuberances.

THE ADULT.[1]

(Pl. III, fig. 1; text fig. 7.)

Elongate-oval, moderately convex. Uniform dull reddish yellow or brownish red. Head broad, eyes small. Antennæ rather narrow, second and third joints smaller than first, the third distinctly triangular; fourth to tenth about as wide as long; eleventh oval. Thorax strongly convex, front angles acute, hind angles wanting. Punctuation of entire upper surface fine, uniform, not dense. Length 2.2 to 3 mm.

FIG. 7.—The tobacco beetle (*Lasioderma serricorne*): Antenna of adult. Greatly enlarged.

LIFE HISTORY AND HABITS.

SUMMARY OF LIFE HISTORY.

The life history of the tobacco beetle may be briefly summarized as follows:

In material kept constantly warm, breeding is continuous and there may be as many as five or six generations in a year. Under usual conditions in warehouses in the latitude of Virginia there are ordinarily three or four generations a year. The beetle lives in its food substances during all stages of its existence, and the time required to complete its life cycle depends mainly upon temperature and may be as short as 45 days. Normally, in summer, the time

[1] Description of adult by W. S. Blatchley (71).

varies from 45 to 70 days. Eggs are deposited in the food substance, and under usual conditions the incubation period is from 6 to 10 days, the larval period from 30 to 50 days, and the pupal period from 6 to 10 days. Adults live ordinarily from 3 to 6 weeks after emergence. In cold climates the species passes the winter mainly in the larva stage. It thrives best in localities where the temperature and humidity are high, and in substances in which the larvæ are protected from rapid evaporation.

THE EGG.

PERIOD OF INCUBATION.

The time required for hatching depends upon the prevailing temperature and probably upon moisture conditions, although considerable variation in the incubation period has been observed, even with eggs from the same female which were kept under identically the same conditions. The variation in the time required for hatching is least when the eggs are not subjected to extreme changes of temperature and humidity, and when the temperature is relatively high. At Key West, Fla., where the temperature is remarkably even, the incubation period varied from 5 to 10 days in numerous experiments conducted in April and May. During the experiments the maximum temperature ranged from 91° to 93° F., and the minimum from 81° to 83° F. The average period of incubation was found to be approximately 7 days.

The length of the egg stage at room temperature at Clarksville, Tenn., in May, ranged from 7 to 14 days. In 22 records obtained during July and August the average period of 7.6 days was recorded.

At Appomattox, Va., at room temperature in July, the average period of incubation was found to be 8.2 days. The shortest period observed was 6 days and the longest period 14 days.

Records obtained at Tampa, Fla., in July and August, show an average incubation period of approximately 8 days. The longest period observed was 10 days and the shortest period 6 days.

In determining the incubation period at a fixed temperature at Richmond, Va., eggs were kept in an electrically heated and automatically regulated incubator. The temperature was fairly constant at 30° C. (86° F.) and the relative humidity at about 80 per cent. During the period of incubation the variation in temperature was less than 1° C. All eggs used in the experiments were obtained from beetles kept in the incubator, the incubation period ranging from 6 to 8 days. In all of 20 different experiments hatching commenced during the sixth day.

THE LARVA.

Injury to tobacco by feeding is caused mainly by the larva or worm stage of the insect. It is this stage of the tobacco beetle that is often referred to by tobacconists as the "grub." Within the egg the embryonic larva lies with the head at the rough end, and when development is complete it eats its way through the shell in this position. Larvæ hatching in glass vials at the laboratory were observed to consume the eggshells almost completely when food was not provided. In rearing the insects for experimental work the young larvæ were often observed to live without food for periods of from 5 to 10 days. On emerging from the egg they are much more active than at other stages of growth and are capable of crawling a considerable distance in search of suitable food. Their activity at this stage accounts for the rather strange infestation of tobacco products, as the extremely minute worms readily enter very small openings in the boxes or containers. On hatching the larvæ are semitransparent, gradually assuming a whitish or creamy color as they become more fully grown. The food within the alimentary canal, seen through the skin, gives them a dark or dirty color, which varies with the amount of food present. When feeding on tobacco the fine particles of dust adhering to the minute hairs of the larvæ give them a brownish appearance, which is more noticeable in the last instar. The larvæ appear more robust, deeply wrinkled, and grublike as they become more fully grown. The young larva lies and crawls extended to full length; the older larvæ usually assume a curved position and are not so active as those newly hatched. At all stages of growth they are negatively phototropic, and when exposed to light disappear within the food substances as quickly as possible.

Larvæ of all ages are capable of crawling for a short distance and often migrate from infested to uninfested material. This habit often accounts for the quick appearance of injury in freshly made cigars. Partly grown larvæ have been found on the cigarmakers' tables and on the pickers' tables. They easily enter the open ends of the cigars that are being handled, and in a very short time their work can be noticed in the bundle or box of cigars. In a box of injured cigars examined, the work of a single larva was traced through four cigars. In another instance, in a box of sliced plug smoking tobacco, a single larva had cut a furrow in the tobacco for almost the entire distance across the top of the slices between the oiled paper covering and the tobacco.

It has been observed by leaf-tobacco dealers that a crop of Cuban tobacco which remains raw and does not cure quickly is apt to be damaged more by the beetle than the same type of tobacco which matures and cures properly. Under laboratory conditions a test was made at Richmond, Va., in 1914, with several types of leaf tobacco which confirms observations made in warehouses and factories. Similar quantities of different kinds of tobacco were closely packed in a tight container and several thousand eggs of the beetle scattered over the top, about the same number being placed on each "hand." The box, thickly wrapped with cloth and paper to avoid sudden changes in temperature, was kept in a warm place where proper breeding conditions could be maintained. At the end of three months the tobacco was examined. The degree of infestation found is given in Table I.

TABLE I.—*Preference shown by larvæ of the tobacco beetle (Lasioderma serricorne) for different types of leaf tobacco.*

Type of leaf tobacco.	Egg distributed.	Tobacco examined.	Degree of infestation.
Virginia heavy dark export, smoke-cured	July 10, 1914	Oct. 10, 1914	Slight.
Tennessee heavy dark export, smoke-cured	do	do	Do.
Burley, medium grade	do	do	Moderate.
Ohio cigar leaf, medium-grade filler	do	do	Do.
Cuban cigar leaf, Santa Clara, medium light	do	do	Heavy.
Florida shade-grown, light cigar wrapper	do	do	Do.
Carolina bright yellow, flue-cured (thin and poorly cured)	do	do	Do.

Strong, heavy types of leaf tobacco ordinarily are not injured to any great extent unless stored for a long time. Leaf tobacco which is "fire" or smoke cured, such as that grown in the "dark-tobacco" sections of Virginia or the "black-patch" sections of Kentucky and Tennessee, is seldom seriously injured. This, perhaps, is due in part to the flavor or quality given the leaf by the smoke, which acts as a repellent, whereas the same type of leaf flue cured is readily attacked, although not to so great an extent as are lighter-bodied types of tobacco. These types, as well as all others, however, are more apt to suffer injury after the leaf has aged. The changes brought about by long storage of any tobacco seem to make it more suitable as food for the beetles.

LENGTH OF LARVA STAGE.

At ordinary room temperatures in summer the larva or feeding stage extends over a period of from 30 to 70 days; the length of the period depends mainly on temperature and on the character and condition of the food substance. There is always considerable variation in the length of the larval period, even with larvæ from the same egg lot, kept in the same food substance, and under the same conditions. In cold weather the larvæ become dormant and may remain in this condition for several months. The insect passes the winter mainly in this stage in cool climates. When the larvæ have finished feeding and are encased within the pupal cells, they are able to stand considerable cold and are more resistant to the action of fumigants. Activity in the larva stage ceases at temperatures ranging from 60° to 67° F. At Clarksville, Tenn., larvæ which hatched about November 10, 1915, and when partly grown were placed in granulated smoking tobacco and kept in a cool room did not transform until April, 1916. The material was protected from severe freezing, but only a small proportion of the larvæ survived the winter. The most favorable conditions for the rapid development of larvæ are created by (1) suitable food substances in compact or concentrated form, (2) high and uniform temperature, (3) high humidity, (4) protection from strong light, and (5) protection from rapid evaporation. At Richmond, Va., during the period between August 1 and November 19, 1914, the shortest larval period observed in six lots of about 20 larvæ each was 39 days, and the longest period was 61 days. Pressed chewing tobacco was used as food. The maximum temperature during the period was 91° F. and the minimum temperature was 51° F. At Key West, Fla., during the period between April 16 and June 24, 1912, in cigars kept at room temperature, the shortest larval period observed was 42 days and the longest period 66 days. The temperature of the room varied from 80° to 94° F.

Numerous experiments have shown that with concentrated foods the larval period is shortened somewhat. In several experiments with different foods kept under the same conditions in an automatically regulated incubator at a constant temperature of 86° F. the larval periods were as follows: In tobacco seed, 2 experiments, 29 and 30 days; in pressed yeast cake, 2 experiments, 27 and 30 days; in pressed plug chewing tobacco, 29 days; in sliced plug smoking tobacco, 30 days; in loose granulated tobacco, 2 experiments, 35 and 38 days; in cigars, 2 experiments, 34 and 36 days; in cigarettes, 42 days.

At Clarksville, Tenn., the following records for the larva stage were obtained at room temperatures during summer:

TABLE II.—*Length of larva stage of the tobacco beetle (Lasioderma serricorne), Clarksville, Tenn., 1914.*

Record No.	Egg hatched—	Larva formed cell—	Larva pupated—	Days as larva.	Food.
1	June 7	July 18	July 22	45	Pressed plug tobacco.
2	do	Aug. 5	Aug. 17	71	Do.
3	do	Aug. 7	Aug. 11	65	Do.
4	do	Aug. 11	Aug. 16	70	Do.
5	June 19	July 16	Aug. 20	31	Tobacco seed.
6	June 25	July 30	Aug. 2	38	Do.
7	June 30	No record	July 25	25	Do.

THE PUPAL CELLS.

After the larva has become fully grown and is ready to transform into the pupa stage it forms, in any convenient place, the cell or cocoon in which transformation takes place. Apparently no special effort is made by the larvæ to reach the surface of the food substance although many of the cells are constructed on the outside. In leaf tobacco the cells usually are formed along the midrib or in the folds of the leaf. In boxes of cigars, cigarettes, and smoking tobacco cells may be found on the sides of the boxes, often within the paper lining; others may be found between closely packed cigars or cigarettes. The larva frequently cuts through the wrapper or binder of a cigar from the outside, forming a cell just within the wrapper, the cell filling the opening made in the cigar. The pupal cells usually are ovoid, but vary considerably in shape and completeness, this depending largely on the location of the larva and the character of the food substance. They average (inside measurement) about 4.5 millimeters long and 3 millimeters wide. They are often without definite shape, flimsy, and fragile, being constructed of small particles of the food substance and refuse cemented together by a secretion of the larvæ. On several occasions larvæ were observed to leave partly formed cells, crawl a short distance, and form other cells in which transformation to the pupa stage finally took place. In leaf tobacco the cells frequently are incomplete, the larvæ utilizing folds of the leaf for part of the cell, and on flat surfaces they simply form coverings over themselves. Within dense substances the surrounding material forms the necessary protection, the walls of the cell being thinly lined.

THE PREPUPA.

Before transformation there is ordinarily a period of from 4 to 12 days during which the larva within the cell undergoes structural changes preparatory to pupation. If exposed to low temperatures, as has been stated, the larva may remain in the cell for a considerable time before marked change in structure or appearance takes place. Before changing to the pupa stage the larva lies in a curved position within the cell, which is large enough to permit free movement. The body contracts and becomes somewhat more deeply wrinkled.

THE PUPA.

When newly formed the pupa is white (Pl. II, fig. 2), but gradually it assumes a brownish tinge before transformation to the adult stage, the eyes becoming reddish or reddish brown. It lies on its back within the pupal cell. Should the cell be broken open and the pupa removed, transformation takes place in an apparently normal manner if protected from rapid evaporation. In handling infested leaf tobacco many bare pupæ can be seen which have been dislodged from the fragile cells or cocoons between the leaves of the tobacco. After transformation has taken place a portion of the pupal skin frequently adheres for a short time to the tip of the abdomen.

The duration of the pupa stage of the tobacco beetle at room temperatures during the warmer months of the year in several localities was as follows: At Key West, Fla., between May 13 and June 4, the average time as shown by 10 records was 6 days and the shortest period 5 days. At Richmond, Va., the average of 11 records at room temperatures was 7.8 days, the shortest period 6 days, and the longest period 12 days. At Appomattox, Va., the average of 12 records obtained during July and August was 8.1 days. During September three records show pupal periods of 7, 8, and 9 days, respectively. At Clarksville, Tenn., 3 records secured during April and May show an average of 13.6 days, and 10 records during the period between July 29 and October 1 an average of 7.8 days. At Tampa, Fla., 21 records during July show an average of approximately 7 days, and 6 records during October show an average of 8.1 days.

THE ADULT.

When transformation to the adult stage has taken place the beetle lies inactive within the pupal cell for a period of three to seven days—usually about five days. After emergence it remains at rest for a day or more on the outside of the cell; the color of the beetle gradually becomes darker, and the normal shade of brown is reached about the time it has completed the resting period. The beetles are comparatively soft immediately after transforming and do not attain their final degree of hardness until they are ready to move away from the pupal cell.

The adults vary greatly in size. This undoubtedly is due to breeding conditions, the quality or abundance of food obtained by the insect while in the larva or feeding stage being the most important factor. The females will average larger in size than the males and they are also less active. In the vicinity of infested warehouses or factories beetles frequently are found in surrounding dwellings, and on several occasions were observed by the writer to fly from one tobacco warehouse to another located on the opposite side of the street. They avoid intense light, moving about most actively in subdued light or in darkness. When in the dark they are attracted toward subdued or artificial lights, and in tobacco warehouses often may be found in great numbers at the windows in late afternoon, the flight toward the windows being heaviest at sunset. Observations made at regular intervals throughout the night in a cigar factory showed that they were taken at a trap light at all hours of the night. During the day the greater number will be found in secluded places, such as crevices in the walls, or along the casings of windows, and within the leaf tobacco. When at rest the head and thorax are drawn downward (Pl. III, fig. 1). They have a habit of feigning death when disturbed, the head and thorax being bent downward and the legs drawn closely together.

MATING.

The adults generally begin to mate the second or third day after leaving the vicinity of the pupal cell. Mating in some cases occurred the first day, and was observed to take place several times during the egg-laying period.

PROPORTION OF SEXES.

The proportion of females seems to be somewhat greater than that of the males. Four lots which had emerged at different times from material kept at the laboratory gave a total of 36 males and 41 females. One hundred beetles collected at lights at a tobacco warehouse at Danville, Va., were dissected by Mr. S. E. Crumb, of the Bureau of Entomology, and of these 36 were males and 64 females.

LENGTH OF THE ADULT STAGE.

The length of life of the adults depends largely upon the temperature after emergence. In summer, or in rooms kept constantly warm, the beetles die much sooner than do those which emerge during cool weather. Normally the adults die in from 3 to 6 weeks after emergence. Although the mouth parts and digestive tract of the adult beetle apparently are complete and they are capable of gnawing through tobacco or other food substances to escape from the locality of the pupal cell, little if any evidence of feeding has been observed. Large numbers of adults, directly after emergence, were put in sealed tubes containing cigars, the open ends of the cigars being sealed to prevent entrance of the beetles. Several cigars prepared in this manner were kept until all adults had died, but no signs of feeding or injury to the cigars could be seen. Other beetles were kept in test tubes with small bits of leaf tobacco. In a few tubes the edges of the leaf had been slightly gnawed and fine particles of the leaf were found. Beetles confined in tubes closed with cork stoppers frequently gnaw into the cork for a short distance. No evidence has been secured to show that cigars or tobacco are directly injured by the adult or beetle except when burrowing out after transforming from the pupa stage. Eggs are deposited and the adults apparently live the normal length of time whether food is present or not. At Clarksville, Tenn., a number of experiments were made by Mr. K. B. McKinney and the writer to determine whether the presence of food has any bearing on egg deposition or length of life of the adults. A brief summary of the results obtained in one series of experiments follows: Number of pairs of beetles under observation, 44; average length of life of males kept without food, 23.4 days; average length of life of males kept with food, 21 days; average length of life of females kept without food, 31.2 days; average length of life of females kept with food, 30.5 days.

Another series of experiments was made to determine the length of life without food at ordinary room temperatures in summer. Twenty-three pairs of beetles were placed in separate tubes directly after emergence. The average length of life was 21 days for the males and 40.4 days for the females. Records from 24 pairs of beetles kept under observation at Clarksville, Tenn., during August and September, 1916, by Messrs. J. E. McMurtrey and E. H. Vance show an average length of life of 17.7 days for males and 21.4 days for females. An average of 30 eggs per female was obtained. The greater number of eggs was deposited between the third and the eighth day after egg-laying began. The period of oviposition ranged from the first until the seventeenth day after mating was observed. A similar experiment during the same period with 18 pairs of beetles kept without food gave the following: Average number of eggs deposited per female, 24; average number of days males lived, 21.2; average number of days females lived, 26.3.

OVIPOSITION.

Egg-laying usually begins in from 2 to 6 days after emergence. A large proportion of the females kept under observation commenced laying eggs the second and third day after mating. Indoors, where infested material is kept warm and is not subjected to much variation in temperature, the eggs may be found at any time. Humidors for storing cigars and tobacco usually are in steam-heated buildings, and the warmth and moisture conditions foster continuous reproduction throughout the year. Eggs usually are not deposited at temperatures below 70° F. The adults are more active at high temperatures, and eggs are most abundant in tobacco during the warmer period in summer. In the Middle and Northern States, when tobacco is subjected to approximately out-of-door conditions of temperature in unheated buildings, the eggs are laid only during the warmer months of the year. At Richmond, Va., the last eggs were obtained on October 28, 1914, from beetles kept in unheated buildings and the first eggs were obtained on May 2 of the following spring. Under ordinary conditions the eggs are deposited singly, usually in depressions or folds of the food substance. Owing to their small size and secluded location they do not ordinarily attract attention. Even to many who are thoroughly familiar with other stages of the beetle in tobacco the egg is an unfamiliar object.

There is a belief quite common that the eggs of the tobacco beetle are laid on the leaf tobacco in the fields or during the process of curing, and that these eggs do not develop until the tobacco is handled or made up into cigars or other products. This is not the case, as the eggs hatch within a few days after they are deposited and the beetles do not infest tobacco until it is cured. The eggs are laid during both day and night. In cigars, the greater number of eggs is deposited in the open end, the beetles frequently burrowing in the filler to a considerable distance.

At Key West, Fla., large numbers of adults were placed in test tubes containing fresh cigars of the panatela and perfecto shapes. After a few days the cigars were cut in sections, unwrapped, and the location of the eggs noted. Results from 10 cigars containing, in all, 372 eggs were as follows: Panatelas, 220 eggs; on outside, 6 eggs; inside, at end, first inch of cigars, 184 eggs; rest of cigars, 30 eggs. Perfectos, 152 eggs; on outside, 11 eggs; inside first inch of cigars, 129 eggs; rest of cigars, 12 eggs. In this experiment the number of eggs deposited on the outside of the cigars was probably more than normal owing to the large number of beetles in the tubes. In a similar experiment at Richmond, Va., with cigars of various shapes, only 5 per cent of a total of 320 eggs were found on the outside. This experiment was made with boxed cigars. All of the eggs recorded as deposited on the outside of the cigars were between two cigars closely packed, or on the edge of the filler exposed at the open end. In no instance were eggs laid on the wrapper where the surface was smooth. With cigarettes the eggs are deposited within the wrappers, the greater number being found near the end. In plug tobacco eggs were found mostly along the roughened edges of the slices, and between the slices when closely packed. The eggs do not adhere readily to leaf tobacco and are easily dislodged by handling.

NUMBER OF EGGS LAID, AND PERIOD OF OVIPOSITION.

The number of eggs laid by individual females varies greatly, depending on the vitality of the beetle, on the food obtained while in the larva stage, and on the temperature and moisture conditions during the egg-laying period. The largest number shown by any record obtained thus far is 103. This record, which also shows the rate of egg deposition, is as follows: On April 16, 1915, a pair in copula was placed with leaf tobacco in a tube and kept in an incubator at a constant temperature of 86° F. and a relative humidity of 80 per cent. The first eggs were laid April 17. The daily egg deposition from April 17 to April 25 is as follows: 24, 17, 18, 14, 11, 10, 2, 4, 3; total, 103. The male died April 21 and the female April 28.

In experiments made by the writer at Tampa, Fla., a total of 567 eggs was obtained from 21 females, or an average of 27 eggs each. The longest period of oviposition was 11 days. The largest number of eggs found in any one of 64 females dissected by Mr. S. E. Crumb on August 3, 1911, was 22.

At Clarksville, Tenn., the average number of eggs laid per female during July, August, and September was 32, as shown by 63 separate records. The longest period of oviposition was 21 days. Approximately 66 per cent of the eggs were laid during the first six days after mating was observed. Each pair of beetles was kept in a shell vial containing leaf tobacco.

INFERTILE EGGS.

Occasionally a female was found to lay infertile eggs, even after mating. No eggs were obtained from unmated females. In one series of experiments, of a total of 182 eggs obtained from 24 different females found in copula, 25 eggs, or 13.7 per cent, were infertile. The eggs were deposited on leaf tobacco and kept at a temperature of about 84° F., the daily variation being about 5°. This infertility probably is much above the average, as hatching in many other lots was almost perfect. The number of infertile eggs in 11 different lots, containing in all 773 eggs, was 30, or approximately 3.8 per cent.

LENGTH OF DIFFERENT STAGES IN DEVELOPMENT OF INDIVIDUAL BEETLES.

The following records from life-history studies made at Richmond, Va., show the time required for each period of development of different beetles from the egg to the adult.

TABLE III.—*Length of different stages in development of individual tobacco beetles (Lasioderma serricorne). Richmond, Va., 1914.*

Record No.	Egg laid—	Hatched—	Larva formed cell—	Larva pupated—	Adult appeared—	Adult left cell—
1	July 1	July 8	Aug. 17	Aug. 22	Aug. 29	Sept. 6
2	...do.....	...do.....	Aug. 19	Aug. 23	Sept. 1	Sept. 5
3	July 5	July 12	Aug. 22	Aug. 28	Sept. 4	Sept. 9
4	June 1	June 7	July 18	July 22	July 29	Aug. 2
5	June 18	June 25	July 30	Aug. 3	Aug. 9	Aug. 16

Record No.	Mated—	Eggs laid—	Food.	Egg to beetle.	Egg to egg.
				Days.	*Days.*
1	Sept. 9	Sept. 11	Tobacco	59	72
2	Sept. 7	Sept. 10	.....do	62	71
3	Sept. 10	Sept. 17	.....do	61	74
4	Aug. 6	Aug. 9	.....do	58	69
5	Aug. 21	Aug. 24	.....do	52	67

PHOTOTROPISM.

Adults of the tobacco beetle are accustomed to darkness or semi-darkness. Up to a certain degree of intensity they respond positively toward light, but they are negatively phototropic if the light is too intense. Observations made in tobacco warehouses and on beetles in specially constructed cages at the laboratory showed that they avoid intense sunlight, but toward sunset, or when the light intensity is lowered, they move toward the source of light.

REACTION TOWARD COLORED LIGHT.

Laboratory experiments made with apparatus which transmitted light through color screens or ray filters which made it practically monochromatic showed conclusively that the tobacco beetle, in common with other insects, reacts most strongly to colors of shortest wave length. The movement toward blue or blue-violet is most pronounced, and the movement toward red least of all. When a series of traps was operated with the light transmitted through color screens placed in regular order from red to violet the number of beetles attracted, in the majority of instances, increased in fairly regular order from red to violet. Experiments made with electric lights showed that the beetles were attracted toward a bulb of clear glass transmitting light rich in rays of short wave length, and scarcely at all toward a bulb of red glass, which transmitted rays of long wave length giving light at the lower or red end of the spectrum.

The adults, in common with other insects reacting negatively toward intense sunlight, are only slightly sensitive to light at the lower end of the spectrum, and rays of longer wave length, limited to red and orange, seem to act on them in much the same manner as darkness. Adults exposed to bright sunlight under color screens of red and blue were observed to collect under the red screen almost as readily as they did when an opaque screen was used in place of the red, although the apparent intensity of light under the two screens was the same. This shows a reaction directly opposite to that observed when the beetles, in darkness, are exposed to lights of low intensity.

EFFECT OF TEMPERATURE ON ACTIVITY OF ADULTS.

A series of laboratory experiments was conducted to ascertain the effect of ascending and descending temperatures on the activity of adults. Beetles were confined in the lower part of a long glass tube 20 millimeters in diameter. A thermometer was passed through an opening in the cork and the tube lowered into an inverted bell jar filled with water. A support was arranged in such a manner that the bell jar could be lowered into melting ice, or into a basin of water which could be heated gradually by an alcohol lamp underneath. By this means the temperature of the tube containing the beetles could be gradually raised or lowered as desired. In experiments with descending temperatures the beetles were taken from a lot reared in confinement and were kept at a constant temperature of 81° F. Those used in tests of rising temperatures were kept for a short time at 32° and were inactive when the experiment was commenced. Ten beetles were used in each test, a different lot being used each time. With increasing temperatures the beetles begin activity at temperatures between 48° and 75° F., one-half being active at 60° and 75 per cent at 64° F. With decreasing temperatures the beetles become inactive between 62° and 48° F., one-half being inactive at 56° and 75 per cent inactive at 55° F. In infested tobacco warehouses the adults are seldom found active at temperatures below 65° F. Activity increases as the temperature becomes higher. At temperatures between 117° and 120° F. all activity ceases, and temperatures above 117° F., if continued, result in death.

SEASONAL HISTORY.

SEASONAL ABUNDANCE AND NUMBER OF GENERATIONS.

Since the tobacco beetle is an indoor or stored-product insect, the terms "brood" and "generation" can hardly be applied in the sense that they are used in dealing with field insects, as the seasonal appearance and number of generations of such insects depend largely upon the variations in climatic conditions. In food substances maintained at constant warm temperatures adults may be found at any season of the year, and the wide variations in the time required for development under the same breeding conditions produce an overlapping of generations. Under ordinary conditions in warehouses there are, however, well-marked periods during which the adults are most abundant. At Key West and Tampa, Fla., most cigar manufacturers state that the adults are most abundant during the months of February and March, and again in August and September. At these places, however, the abundance of adults at any time may depend more upon the time the heaviest shipments of cigar tobacco from Cuba are received than upon local climatic conditions.

In the latitudes of Virginia and Tennessee there seems to be a period of greater abundance with the advent of the first warm weather in June, and again a marked increase occurs during September.

In tobacco warehouses at Clarksville, Tenn., adults usually begin to appear about May 1, and after November 1 comparatively few adults can be found. In unheated buildings three generations are possible between May 1 and November 1.

In the laboratory at Clarksville, Tenn., beetles were kept under observation continuously by Mr. S. E. Crumb during 1910–11. The rearing material was kept in a room heated only during the day during winter. Larvæ which constructed pupal cells in November, 1910, became adults May 18, 1911. These beetles deposited eggs about May 31, from which adults were obtained about July 29. These beetles deposited eggs August 13, from which adults were obtained on September 28. Eggs were obtained from these adults October 5. Larvæ from this lot of eggs constructed cells in which they passed the winter of 1911–12. This gives for the locality three distinct generations, emerging in the adult stage in May, July, and September. In localities farther south from three to six generations may occur, since under laboratory conditions at normal summer temperatures the entire life cycle was found to average 60 days.

At Richmond, Va., it was determined that three generations may occur under warehouse conditions. On October 14, 1913, eggs were placed in tobacco, and larvæ were found in cells in a dormant condition during December, which transformed the following spring. Adults collected from the lot May 5, 1914, deposited eggs on May 6–7. Adults reared from these eggs were obtained July 22, and eggs were laid about July 25. From these eggs adults were again obtained about October 2. Eggs deposited by beetles from this lot hatched October 18, the larvæ becoming dormant during the latter part of November. This shows that for this locality there are three complete life cycles, the adults appearing in May, July, and October, and that from the adults which emerge earliest there is a possibility of a fourth generation reaching the adult stage before winter.

In the Middle and Northern States, in warehouses and tobacco factories, a sudden appearance of large numbers of adults in spring or early summer is frequently observed. The greater number of larvæ which survive the winter complete their transformation and emerge in the adult stage with the advent of warm weather.

INSECTS LIKELY TO BE MISTAKEN FOR THE TOBACCO BEETLE.

Belief still prevails in many sections that the tobacco beetle is found on growing tobacco and that it continues to feed upon the tobacco after it has been cured. This impression is due perhaps to its slight resemblance to a smaller and very common insect, the tobacco flea-beetle (*Epitrix parvula* Fabricius) (fig. 8), which is abundant on growing tobacco in the field and in tobacco plant beds. Contrary to this belief the tobacco beetle (*Lasioderma serricorne*) does not attack growing tobacco and is not present in tobacco fields. It is not a field insect, but feeds and lives in dried substances, its more common food being cured tobacco. The habit of the tobacco flea-beetle of hopping when disturbed, its occurrence on growing tobacco, its smaller size, and its general appearance will serve readily to distinguish it from the tobacco beetle. Several species of insects which occasionally are found living or feeding in dried tobacco are likely to be mistaken for the tobacco beetle. These are enumerated below.

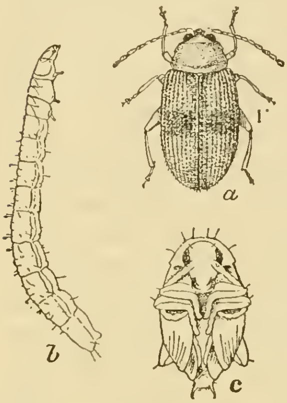


Fig. 8.—The tobacco flea-beetle (*Epitrix parvula*): *a*, Adult; *b*, larva, side view; *c*, pupa, from below. Enlarged. (Chittenden.)

A reddish-brown beetle (*Thaneroclerus girodi* Chevrolat), considerably larger than the tobacco beetle, often may be found in tobacco or in boxes of cigars. This species feeds on the different stages of the tobacco beetle. The adult, larva, and pupa stages are shown in Plate II, figure 3; Plate III, figure 5; and Plate IV. This insect is fully discussed in the section dealing with the parasitic and predacious enemies of the tobacco beetle.

The larger tobacco beetle (*Catorama tabaci* Guérin) (Pl. II, fig. 1; Pl. III, figs. 2, 4; text figs. 9 and 10) attacks cured tobacco and tobacco seed in much the same manner as does the common tobacco or "cigarette" beetle (*Lasioderma serricorne*) and its larger size makes it still more destructive than is the common species. Cigar tobacco injured by *Catorama tabaci* is shown in figure 6. So far as known this species has been reported only from three localities in the United States. It was found in tobacco in this country for the first time in 1912. One of the leading cigar companies at Key West, Fla., reported the insect to the Bureau of Entomology and sent specimens collected in a shipment of cigar tobacco from Habana, Cuba. At about the same time a similar report accompanied by specimens was received from a cigar company located in Philadelphia, the beetles having been found also in a shipment of Habana tobacco. In the following year specimens of the Catorama were taken by Mr. A. C. Morgan of the Bureau of Entomology in bales of Habana tobacco which were being removed from a bonded warehouse at Key West, Fla., and also by the writer, in a bonded warehouse in Tampa, Fla. The records obtained indicate that the insect is native to Cuba. It was introduced into Paris, France, from Cuba and was first described by Guérin-Méneville (11) from the Paris importations in 1850, having been found in Habana cigars.

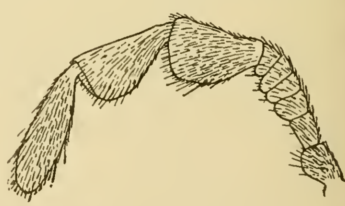
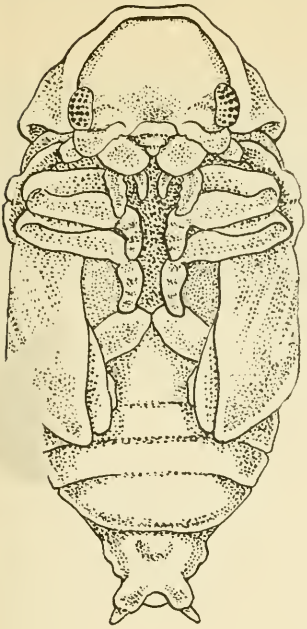


Fig. 9.—The larger tobacco beetle (*Catorama tabaci*): Antenna of adult. Greatly enlarged.



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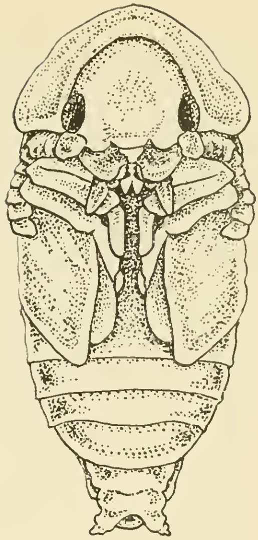

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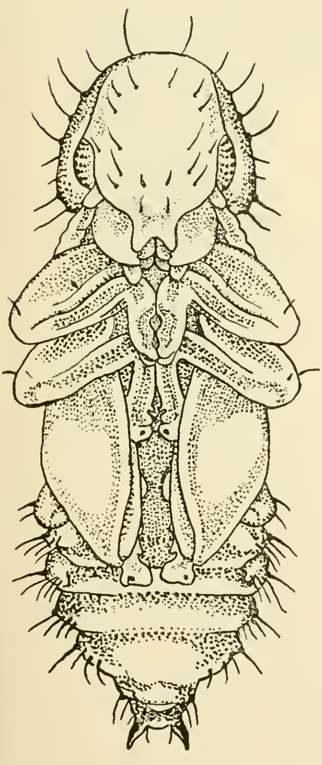

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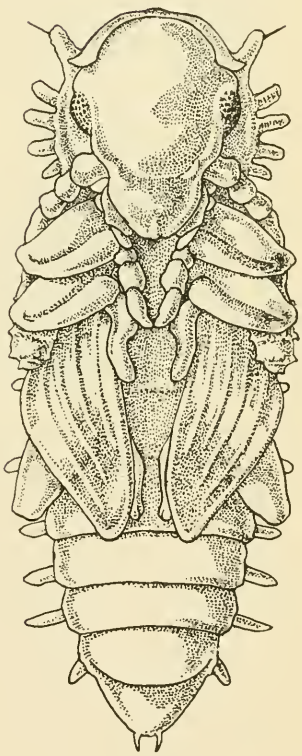

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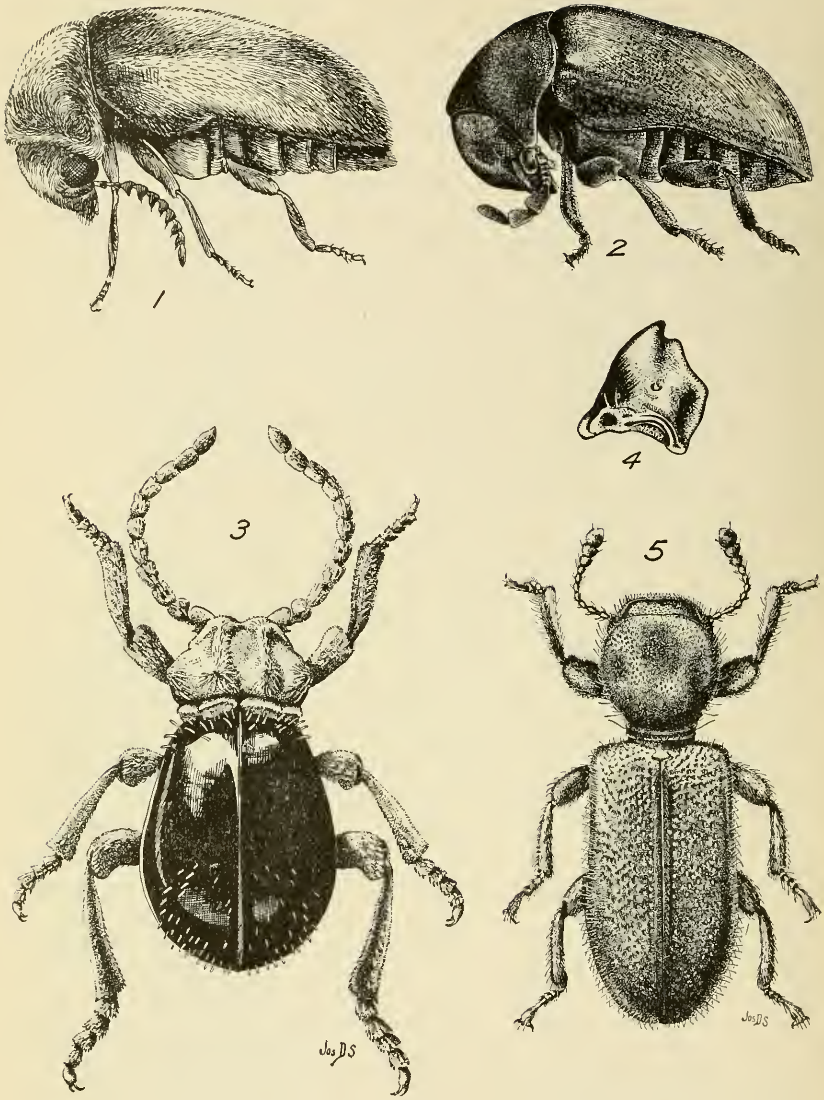
PUPÆ OF BEETLES THAT FREQUENT CURED TOBACCO.

FIG. 1.—The larger tobacco beetle (*Catorama tabaci*). FIG. 2.—The tobacco beetle (*Lasioderma serricorne*). FIG. 3.—*Thaneroclerus girodi*, a predatory enemy of the tobacco beetle. FIG. 4.—Saw-toothed grain beetle (*Silvanus surinamensis*). (Drawings by Joseph D. Smith.)



BEETLES THAT FREQUENT CURED TOBACCO.

FIG. 1.—The tobacco beetle (*Lasioderma serricorne*). FIG. 2.—The larger tobacco beetle (*Catorama tabaci*). FIG. 3.—*Mezium americanum.* FIG. 4.—*Catorama tabaci:* Left mandible of larva, dorsal view. FIG. 5.—*Thaneroclerus girodi*, a predacious enemy of the tobacco beetle (*Lasioderma serricorne*). (Drawings by Joseph D. Smith.)

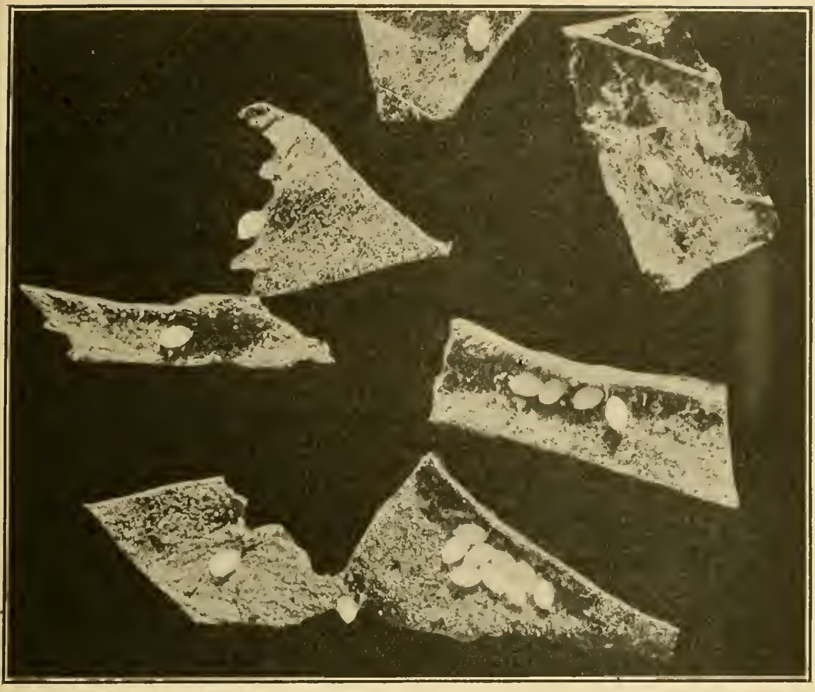


FIG. 10.—Eggs (enlarged) of the larger tobacco beetle (*Catorama tabaci*) on leaf tobacco.

Silvanus surinamensis Linnaeus and *Cathartus advena* Waltl are occasionally extremely abundant in tobacco warehouses, and the first-named species has been found to feed to a slight extent on tobacco and tobacco seed. The pupa of *S. surinamensis* is shown in Plate II, figure 4.

Jones (77) states that in the Philippines a species of Bostrychidae and the shot-hole borer of bamboo (*Dinoderus brevis* Horn) are abundant and often are mistaken for the tobacco beetle. Like other insects often found in tobacco, their occurrence, however, is purely accidental. Three other species of beetles have been recorded (43) as injuring cured and manufactured tobacco. These are the drugstore beetle (*Sitodrepa panicea* Linnaeus), the rice weevil (*Calandra oryza* Linnaeus), and the leather beetle (*Dermestes vulpinus* Fabricius). The first of these insects is similar in general appearance to the tobacco beetle and might be mistaken for it, but the form of antenna (fig. 11) serves to distinguish it from the tobacco beetle (fig. 7).

FIG. 11.—The drug-store beetle (*Sitodrepa panicea*): Antenna of adult. Greatly enlarged.

In addition to the insects already mentioned the following species have been found frequenting cured tobacco: *Trogoderma tarsale* Melsheimer, *Attagenus piceus* Olivier, *Tenebrioides mauritanica* Linnaeus, *Mezium americanum* Laporte. *Catorama impressifrons* Fall and *Attagenus piceus* Olivier have been recorded by Morgan (70) as infesting tobacco seed. *Mezium americanum* Laporte (Pl. III, fig. 3) has been found breeding in tobacco seed by Mr. S. E. Crumb of the Bureau of Entomology.

NATURAL CONTROL.

Numerous natural agencies are concerned in the control of the tobacco beetle. These forces, singly or combined, serve to keep the insect in check.

CLIMATIC CONTROL.

In the temperate zones, at least, the most important factor in holding the beetle in check is the cold of winter. Under ordinary conditions in cool climates their activities are confined to about one-half of the year. A comparatively small proportion of the insects survive the winter when exposed to even moderate cold if it is long continued, or to sudden abnormal changes of temperature. Severe freezing at temperatures lower than 10° F., if continued even for a short time, will result in extermination. At different times in order to determine the effect of exposure to variations of temperature in unheated buildings, heavily infested cans of smoking tobacco were wrapped in paper and kept over winter in various localities. The records obtained are as follows:

AT APPOMATOX, VA., WINTER OF 1910–11.

About 10 pounds of pressed plug and granulated smoking tobacco heavily infested were placed in original packages, in a large pasteboard box, wrapped with paper, and kept in an unheated room. A self-registering thermometer in the package showed that the lowest temperature reached was 11° F. Practically out-of-door conditions were experienced from December, 1910, until April, 1911. The beetles were exterminated. The tobacco was kept for several months but did not show signs of reinfestation.

AT RICHMOND, VA., WINTER OF 1913–14.

Two 5-pound packages of infested smoking tobacco were wrapped in paper. One package was placed in an unheated cellar, the other in a partly open building giving approximately out-of-door temperature variations. Both lots of tobacco were heavily infested. The exposure extended from November, 1913, until March, 1914. A self-registering thermometer in the open building showed the lowest temperature to be 12° F., and this temperature was reached several times during the winter. The lowest point reached in the cellar was not determined, but the protection afforded gave somewhat higher temperatures than obtained in the open building. On examination in March a very few live larvæ were found in the tobacco kept in the cellar. The tobacco in the open building was completely sterilized. The package was sealed and kept under observation until June, 1914, but no live stages of the beetles were found.

AT OAK HARBOR, OHIO, WINTER OF 1914–15.

A package prepared at Richmond, Va., contained about 5 pounds of heavily infested smoking tobacco, part pressed or sliced plug and the rest granulated, and a package of infested cigars and cigarettes. About 1,000 eggs of the tobacco beetle had been placed in the smoking tobacco November 1, 1914. This was mailed on November 14 to Oak Harbor, Ohio, where it was placed in an unheated building on November 17. It was examined June 10, 1915. No live stages of the beetle were found. The lowest temperature registered in the building was 10° F.

AT CLARKSVILLE, TENN., WINTER OF 1915–16.

About 10 pounds of smoking tobacco wrapped in paper were kept over winter in an unheated room in the laboratory. The tobacco contained all stages of the beetle. On November 1, 1915, about 1,000 eggs of the beetle were placed in the tobacco. These eggs hatched about November 10. No record was secured of the lowest temperature in the room. The lowest record out of doors was 5° F. The tobacco was examined during April, 1916. No live stages of the beetle were found. Although the tobacco was kept under observation for several months no signs of infestation were observed.

Evidence of the effect of freezing on the tobacco beetle has been observed on numerous occasions and it is not uncommon to find leaf tobacco or other food substances which have been exposed to low temperatures completely free from the beetle although its condition showed that it had been heavily infested previously. It has been the experience of those familiar with the tobacco industry that beetles always become more abundant and destructive after a mild winter.

DRYING OUT OF FOOD SUBSTANCES.

The tobacco beetle thrives best in tobacco that is protected from rapid evaporation and when the humidity is high. If the tobacco remains very dry for a considerable length of time the rate of multiplication is largely checked. In all cases observed in rearing experiments, the insects failed to develop properly if the food substance became too dry or if the larvæ or pupæ were not protected from excessive evaporation.

MOLD IN FOOD SUBSTANCES.

The growth of mold in the food substance usually results in the complete extermination of the beetle. This has been observed in many instances. It is often owing to this fact that infestation from damaged or worthless products does not extend to uninfested products near by.

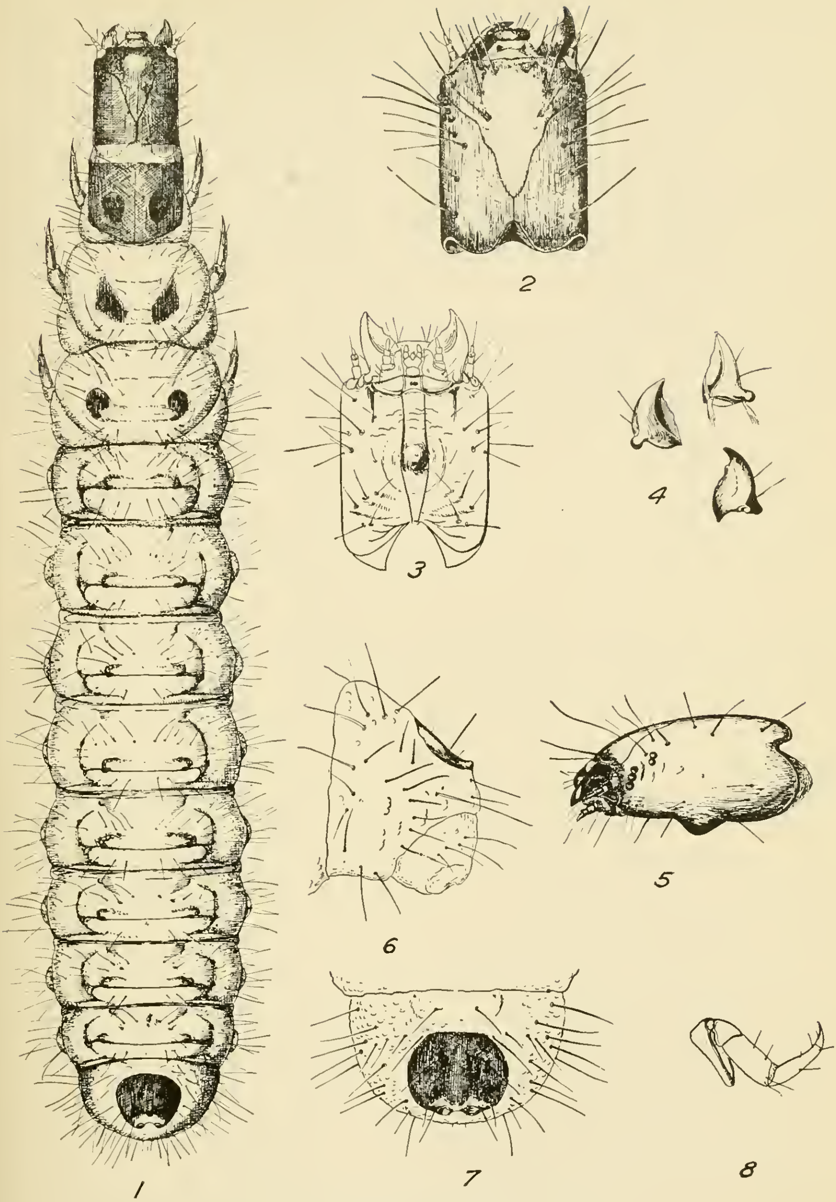
INSECT ENEMIES.

Several species of insects have been found to destroy the tobacco beetle and some of these appear to be widely distributed. While both predatory and parasitic insects are important factors in the repression of the tobacco beetle, the insect still is able to maintain itself successfully in all localities where it has become established.

PREDACIOUS INSECTS.

THANEROCLERUS GIRODI Chevrolat.

Among predatory enemies of the tobacco beetle the most important, so far as is known, is the clerid beetle *Thaneroclerus girodi* Chevrolat (Pl. II, fig. 3; Pl. III, fig. 5; Pl. IV). This beetle was found in unusually large numbers at Key West, Fla., and is a very important factor at that cigar-manufacturing center in keeping the tobacco beetle in check. It was first found in the United States by Dr. W. D. Hunter and Mr. A. C. Morgan, of the Bureau of Entomology, at Key West, Fla., in April, 1912 (78). Specimens of the beetle were determined by Mr. E. A. Schwarz, of the Bureau of Entomology. The insect has since been found by the writer to be more or less common, but much less abundant, at Tampa, St. Petersburg, Jacksonville, and Quincy, Fla., and was found in tobacco stored in a tobacco barn at Tallahassee, Fla., in 1914 by Mr. J. R. Watson, State entomologist of Florida. Specimens were also located at Richmond, Va., in a package of smoking tobacco infested with the tobacco beetle, which had been returned to the manufacturers from Galveston, Tex. Mr. John Wardlow, of Key West, Fla., stated that he had observed the beetle frequently in the bales of cigar tobacco imported from Habana, Cuba. Among Cuban cigar makers the insect seems to be well known. They state that it is common in cigar factories in Habana, where it is called the "bicho grande" or "big bug" to distinguish it from the smaller species, the tobacco beetle (*Lasioderma serricorne*), upon which it



LARVA OF THANEROCLERUS GIRODI.

FIG. 1.—Dorsal view of body. FIG. 2.—Dorsal view of head. FIG. 3.—Ventral view of head. FIG 4.—Views of mandible. FIG. 5.—Side view of head. FIG. 6.—Lateral view of ninth and tenth abdominal segments. FIG. 7.—Dorsal view of ninth abdominal segment. FIG. 8.—Leg. (Drawings by Adam G. Böving.)

feeds. Jones (77) has described the habits of an undetermined clerid beetle which, he states, feeds in both the larva and adult stages upon the tobacco beetle in the Philippines. The drawings of the different stages of the clerid, given by Jones, show it to be either *Thaneroclerus girodi* or a very closely related species. Wolcott (72) records its presence in the United States.

The insect is new to the fauna of the United States and there is, in addition to the foregoing records, only a single reference to it in entomological literature, this being the original description by Chevrolate (18).

The Adult.

The adult (Pl. III, fig. 5) is a reddish-brown beetle about 6 mm. in length. The wing covers and thorax are pitted and somewhat pubescent. The indentations are smaller and somewhat more regular on the thorax than on the elytra. The original description by Chevrolat (18) is as follows:

Thanerocleru Girodi.—Long. 6 mill.; lat. 2–1/3 mill. Elongatus, sanguineus, pilosus creberrime punctulatus; capite magno convexo, antice semicircuiter emarginato et crassiusculo; mandibulis nigris; antennis elongatis, art. 2 primis funiculi a equalibus modice elongatis, clava 3 articulata; prothorace minute et crebre punctulato, medio depresso et anguste sulcato; scutello rotunde transverso, longitudine sulcato; elytris in medio depressis; pedibus pallidioribus.

The following descriptions of the egg and pupa stages were prepared by Mr. S. E. Crumb from specimens collected at Quincy, Fla., in 1913. Dr. Adam G. Böving has drawn up the technical description of the larva.

The Egg.

Egg elliptical oval, faintly yellowish, 1.2 mm. long and 0.38 mm. broad at middle, membranous, without apparent sculpture, bearing on one side about one-third from the larger end two small, short, distant bristles.

The Larva.[1]

(Pl. IV.)

GENERAL CHARACTERS.

Ventral side of epicranium continued horizontally behind posterior end of hypostoma and its tentorial pits; gula a rectangular plate between ventral margins of epicranium; occiput vertical. Mouthparts prognathous; labrum and clypeus present; antenna three-jointed; mandible without molar part, with simple apex and deep groove along cutting edge; ventral mouthparts not retracted; maxillary cardo as large as stipes, only posterior half chitinized; maxillary palpiger present, carrying a three-jointed palp; lacinia bilobed, extending from distal end of stipes; submentum well defined, in front of gular plate; no maxillary articulating area; mentum freely projecting; stipes labialis with well developed palpiger, two-jointed palp, and ligula; buccal cavity with a pair of small, widely separated, bidentate, hypopharyngeal chitinizations and a pair of flat, rounded, pharyngeal plates. Tentorium represented by a

[1] The descriptions of the larva, with figures (Pl. IV), are by Dr. Adam G. Böving.

pair of thin membranous rods, attached near antennal ring; no hypopharyngeal bracon. Body orthosomatic, elongate, fleshy. Legs five-jointed, with clawlike tarsal joints, no claws; thoracic prehypopleural and posthypopleural parts present and chitinized. Prothorax with large subsellate tergal shield; presternites rounded, paired; prebasisternum and basisternum covered by an unpaired, median, longitudinal, lanceolate chitinization; no sternellum; poststernellum well developed. Mesothorax and metathorax with large, poorly defined prescutum; on each side of scuto-scutellar region a small, rounded chitinization, larger on mesothorax than on metathorax; no median epipleural lobe; large triangular postepipleural arm; preepipleural arm united with the presternite into a fleshy, subtriangular spiracle-bearing region reaching ventrally the spina of the prothoracic poststernellum; no definite sternellum; poststernellum present on mesothorax, absent on metathorax. Abdomen with ten segments; prescutal area faintly indicated; dorsal parts of scutum and scutellum on several segments developed as feeble ampullatory lobes; postscutellum narrow, bandlike; epipleurum well developed with preepipleural and postepipleural arms and a median epipleural lobe; ventral side with parasternum anteriorly limited by a straight line, in front of which there is no longitudinal muscle impression; ninth abdominal segment with a dorsal chitinous plate; tenth abdominal segment fleshy, wart-shaped, with five small lobes encircling the anus. Spiracles annuliform-bifore; the developed thoracic spiracles plainly mesothoracic; the rudimentary thoracic spiracle metathoracic; eighth abdominal spiracles present.

GENERIC AND SPECIFIC CHARACTERS.

Head elongate, with parallel sides, frons not reaching the occipital foramen; epicranial suture present; ocelli five, three in anterior, two in a posterior vertical line; gular plate with a large median, unpaired projection; cutting edge of mandible slightly sinuate; prothoracic shield as wide as head. Cerci rudimentary.

LARVAL INSTARS.

Last-instar larva 7 mm. long; body enlarging slightly posteriorly, pink, set with long, weak, pale yellowish-brown hairs; chitinous parts dark fuscous; head approximately 0.7 mm. broad and about twice as long; shield of ninth segment transversely oval.

THE PUPA.

(Pl. II, fig. 3.)

Pupa pink to reddish, about 5 mm. long and 1.5 mm. broad; head beneath prothorax, prothorax broadly oval dorsally, eight tubercles on margin of anterior half, the most anterior pair forming a trapezoidal figure with two bristles posterior to them. Behind these two bristles and forming an arc with the adjacent marginal bristles are three equidistant transverse rows of bristles and on the posterior margin is a median group of four. Tubercles subconical and set with long, weak, yellowish-brown bristles. Antennal joints apically bearing large angular tubercles. Tip of abdomen bearing dorso-laterally a pair of curved divergent horns and apically a pair of conical fleshy appendages each apparently composed of three segments.

NOTES ON HABITS AND LIFE HISTORY.

To the description given by Chevrolat a brief note is added, of which the following is a translation:

This insect, peculiar to Cuba, has been found by Girod in cases of injured tobacco (injured presumably by the cigarette beetle) and was given to me by M. Ant. Grouvelle. It is likely to be predacious upon the larvæ and perfect insects of the genus Catorama.

As the tobacco beetle, *Lasioderma serricorne*, was formerly included in the genus Catorama, the surmise made by Chevrolat concerning the food habits of the clerid has been found correct. Studies of the life history of the insect were made by the writer at Key West, Fla., in 1912. At temperatures varying from 80° to 90° F. the period of incubation was found to average about nine days. The eggs were laid singly as a rule, but sometimes were found in groups of two and three. Eggs usually were found in the burrows in cigars formed by the tobacco beetle. The largest number secured from a single female was 18 eggs. Pupation required from five to eight days, the average pupal period being about seven days. Pupation may take place in any secluded locality. The greater number of pupæ were found in holes in infested cigars. The larval periods as observed from three specimens were 42, 51, and 62 days respectively. From the development of a number of partly grown larvæ kept for about 30 days the larval period is thought to correspond closely to that of larvæ of its host, the tobacco beetle, the exact length of the period varying with temperature conditions and the abundance of food. Adults kept in tubes with cigars did not bore into the wrapper, but holes already made by the tobacco beetle were considerably enlarged. Adults of *Thaneroclerus girodi* feed on the larva, pupa, and adult stages and on dead adults of *Lasioderma serricorne*, as well as on dead adults of their own species. The larvæ of the predacious beetle feed on eggs, larvæ, and pupæ of Lasioderma. Both larvæ and adults are cannibalistic when deprived of other food, this habit enabling the species to survive for a considerable length of time after all the Lasioderma obtainable have been devoured. When other food can not be obtained, these predacious larvæ feed upon the eggs, larvæ, and pupæ, and the predacious adults on the eggs, larvæ, and pupæ of their own species. The abundance of these beetles at times doubtless accounts for the complete disappearance of the tobacco beetle in boxes of damaged cigars, so often noticed in certain cigar factories.

Parasitic Insects.

Several species of hymenopterous parasites of the tobacco beetle have been recorded. Some of these are extremely abundant in infested leaf tobacco in warehouses and are without doubt important in natural control.

Aplestomorpha pratti Crawford is one of the more common species and has been found in various localities from Richmond, Va., southward to Key West, Fla.

Aplestomorpha vandinei Tucker was found abundant in a tobacco warehouse at Clarksville, Tenn. Specimens of this parasite were collected by Mr. J. U. Gilmore, of the Bureau of Entomology, and placed with larvæ of the tobacco beetle, from which specimens of the parasite were reared later. The egg and also the larval period was found to be six days, and the pupal period about 7 days. The larvæ were observed to feed externally on both larva and pupa stages of the tobacco beetle. Specimens were determined by Mr. A. A. Girault, of the Bureau of Entomology. Fullaway (79) records an undetermined species of Pteromalus reared from the tobacco beetle in Hawaii. Jones (77), in the Philippines, describes and figures *Norbanus* sp., which attacks larvæ and pupæ of the tobacco beetle while in the pupal cells.

Catolaccus anthonomi Ashmead has been recorded as a parasite of *Lasioderma serricorne* (43), but Mr. J. C. Crawford considers this an error. The original specimen can not be found.

Other Enemies.

Various species of mites are found frequently in tobacco, and some of these have been found to feed on eggs of the tobacco beetle. At

Fig. 12.—Cigars showing work of a jointed spider (Order Solpugida). Holes torn by the solpugid in order to reach larvæ or pupæ of the tobacco beetle (*Lasioderma serricorne*) within the cigar.

Tampa, Fla., considerable difficulty was experienced in keeping eggs used in experimental work from being destroyed by the mites. Specimens of these were examined by Mr. Nathan Banks, then of the Bureau of Entomology, and found to be a species of Cheyletus. The larva form of a mite belonging to this genus was observed to insert its beak into the eggs of the tobacco beetle, remaining in this position for some time, and leaving the eggs more or less collapsed. The adult females of this species were observed to stand guard over their own eggs, which were deposited in clusters and kept underneath the female. The clusters contained from 20 to 30 eggs. A mite belonging to the family Eupodidae, genus Rhagidia, has been recorded as attacking the tobacco beetle in all stages except the adult, in the Philippines (77). It is not uncommon to find mites of the genus Tyroglyphus feeding on dead larvæ and pupæ of the tobacco beetle. It is probable that live stages of the tobacco beetle are not attacked and that the mites present in these instances are merely acting as scavengers.

At Key West, Fla., a species of jointed spider of the order Solpugida and a small arachnid belonging to the order Pseudoscorpiones were found by the writer to destroy larvæ of the tobacco beetle. While these arachnids may destroy a considerable number of beetles and do no particular damage to the leaf tobacco, the work of the solpugid in cigars would hardly be considered beneficial, as the cigars are badly torn by the spider in its efforts to dig out the larvæ. The nature of this injury is shown in figure 12.

REMEDIAL MEASURES.

COLD STORAGE.

A readily available and effective means of treating infested tobacco is found in the modern cold-storage plant. This treatment has been used to a considerable extent, but usually the temperatures in operation have the effect of suspending insect activity rather than of causing death. The beetles become inactive at temperatures below 65° F., and the storage of infested materials at temperatures between 32° and 65° F. prevents further damage as long as the material is held in storage. When lower temperatures are available a more satisfactory and effective method, although somewhat more expensive, is to subject the tobacco for a week or more to the lowest temperature that can be obtained. Cigars or manufactured tobacco should either be removed from cold storage when the air is dry, to prevent "sweating," or the temperature should be raised gradually before removal. Air-tight receptacles for holding the cigars or tobacco and an atmosphere as dry as can possibly be secured are desirable when the cold-storage method is used. If the material is removed when the air is damp the condensation of moisture may cause the boxes to be discolored or develop mold in the tobacco or cigars.

A large number of cigars in boxes, placed in cold storage, were kept under observation by the writer. These cigars were not put in sealed containers but were merely placed in piles on the floor of the cold-storage room. They were removed when the air outside was dry and cool, put under presses in a dry room, and left for a time to prevent warping of the boxes. The treatment proved thoroughly effective in sterilizing the cigars, and the manufacturer reported that no injury was apparent. Different lots were kept at a temperature of about 12° F. for from one to four weeks.

Although there are certain objections to the method, such as loosening the wrappers of fine cigars by sudden changes in temperature, danger of injury from "sweating" on removal from cold storage, and injury to quality from too rapid aging, it has certain advantages and in some cases may be found more desirable than other methods of treatment. When care is taken to prevent "sweating," it is evident that the exposure of manufactured or leaf tobacco in cold storage is not more apt to produce injury than would be the exposure of the same material to low temperatures during the winter.

In determining the effect of cold-storage temperatures upon different stages of the tobacco beetle, experiments were conducted during 1913 and 1914 at Richmond, Va. The temperatures available for most of the experiments ranged from 12° to 16° F. At the laboratory an automatically regulated incubator heated by an electric current was used in rearing the beetles for experimental work and for holding the material used in the tests after it had been removed from the cold-storage room. By this means the proper temperature and degree of moisture favorable for the development of different stages of the beetle could be kept constant. A large quantity of infested manufactured tobacco of different kinds was secured from dealers and manufacturers. In many of the experiments the exposure to cold was made with the tobacco in original packages. Tobacco found slightly infested was kept in the incubator and eggs or other stages of the beetle placed in it until the degree of infestation desired for the experiments was obtained. Experiments were made with eggs on the tobacco or cigars on which they had been deposited, and also, for convenience in making examinations, with the eggs in glass-covered cells on microscope slides.

The results of some of the experiments made by the writer during 1913, and by Mr. S. E. Crumb and the writer during 1914, are given in Table IV.

TABLE IV.—*Effect of cold storage on the tobacco beetle (Lasioderma serricorne). Experiments at Richmond, Va., 1913–14.*

Temperature.		Humidity (relative).		Exposure.		Stages alive.			Stages dead.			Success of Experiment.	Material used.
Minimum.	Maximum.	Minimum.	Maximum.	Days.	Hours.	Adults.	Pupæ.	Larvæ.	Adults.	Pupæ.	Larvæ.		
° F.	° F.	Per cent	Per cent										
11	12			4			0	0		All.	All.	Completely effective	Sliced plug smoking tobacco.
11	12	86	86	5		0	0	0	All.	All.	All.	do	1 box smoking tobacco.
14	16	87	89	4		0	0	0	All.	All.	All.	do	4 boxes granulated smoking tobacco.
14	16	84	86	5		0	0	0	All.	All.	All.	do	Sliced plug smoking tobacco.
14	14	89	89		3.16	4		23		10	11	Partially effective	Cut-plug smoking tobacco heavily infested. Exposure made in original boxes. Tobacco undisturbed. Examined two days after exposure.
14	14	86	86		10		×	×		×	×	do	1-pound can badly infested smoking tobacco.
14	16	87	89	1		0	0	Few.	×	×	×	Partially effective; eggs shrunken.	1 box granulated smoking tobacco. 20 eggs in glass cell placed within the tobacco.
14	16	87	89	1				15			60	Partially effective	1 box sliced plug smoking tobacco.
14	16	87	89	2		0	0	3	12	11	18	Partially effective; eggs shrunken.	1 box sliced plug smoking tobacco. Eggs on leaf tobacco placed in same box.
15	16	89	89		21			×			×	Partially effective	Badly infested sliced plug smoking tobacco in original packages. Examined 5 days after exposure.
16	16			4		0	0	3	×	×	×	do	5-pound lot granulated smoking tobacco wrapped in paper.
16	16	86	86		23			Few.			×	do	Infested smoking tobacco (pressed) in sealed glass jars.
16	17			3		0	0	6	9	11	26	do	2 packages infested sliced plug smoking tobacco.
16	17	87	87		3	0		×	×		×	do	Larvæ and adults in cut plug tobacco placed in sealed glass jars. Examined 1 day after exposure.
16	42	35	35	1		0	3	31	100	97	69	do	Granulated smoking tobacco. Examined 2 days after exposure.
17	17	87	87		1½	×	×	×	×	×	×	do	Infested cut plug tobacco. Box not wrapped.

Most of the tests recorded in Table IV were made with the different stages of the beetle in smoking tobacco. In this series the time of exposure to cold varied from 1½ hours to 5 days. The treatment did not prove completely effective on all stages of the beetle at temperatures between 14° and 16° F. with exposures under 5 days. In all experiments under the same conditions exposures of over 5 days gave satisfactory results, all stages of the beetle in various classes of manufactured tobacco being killed. At temperatures below 20° F. the time of exposure in a long series of tests varied from 1½ hours to 56 days. Experiments with infested tobacco exposed for 56 days at temperatures between 33° and 40° F. were not entirely satisfactory, a few larvæ remaining alive. For short exposures it was found that results depended largely upon the insulation afforded by wrapping and upon the quantity of material used. Larvæ within the cells were found to be more resistant to cold than other stages of the insect. After treatment the material used in the experiments was placed in an incubator and kept for some time under observation at a constant temperature of 86° F.

Six additional experiments were made with cigars that were heavily infested. The boxes were wrapped with paper and kept in cold storage in sealed metal containers. The temperature varied from 12° to 20° F., but was fairly constant at 14° F. The time of exposure was 7 days for three experiments, 21 days for one experiment, and 31 days for two experiments. All stages of the beetle, including large numbers of eggs, were present in five lots of cigars. In the experiment in which the time for exposure was 21 days two boxes of 25 cigars each, in which large numbers of newly hatched larvæ had been placed, were used. In all the experiments the treatment proved completely effective. The boxes were kept under suitable rearing conditions at the Richmond laboratory for several months and no reinfestation developed.

At a temperature of approximately 14° F., three separate tests were made with cigarettes. Three boxes containing 100 cigarettes each, heavily infested with adults, larvæ, and pupæ, were utilized, the duration of the experiments being 14, 15, and 42 days respectively. In each lot all stages of the beetle were killed. In another series of experiments 30 separate tests were made with various quantities and classes of manufactured tobacco. The temperature of the cold-storage room was fairly constant, approximating 14°F., the variations during the entire period being from 12° to 18° F., and the relative humidity ranging from 84 to 90 per cent. In these as well as other experiments temperature and humidity records were obtained by means of a self-recording thermograph and hygrograph. Part of the material was exposed in air-tight containers and part exposed in the original containers, not sealed, or in paper-wrapped packages.

The amount of material varied from a few ounces of tobacco up to 20 pounds of loose tobacco or tobacco refuse, and the time of treatment varied from 1½ hours to 30 days. Exposures of over 5 days, in all experiments, gave satisfactory results, the tobacco being completely sterilized. A bale of infested cigar tobacco kept in cold storage for 28 days under the conditions mentioned above at a temperature of approximately 14° F. was found to have been completely freed from all stages of the beetle.

EFFECT OF COLD STORAGE ON EGGS OF THE TOBACCO BEETLE.

A large number of separate experiments were made with eggs of the tobacco beetle to determine the effect of low temperatures in cold storage. In these experiments eggs were placed in cigars and exposed at temperatures ranging from 12° to 20° F., the length of exposure varying from 24 hours to 16 days. All boxes of cigars were wrapped with paper. After removal from cold storage the material was placed in an incubator and kept at a constant temperature of 86° F. with humidity from 80 to 90 per cent. The checks were kept in the same incubator until the period of incubation had passed. In these experiments none of the eggs exposed to cold hatched, while hatching of the check lots was normal.

In another series eggs on leaf tobacco or in cells on microscope slides were exposed. Exposures to cold were made without special protection such as ordinarily is afforded by the food substance of the insect. Other conditions of the experiments were practically the same as described in the preceding series. The time of treatment ranged from 5 hours to 7 days, with temperatures varying from 14° to 18° F. In most experiments in which the time of exposures was shorter than 24 hours, the temperature was constant at 14° F. Exposures of less than 24 hours did not give satisfactory results, as all or part of the eggs hatched in most of the experiments. In experiments in which the duration of treatment was more than 24 hours all eggs were killed.

EFFECT OF REFRIGERATION ON QUALITY OF MANUFACTURED TOBACCO.

In order to determine whether or not cold storage seriously injures manufactured tobacco, cigars, cigarettes, and smoking and chewing tobacco were placed in cold storage for periods ranging from 30 to 50 days. The stock used for the experiment was fresh and in good condition. An exact duplicate of each brand was kept for the same period, in perfect condition, in the humidor or storage room at a cigar store. Part of the material put in cold storage was in sealed metal containers and part merely wrapped with paper in order to avoid sweating which ordinarily would occur upon removal from cold storage. When removed from cold storage it was placed in a dry room for several hours, then placed in the humidor or storage room at the cigar store with the control or check packages. At frequent intervals the treated tobacco was compared with check tobacco by Mr. J. M. Holt, a tobacco expert of Richmond, Va., and the writer. The tobacco put in cold storage seemed in perfect condition in every respect, and could not be distinguished from that which had been kept at the cigar store.

ALTERNATIONS OF HEAT AND COLD.

The alternation of a low temperature with a comparatively high temperature is apparently more effective on the tobacco beetle than is a single exposure to cold. During the course of cold-storage investigations at Richmond, Va., in 1914, two lots of badly infested smoking tobacco were put in cold storage for 2 days at temperatures ranging from 14° to 16° F. Lot A was not removed from the storage room, whereas at the end of 24 hours lot B was removed and kept in a warm room for 24 hours, then put back in cold storage for a further period of 24 hours. On March 22, 2 days after treatment, both lots were examined and no live stages of the beetle were found in lot B. In lot A about 90 per cent of the different stages were dead. The tobacco used in the experiments was kept until August 28, 1914, and upon examination lot A was found heavily infested whereas lot B was uninfested.

HIGH TEMPERATURES.

EXPERIMENTS WITH DRY HEAT AS A MEANS OF STERILIZING TOBACCO—TESTS IN TOBACCO FACTORIES.

Two series of tests were made, one at Richmond, Va., in a factory where smoking tobacco is manufactured, and the other at New Providence, Tenn., in a factory in which special processes are used in the preparation of leaf tobacco for export to Africa.

Excellent facilities were secured for determining the effect of high temperatures on different stages of the beetle, and for determining to what extent the tobacco is sterilized by the various processes of manufacture. It was found that in these factories the temperatures reached were sufficiently high to kill all stages of the beetle, reinfestation depending on methods of handling, packing, or storing the manufactured product.

At Richmond, Va. (May, 1915), large numbers of eggs of the tobacco beetle on leaf tobacco and in cells on microscope slides, pupæ, adults, and newly hatched and mature larvæ were placed in boxes of granulated smoking tobacco and passed during the regular course of manufacture through the drying processses in use in a large factory where smoking tobacco is manufactured. All stages of the beetle were destroyed. In one of the driers a temperature of 180°F. was reached, which is sufficiently high to sterilize the tobacco quickly and effectively.

In the New Providence factory the leaf tobacco, after treatment with vaseline, is compressed into packing cases, placed in drying rooms, and subjected to heat for some time. The maximum temperature reached was found to be about 150°F. This process is used for a certain grade of tobacco shipped to Africa and it is said that little or no damage has ever been reported from mold or insect injury. In the experiments made (Oct. 20–24, 1915) by Mr. A. C. Morgan and the writer to determine the effect of the heating process in destroying the different stages of the tobacco beetle, infested tobacco was placed in the heating room and a continuous record of the temperature obtained by means of a self-recording thermograph. Humidity records were taken at the beginning and close of each experiment. Part of the eggs used were on leaf tobacco on which they had been deposited, and part in cells on microscope slides, and control lots were kept for each of the different stages. In all of the controls development was normal, but it was found that the temperature reached in the heating room resulted in killing all stages of the beetle. The details of several of the experiments are given in Table V.

TABLE V.—*Effect of heat on different stages of the tobacco beetle (Lasioderma serricorne). Experiments at New Providence, Tenn., 1915.*

Stage of insect.				Relative humidity.	Temperature.		Time of exposure.	Results.	Remarks.
Eggs.	Larvæ.	Pupæ.	Adults.		Min.	Max.			
				Percent.	*°F.*	*°F.*	*Hours.*		
105	41	8	51	38–40	97	140	24	All stages killed.	Eggs 4 and 5 days old.
114	10	10	75	38–49	101	138	48	.....do......	Eggs 1 day old.
32	42	10	28	38–49	93	140	72	.....do......	Eggs 1 to 5 days old.

EFFECT OF HIGH TEMPERATURES ON DIFFERENT STAGES OF THE TOBACCO BEETLE—LABORATORY EXPERIMENTS.

At Clarksville, Tenn. (1916), numerous laboratory experiments were conducted to determine the effect of high temperatures. The incubators or ovens used in making the tests were fitted with water jackets which permitted exposures to be made without much variation in temperature. The different lots were kept with suitable food in sealed glass tubes for a considerable time after exposure. The eggs used were on leaf tobacco or in cells on microscope slides. Controls were kept corresponding to the different stages. It was found that adults and larvæ become inactive after a few minutes exposure to heat above 117° F., but recover if the temperature is not kept higher than 120° F. for a considerable length of time. An exposure of 1 hour at 140° F. killed all stages of the beetle in small quantities of tobacco but it was found that both larvæ and pupæ are more resistant to heat while in the cells formed before pupation, the cells serving as a protection. The results of several of the experiments are given in Table VI.

TABLE VI.—*Effect of high temperatures on the tobacco beetle.—Laboratory experiments at Clarksville, Tenn., 1916.*

Stage of insect.	Exposure.	Temperature.		Results.	Remarks.
		Min.	Max.		
	Hours.	°*F.*	°*F.*		
Larvæ	1	110	115	Not effective	In leaf tobacco.
Adults and larvæ	1	110	115	do	In cigar.
Adults	1	117	120	do	Became inactive, but recovered after treatment.
Adults and larvæ	1	128	130	do	Part of each stage killed; remainder recovered.
Eggs	1	128	131	Effective	None of eggs hatched. Check eggs hatched normally. Eggs 1 day old.
All stages	2	130	140	do	Eggs on leaf tobacco.
Eggs	½	138	140	do	In cigars.
Larvæ	½	138	140	do	Do.
Larvæ and pupæ	1	138	140	do	In yeast cake and tobacco.
All stages	1	144	145	do	In leaf tobacco.
Do	¾	146	150	do	Do.
Do	½	158	164	do	Eggs on leaf tobacco.
Do	1	158	165	do	Do.
Do	¼	180	181	do	Do.

In these tests only a small quantity of the food substance was used. The time required for treatment will therefore depend on the amount and character of the food substance and the insulation furnished by the container or wrapping material. The results of the numerous tests made show that comparatively mild heat, if long continued, is sufficient to kill all stages of the beetle. The temperatures found effective are in no way injurious to certain classes of tobacco, which in many cases are subjected to a much higher degree of heat in the process of manufacture.

STERILIZING TOBACCO WAREHOUSES BY MEANS OF STEAM.

At Quincy, Fla., in July, 1913, an experiment was conducted by Mr. D. C. Parman, of this bureau, and the writer in a large warehouse. It is the custom of the managers to clean up and sterilize the warehouses as far as possible, usually by fumigation, before the new crop is brought in. The warehouse used for the experiment was empty and the owners wished to ascertain to what extent steam could be employed.

Two tests were made, one in which the room was heated by turning the steam into radiators, and one in which the entire basement of the building was heated by admitting the live steam direct from the boiler. Evaporation during the experiment was about 75 gallons per hour.

The experiment in the room fitted with radiators was commenced on July 7, the temperature of the room being 85° F. Steam was turned on at 2 p. m.[1] All stages of the tobacco beetle were used in the experiment and were placed in cans of smoking and chewing tobacco in the middle of the room. Controls were kept for each lot. At 3.30 p. m. the temperature reached 100° F., and at 4.30 p. m. 117° F. This temperature was held until 6 p. m. and then gradually lessened until 7 a. m., July 8, when it registered 89° F. The steam was again turned on and the temperature gradually increased until, at 10 a. m., it registered 138° F. This temperature was held until noon, when the experiment was ended. At different times some of the material was taken out and the boxes labeled and kept for later examination. Tobacco exposed for 2½ hours at temperatures between 100° and 117° F. when examined on July 8 was found to contain live adults, pupæ, and larvæ. In all material kept in the room during the entire time, and which had been subjected to a temperature of 138° F. for 2 hours, all stages of the beetle were killed. In this experiment the air was dry. A hygrometer at 6 p. m. registered about 35° F.

In the second experiment the entire basement of the building was heated by live steam which was admitted directly through four half-inch nozzles. Three nozzles were fitted to the main steam pipe extending through the basement from end to end, and one nozzle fitted to the return pipe. Records of temperature were secured by means of self-recording thermometers placed in or near the packages of infested tobacco, which were divided into several lots and placed in different parts of the basement. The tobacco used in the experiment was badly infested with all stages of the beetle. The experiment was commenced at noon. The outside temperature in the shade was 92° F. A boiler pressure of 40 pounds was kept until noon of the following day, July 9, when the fire under the boiler was allowed to die out gradually to avoid too sudden cooling of the walls of the building. The tobacco used in the experiment was taken to Tampa, Fla., and kept under observation until July 15. The results were as follows: At temperatures under 114° F., with exposures of 6, 12, and 18 hours, results were practically negative. Exposure at temperatures between 118° and 130° F. for 24 hours killed part of the different stages, but was not entirely effective. Mate-

[1] All references to clock time refer to standard time.

rial was effectively sterilized when exposed for 24 hours in a part of the building where a temperature of 137° F. was reached, and all stages of the beetle were killed.

The tests made show that under certain conditions steam may be used to advantage in sterilizing empty warehouses, as much higher temperatures could easily be obtained than were reached in the experiments. Dry heat, secured by fitting the building or storage room with sufficient radiating surface, would, of course, be the most practical means of heating, as steam turned directly into a room for some time might cause injury to the building by expansion of beams from moisture and heat combined.

Other experiments have shown that temperatures of from 130° to 150° F. result in the death of all stages of the tobacco beetle, and it is probable that very little if any damage to most grades of tobacco would follow. In cleaning storage rooms, etc., live steam or hot water applied through a flexible pipe fitted with a nozzle can often be used to advantage in destroying the insects in refuse or dust in crevices in the floor or walls.

The expense of steaming in the foregoing experiment for 24 hours amounted to $15.20, as follows:

Engineer, 2 days @ $4 per day	$8.00
Fireman, 2 days @ $1 per day	2.00
Fuel	4.50
Water	.70

The expense of fumigating the same space (108,000 cubic feet) with hydrocyanic-acid gas would have amounted to about $75, or with carbon disulphid $60, these estimates being based on prices of chemicals used for fumigation at the time of the experiment.

USE OF STEAM AS A MEANS OF STERILIZING INFESTED TOBACCO.

Although steam furnishes, under some circumstances, an effective and convenient method of sterilizing storerooms or warehouses there are numerous difficulties which prevent its use in sterilizing infested tobacco. Leaf tobacco becomes more brittle if exposed to steam at high temperatures for any length of time, the texture and aroma are changed, and the color becomes darker. In spite of the general objection against steaming, however, there seems to be considerable evidence that mild steaming may be used to advantage in treating certain classes of cigar tobacco. In the application of steam the principal requisite is that the tobacco does not become too wet, and that unnecessarily high temperatures are avoided.

A method of treating cigar tobacco in revolving steam drums has been tested in the Philippines (77). Steam was applied for 20 minutes at a pressure of about 4 atmospheres, the temperature ranging from 140° to 194° F. The treatment was said to be thoroughly effective in killing all stages of the beetle, and cigars made from the steamed tobacco were pronounced indistinguishable from those made from unsteamed tobacco, the only apparent damage in any instance being that steaming the wrapper tobacco made it darker and somewhat more brittle.

EFFECT OF STEAM ON DIFFERENT STAGES OF THE BEETLE—LABORATORY EXPERIMENTS.

At Richmond, Va. (January, 1915), tests were made to ascertain the effect of steaming various classes of tobacco infested with the beetle. Steam under pressure was admitted directly into a tightly closed fumigating drum. Temperature records were obtained by inserting a chemical thermometer through a cork in the lid of the drum. The eggs used were on bits of leaf tobacco. Examinations of the treated eggs were made after the controls had hatched. All tobacco containing other stages of the beetle was put in seperate jars and sealed after treatment. Each lot was kept under observation for several months. The results of the experiments may be briefly summarized. Thirty-minute exposures at 115°F. gave practically negative results. All stages of the beetle were killed by the following exposures: 20 minutes at 160° and 165°F.: 30 minutes at 163°F.; 1 hour at 138° and 150°F.; 40 minutes at 140°F.

ULTRA-VIOLET RAYS.

At the request of a firm manufacturing apparatus for ultra-violet sterilization of water, a series of experiments were made to ascertain the effect of ultra-violet rays on different stages of the tobacco beetle and to determine whether or not the process could be successfully used in sterilizing tobacco. Apparatus for the work was installed at the laboratory at Clarksville, Tenn.. the equipment consisting of a mercury arc rectifier for transformation of 110-volt, 60-cycle alternating current to 110-volt direct current, and 2 quartz mercury arc burners operated on direct current at 110 volts and consuming 3.5 amperes. The quartz mercury vapor burners, or lamps, were of different types: One was operated at a voltage of 66–67, consuming 3.3 amperes of current, and the other at a voltage of 70–75, consuming 3 amperes of current.[1] To avoid any effect of heat, all exposures were made with the material in a quartz glass container under distilled water kept at normal room temperatures (quartz glass and chemically pure water are transparent to the ultra-violet rays). In experiments with eggs of the tobacco beetle 3 lots were used in each test, arranged as follows: (*a*) Eggs on upper side of leaf tobacco, (*b*) eggs on under-

[1] The burners were operated under a hood to protect the eyes of the operator from injury, and glasses were worn as an additional precaution.

side of leaf tobacco, (*c*) eggs under glass cover. A check was kept for each experiment. It was found that with eggs exposed directly to the rays, without covering as under arrangement (*a*), at a distance of about 8 inches from the quartz mercury arc, an exposure even as short as 30 seconds was effective in sterilizing eggs under two days old. As has been found with Röntgen-ray radiation, the further embryonic development has advanced, the more resistant the eggs become, and longer exposures are required for their successful sterilization. Eggs exposed on the underside of the leaf, arrangement (*b*), and those under a cover of ordinary glass, arrangement (*c*), hatched normally. Ordinary glass has the property of transmitting ultra-violet rays only to a slight degree; its transmission being approximately only one one-thousandth that of quartz glass. It was found that a screen over the eggs, even of the thinnest glass such as is used for cover glasses on microscope slides, was sufficient to protect them completely from the effect of ultra-violet rays. These exposures served as an additional check on the results obtained from direct exposures to the rays. The experiments with the eggs on the underside of the leaf showed that the ultra-violet rays would not penetrate even the thinnest leaf of cured tobacco. This fact makes it impracticable to apply the method in treating infested tobacco.

Although eggs of the tobacco beetle when exposed directly to the ultra-violet rays can be quickly and effectively sterilized, experiments made so far do not indicate that other stages of the beetle are destroyed by the same exposure. Treated larvæ and pupæ completed transformations to the adult stage, and treated adults laid fertile eggs and died off at a normal rate. The effect of more intense radiation or of prolonged exposure of adults, pupæ, and larvæ has not been determined.

In order successfully to treat leaf tobacco containing eggs, it has been suggested that in preparing the leaf for use it might be possible to devise means for smoothing out the leaves and thus make more powerful exposures of ultra-violet rays from all sides while the tobacco passes through an exposure chamber containing the lamps. As it would be extremely difficult, or perhaps impossible, by any mechanical means, to smooth out completely all the creases or wrinkles in the leaf tobacco, and as the rays do not penetrate opaque substances like tobacco, the method, in the opinion of the writer, is not likely to prove entirely effective or practicable, as the eggs of the tobacco beetle ordinarily are deposited in wrinkles of the leaf. The results obtained from several of the experiments with ultra-violet rays are briefly summarized in Table VII.

TABLE VII.—*Effect of exposure of stages of the tobacco beetle* (*Lasioderma serricorne*) *to ultra-violet rays. Experiments at Clarksville, Tenn., 1916.*

Date.	Stage of insect.	Age of eggs.	Current.	Voltage.	Exposure.		Results.		
					Distance from mercury vapor arc.	Time.	Eggs on upper side of leaf; exposure direct.	Eggs on underside of leaf.	Eggs under glass cover.
1916.		*Days.*	*Amp.*		*Inches.*	*Min.*			
July 20	Eggs......	1	3.3	66–67	8	½	None hatched	All hatched...	All hatched.
Aug. 11	.....do.....	1–2	3.3	66–67	7.5	½	.....do.......	.....do........	Do.
Do...	.....do.....	4–5	3.3	66–67	8	½	Nearly all hatched.	Hatching normal.	Hatching normal.
July 20	.....do.....	3	3	70–75	7.5	5	None hatched	.....do........	Do.
July 21	.....do.....	·2	3.3	66–67	8	10	.....do.......	.....do........	Do.
July 24	.....do.....	4	3	70–75	8	45	.....do.......	.....do........	Do.
July 20	All stages..	1–3	3.3	66–67	7.5	8	Exposed directly to rays. Eggs sterilized. No effect apparent on other stages.		
July 24	Adults and eggs.	2–3	3	70–75	8	5	Exposed directly to the rays. Eggs sterilized. No apparent effect on adults. Fertile eggs deposited after exposure.		

TRAPPING.

ATTRACTION TO LEAF TOBACCO.

In cigar factories it has often been noticed that the adult beetles collect on hands of leaf tobacco suspended for the purpose of ascertaining the humidity. Eggs in large numbers frequently can be found on the leaves, and in the rooms where cigars are made or handled young larvæ from these eggs may easily find their way to the cigars. Numerous experiments were made by liberating large numbers of the beetles in a closed room in which hands of leaf tobacco had been suspended about the walls. It was found that a large proportion of the beetles collected on the tobacco. This habit of the insect suggests the possibility, where conditions permit, of trapping the adults in this manner. The tobacco could be collected at frequent intervals and the eggs and beetles killed by heating or fumigating the leaves, and then replaced; thus, instead of being a source of infestation, this tobacco would to a large extent protect the cigars or other material in the room. The method is said to have been tested in a cigar factory in the Philippines and to have shown excellent results (78).

TRAP LIGHTS.

The movement of adults toward light has been discussed under "Phototropism" (p. 25). Specially constructed trap lights may often be used to advantage in factories or warehouses, and a large number of the beetles destroyed. A very efficient trap can be made quickly and easily by pinning together sheets of sticky fly paper in the form of a cylinder and suspending it around an electric light. The trap is more effective if the sheets of fly paper are pinned so that the surface on both the inside and outside of the cylinder is sticky. Traps of this type operated in a large tobacco warehouse were under observation for some time and were found to destroy large numbers of beetles (fig. 13). Another form of trap consists of a large globe, such as is used for street lights, placed over a funnel, the lower part of the spout of the funnel opening into a cyanid jar in which the beetles are killed. An electric-light bulb can be used in the globe, or a trap light of the same type can be operated with acetylene or other light. Another method of destroying the beetles consists of placing shallow pans of oil underneath the lights. A heavy odorless oil is best for this purpose in case leaf tobacco, which may take up odors of kerosene or other oils, is stored near by. The traps fitted with cylinders of fly paper will perhaps be found best adapted to most conditions. While adults fly more readily toward blue or blue-violet light than toward red or orange, colored light bulbs or colored screens cut down the intensity of a source of light. Ordinary electric-light bulbs of clear glass of the nitrogen-filled and other types which transmit lights rich in rays of short wave length have been found well adapted to trapping.

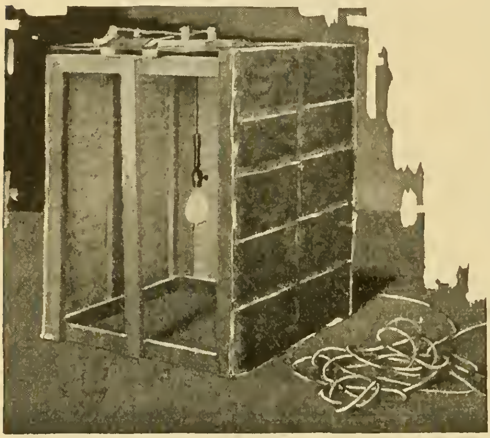


FIG. 13.—Arrangement for using sticky fly paper in collecting adults of the tobacco beetle in warehouses.

Sex of beetles collected at light.—A sheet of sticky fly paper which had been suspended around an electric light in a tobacco warehouse at Danville, Va., in July, 1911, was examined by Mr. S. E. Crumb. Of 100 beetles that were removed and dissected, 36 were males and 64 females. Four females contained, respectively, 2, 2, 17, and 22 mature eggs. Seventeen females contained immature eggs, half developed or more, as follows: 2, 2, 2, 2, 3, 3, 4, 5, 6, 7, 7, 8, 10, 10, 11, 12, and 36. Forty-three females were without eggs. Approximately 32 per cent of the females contained eggs and 68 per cent of the females did not.

COLLECTING AT WINDOWS.

As the light becomes dim in late afternoon in infested warehouses or factories the adult tobacco beetles fly to the windows, often collecting in large numbers on the glass and casings. The beetles may be easily destroyed at such times by brushing them down into pans of water or oil, or onto sheets of sticky fly paper. In a tobacco warehouse visited by the writer the owners make it part of the regular duties of the watchman to visit each window in the building where the beetles collect and sweep them down on sheets of fly paper spread out on the window sills. Immense numbers of the beetles are destroyed in this way at very little cost.

COLLECTING BEETLES BY SUCTION.

The use of suction fans operated at lights for collecting the beetles in warehouses has been reported. There has been no opportunity to

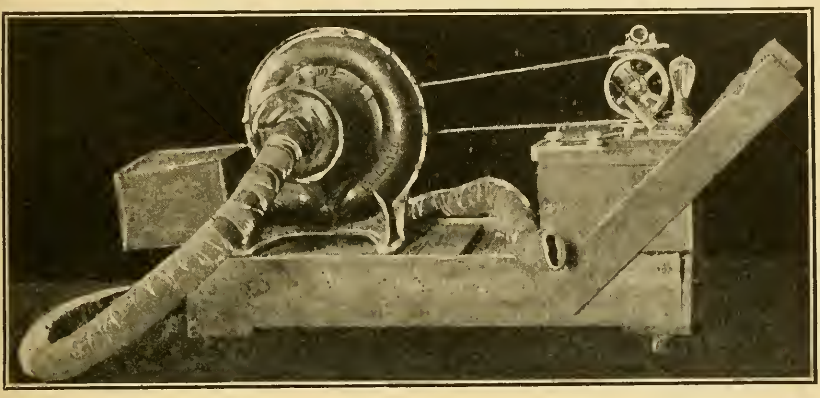


FIG. 14.—Suction fan used for collecting adults of the tobacco beetle in a tobacco warehouse.

test this method. The use of vacuum cleaners operated by electric current might possibly prove to be an effective method of collecting beetles at the windows of warehouses. At Lancaster, Pa., a suction fan was used in one of the large tobacco warehouses. Beetles could be readily drawn from cracks in the building and from about windows, and large numbers were said to have been collected in a short time on several occasions. A photograph of the apparatus used is shown in figure 14.

OTHER REMEDIES.

EXPOSURE TO VACUUM.

In 1912, a series of experiments were made at Clarksville, Tenn., by Mr. A. C. Morgan and the writer to ascertain the effect of treating infested tobacco in vacuum. With the apparatus used, a vacuum of about 28.5 inches could be readily obtained. When the air in the vacuum chamber was exhausted the beetles became inactive, but after exposures varying from 1 to 24 hours they again became active when normal air pressure was restored. In some of the experiments a few adults were killed. The eggs hatched normally after exposure. While the experiments with vacuum apparatus alone from a practical standpoint gave negative results it has been found that the process may be employed in connection with the fumigation of infested tobacco (fig. 15).

SEALED CONTAINERS FOR MANUFACTURED TOBACCO.

Investigations of factory conditions show that during the process of manufacture tobacco is, in many cases, thoroughly sterilized by heat. In one factory, in which experiments with different stages of the beetle were conducted, the tobacco was subjected to a temperature of 180° F. as it passed through the driers. This degree of heat has been found to destroy all stages of the beetle quickly, and is sufficiently high to sterilize tobacco thoroughly under any ordinary conditions. Tobacco may become infested before it leaves the factory, but it is evident from the usual condition of the tobacco which is returned with complaints of infestation, and from the time required for development of the beetle, that much of this tobacco becomes infested after it leaves the factory.

It is not unusual to find badly infested material in wholesale and retail establishments in the same room used for storing fresh stock. The grubs or larvæ of the tobacco beetle are very minute when hatched, and at this stage are most active and readily find their way through small openings in the boxes or containers. In containers sealed perfectly tight at the factory it is very unusual to find the tobacco injured.

In order to determine whether or not newly hatched larvæ could find their way into uninfested boxes used by different firms for packing smoking tobacco, experiments were made at Richmond, Va., and at Tampa, Fla. The boxes of tobacco were thoroughly sterilized by heat and then put in sealed jars in which eggs of the tobacco beetle were placed at frequent intervals. The boxes were sufficiently tight to exclude partly grown larvæ and the adult beetles, but all showed openings along the edge of the cover and at the hinge of the lid large enough to admit newly hatched larvæ. In the experiments 16 boxes were used and of these 12 boxes became infested after a time whereas none of the control boxes showed the least sign of infestation. In other experiments it was found that some of the larvæ hatching from eggs placed in empty boxes of the same kind escaped through even the smallest openings along the edges of the cover or at the hinges of the boxes.

CASING CIGAR TOBACCO IN A DECOCTION OF TOBACCO STEMS.

Soaking tobacco stems in water from 12 to 24 hours gives a solution which is said to hasten fermentation of leaf tobacco. Several cigar manufacturers, both in this country and in Cuba, have reported that when this solution was used in casing stripped tobacco there was in some cases a noticeable decrease in the number of infested cigars. It was suggested that the quicker and higher fermentation destroys some of the eggs or other stages of the beetle and that the solution may have a toxic effect when applied externally. No exact data have been secured as to the efficiency of the remedy.

USE OF COLD WATER IN CASING CIGAR TOBACCO.

Several cigar manufacturers have reported some success in preventing infestation of finished cigars by casing the leaf in cold water and thoroughly shaking out the tobacco before it is used.

BORIC ACID.

Boric acid has been used as a remedy for the tobacco beetle, but to what extent and with what success is not known. In a letter received by the Bureau of Entomology in 1909 from an importer of leaf tobacco in Boston, Mass., reference is made to the use of this remedy in Cuba, it being stated that a 5 per cent solution of boric acid [$B(OH_3)$] used in the water in which tobacco is cased before packing will prevent the tobacco from becoming wormy. The effect of boric acid on the quality of the tobacco has not been determined, but it is probable that no serious injury would occur if used in as dilute a solution as described. Both boric acid and borax are known to have some insecticidal value, and the treatment of manure piles with borax has proved effective against the larvæ of the house fly.[1]

While preliminary tests made with boric acid indicate that it has a toxic effect on larvæ of the tobacco beetle, there has been no opportunity to make tests of the substance on cigar tobacco in the manner mentioned above, nor to determine whether or not the remedy has any practical value in preventing or controlling infestation.

PREVENTIVE MEASURES.

In cigar stores and comparatively small establishments it is not a difficult matter to eradicate the tobacco beetle. By means of different remedies, infested stock may be treated and the building thoroughly cleaned. The humidors, or storage closets, should be perfectly tight and infested stocks promptly destroyed or treated as soon as signs of infestation are noticed.

In large factories and tobacco warehouses, however, complete eradication in many instances is extremely difficult, or perhaps impossible. The factories are in some cases old wooden buildings, roughly built, and containing innumerable cracks and crevices in

[1] U. S. Dept. Agr. Buls. 118, 245, and 408.

which tobacco dust and refuse have accumulated. These places make ideal hiding and breeding places for the beetles. Even in modern factories of brick or concrete construction it is difficult to eradicate the insect completely after it has once become established, but it is very much easier to keep such buildings clean and free from accumulations of refuse in which the beetles may breed. The measures to be employed in eradication work in sterilizing buildings will depend largely on local conditions.

For destroying the different stages of the beetle in crevices of floors or walls, live steam applied through a nozzle from movable pipes or hose, hot water, gasoline, carbon disulphid, dilute ammonia, paradichlorobenzene, or other suitable substances may be used. Suction cleaners may also be employed to advantage for such work. In cigar factories the stock of leaf tobacco should be kept in a tight or screened room, located as far as possible from the rooms in which the cigars are made or handled. Trays of unsorted cigars should be covered or preferably kept overnight in a screened compartment, as eggs deposited on the cigars at this time may be the cause of heavy loss afterwards.

In sections of the country where severe freezing occurs in winter the doors and windows of warehouses or other buildings in which tobacco is stored may be thrown open and the tobacco subjected to low temperatures. This control measure has been employed by tobacco men in different localities, and when severe freezing weather occurred excellent results were reported.

OPEN STORAGE OF LEAF TOBACCO.

The modern method of storing leaf tobacco in hogsheads in specially constructed buildings or sheds, giving practically out-of-door conditions and variations of temperature, furnishes an effective means in cool climates of reducing or preventing injury from the beetle to the classes of leaf tobacco which may be stored in this manner.

SOURCES OF INFESTATION IN FACTORIES.

In cigar and tobacco factories the greater number of beetles are brought in with the leaf tobacco. Factories are in some instances in close proximity to tobacco warehouses where beetles are present in large numbers. A comparatively small number of beetles in a room in which cigars are made, however, or in rooms where the cigars or other classes of manufactured tobacco are packed, are sufficient to infest the stock seriously. The protection of the finished product before it is packed is generally of more importance than the condition of the raw material, as the process of manufacture wholly or partly frees it from different stages of the beetle which were present in raw material.

FUMIGATION.

Fumigation is now generally employed as a means of destroying certain classes of insects, and is a standard remedy against insects which damage stored products and those infesting mills and factories.

The tobacco beetle has been found to be exceedingly resistant to fumigants. Numerous experiments have shown that it is necessary to use much stronger dosages of fumigants in treatment of this beetle than are employed usually against other insects. The insulation afforded by the pupal cells and by the compactness of food substances seems to protect the contained larvæ or pupæ from the action of the fumigant. In many instances only a small percentage of the tobacco-beetle larvæ survives treatment, but adults transforming from these small numbers serve to reinfest tobacco if it is kept for any length of time.

The properties and characteristics of the various chemicals used for fumigation should be thoroughly understood in every particular by the operator in order that necessary precautions may be taken and the work properly done. The treatment is simple, however, easily applied, and fairly effective.

Fumigation with Hydrocyanic-acid Gas.

In generating hydrocyanic-acid gas in fumigation sodium cyanid ($NaCN$), or potassium cyanid (KCN), sulphuric acid (H_2SO_4), and water are necessary. The hydrocyanic-acid gas, which is the killing agent, is produced by the action of the sulphuric acid (diluted with water) on the sodium or potassium cyanid. The cyanid is usually employed in the crystal form. It is now sold in molds weighing 1 ounce each. When small quantities are used, this form is best, as it avoids the trouble and danger of weighing. A high grade of cyanid should be used for fumigation, as the presence of adulterants greatly reduces the amount of hydrocyanic-acid gas evolved. Potassium cyanid should be guaranteed to be 98 or 99 per cent pure. A high grade of sodium cyanid should be used which is guaranteed to contain not less than 51 per cent cyanogen. Commercial sulphuric acid, sp. gr. 1.84 or 66° Baumé, which is approximately 93 per cent pure, is commonly used for fumigation.

DANGER ATTENDING USE.

Hydrocyanic-acid gas and the chemicals employed to produce it are extremely dangerous, and as hydrocyanic-acid gas is fatal to human beings if breathed in any quantity considerable care is necessary in its use. Sodium cyanid and potassium cyanid are violent and fatal poisons if taken internally, and sulphuric acid produces burns when coming in contact with the skin. When the chemicals are handled with care and all details of the method understood, however, there is no special danger and the method has been used in insect control for many years with few records of serious accidents.

EFFECT OF HYDROCYANIC-ACID GAS ON THE QUALITY OF TOBACCO.

Hydrocyanic-acid gas is slightly lighter than air and all traces of the gas are quickly removed from the tobacco by thorough airing. In order to determine whether or not any deposition of cyanogen in the cigars occurs as a result of the cyanid treatment different lots of freshly made cigars were fumigated at Key West, Fla., in 1912, and sent to the Bureau of Chemistry, United States Department of Agriculture, for examination. A list of the different lots of cigars sent is shown in Table VIII.

TABLE VIII.—*Effect of hydrocyanic-acid gas on quality of cigars. Fumigation tests at Key West, Fla.*

Date fumigated.	Cyanid of potash to 100 cubic feet of space.	Exposure.
1912.	*Ounces.*	*Hours.*
Apr. 20	8	24
May 4	8	24
May 10	4	48
May 29	4	24
June 8	8	36
June 14	8	24
June 18	8	24
Not fumigated. (Used as check on treated lots.)		

All lots of cigars were exposed to the air for a short time after fumigation, and then sealed. As the amount of potassium cyanid used was greater than is ordinarily employed in fumigation, the test was a severe one. The cigars were received by the Bureau of Chemistry on July 8. The following report was received on November 12, 1912, from Mr. R. E. Doolittle, acting chief of the Bureau of Chemistry: "We have made a careful examination of the eight samples of cigars submitted by you on July 8 last, and we are unable to detect the slightest trace of hydrocyanic acid in any of the samples."

Samples of cigars fumigated by the cyanid process and untreated cigars of the same brand were submitted to a number of expert cigar men at Key West, Fla., in order to ascertain if fumigation in any way affected the flavor or quality of the cigars. All reported that no difference between the treated and untreated cigars was apparent, the uniformity of burn, capacity for retaining a light, and color of ash appearing normal.

PREPARATIONS FOR FUMIGATION.

The fumigating closet or box should be perfectly tight to prevent escape of gas. In fumigating storage rooms or warehouses all openings should be closed and the windows and doors arranged so that they may be opened from the outside when the building is aired. *Do not enter the room until it is thoroughly aired.* The cubic contents of the closet, room, or box to be fumigated should be determined, so that the exact quantity of the different chemicals needed may be known. Food supplies that may be stored in the building should be removed, as moist foods, such as meats and vegetables or fruit, may absorb or retain the gas.

Care must be taken in fumigating large warehouses in close proximity to dwellings, as the liberation of a vast quantity of hydrocyanic-acid gas may endanger the persons within.

For generators use stoneware or crockery jars. They should be sufficiently deep that the liquid will not boil over when the gas is generated.

Hydrocyanic-acid gas is lighter than air. For this reason *place the generator underneath the material to be fumigated or on the floor of the room.* Whenever the room or building is of large size it is advisable to use two or more generators, limiting the amount of cyanid to 2 or 3 pounds in any one generating jar. The jars should be of small diameter in order that the cyanid may be completely covered by the acid and water.

PROCESS OF FUMIGATION.

The chemicals used in generating hydrocyanic-acid gas are placed in the generating jar in the following order: *First, water; then sulphuric acid; last, just before closing the fumigating closet or building, the cyanid.* Measure into the generating jar the proper amount of water, then add the acid slowly in the proper amount. Considerable heat will be developed by the addition of the acid, and for this reason it is best not to mix the water and acid until just before the cyanid is put in, as the heated liquid will act more quickly on the cyanid. The water and acid should be mixed as directed above. *Do not pour water into acid.* Severe burns may result from the ebullition or sputtering of the liquids if the order of mixing the water and acid is reversed. The acid should be kept in glass-stoppered bottles. Cyanid should be kept tightly sealed, as it deteriorates rapidly when exposed to the air. For convenience the cyanid may be put into thin paper sacks and these dropped into the generating jar. This method is applicable if large dosages are used; if only a small quantity of the cyanid is required, however, it is not best to use a paper wrapper, as the generation of the gas is somewhat retarded. An enameled dipper has been found convenient in placing the cyanid in the generators. *The reaction of the chemicals is extremely rapid, and the generation of the deadly gas begins at once.* In fumigating large buildings, where a considerable number of generators are required, the operator should have several assistants. In such cases it is best to have the proper amount of cyanid in paper sacks placed beside the jars holding the acid and water. Begin dropping the cyanid in the jars farthest from the door first, going from one jar to the next as rapidly as possible.

TEMPERATURES FAVORABLE FOR EFFECTIVE FUMIGATION.

In using fumigants for the control of the tobacco beetle, best results have been secured in warm weather and at temperatures above 70° F. Under 60° or 65° F. the beetles are more or less dormant and while in this condition are considerably more resistant to the action of the gas.

DOSAGES TO USE.

Sodium cyanid (*NaCn*).—This substance when pure liberates nearly one-third more hydrocyanic-acid gas per pound than does potassium cyanid and at present it is more generally used for fumigation.

Sodium cyanid should be combined with acid and water to generate the hydrocyanic-acid gas according to the following formula:

Sodium cyanid (grade guaranteed to contain not less than 51 per cent cyanogen)____________avoirdupois ounce__	1
Sulphuric acid (commercial)_____________fluid ounces__	1½
Water ___________________________________fluid ounces__	3

Use multiples of the formula given above to secure the dosage desired. Fumigate for 24 hours. The dosage to use will depend upon the penetration required. For general use 4 ounces of the cyanid to 100 cubic feet will be found satisfactory. (This dosage requires 4 ounces of the cyanid, 6 fluid ounces of acid, and 12 fluid ounces of water.) For baled or closely packed tobaccos a somewhat heavier dosage may be used, or the time of exposure increased. An increase of the amount of cyanid above 4 ounces per 100 cubic feet, however, has not greatly increased the effectiveness of the treatment in many instances.

Potassium cyanid.—Should potassium cyanid be used in place of the sodium cyanid, it should be combined with the sulphuric acid and water according to the following formula:

Potassium cyanid (98–99 per cent)____avoirdupois ounce__	1
Sulphuric acid (commercial)_______________fluid ounce__	1
Water ____________________________________fluid ounces__	3

For every 100 cubic feet of space use multiples of this formula to secure the dosage desired. The dosage used may be the same as with sodium cyanid. It will be noted that the amount of acid required with potassium cyanid is less than with sodium cyanid.

In using either potassium cyanid or sodium cyanid for fumigating, a greater amount of water than that given in the formulas should not be used, as any quantity of water above 3 fluid ounces for each ounce of cyanid results in a smaller yield of hydrocyanic-acid gas.

In preparing chemicals for fumigation the cyanid is *weighed*, and the acid and water are *measured*. The time of exposure has been found to be an important factor in fumigation and it is not advisable to make the time less than 24 hours, unless the vacuum process of fumigating is employed. A comparatively small dosage with a long exposure appears to be as effective as is a heavier dosage with a shorter exposure.

SUMMARY OF RESULTS OF FUMIGATION EXPERIMENTS.

A brief summary of the average results obtained in a series of 34 fumigating experiments with material infested by the tobacco beetle follows. Different dosages of sodium cyanid varying from 1 to 8 ounces per 100 cubic feet of space were used. The time of treatment was 24 hours. The tests were made during July, August, and September, the maximum temperatures varying from 82° to 92° F. and the minimum temperatures from 42° to 72° F. All stages of the beetle in leaf tobacco, in different classes of manufactured tobacco, and in pressed yeast cake, were utilized. Part of the eggs, for convenience in making examinations, were placed in cells on microscope slides, and part were located on the original leaf tobacco on which they had been deposited. The eggs used were from 1 to 6 days old. Multiples of the 1–1½–3 formula were used with the sodium cyanid. The results obtained with different dosages were as follows:

Dosage 1 ounce per 100 cubic feet of space.—In three experiments only a few eggs hatched. In these embryonic development was nearly complete at the time of treatment. Newly hatched larvæ were nearly all killed, about 4 per cent in dense tobacco survived, and of the other stages, including adults, pupæ, and fully developed larvæ, about 22.3 per cent survived treatment.

Dosage 1.5 ounces per 100 cubic feet of space.—In four experiments eggs and newly hatched larvæ were killed. Approximately 21 per cent of other stages survived treatment. The adults remaining alive were mainly those which had not emerged from the pupal cells.

Dosage 2 ounces per 100 cubic feet.—This treatment destroyed eggs and newly hatched larvæ. In four experiments 18.6 per cent of the other stages survived.

Dosage 2.5 ounces per 100 cubic feet.—This gave somewhat better results. In one experiment all stages were killed. In three experiments all unprotected adults and newly hatched larvæ were killed. Of the other stages approximately 11.8 per cent survived.

Dosage 3 ounces per 100 cubic feet.—In four experiments this gave practically the same results as the 2½-ounce dosage.

Dosage 4 ounces per 100 cubic feet.—In six experiments this dosage killed eggs, newly hatched larvæ, and practically all unprotected stages. Approximately 9 per cent of the larvæ, pupæ, and adult stages within the pupal cells survived treatment. In one of the six experiments all stages were killed.

Dosage 6 ounces per 100 cubic feet.—Practically the same results were shown in five experiments with the 6-ounce dosage. Eggs, newly hatched larvæ, and unprotected adults were killed. About 9.4 per cent of the other stages, mainly mature larvæ protected by dense substances or by the pupal cells, survived. In two of the five experiments all stages were killed.

Dosage 8 ounces per 100 cubic feet.—In four experiments with an 8-ounce dosage about 10 per cent of the protected stages survived. All adults which had emerged from the pupal cells and all eggs, newly hatched larvæ, and unprotected larvæ and pupæ were killed. In one experiment all stages were killed.

The results obtained in other experiments made by Mr. Joseph Smith and the writer at Clarksville, Tenn., with both sodium cyanid and potassium cyanid in amounts from 1 ounce up to 8 ounces per 100 cubic feet did not differ materially from those obtained with sodium cyanid in the series described. With both substances, in many instances, an increased dosage above 4 ounces per 100 cubic feet did not show a very decided increase in effectiveness, possibly due to the inability of the gas to penetrate dense food substances or pupal cells.

DOUBLE FUMIGATION.

Fumigation under most circumstances has not been found entirely effective in sterilizing tobacco, as a few of the insects in either the larva, pupa, or adult stage, protected by the pupal cells or by dense food substances, are apt to survive. In comparatively few of the experiments were the beetles completely exterminated. While a single treatment may be fairly satisfactory, since the few live stages left will require considerable time to increase to sufficient numbers to reinfest the tobacco badly, it is desirable under some circumstances to give a second treatment later in order to destroy the beetles remaining after the first treatment. This can be accomplished easily after the beetles have emerged from the pupal cell. With tobacco kept at ordinary room or summer temperatures the second fumigation should be given about two or three weeks after the first treatment, as by this time most of the beetles will have emerged from the cells, and the adults, eggs, or newly hatched larvæ then present can be easily destroyed by fumigation. In two of the experiments already referred to, a second treatment was given 12 days later, resulting in the complete extermination of the beetles. Similar results were secured in several experiments not included in the series of tests described.

FUMIGATING IN A VACUUM.

In cooperation with the Federal Horticultural Board, a series of experiments was conducted at Washington, D. C., to determine the

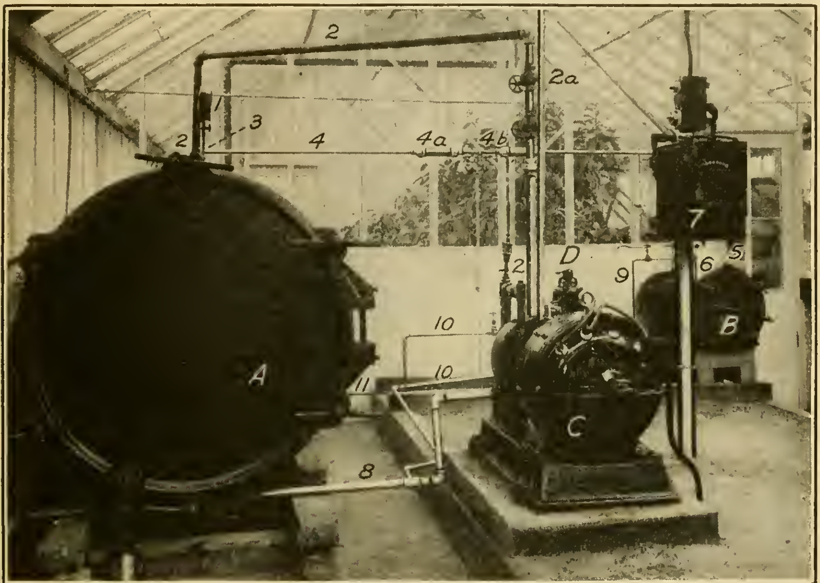


FIG. 15.—Apparatus used for fumigating in partial vacuum.

effects on the tobacco beetle of hydrocyanic-acid gas in the presence of a partial vacuum. The apparatus used for the work was designed by Mr. E. H. Sasscer, Chief Inspector of the Federal Horticultural Board.[1] (Fig. 15.)

By means of vacuum apparatus a very much greater penetration of the gas can be secured than is possible in fumigating at normal air pressure. It has been found in the tests made by the Federal Horticultural Board that hydrocyanic-acid gas when applied in vacuum readily penetrates to the interior of closely compressed bales

[1] A detailed description of the apparatus and process of fumigation in vacuum has been given by the designer, Mr. E. R. Sasscer, in Service and Regulatory Announcements, Federal Horticultural Board, for October, 1915.

of imported cotton. This shows a degree of penetration beyond anything likely to be found in the fumigation of hogsheads or bales of leaf tobacco, or of cigars, or other classes of manufactured tobacco. The exposures found effective with vacuum apparatus in destroying several other species of insects have not proved effective, however, in destroying all stages of the tobacco beetle. A series of 19 experiments with different amounts of sodium cyanid varying from 1 ounce to 6 ounces per 100 cubic feet of space, with an exposure of 1 hour and 45 minutes at a vacuum of about 25 inches; and a series of 14 experiments with 1, 3, and 6 ounces of sodium cyanid to 100 cubic feet of space, with an exposure of 2 hours and 30 minutes at a vacuum of approximately 25 inches, did not show the process, under the conditions specified above, to be more effective than fumigation with the same dosages for 24 hours at normal air pressure.[1] All stages of the tobacco beetle were used in the experiments. These were in baled cigar tobacco, in various classes of manufactured tobacco, and in pressed yeast cakes and tobacco refuse. The principal advantage shown was the gain in time, as large quantities of manufactured tobacco can be quickly treated by the vacuum process. It is thought that changes in the present method of vacuum fumigation will make the process better adapted to the treatment of tobacco. A repetition of treatment in the majority of instances will be found necessary for complete sterilization.

Fumigation with Carbon Disulphid.

Carbon disulphid (CS_2) is quite generally used for the destruction of the insect pests which infest grain, food products, etc., and has been used extensively in control of the tobacco beetle. It is a colorless liquid about one-fourth heavier than water, extremely volatile, evaporating with great rapidity when exposed to the air. If the temperature of the air is high and the evaporating surface large the rate of evaporation is increased. In the liquid state it is inflammable, but not explosive, and can be safely handled if the cans are kept perfectly tight and away from the fire. The vapor takes fire in the air at about 200° F. under certain conditions. It is a violent and dangerous explosive when mixed with air in the proportion of 1 volume of vapor to approximately 14.3 volumes of air, in the presence of fire of any kind, or at a temperature without flame of about 300° F. The vapor is considerably heavier than atmospheric air. For this reason carbon disulphid when used for fumigating should be placed at the *top* of the fumigating compartment, if possible *above* the material to be treated. *Care must be taken not to inhale the fumes, as the gas is*

[1] In the above experiments the writer was assisted by Mr. H. L. Sanford, of the Federal Horticultural Board, and by Mr. J. L. Webb, of the Bureau of Entomology.

poisonous. All traces of the fumigant quickly disappear from the substance treated when exposed to the air, and even foodstuffs have been treated without affecting their edibility in any way. Tobacco or cigars when properly aired do not retain the odor of the gas, and the quality and flavor are not perceptibly changed.

While carbon disulphid is not as effective as hydrocyanic-acid gas, the ease with which it may be employed makes it the more desirable fumigant, particularly when the material to be fumigated occupies a small space. The liquid carbon disulphid has merely to be poured into a shallow dish, placed near the ceiling of the compartment to be fumigated, and allowed to evaporate. The method is a favorite one with many cigar dealers, the main objection being the danger of fire. A dealer known to the writer, in fumigating small lots of infested stock, makes use of an old refrigerator so fitted that the door closes perfectly tight. This is placed in a building outside the cigar store, to avoid danger of fire and for convenience in airing after treatment. As soon as infested stock is detected it is fumigated promptly, and in this case there has been small loss from the tobacco beetle.

Fig. 16.—A closet for fumigating cigars or manufactured tobacco. *A*, Removable tray for holding cigars; *B*, generating jar.

The fumigating closet, shown in figure 16, was found to be a convenient size for cigar fumigation. Its dimensions are 2.5 by 2.5 by 6.5 feet. The sides are of matched boards. The inside is lined with sheet zinc. The door and fastenings are similar to those commonly used on refrigerators. Strips of heavy felt were attached where the edges of the door fitted. Boat clamps were used at top and bottom to insure perfect fitting of the door. The closet was fitted with removable trays to insure easy and rapid handling of the cigars. The trays have bottoms of one-half-inch wire screen.

Fumigation is more effective when the temperature is high, and it is not advisable to use carbon disulphid when the air temperature is much below 70° F. To be fairly effective against all stages of the beetle in tobacco, carbon disulphid should be used at a rate of not less than 4 pounds to 1,000 cubic feet of space. When only a small space is to be fumigated and the cost of the treatment is consequently slight, the exact amount of the carbon disulphid used is of no particular importance, even if the amount is very much in excess of the dosage advised above. The period of exposure should be from 24 to 48 hours. The results obtained in a number of experiments with carbon disulphid are given in Table IX. The time of exposure was 24 hours, except in experiments 5 and 11, in which the time of exposure was 48 hours.

TABLE IX.—*Experiments with carbon disulphid in control of the tobacco beetle (Lasioderma serricorne). Experiments at Clarksville, Tenn., 1915.*

Exp. No.	Date.	Dosage (rate per 1,000 cu. ft.).	Stage of insect.	Placement.	Results.
	1915.	*Pounds.*			
1	Aug. 3	1	Larvæ and adults	In smoking tobacco	Partially effective.
2	Aug. 4	1	Adults, larvæ, and pupæ	do	Do.
3	Sept. 16	2	Larvæ (87)	In pressed yeast cake	3 days after treatment, 16 alive, 71 dead.
4	Sept. 4	2	Larvæ (73)	In wire cage, no protection.	All killed.
5	Sept. 3	3	Larvæ	In plug tobacco	2 days after treatment, 1 alive, 26 dead.
6	Aug. 20	3	Adults, larvæ, and pupæ	In glass tubes with cloth cover.	All killed.
7	Aug. 9	3	All stages	do	Do.
8	Sept. 18	4	Larvæ (22)	In cigars	2 days after treatment, all dead.
9	Sept. 22	4	All stages	In smoking tobacco	No live stages found 2 days after treatment. Eggs did not hatch. Check eggs hatched normally.
10	Aug. 9	5	All stages	In cigars and refuse tobacco.	All stages killed.
11	Aug. 17	5	Eggs	About 50 on leaf tobacco.	Eggs did not hatch. Check eggs hatched normally.
12	Sept. 26	10	Eggs and larvæ	In cigars	Cigars kept for 6 months. No signs of infestation.

FUMIGATING WITH CARBON TETRACHLORID.

Carbon tetrachlorid (CCl_4) has been used to a considerable extent as a substitute for carbon disulphid in fumigation. It is not as efficient an insecticide as carbon disulphid, heavier dosages are required, and the cost of treatment is greater. The substance is noninflammable, however, and owing to this property is convenient for use when only a small space is to be fumigated where there might be danger of fire or explosion if carbon disulphid were used. When pure, carbon tetrachlorid is a thin, oily fluid, and in the open air quickly evaporates. It is heavy (sp. gr. 1.599), transparent, colorless, and has a pungent odor—not, however, as disagreeable as in the case of carbon disulphid.

For fumigating it is used in the same manner as carbon disulphid, being evaporated from shallow pans placed *over* the substance treated. The evaporating area of the pans holding the liquid should be large. As with carbon disulphid, an exposure of from 24 to 48 hours should be given. Tests made with carbon tetrachlorid in quantities up to 5 pounds per 100 cubic feet did not give satisfactory results in sterilizing tobacco. As carbon tetrachlorid is more likely to be employed in small compartments it is well to use very heavy dosages, as the increase in cost will be slight. The killing effect is greater when the air temperature is high.

Formaldehyde as a Fumigant.

Tests were made of 40 per cent formaldehyde at the rate of 2½ ounces to 100 cubic feet of space. All stages of the tobacco beetle were used and the formaldehyde was vaporized by means of heat. The substance at this strength was found to be only partially effective.

THE EFFECT OF RÖNTGEN OR X RAYS ON THE TOBACCO BEETLE.

The effect of the X rays on the higher animals, including human beings, is well known. Sensitiveness to the rays has been found by different investigators to vary with the species of animal. Newly formed, especially embryonic tissues, have been found to be more easily affected by exposure to the rays than are those more mature. Certain bodies of cells are remarkably susceptible, their functions being retarded, modified, or completely inhibited, although morphologically they are apparently normal. The rays are known to have a marked effect on the reproductive organs, prolonged exposure causing an animal to become temporarily or permanently sterile. In general it may be said that when living tissues of an animal are exposed to the action of the rays, the functions of the cells are retarded or depressed, and permanent injury, or even the eventual death of the animal, may result. The exact effect of the rays depends upon the intensity of the radiation, the duration of the exposure, and the distance of the organism exposed from the source of radiation. When the energy input through a Röntgen tube is great, the intense radiation resulting is correspondingly more active, and more injurious to living tissue, producing more marked physiological results. Exposure to rays of great intensity has been shown to retard or stop growth, differentiation and regeneration, and to interfere with the processes of cell division or multiplication, causing, in some cases, degenerative changes to take place or a decrease in the rate of cell division. On the other hand, an exposure of slight intensity or short duration may be without perceptible effect, or may even be accelerative, and perhaps increase the rate of cell division. It seems to be well established that the effects of repeated exposures to the rays are to a certain extent cumulative, an exposure of say 5 milliampere minutes having identically the same effect, whether the exposure is given in one treatment or in several treatments applied at different times so that the total exposure amounts to 5 milliampere minutes. The effect of the rays on the simpler forms of animal and plant life has been studied by numerous investigators and in general their action seems to be the same as on the higher animals.

The X-ray process of treating tobacco has been exploited commercially for sterilizing cigars infested with the tobacco beetle, and satisfactory results have been reported. Improvements in the method of treatment and in the apparatus have been made from time to time, and the modern forms of Röntgen tubes used make possible continuous and unchanging Röntgen-ray radiation of great power and intensity. Effects can now be obtained which were not possible or practicable in commercial work with the earlier forms of apparatus.

During 1912 experiments were made by Mr. A. C. Morgan and the writer (76) with apparatus designed to sterilize cigars on a commercial scale. The experiments, from a practical standpoint, gave negative results. Later experiments made with apparatus capable of producing and maintaining a much more powerful radiation have shown that the earlier tests failed to give satisfactory results owing to the comparatively light exposures obtainable with the apparatus then used.

A brief statement of the results obtained by the writer (86) in a series of experiments conducted under laboratory conditions at Schenectady, N. Y., in 1915, is presented.[1] These experiments were a continuation of investigations of a similar nature commenced at Tampa, Fla. In previous experimental work it had been found in sterilizing cigars or tobacco that light dosages are ineffective from a practical standpoint. To be effective the radiation must be intense, and it is evident that if the process can be applied successfully to commercial work the apparatus used must be capable of producing and maintaining such radiation during the entire period of exposure.

The results obtained in the experiments have been briefly summarized as follows:

[1] A detailed report of these experiments has been published (86).

Under laboratory conditions tests made with a Röntgen-ray tube permitting a high-energy input and giving an intense and powerful radiation produced results which promise that the X-ray process may be used successfully in treatment of cigars or tobacco infested with the tobacco or cigarette beetle.

Heavy dosages must be given, as is indicated by the results of exposures given in several series of experiments.

In treatment of the egg stage, heavier exposures are required to sterilize eggs which are near the hatching point than are required to sterilize eggs newly laid.

In experiments performed by the writer a dosage equivalent to 150 milliampere minutes exposure with a spark gap of 5.5 inches gave satisfactory results with eggs in tobacco placed 7.5 inches from the focal spot of the tube. With this exposure the eggs in which embryonic development was well advanced hatched, but in all cases where these larvæ were kept under observation they failed to reach the adult stage.

The minimum lethal dosage at a given distance from the focal spot of the Röntgen tube used was not determined.

In two separate experiments adults were given an exposure of 600 milliampere minutes (amperage × time), with a spark gap of 5.5 inches, giving an approximate voltage of 65,000. The distance from the focal spot of the Röntgen tube was 7.5 inches. The results were as follows:

(1) No effect on length of life was apparent, as the beetles died at about the same rate as the same number of beetles kept as check.

(2) Large numbers of eggs were deposited after exposure. These eggs were infertile. Eggs laid by the check beetles hatched normally.

Larvæ were given an exposure of 600 milliampere minutes, other conditions of the experiment being the same as in the experiments with adults given above. While no immediate effect was apparent the treatment had the effect of stopping activity and development, the larvæ remaining in a dormant condition for a prolonged period. All treated larvæ died before reaching the pupa stage.

Two methods of treating cigars in factories with the X-ray process are employed at the present time. In one method the finished cigars in closed boxes are conveyed by a belt very slowly through an exposure chamber containing the Röntgen tubes. The walls of the exposure chamber are constructed of thick sheets of lead (lead is not penetrated by the Röntgen rays) in order to protect the operator of the machine from injury.

In the other method of treatment a large room used as a humidor at the factory was completely lined with sheet lead. In a narrow compartment within the humidor, extending along one side, a series of 16 powerful Röntgen-ray tubes are arranged in two lines extending from end to end, and placed so that the rays penetrate the humidor from various angles. A rotary fan forces cold air through the tube compartment and over the tubes, keeping the temperature of the humidor normal. The finished cigars in closed boxes are placed on a long shelf extending along the partition of fibrous material (permeable to the rays) separating the tube compartment from the rest of the humidor. An exposure of 42 minutes is given by an automatic control of current. Cigars are left on the shelf until all space is taken up, then placed in other parts of the humidor, where they are kept until shipped out. This arrangement gives a minimum exposure, close to the Röntgen tubes, of 42 minutes. Ordinarily the method of handling gives many repeated exposures, on the shelf close to the tubes or at distances farther out in the humidor. A test of this process was made by the writer on November 7, 1916, to determine the effect on the egg stage of the tobacco beetle. About 200 eggs deposited on leaf tobacco were placed in a sealed cigar box and treated. An equal number of eggs were kept as a check. The eggs treated were placed in the humidor 7½ feet from the wall of the tube compartment and given three periods of 42 minutes' exposure; then placed on the shelf directly in front of the tubes and given one period of 42 minutes' exposure. This gave a total of three accumulative periods of 42 minutes each 7½ feet from the nearest tube and one period of 42 minutes on the shelf close to the tube compartment. By November 18 most of the check eggs had hatched, but all of the treated eggs were more or less shrunken and none had hatched.

SUMMARY AND RECOMMENDATIONS.

The tobacco beetle, a stored-product insect, is practically cosmopolitan and occurs wherever large quantities of leaf or manufactured tobacco are handled or stored. It attacks a variety of dried substances, its most common food being tobacco.

In tobacco factories, the principal sources of infestation of the finished products are:

(1) Infested leaf tobacco brought into the factory.

(2) Tobacco warehouses, where beetles are present in large numbers, close to the factory.

(3) Infested tobacco, refuse material, cigars, or manufactured tobacco which has accumulated. (Beetles breeding from this material quickly spread to all parts of the factory.)

A very few beetles present in storage or packing rooms in factories may be the cause of serious loss, by depositing their eggs on the finished product. The protection of the product at this time is usually of more importance than the condition of the raw material, since the leaf tobacco in most cases is partly or completely freed from different stages of the beetle by handling or by the process of manufacture. Whenever possible manufactured tobacco should be packed in insect-proof containers.

The more important means of controlling the tobacco beetle may be summarized briefly as follows:

(1) Scrupulous cleanliness in the factory, wholesale or retail establishment, including the prompt destruction or treatment of all refuse material, damaged stock, etc., in which the beetles may breed.

(2) In factories, screening or otherwise protecting the finished product from infestation.

(3) Constructing or refitting packing or storage rooms, especially in warm localities, so that they can be quickly and easily cleaned, and with a view to the exclusion of beetles which may be present in other parts of the factory.

Among destructive agencies which may be employed in control of the insect are:

(1) Freezing. (Treatment by cold storage or exposure to low temperatures in cold climates.)

(2) High temperatures or steam. (A temperature of from 125° to 140° F. continued for several hours, or 150° F. for a short time, kills all stages of the beetle.)

(3) Trapping or destruction by mechanical means.

(4) Fumigation with carbon disulphid, hydrocyanic-acid gas, or other fumigants.

(5) Sterilization of infested tobacco by means of exposure to Röntgen or X rays.

The modern method of storing leaf tobacco in hogsheads in specially constructed buildings or sheds, giving practically out-of-door conditions and variations of temperature, furnishes an effective means, in cool climates, of reducing or preventing injury from the beetle to the classes of leaf tobacco which may be stored in this manner.

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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER April 18, 1919

THE SUGAR-CANE MOTH BORER

By

T. E. HOLLOWAY and U. C. LOFTIN
Entomological Assistants, Southern Field Crop Insect Investigations

WITH TECHNICAL DESCRIPTIONS BY
CARL HEINRICH

CONTENTS

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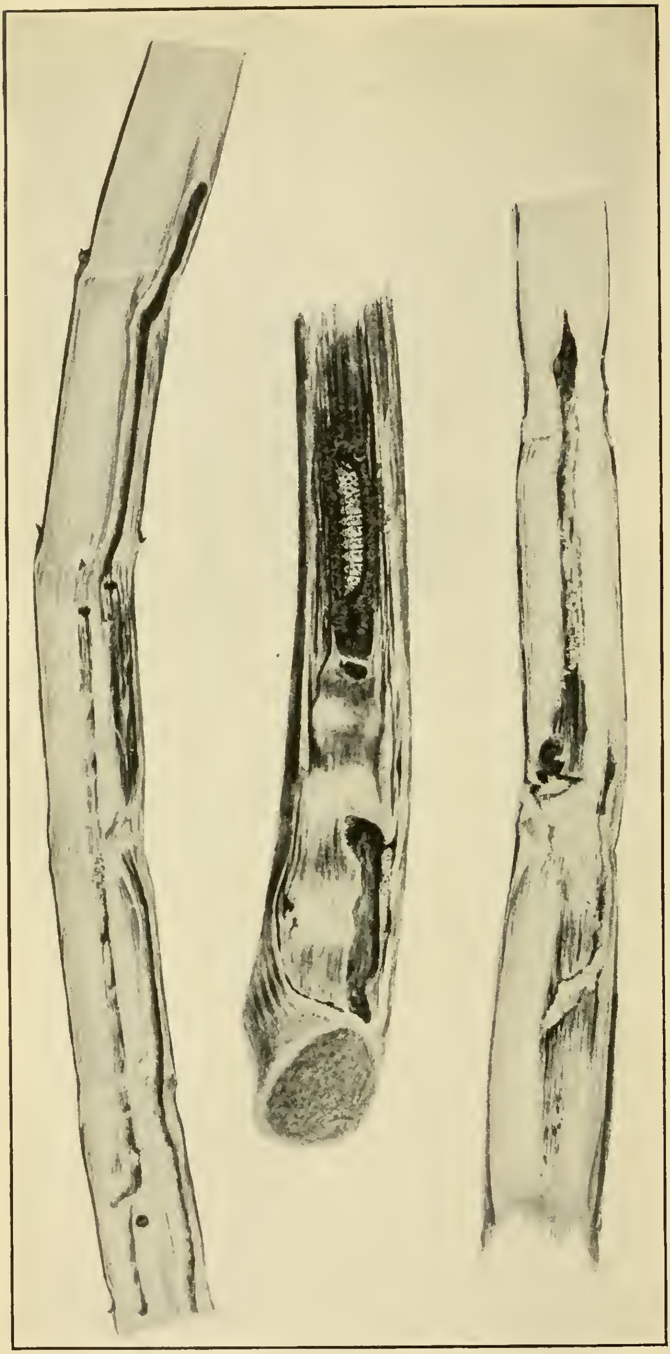

INTERIOR OF STALKS OF SUGAR CANE SHOWING HOLES MADE BY SUGAR-CANE MOTH BORER AND A BORER IN ITS TUNNEL.

The normal tissue is white or yellowish, and the reds and other colors, appearing dark in the illustration, are the results of diseases, especially "red rot," which follow the borer in the cane stalk, causing additional deterioration.

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THE SUGAR-CANE MOTH BORER.[1]

By T. E. Holloway and U. C. Loftin,[2]
Entomological Assistants, Southern Field-Crop Insect Investigations.

With Technical Descriptions by Carl Heinrich.

CONTENTS.

INTRODUCTION.

For the information of those who are not familiar with sugar cane, especially as grown in the United States, it may be said that the plant is a giant grass known botanically as *Saccharum officinarum*

[1] *Diatraea saccharalis crambidoides* Grote; order Lepidoptera, family Pyralidae.

[2] The writers acknowledge their indebtedness to Dr. W. D. Hunter for his interest and direction, and for the suggestions of Dr. W. Dwight Pierce and Mr. D. L. Van Dine, of the Bureau of Entomology. The tables and charts for life history were made under Dr. Pierce's supervision. The active cooperation of the Louisiana Sugar Experiment Station at Audubon Park, New Orleans, has been of the highest value, credit especially being due to Mr. W. G. Taggart, assistant director, for his suggestions concerning the practical application of methods of control. Mr. S. G. Chiquelin, the former assistant director, cooperated in the work and later made valuable suggestions concerning localities in Cuba where parasites could be obtained. Laboratory space was furnished gratis by the Louisiana Experiment Station, and the writers thank Prof. W. R. Dodson, director, for his many courtesies.

For the technical descriptions of the larva and pupa stages of the insect, the writers thank Mr. Carl Heinrich, of the Bureau of Entomology.

The writers have had the assistance in field and laboratory work of Mr. Ernest R. Barber and others. Valuable cooperation was maintained with Mr. George N. Wolcott, formerly entomologist of the Insular Experiment Station of Porto Rico and later for a short time connected with this investigation. Prof. J. T. Crawley, formerly director, and Prof. P. P. Cardin, entomologist, of the Cuba Experiment Station at Santiago de las Vegas, have been of material assistance in connection with the introduction of the parasitic flies from Cuba. Mr. Edward Foster, of the office of the State entomologist of Louisiana, has assisted with bibliographical and other information.

The drawings were made by Mr. Harry Bradford, of the Bureau of Entomology.

Linnaeus, that it is grown from cuttings which are laid lengthwise in the rows, that it grows from late spring through the warm months of the year, and that it must be cut before it is damaged seriously by cold weather.

The plant does not produce seeds in Louisiana, though it does in tropical countries and occasionally in southern Florida and the southern tip of Texas. The stalks are cut in the fall, the leafy tops and side leaves are trimmed off and left on the fields, and the stalks are ground in the mill, this being the first step in the manufacture of sugar. The leaves and tops left on the ground usually are called the "trash," but by some "shucks," and by others "flags."

The principal insect injurious to sugar cane in the United States is a moth generally known in the larva stage as "the borer," but it is distinguished from other boring insects of sugar cane by the names "moth borer" and "lesser moth borer." It is a member of the order Lepidoptera, family Pyralidae and subfamily Crambinae, and has the scientific name *Diatraea saccharalis* Fabricius, variety *crambidoides* Grote. It is this insect which is considered in the following pages.

CHARACTER OF INJURY TO SUGAR CANE.

The work of many insects is apparent immediately, even to the untrained observer, but the injury due to the sugar-cane moth borer, familiarly known as the "borer," is the more serious for the reason that it is not noticeable except on close examination. To the casual observer one field of sugar cane is like many others. If the leaves are pulled away from a stalk, however, a few holes may be observed in the rind and perhaps a quantity of sawdustlike material may be seen clinging to the stalk. This is evidence that the moth borer has been at work. If the stalk is split lengthwise, tunnels about an eighth of an inch wide may be found running for several feet, several tunnels sometimes joining in such a way that the plant is greatly weakened and is easily blown down by a high wind.

It is evident that such injury must occasion various forms of loss, in tonnage of cane, pounds of manufactured sugar, etc. The injury is rendered even more serious by the insidious habits of the insect, since the full amount of damage is underestimated by the average planter. Only by walking through the field and examining stalk after stalk can any definite idea of the full amount of injury be obtained.

ESTIMATE OF LOSSES.

Not only are the mature canes injured greatly by the moth borer, but many young plants, especially in the early summer, are killed. (See "Effect on young cane—'dead hearts,'" p. 5.) As many as 100 plants per acre may be destroyed, but so many plants remain in the field that this loss is not great. It should be prevented, however, because it is on these young plants that the borers multiply in sufficient numbers to become a serious menace to larger canes.

Under calculable losses the injury to mature cane alone will be considered. The full amount of injury is shown only by chemical analysis. Infested and uninfested cane from Texas, not affected by red rot, a disease which often follows borer damage, was analyzed, with the following results:

Uninfested.	*Per cent.*	*Infested.*	*Per cent.*
Brix	19.5	Brix	17.55
Sucrose	17.45	Sucrose	15.1
Purity	89.5	Purity	86.0

Dr. William E. Cross, at that time of the Sugar Experiment Station, New Orleans, La., who made the analyses, stated that the loss due to the moth borer was about 20 per cent of the sugar—a greater loss than might be expected from the figures. Mr. John Allbright, chief of the laboratory at Central Chaparra, Cuba, analyzed infested and uninfested cane from a field at that central factory. The results follow:

Uninfested.	*Per cent.*	*Infested.*	*Per cent.*
Brix	21.3	Brix	18.8
Sucrose	19.9	Sucrose	16.85
Purity	93.4	Purity	89.6
Extraction	47.2	Extraction	36.4

Loss in sucrose, 3.3 per cent in cane.
Loss in sucrose, 15.3 per cent in juice.

Messrs. D. L. Van Dine (169)[1] and T. C. Barber (14) have investigated the losses due to the moth borer in considerable detail. Mr. Barber sums up the effect on sugar content in Table I.

TABLE I.—*Analysis of sugar cane (D. 74) to determine effect on sugar content of the borer injury to cane.*

No. of sample.	Nature of sample.	Weight of cane.	Weight of juice.	Per cent of juice.	Loss of juice due to borer.	Total solids in juice.	Loss in total solids due to borer.	Glucose in juice.	Solids not sugar in juice.	Glucose ratio.	Sucrose in juice.	Loss in sucrose due to borer.	Purity.	Loss in purity due to borer.
		Gms.	*Gms.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	Borer-free	9,990	6,108	61.1	.....	17.1	......	1.6	1.1	11.1	14.4	......	84.2	.....
2	Medium infested	11,081	6,735	60.8	0.3	16.1	1.0	1.7	1.2	12.9	13.2	1.2	82.0	2.2
3	Heavily infested	8,824	5,190	58.8	2.3	13.7	3.4	2.1	1.8	21.4	9.8	4.6	71.5	12.7

NOTE.—Each sample consisted of 10 canes. Each of the medium-infested canes contained from one to three infested joints, and each of the heavily infested canes five or more infested joints. Analysis made Nov. 12, 1910.

[1] Figures in parentheses refer to entries in the bibliography, pages 63–74.

TABLE I.—*Analysis of sugar cane (D. 74) to determine effect on sugar content of the borer injury to cane*—Continued.

RESULTS OF ABOVE ANALYSIS FIGURED ON A BASIS OF 1 TON OF CANE TO THE SAMPLE.

No. of sample.	Nature of sample.	Weight of cane.	Weight of juice.	Loss of juice per ton due to borer.	Total solids per ton.	Loss in total solids due to borer.	Glucose per ton.	Increase in glucose due to borer.	Solids not sugar per ton.	Increase in solids not sugar due to borer.	Sucrose per ton.	Loss in sucrose due to borer.	Actual loss in sucrose due to borer.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*P. ct.*
1	Borer-free	2,000	1,222	......	208.96	....	19.55	......	13.44	......	175.97	....	......
2	Medium infested	2,000	1,216	6	195.77	13.19	20.67	1.12	14.59	1.15	160.51	15.46	8.78
3	Heavily infested	2,000	1,176	46	161.11	47.85	24.69	5.14	21.17	7.73	115.25	60.72	34.51

He summarizes his results as follows:

The sugar-cane borer damages cane in the field by destroying a considerable percentage of the eyes, thus reducing the stand of plant cane; by stunting the growth of the cane, owing to the physical injury of the stem; by admitting fungous diseases through the wounds in the stem; and is the main cause of injury by the wind, owing to the weakening of the stalk due to the tunnels and burrows. These classes of injury have been appreciated by planters. It now develops that there is another and very important class of injury which has been overlooked. This is the reduction of both the quantity and quality of the juice, which is dealt with specially in this circular. It becomes evident that both the planters and the manufacturers are vitally interested in the work of the sugar-cane borer.

Mr. Van Dine states:

There is a direct loss in sugar and a decided reduction in the purity of the juice of cane infested by the moth stalkborer. This loss in Porto Rico exceeds 670 pounds of sugar per acre of cane in which the infestation was not apparent except upon examination, the yield averaging 41 tons of cane per acre and the stalks being normal and healthy in appearance. The loss increases in direct proportion to the number of joints of the cane stalks infested by the borer. There is more fiber and less juice in borer-infested cane. The actual weight of borer-infested cane is less than that of sound cane, and it is considered that the juice deteriorates more rapidly in infested cane when cane is allowed to stand without being crushed for any length of time after harvest.

In the early bulletin on the moth borer by Dr. W. C. Stubbs and Prof. H. A. Morgan (152) it is found that after the borer became established on Belle Alliance Plantation, in Louisiana, there was "a falling off of 4.98 tons per acre and about 25 pounds of sugar per ton." From the figures given in that bulletin it is calculated that an average yield of 3,455 pounds of sugar per acre accrued on Belle Alliance Plantation before the borer made its appearance, whereas the average yield thereafter was only 2,393 pounds per acre. The loss in sugar from these figures would be 1,061 pounds per acre. At 4.35 cents per pound, which is given as the average price of (white) sugar for three years, the annual money loss per acre due to the moth borer would be $46.15. At the present ruling prices the loss would be correspondingly greater.

"DEAD HEART" CAUSED BY THE SUGAR-CANE MOTH BORER.

Injury of this character results, in a few days, in the death of the young plant.

As calculated from the figures of Mr. T. C. Barber, a similarly high loss is obtained. Mr. Barber estimates a total loss of 1,078 pounds of sucrose per acre where canes are all bored, as they sometimes are. The present writers estimate the loss of 96 test sugar as 1,082.33 pounds per acre. The average price of this grade of sugar on the New Orleans market during the 14 years from 1900 to 1913, inclusive, was approximately 3.87 cents per pound. At this price the money loss where all canes are bored is $41.88 per acre.

During the six-year period from 1912 to 1917, inclusive, in which observations have been made, the average infestation has been about 58 per cent of all the canes in the infested area in Louisiana, which includes the whole sugar belt, except the parishes of Rapides and most of Avoyelles, or about 300,000 acres planted in sugar cane. Fifty-eight per cent of the maximum loss ($41.88) is $24.29 per acre. For 300,000 acres it reaches the high figure of $7,287,000. The losses in southern Florida and the lower Rio Grande Valley, in Texas, would correspond to the acreage. The infestation in Texas is always high.

These figures do not take into consideration the loss due to injury to corn, which must be considerable but is difficult to estimate.

EFFECT ON YOUNG CANE—"DEAD HEARTS."

The first injury of the moth borer to the young sugar-cane plant produces what is known as the "dead heart." This injury is illustrated in Plate I. Among plants from 6 inches to 3 feet in height some usually are to be found in which the outer leaves are a healthy green while the young inner whorl is yellow and dry. The central portion, or "heart," of the plant is dead, and the dying of the rest of the plant is only a matter of days.

This peculiar reaction to injury is rather characteristic of young cane. It is often due to the work of the borer, but it may result from various other causes. Thus some "dead hearts" are caused by a twisted growth of the inner tissues of the plant, the tissues above such a twist ultimately dying. Other "dead hearts" result from accidents of cultivation. A false step of the mule or the plowman may break the brittle inner tissues near the ground, while the outer portion of the plant, being stronger and more elastic, springs erect after the weight is removed. In a short time the heart dies, and an investigation will show that the inner tissues have been broken cleanly and have turned slightly brown at the point of separation.

Insect injury other than that of the moth borer also is responsible for "dead hearts." The work of the sugar-cane beetle (*Ligyrus*) *Euetheola rugiceps* Le Conte, and other insects produces similar injury, the inner portion of the plant being killed before the outer portion.

The "dead hearts" due to the moth borer are caused in the following manner: The adult moths emerge in the spring, when the cane plants are small, and deposit clusters of eggs on the leaves of the young plants. The eggs hatch, and the small larvæ feed here and there on the tender whorls, rolls of holes appearing on the leaves as they expand. Many of the larvæ seem to perish during this period, partly because of their cannibalistic habits. Not more than three larvæ, usually only one, seem to find their way to the interior of a young cane plant. When about half grown a larva crawls down the outside of the stem to a point near or even below the surface of the ground. Gnawing a hole through the outer layer of the stem it works its way to the interior of the plant, cutting the tender inner shoot and forming a "dead heart." The inner shoot does not dry up immediately, so that the larva has some time to work before the injury can be noticed. Tunneling within the plant the insect reaches its largest size, pupates, and finally leaves the plant as an adult moth.

During a year when few plants were killed in this way it was estimated that there were about 10 "dead hearts" per acre. In other years as many as 100 "dead hearts" have been counted per acre.

EFFECT ON MATURE CANE.

While the work of the larvæ on the small plants kills the plants, larger stalks usually do not die. In these the larvæ burrow up and down, sometimes gnawing their way out through the hard rind and reentering at another point. Frequently a mature stalk will harbor two or three larvæ which work in different parts of the cane from the top to the bottom. Three sections of infested cane are illustrated in the frontispiece.

A red coloration, showing dark in the canes illustrated in the frontispiece, usually is observed in the pith along the tunnels. This is the disease "red rot," which is caused by the fungus *Colletotrichum falcatum*. "By far the largest number of stalks become infected [with red rot] through the burrows made by the cane borer," writes Dr. C. W. Edgerton (50), who sums up the injury due to red rot as follows: "First, the loss in stand; second, the killing of the young plants; third, the injury to the leaves; fourth, the loss in per cent of sucrose with a corresponding increase of glucose." "Knowing that a large per cent of the red-rot infection in cane is by means of borer channels," Dr. Edgerton continues, "a greater effort should be made to control the insect."

The spores of other fungi, as well as bacteria,[1] also gain entrance through the borer holes. Cane badly bored is found to be hard and dry, making it more difficult to grind. The growth is checked, and

[1] Prof. Wm. L. Owen (119), formerly bacteriologist of the Sugar Experiment Station at Audubon Park, New Orleans, La., has studied and described a bacterium which he found in the tunnels made by the moth borer in sugar cane. He has given it the name of *Bacillus saccharalis*.

the bored stalks are often blown down by a strong wind. The purity of the juice is lowered, the tonnage decreased, and the sucrose content materially diminished. The eyes are destroyed in many cases, which lessens the value of the infested cane for seed.

EFFECT ON CORN.

The damage of the moth borer[1] to the corn plant has been well described by Mr. George G. Ainslie (2).

> Corn is damaged by these caterpillars in two ways. First, in the early part of the season, while the plants are small, they work in the throat of the young corn, and if the tender growing tip within the protecting leaves is once damaged all chances that the plant will become a normal productive specimen are gone. In many sections of the South this is commonly known as "bud-worm" injury, and though there are several other insects which cause a similar mutilation of the leaf, a very large proportion of the so-called "bud-worm" damage may be charged to this insect. The effect of its work on the leaves of the young corn plants is similar to that resulting from attacks by the corn billbugs (*Sphenophorus* spp.) and is evidenced by the familiar rows of small circular or irregular holes across the blades of the plant.
>
> The other form of serious damage chargeable to this pest occurs later in the season. The larvæ, having then left the leaves and descended to the lower part of the stalk, tunnel in the pith. If the larvæ are at all numerous in the stalk, their burrows so weaken the plant that any unusual strain will lay it low and destroy all chance of its maturing. While frequently ten or more larvæ may live and mature in one plant, it must be remembered that any infestation, however light, will lessen in some degree the vitality of the plant and cause a corresponding loss in the quality and quantity of the harvest.

Not only the stalks of corn, but sometimes the ears are found to contain borers.

The cornstalks, maturing about July or August, when the cane is hardly half grown, become dry and the plants are no longer attractive to the moths for the deposition of eggs. Corn and cane are grown in adjacent fields on sugar plantations, and moths from corn find cane an attractive food plant. Consequently the cane in the middle of the season is attacked not only by moths which have passed their immature stages in cane plants, but by numbers of those which have grown to maturity in corn. It is notable that the number of cane stalks infested by borers increases rapidly from the middle of the growing season until the cane is cut.

HISTORY.

Dr. L. O. Howard (77) wrote an article on the moth borer for the official entomological journal, Insect Life, in 1891, introducing his remarks with an account of the history of the species. We quote him as follows:

[1] Though this account was doubtless written with *Diatraea zeacolella* Dyar in mind, it is correct when applied to the closely allied species *D. saccharalis crambidoides*, which also attacks corn.

The attention of English-speaking people was first called, in a scientific way, to the ravages of a lepidopterous borer in sugar cane by the Rev. Lansdown Guilding in his account of the insects infesting sugar cane, in the Transactions of the Society of Arts, 1828, vol. XLVI, pp. 143–153. He described the insect as *Diatraea sacchari,* and for his paper, which comprehended also an account of the sugar-cane and palm weevils, he was awarded the gold Ceres medal of the society. His studies were made in the Island of St. Vincent in the West Indies, and from its occurrence there at this early date, and from Guilding's statement that it had been long known, there is reason to suppose that the insect may be an indigene of South America or of the West Indies, where the cultivation of sugar cane was first begun in America.

In 1856 a select committee, appointed to investigate the damage caused by the cane borer in Mauritius, reported through W. Bojer, and the insect, which is called in the report *Proceras sacchariphagus*, was treated at some length, and an account was given of its introduction into the island. In the same year Westwood reviewed this report at length in the Gardeners' Chronicle of July 5, gave a woodcut of the insect, and pointed out that it was probably identical with the species described by Guilding at St. Vincent. He also called attention to the fact that the species named many years previously by Fabricius as *Phalaena saccharalis* is probably the same thing. This insect was described by Fabricius (Entomologia systematica, vol. III, part 2, p. 238), from South America, no more definite locality being given. The probabilities are, however, that he refers to Dutch Guiana on account of the early settlement of that country and from the fact that he refers to a figure of the larva by Myhlenfels. He makes the statement that it feeds in sugar-cane, perforating and destroying the stalks and becoming a pest in plantations. He describes the larva as six-footed, of a pale hyaline color, and with the head and eight spots brown. The larval description, however, is drawn from a figure by Myhlenfels, which may have been inaccurate. As Fabricius's work was published in 1793, further evidence is thus afforded that the insect is indigenous to the western hemisphere. This insect still does similar damage in the vicinity of the original source of our information, as is indicated by two articles by Miss Ormerod in the Proceedings of the Entomological Society of London, 1879, XXXIII–XXXVI and XXXVI–XL, and by reports of Mr. Im-Thurm, curator of the British Guiana Museum at Georgetown, published some time previously, but which we have not seen.

In an added note to his Gardeners' Chronicle article, Westwood states that according to information given him by "an intelligent Jamaica cane-grower" the borer was very destructive in Jamaica some 15 years previously (1842), but that its ravages had been greatly checked by allowing the refuse to accumulate on the ground and then firing the whole plantation, the old roots subsequently throwing up more vigorous shoots.

Mr. H. Ling Roth has studied what he believes to be the same species in Queensland (Parasites of the Sugar-Cane, reprinted from the Sugar Cane, March and April, 1885. London, 1885). And in the same year M. A. Delteil (La Canne à Sucre, Paris, 1885) treats of the Mauritius borer and considers it to have been imported from Java, whereas the 1856 commission had considered that it was derived from Ceylon. In 1890 Dr. W. Kruger published in the Berichte der Versuchsstation für Zuckerrohr in West Java, Heft 1, Dresden, 1890, an account of the sugar-cane borers, and figures and describes a species determined as *Diatraea striatalis* Snell., which almost precisely resembles our species, and which he says occurs not only in Java, but also in Borneo, Sumatra, and Singapore. In this same report another similar borer is described by Snellen as *Chilo infuscatellus.*

The West Indian cane borer made its appearance in the sugar-cane plantations of Louisiana at an early date. J. B. Avequin, writing in the Journal de Pharmacie for 1857 (vol. xxxii, pp. 335–337), upon the enemies of the sugar cane in the Antilles and Louisiana, stated that during the two or three preceding years this insect had spread over some of the cane fields of Louisiana, but without having caused up to that time any great damage. He thought that the early frosts towards the end of October or November destroyed great numbers. It appears to have been first noticed in the Parish of St. John Baptist in the year 1855.

Since this time the insect must have been constantly present in the Louisiana cane fields, and has probably been reintroduced from time to time with fresh shipments of seed cane from the West Indies. In the fall of 1878 a few specimens were sent to Dr. Riley by a correspondent of Assumption Parish, Louisiana, and in the spring of 1879 Mr. E. A. Schwarz sent in a bit of cane containing larvæ from the Bahamas. In the spring of 1881, I was sent to Louisiana by Professor Comstock, then entomologist of the Department of Agriculture, to study the sugar-cane beetle (*Ligyrus rugiceps*), and had the opportunity of studying this borer upon the plantation of Dr. J. B. Wilkinson, some 40 miles south of New Orleans on the Mississippi River. Dr. Wilkinson informed me that in 1857 they were very abundant in the Lower Mississippi, and that the crop upon one plantation was utterly destroyed, the cane breaking to pieces as they attempted to cut it.

Concerning the date of the introduction of the moth borer into Louisiana, Stubbs and Morgan (152) conclude that it was introduced long before 1857. "How and when the borer was introduced is not certain," they decide, "but the separate corroborating testimony of Mr. Chamberlain and Mr. Maurin would rather fix the date at 1857, and as canes in large quantities from South America were that year introduced, it is reasonable to conclude that they came from that country as asserted by Mr. Maurin, and not from the West Indies, as Mr. Chamberlain thinks. However, if Col. Pugh and Mr. Bird are accurate in their dates, it was here in quantities before that year." In a footnote to the foregoing these investigators add: "Subsequent investigations have proven that the borer was here in quantities long before the importations of cane described above."

A little-known book by Champomier (32), who issued a series of statistical reports on the sugar industry of Louisiana about the middle of the last century, mentions the "borer worm" in his report for 1856–7. This reference was brought to the attention of the writers by Mr. Edward Foster, of New Orleans.

DISTRIBUTION.

The distribution of the sugar-cane borer (*Diatraea saccharalis crambidoides*) in the United States coincides rather closely with the area devoted on an intensive scale to sugar-cane growing. It is limited to the southern part of Louisiana, the southern tip of Texas, and the southern part of Florida. The borer does not occur in Rapides Parish of Louisiana and is present in only the southeastern part of

Avoyelles Parish. It has not been found in the cane-growing sections of Wharton, Sugarland, and Victoria, Tex.

It is noteworthy that the territory infested in the United States is mostly within the limits of an area known as the Gulf Strip of the Lower Austral Zone.[1] This strip along the coast is indicated in the accompanying map (fig. 1), which shows also the infested regions.

That the insect is found only in three such widely separated places as the southern parts of Texas, Louisiana, and Florida may be explained by the fact that it is a tropical species and probably was brought to these three cane-growing sections independently in shipments of seed cane. Where sugar cane is only an incidental crop it

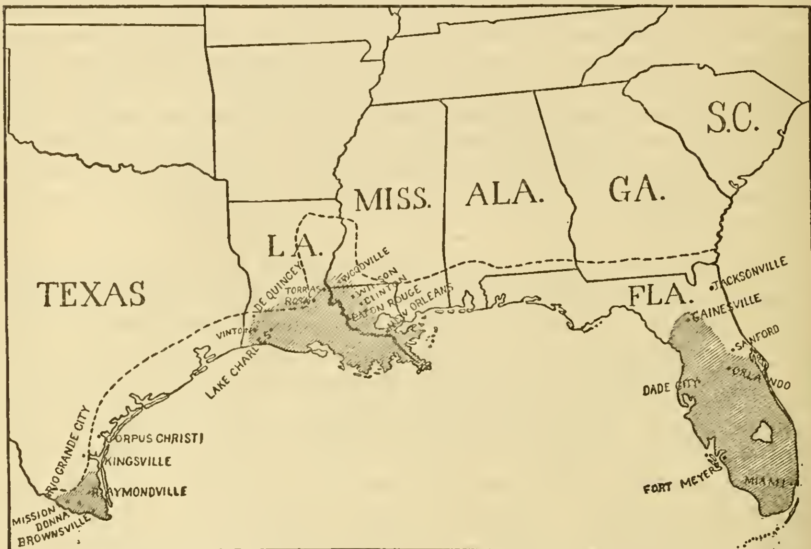


Fig. 1.—Map showing distribution of the sugar-cane moth borer (*Diatraca saccharalis crambidoides*) in the United States. The area below the line of dashes is the "Gulf Strip." Note that the territory infested is practically well within the limits of this biological zone.

does not occur, although a nearly related species attacks corn and very seldom sugar cane in Georgia, northern Florida, North Carolina, South Carolina, and Virginia (75).

SPECIES OF DIATRAEA.

Dr. Harrison G. Dyar (45) records three species of Diatraea in the United States. These are:

Diatraca saccharalis saccharalis Fabricius. French Guiana, Cuba, Trinidad, Peru. Also a female from southern Florida. Probably Santo Domingo.

Diatraca saccharalis crambidoides Grote. Mexico, numerous localities; Gulf States and lower Mississippi Valley.

Diatraca zeacolella Dyar. North Carolina, South Carolina, Virginia.

Diatraca lineolata Walker. Cuba, Trinidad, the Guianas. Venezuela, Costa Rica, Mexico, and southern Arizona.

[1] Merriam, C. Hart. Life Zones and Crop Zones of the United States. U. S. Dept. Agr. Div. Biol. Surv. Bul. 10. 79 p., 1 col. map. 1898.

Dr. Dyar has determined the species from Louisiana as *Diatraea saccharalis crambidoides.*

The authors' observations indicate that *D. zeacolella* occurs in Georgia and northern Florida, as well as in the Carolinas and Virginia. In places in these States where both corn and sugar cane are grown this species has been found to be abundant in corn while rare or absent in adjoining cane fields. Practically, it may be regarded as an enemy of corn exclusively. The larval characters which distinguish *D. zeacolella* from *D. saccharalis crambidoides* have been noted elsewhere by the senior writer (75) and have been further investigated by Mr. Carl Heinrich. (See description of larva, p. 13.)

The southern Arizona species (*D. lineolata*), observed by the authors at Phoenix, Ariz., on sugar cane and Johnson grass, has the distinctive habit of feeding on the leaves of cane until quite large before entering the stalk.

D. saccharalis crambidoides occurs in both corn and sugar cane in the area infested by this variety. It will be noted that the observations of the authors, limiting the variety to southern Louisiana with a small portion of Mississippi, southern Florida, and the lower Rio Grande Valley in Texas, are not at variance with Dr. Dyar's general statement, "Gulf States and lower Mississippi Valley."

The following species of Diatraea are recorded from various parts of the world:

TABLE II.—*Records of species of Diatraea.*

Species.	Distribution.	Authority.
amnemonella Dyar	Castro, Parana, Brazil	Dyar (45)
angustella Dyar	Castro, Parana, Brazil	Dyar (45)
bellifactella Dyar	Sao Paulo and Castro, Parana, Brazil	Dyar (45)
berthellus Schaus	Castro, Parana, Brazil	Dyar (45)
canella Hampson	Grenada; Trinidad; Guiana	Dyar (45)
	British Guiana	Bodkin (17)
continens Dyar	Castro, Parana, Brazil	Dyar (45)
culmicolella Zeller	Colombia	Dyar (45)
grandiosella Dyar	Guadalajara, Mexico	Dyar (45)
instructella Dyar	Popocatepetl Park, Mexico	Dyar (45)
lineolata Walker	Cuba; Trinidad; Guiana; Venezuela; Costa Rica; Mexico; southern Arizona	Dyar (45)
	British Guiana	Bodkin (17)
magnifactella Dyar	Various points in Mexico	Dyar (45)
mauriciella Walker	Mauritius	Hampson (65)
minimifacta Dyar	Trinidad	Dyar (45)
pallidostricta Dyar	Sao Paulo, Brazil	Dyar (45)
pedibarbata Dyar	St. Laurent, Maroni River, French Guiana	Dyar (45)
pedidocta Dyar	Cordoba, Mexico	Dyar (45)
saccharalis Fabricius	British Guiana	Bodkin (17)
	Australia	Jarvis (83)
saccharalis crambidoides Grote	Mexico; United States (Gulf States and lower Mississippi Valley).	Dyar (45)
saccharalis grenadensis Dyar	Grenada	Dyar (45)
saccharalis obliteratellus Zeller	Brazil; Paraguay	Dyar (45)
	Argentina	Rosenfeld and Barber (137)
saccharalis saccharalis Fabricius.	French Guiana; Cuba; Trinidad; Peru; Florida; probably Santo Domingo.	Dyar (45)
saccharalis tabernella Dyar	Canal Zone; Panama; Nicaragua	Dyar (45)
saccariphaga (*mauritella* Walker).	Ceylon; Mauritius	DeCharmoy (52)
strigipennella Dyar	Guiana; Brazil	Dyar (45)
venosata Walker (*striatalis* Snellen).	Java; Borneo	Van Deventer (166) Van der Goot (58), Hampson (65)
zeacolella Dyar	Southeastern United States	Dyar (45)
sp.	Philippines	On authority of Muir.

FOOD PLANTS.

Food plants other than sugar cane and corn are broom corn, Kafir corn, milo maize, sorghum (*Sorghum halepense*), Sudan grass (*Andropogon sorghum* var. *sudanensis*), Para grass, vetiver (*Andropogon muricatus*), and feather grass (*Lectochloa mucronata*). Bodkin (20) records rice as a food plant in British Guiana.

A large larva will almost fill the interior of a stalk of grass, but nevertheless will develop successfully.

The number of food plants, some of which grow wild about plantations, makes the species more difficult to control than if it were limited to corn and sugar cane, the larvæ being able to grow to maturity on wild grasses and the adults migrating to the corn and cane fields.

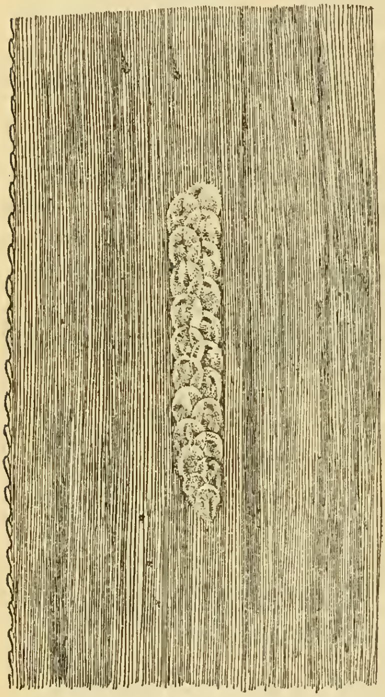


Fig. 2.—Cluster of sugar-cane moth-borer eggs nearly ready to hatch. Much enlarged.

SUMMARY OF LIFE CYCLE.

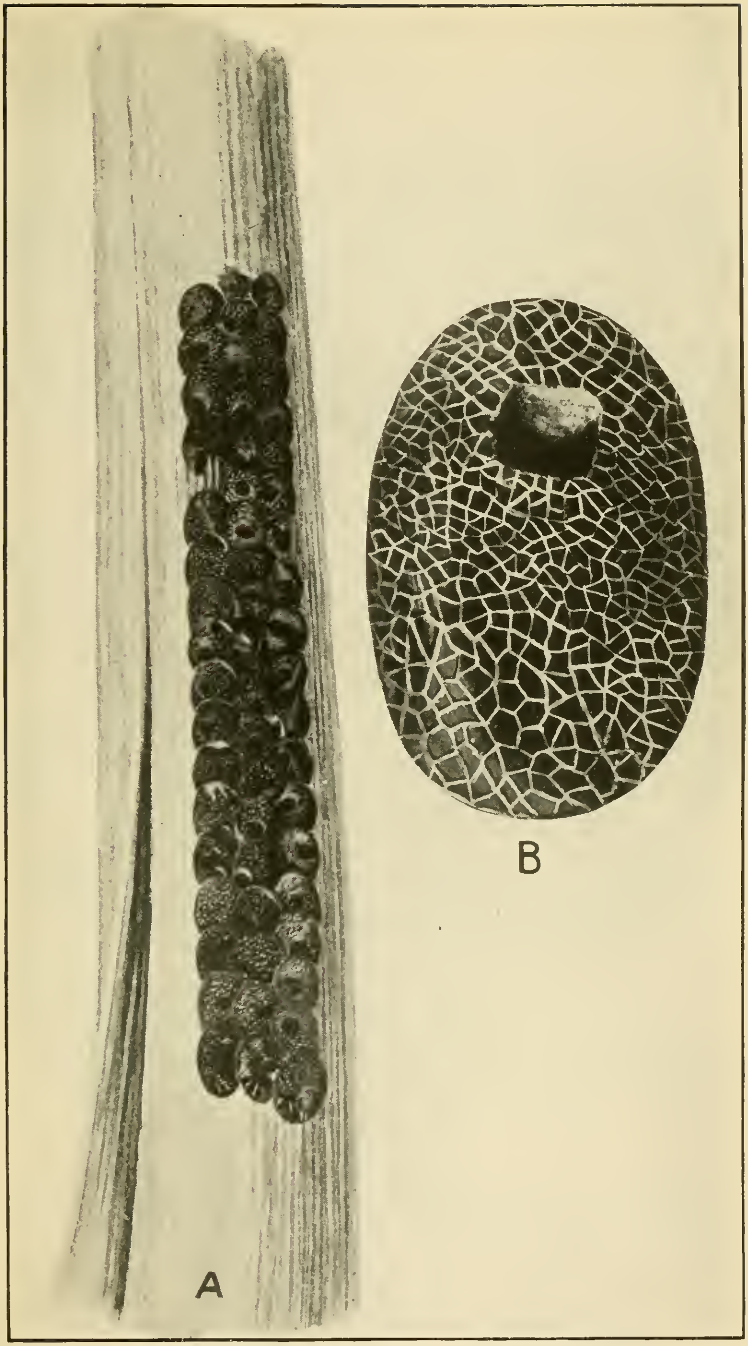
Emerging in the spring, the adult females deposit their eggs on the young plants of sugar cane, corn, etc. These eggs hatch, the young larvæ feeding here and there on the leaves for a short time and then boring into the stalks. After reaching their full development the "borers" pupate and in a few days the moths emerge. Eggs are again deposited, and the life cycle is repeated again and again until winter, during which the larval period is prolonged until spring. The overwintering larvæ then pupate, moths emerge and mate, and the cycle is repeated.

DESCRIPTIONS OF STAGES IN LIFE CYCLE.

THE EGG.

The eggs are round-oval, flattened, about 1.16 mm. long by about 0.75 mm. wide,[1] and are deposited in clusters. Beginning at the top of a cluster they overlap one another (see fig. 2), like scales on a fish. A group or cluster contains from 2 or 3 to 50 or more eggs. The clusters vary in shape as well as in size, a small one often being irregularly round, while the larger ones are much longer than wide—sometimes

[1] One millimeter is about one twenty-fifth of an inch.



PARASITIZED EGGS OF THE SUGAR-CANE MOTH BORER.

A.—Cluster of moth-borer eggs which have been parasitized. Much enlarged. Note dark appearance and emergence holes of parasites. B.—Individual parasitized egg, showing dark appearance and emergence hole of parasite. Very greatly enlarged.

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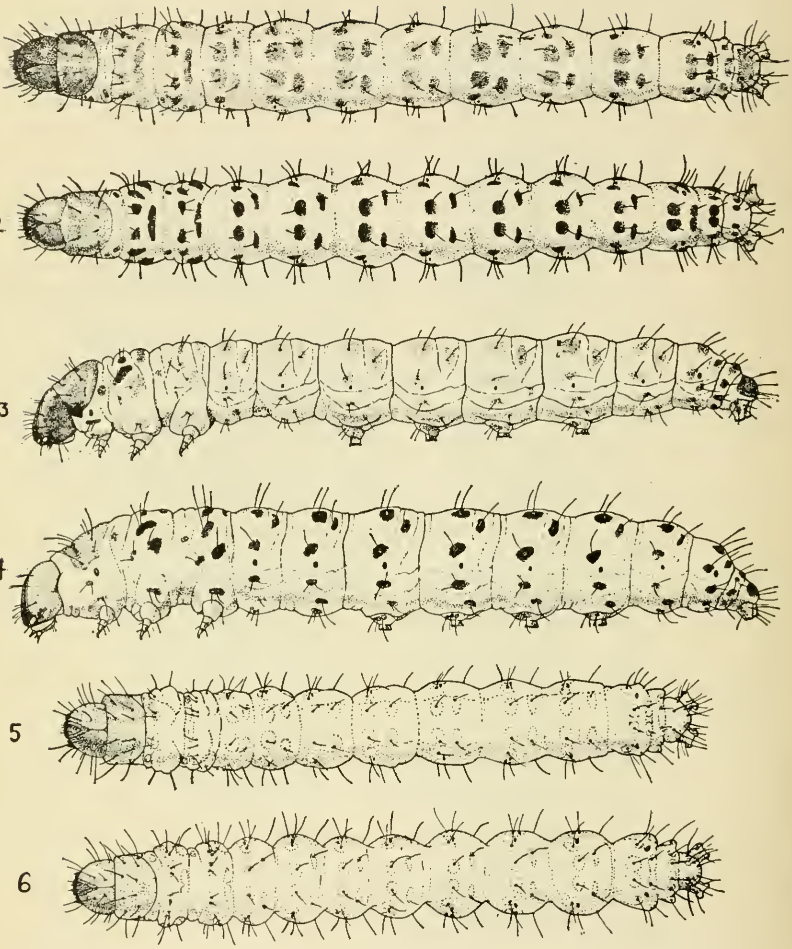
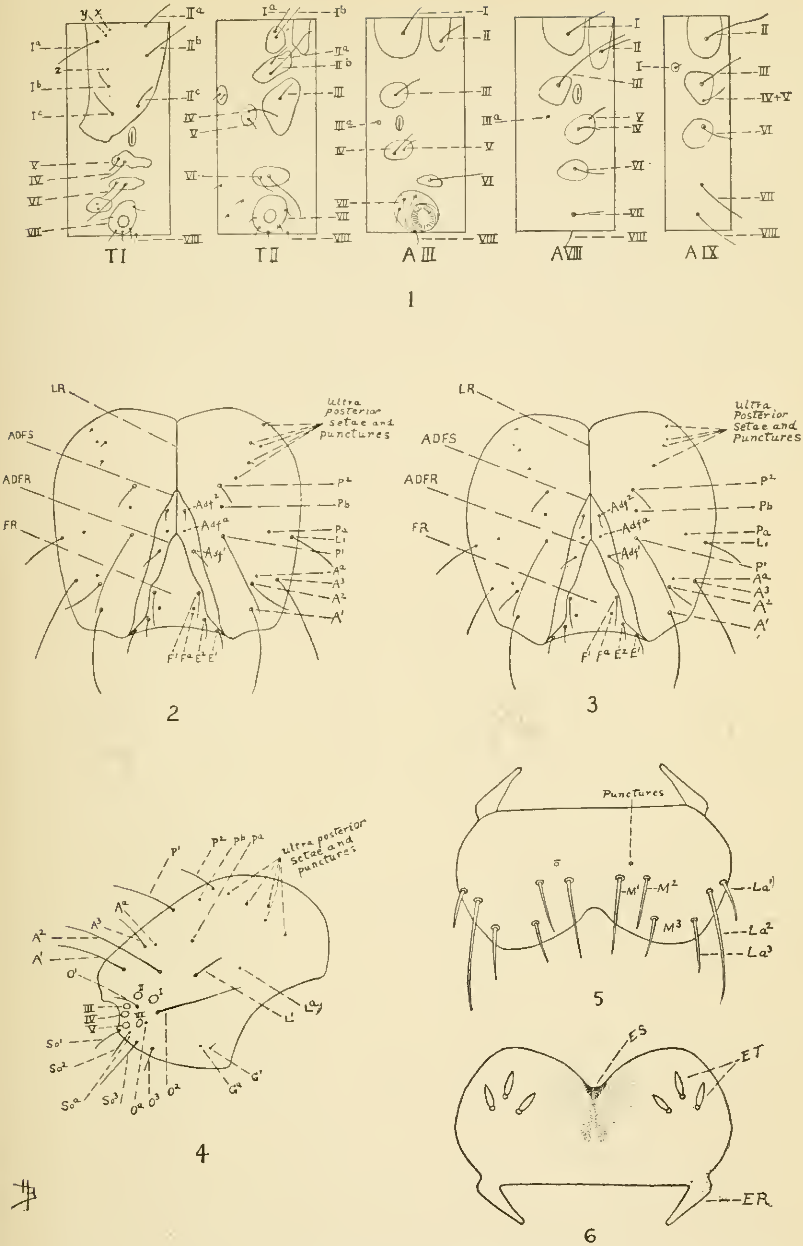


LARVAE OF THE SUGAR-CANE MOTH BORER AND THE LARGER CORN STALK-BORER.

FIG. 1.—The sugar-cane moth borer (*Diatraea saccharalis crambidoides*): Larva, summer form, dorsal view. FIG. 2.—The larger corn stalk-borer (*D. zeacolella*): Larva, summer form, dorsal view. FIG. 3.—*D. saccharalis crambidoides:* Larva, summer form, side view. FIG. 4.—*D. zeacolella:* Larva, summer form, side view. FIG. 5.—*D. saccharalis crambidoides:* Larva, winter form, dorsal view. FIG. 6.—*D. zeacolella:* Larva, winter form, dorsal view.



LARVAL DETAILS OF THE SUGAR-CANE MOTH BORER AND THE LARGER CORN STALK-BORER.

FIG. 1.—The sugar-cane moth borer (*Diatraea saccharalis crambidoides*): Larva, setal maps of body. FIG. 2.—*D. saccharalis crambidoides:* Larval head capsule, dorsal view. FIG. 3.—The larger corn stalk-borer (*D. zeacolella*): Larval head capsule, dorsal view. FIG. 4.—*D. saccharalis crambidoides:* Larval head capsule, lateral view. FIG. 5.—*D. saccharalis crambidoides:* Larval labrum. FIG. 6.—*D. saccharalis crambidoides:* Larval epipharynx.

more than 12 mm. long by 3 mm. wide. They are white at first, but later an orange hue develops. They are lightly sculptured with an irregular network of depressed lines which is visible with a microscope. This sculpturing resembles the "pebble grain" of leather. Just before hatching the black heads of the young larvæ are plainly visible through the eggshell, and the eggs assume a blackish hue.

Eggs may be deposited on either side of a leaf. The fresh ones are very difficult to find, their whiteness blending with the green of the cane or corn leaf. They are securely glued to the leaf surface and in nature are never detached before hatching. Having hatched, the empty shells become translucent white. The appearance of a cluster of eggshells from which the larvæ have emerged has been well likened to a fragment of cast snake skin.

When parasitized the eggs gradually turn jet black and remain so even with the emergence of the parasites. Because of their color, parasitized eggs are much more easily detected in the field than are the normal eggs. The holes made by the parasites in emerging are readily discernible. (Pl. II.)

THE LARVA.

The larva, which is the form of the insect most familiar to sugar planters, is about 1 inch long by one-eighth inch wide. In this form the insect commits its ravages. The head is brown and the body white with brown spots. This is the summer coloration of the larva, but in the winter it loses its spots and the body assumes a uniform dirty white.

Technical descriptions of both the winter and summer forms (full-fed larvæ) have been published elsewhere by the senior writer (75), and they have now been corrected by Mr. Carl Heinrich to conform to the latest knowledge of lepidopterous larval characters. His descriptions are given below.

General Characters.

No secondary hairs. Legs and prolegs normal. Crochets triordinal and in a complete circle. No anal fork. Prothoracic shield broad, divided. A narrow pigmented shield on mesothorax, caudad of setæ I*a* and I*b*, bearing no setæ. Spiracles elongate oval; prothoracic spiracle twice the size of those on abdominal segments 1 to 7; that on segment 8 slightly larger than prothoracic and slightly dorsad of other abdominal spiracles. (Pl. III, figs. 1, 3, 5.)

Body setæ (Pl. IV, fig. 1) moderately long; tubercles prominent, broadly chitinized; IV and V on abdominal segments 1 to 8 under the spiracle and approximate; prespiracular shield of prothorax narrow, horizontally elongate, bearing only two setæ (IV and V) situated ventro-cephalad of the spiracle, III of prothorax absent; group VI bisetose on prothorax, mesothorax, and metathorax;[1] IV and V united on abdominal segment 9 and approximate to III;

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[1] This is the Pi group of Fracker which he erroneously describes as unisetose in the Crambinae. See Fracker, S. B. The classification of lepidopterous larvæ. Illinois Biological Monographs, v. 2, No. 1. 169 p., 10 pl. 1915. (See p. 87, 91.)

III above the spiracle on abdominal segments 1 to 7, before the spiracle on abdominal segment 8; III*a* rudimentary or indistinguishable, before the spiracle on abdominal segments 1 to 7, ventro-cephalad of the spiracle on abdominal segment 8; group VII trisetose on abdominal segments 3 to 7, unisetose on abdominal segments 8 and 9; abdominal segment 9 bearing six prominent setæ in a nearly vertical line, I rudimentary or absent, when distinguishable it is latero-cephalad of II and equidistant from II and III; on the other abdominal segments II is slightly shorter than, and latero-caudad of I; setæ and punctures on prothoracic shield as follows: I*a*, *b*, *c* behind the frontal margin of the shield, distance separating I*b* and I*c* equal to that between II*a* and II*b*, II*a* dorso-caudad of I*a*, puncture *z* slightly lower than the level of II*b*, punctures *x* and *y* dorso-caudad of I*a*, distance between I*c* and II*c* slightly less than that between I*b* and I*c*.

Head capsule (Pl. IV, figs. 2, 4) spherical, slightly trapezoidal or broadly oval (nearly square) in outline viewed from above, as wide or a trifle wider than long; greatest width back of middle of head; incision of dorsal hind margin slight; distance between dorsal extremities of hind margin less than one-half the width of the head. Frons (FR) a trifle longer than wide, not quite reaching to middle of head; adfrontal ridges (ADFR) parallel from lower limit of epistomal area to point of juncture of tentorial arms, thence converging in slightly curved lines to the longitudinal ridge (LR); longitudinal ridge slightly longer than frons: adfrontal sutures (ADFS) meeting longitudinal ridge slightly behind middle of head. Projection of dorsal margin over ventral less than one-half the diameter of the head.

Ocelli six (Pl. IV, fig. 4); I larger and III smaller than the others; III and IV closer together than any of the others.

Epistoma (Pl. IV, figs. 2, 4) with the normal setæ (E^1, E^2).

Frontal punctures (Pl. IV, figs. 2, 4) (F^a) well separated; distance between punctures considerably greater than distance from puncture (F^a) to seta (F^1); distance from frontal seta (F^1) to seta Adf^1 about equal to distance separating adfrontal setæ (Adf^1 and Adf^2); Adf^2 well behind beginning of longitudinal ridge; puncture Adf^a equidistant from Adf^1 and Adf^2 and approximate to beginning of longitudinal ridge.

Epicranium (Pl. IV, figs. 2, 4) with the normal number of primary setæ and punctures and with three ultraposterior setæ and one or two ultraposterior punctures. Anterior setæ (A^1, A^2, A^3) in a right angle; A^2 equidistant from A^1 and A^3; anterior puncture posterior to A^2. Posterior setæ (P^1, P^2) and puncture (P^b) of posterior group lying parallel with longitudinal ridge; P^1 nearly on a level with beginning of longitudinal ridge; P^2 on, or nearly on a level with place of juncture of adfrontal sutures with longitudinal ridge; P^b between P^1 and P^2; P^a slightly nearer to L^1 than to any other seta, lying between L^1 and P^1. Lateral seta (L^1) remote from A^3, on a level with P^1; lateral puncture (L^a) directly posterior to the seta, remote. Ocellar setæ (O^1, O^2, O^3) well separated; O^1 equidistant from and ventrad of ocelli II and III; O^2 directly ventrad of and approximate to ocellus I; O^3 remote from and ventrad of O^2, nearer to SO^3 than to O^2; puncture O^a closely approximate to ocellus VI. Subocellar setæ (SO^1, SO^2, SO^3) triangularly placed; puncture SO^a equidistant from setæ SO^2 and SO^3. Genal puncture (G^a) anterior to seta (G^1).

Labrum (Pl. IV, fig. 5) with median incision moderately concave; setæ M^1, M^2, and M^3 triangularly placed; M^1 and M^2 nearly on a line with La^1; La^1 and La^2 closely approximate; M^3 and La^3 on a line; distance separating M^3 and La^3 about equal to that between M^2 and M^3; puncture equidistant from and slightly back of M^1 and M^2.

Epipharyngeal shield (Pl. IV, fig. 6) (ES) not sharply defined, merging in a broadly chitinized area on the central forward part of the labrum. *Epipharyngeal setæ* (ET) triangularly grouped, well behind anterior margin of epipharynx, moderately long, narrow, equidistant. *Epipharyngeal rods* (ER) indicated only by their prominent posterior projections.

Maxillulæ normal.

SPECIFIC DESCRIPTION.

Summer form (Pl. III, figs. 1, 3; Pl. IV, fig. 2): Head slightly trapezoidal in outline viewed from above; widest at the level of the posterior seta P^2; lateral and frontal margins nearly straight; posterior region broad, not constricted; ultraposterior setæ of epicranium forming a very obtuse angle, with the apex of the angle pointed to the longitudinal ridge (LR); color rich brown, varying to black at mouth parts and to orange on dorsal aspect. Prothoracic plate pale brown, tinged with black ventrally. Body white. Tubercles light brown or paler. Abdominal tubercles II oval and about twice as far apart as tubercles I. Setæ yellow to brown. Imaginary lines connecting setæ I and II of abdominal segments 3, 4, and 5 (text fig. 3, *a*) on each side, if prolonged, form angles averaging 30.2 degrees. Tubercle I on ninth abdominal segment discernible. Spiracles dark brown. Average length (10 specimens) 25.6 mm.

Winter form (Pl. III, fig. 5): Differs from the summer form in the following characters: Color yellow to rich brown, varying to black at mouth parts and to yellow on dorsal aspect. Prothoracic plate yellow. Body tubercles white or pale yellow and not easily distinguished from ground color of body. Spiracles dark brown, distinct and sharply contrasting with rest of body. Average length (10 specimens) 22.4 mm.

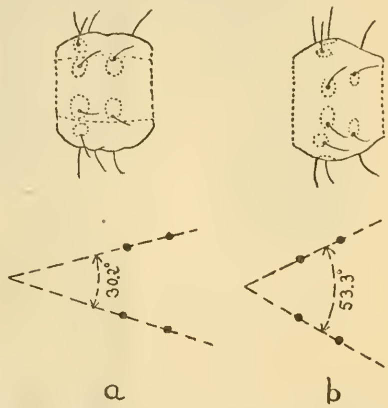


FIG. 3.—*a*, Fourth abdominal segment, dorsal view, of larva of sugar-cane moth borer (*Diatraea saccharalis crambidoides*), and diagram of angle formed by imaginary line through bases of setæ; b, same for larger corn stalk-borer (*Diatraea zeacolella*).

As the nearly related species *Diatraea zeacolella* is liable to confusion with *D. saccharalis crambidoides*, Mr. Heinrich has furnished the following descriptions:

SPECIFIC DESCRIPTION OF LARVA OF DIATRAEA ZEACOLELLA.

Summer form (Pl. III, figs. 2, 4): Head broadly oval, widest at the level of posterior puncture P^b; the lateral and frontal margins slightly but evenly rounded; posterior region slightly constricted, narrower than middle of head; ultraposterior setæ forming a very obtuse angle, with the apex of the angle pointed to the lateral margin. (Pl. IV, fig. 3.) Color yellow, varying to black at mouth parts. Prothoracic plate yellow. Body white. Tubercles dark brown, contrasting sharply with ground color of body. Abdominal tubercles II narrowed and about four times as far apart as tubercles I. Setæ yellow to brown. Imaginary lines connecting setæ I and II of abdominal segments 3, 4, and 5 (text fig. 3, *b*) on each side, if prolonged, form angles averaging 53.3 degrees. Tubercle I of ninth segment not discernible. Spiracles black. Average length (3 specimens) 25.2 mm.

Winter form (Pl. III, fig. 6): Differs from summer form in the following characters: Body tubercles white or pale yellow and not easily distinguished from ground color of body. Spiracles black, very distinct, and sharply contrasting with rest of body. Average length (4 specimens) 24.5 mm.

THE PUPA.

On molting for the last time the larva enters the pupa stage, the quiescent period of the insect. The pupa (fig. 4) at first is white, but soon changes to a dark brown. It is cylindrical in form and bears little resemblance to either the larva or the moth. The following technical description has been written by Mr. Carl Heinrich:

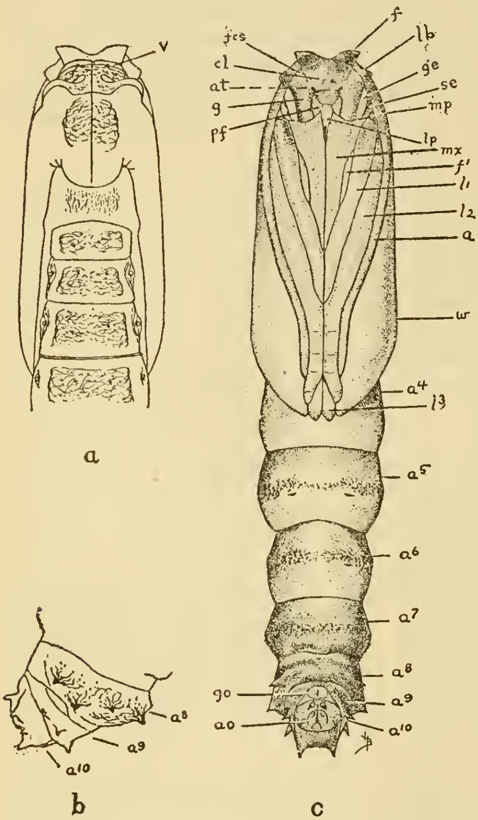


FIG. 4.—Pupa of sugar-cane moth borer: *a*, Dorsal view of anterior portions; *b*, lateral view of anal segments; *c*, ventral view of entire pupa.

GENERAL CHARACTERS.

Elongate; slender, pilifers well developed; maxillary palpi present; prothoracic and mesothoracic legs not extending cephalad between sculptured eyepiece and antenna; sculptured and glazed eyes, labrum, frontoclypeal suture, and invaginations for anterior arms of tentorium clearly indicated; front extended upward into two hornlike projections; maxillæ prominent, only half the length of the wings; wings extending to midventer of fourth abdominal segment; mesothoracic legs not extending to end of wings; metathoracic legs extending to, or a trifle beyond, tips of wings; femora of prothoracic legs clearly indicated; antennæ not reaching tips of wings; body roughened but without hooks or prominent setæ; cremaster absent; posterior end broad; tubercles of the eighth, ninth, and tenth segments developed into stout, sharp, thornlike projections; dorsum of prothorax, mesothorax and metathorax and the first nine abdominal segments rugosely scobinate; on segments 5, 6, 7, and 8 of the abdomen the scobinations form a median band encircling each segment; a deep furrow on dorsum separating ninth and tenth abdominal segments; genital opening single and slitlike in both sexes; anal opening a slit terminating in two short lines (|⋏); spiracles elongate, oval, moderate, easily distinguishable.

SPECIFIC DESCRIPTION.

Sixteen to 20 mm. long; yellow or yellowish brown, darkest at caudal and cephalic ends; the front, clypeus, scobinate areas, and enlarged abdominal tuber-

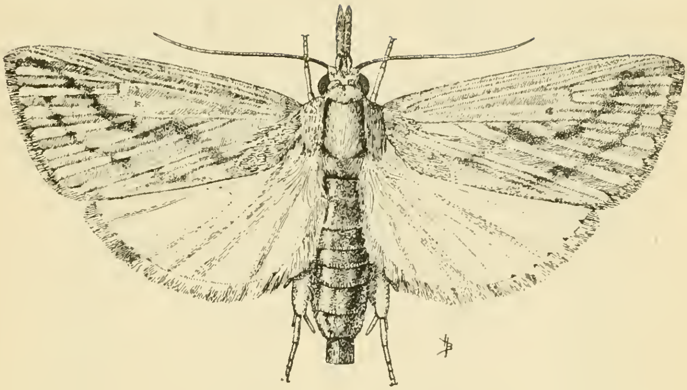


FIG. 1.—ADULT MALE.

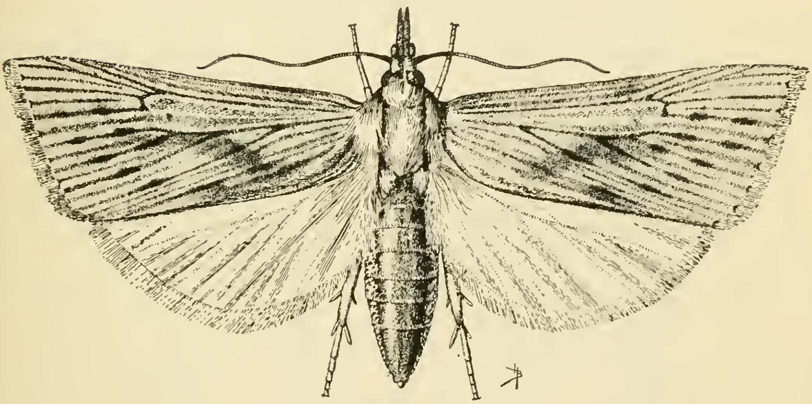
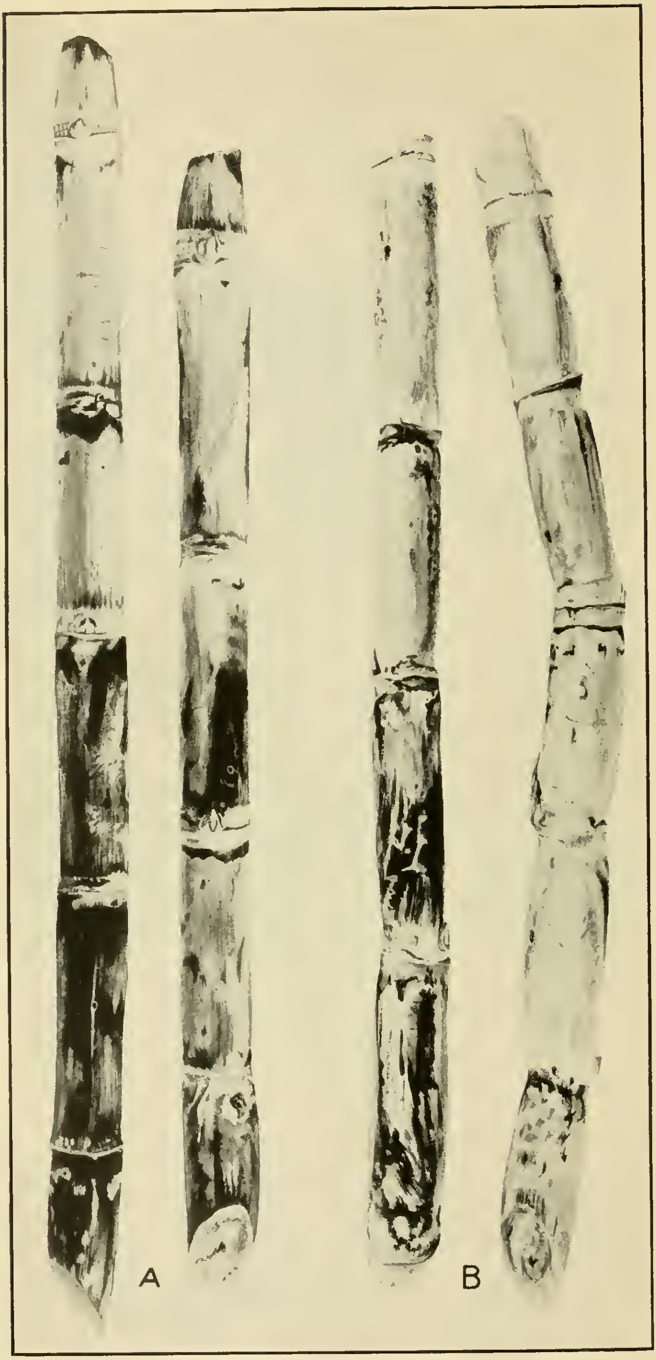


FIG. 2.—ADULT FEMALE.

THE SUGAR-CANE MOTH BORER (DIATRAEA SACCHARALIS CRAMBIDOIDES).



MATURE STALKS OF SUGAR CANE, SHOWING EMERGENCE HOLES OF MOTH BORER.

A.—Variety "Louisiana Purple." B.—Variety "D 74."

cles dark brown, in some specimens almost black; thornlike tubercles of abdominal segments 8, 9, and 10 stout and very prominent.

THE ADULT.

The adult (fig. 5; Pl. V) is a straw-colored moth, the forewings marked with darker lines. It varies in size, average specimens measuring about an inch across the wings.

FIG. 5.—The sugar-cane moth borer: Adult with wings folded.

In his article, "The American Species of Diatraea Guilding," Dr. Harrison G. Dyar (45) describes the moth as follows:

Diatraea saccharalis Fabricius.

This species is divisible into a number of well-marked geographical forms. Two of them occur in the United States. The typical *saccharalis* reaches us by the way of the West Indies and occurs in Florida. The race *crambidoides* Grote comes from Mexico and occurs in the Gulf States. . . .

Diatraea saccharalis crambidoides Grote.

Chilo crambidoides Grote, Can. Ent., XII, 15, 1880.

? Crambus lineosellus Walker, Cat. Brit. Mus., XXVII, 162, 1863.

In this form the front is roundedly prominent, slightly projecting above the eyes, but without cone or tubercle. The male has the hind wings dusky, those of the female are white. The wings are narrow, outer margin oblique, apex pointed. The male is brownish ochre in color, the female straw yellow; the two rows of brown dots are distinct in both sexes.

Range: Mexico, numerous localities, Gulf States, and lower Mississippi Valley.

Grote's *crambidoides* was described from Kansas, so there can hardly be any doubt of the application of the name. Walker's *lineosellus* was described from Honduras, whence I have no material. If the names shall be found to refer to the same form, Walker's name would have priority.

INSECTARY METHODS.

Experiments with the sugar-cane moth borer were conducted at New Orleans in a room open on all sides, wire screen taking the place of walls and allowing free access of air and moisture.

Cylindrical cages of wire screen were used for the adults. Shortly after emergence the moths were transferred to these cages, which were made by sewing together with wire the edges of pieces of ordinary window screen, these pieces being cut of such a size as to form cages about 7 inches high by 6 inches wide. Some of the horizontal strands of wire were pulled off the top and pieces of cheesecloth were stretched across so that the exposed ends of the vertical wires would extend through the cloth, thus holding it firmly in place. These cages were placed over saucers of damp sand, and the adults were supplied with young cane or corn leaves in tubes of water for oviposition. The females laid eggs readily on the leaves and also on the sand and the sides and tops of the cages.

The leaves with the masses of eggs were then transferred to specimen jars about 3½ inches wide by 12 inches high, covered with cheesecloth. On hatching, fresh food was supplied as needed, and the young larvæ were allowed to remain until after the first molt, when they were transferred to individual tubes. These were about half an inch in diameter by 7 inches long, made by breaking ordinary glass tubing. One larva, with pieces of fresh stalks of cane or other food plants, was placed in each tube, the ends of which were firmly plugged with cotton batting. A number of tubes were placed in a cigar box, the dark interior of which was somewhat similar in degree of illumination to the interior of a cane plant. The actions of the larvæ were easily observable through the glass. The tubes were very easily cleaned by forcing a wad of cotton through them from end to end with a rounded stick or plunger.

The pupæ were placed on damp sand under ordinary drinking glasses.

Temperature and humidity apparatus used in the experiments were maximum and minimum thermometers, sling psychrometer, and recording hygrothermograph.

LIFE HISTORY.

MOTH.

EMERGENCE.

The moth, or adult, emerges from the pupa, which is in a stalk of cane, corn, or other food plant, easily breaking the threads of silk spun by the larva in the tunnel, and forcing its way through the side of the stalk by breaking a thin membrane of plant tissue left by the larva for its ready emergence when it should reach the adult stage. The emergence holes are shown in Plate VI. On emerging the wings are still close to the body, and the moth rests on a convenient leaf or stalk for some time to allow them to expand.

PROTECTIVE HABITS.

An adult of the moth borer is very seldom seen, even in the fields of an infested plantation. The moths fly at night and hide among the corn or cane leaves in the daytime, moving only if disturbed. As they are small and of a light-brown color, similar to the dead leaves of cane or corn, they are not readily observed at any time.

The eggs, which are deposited on the leaves of food plants, blend with the leaves and can be found only with difficulty. The entire pupal period, with most of the larval period, is spent in the burrows formed in the stalks, and in this protected situation the borers are safe from birds and most predacious insects.

FERTILIZATION.

The mating of the moths undoubtedly occurs at night, but it has not been observed by the writers. Pairs of moths were placed in small cages made of wire screen and cheesecloth and examined during the evening and at intervals through the night, but the moths were never found in copula. Examinations were begun as early in the evening as 5.40 p. m.,[1] and were continued on one night at short intervals until 11.20 p. m., with three more observations at 2.50, 3.05, and 5.45 a. m. On another night examinations were made at 5.40, 6.40, and 9 p. m., at 11.45 p. m. to 12.30 a. m. (continuously), at 1.35 to 1.50 a. m. (continuously), and at 2.15, 3.50, and 7.15 a. m.

OVIPOSITION.

In ovipositing the female stands on a leaf with the head upward. She feels about on the leaf with the extended ovipositor and then deposits one egg, pressing it down and flattening it against the leaf with the end of her ovipositor, the egg adhering to the leaf like a tiny fish scale. Then she moves the ovipositor down or to one side,

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[1]All references to clock time refer to Standard Time.

and another egg is deposited, part of it extending over a portion of the surface of the first egg. More eggs are deposited in the same way, the female gradually moving downward and backward, so that she stands over the slowly enlarging cluster. As the eggs overlap, one being deposited partly over the other, the completed cluster more than ever resembles a group of fish scales (see Pl. II).

In this action the moth is very quiet, her wings folded, antennæ back, and legs apart. She keeps the tip of her ovipositor pressed against the leaf continuously, making it difficult for an observer to ascertain the exact time any one egg is deposited. During the action she raises the body "on tiptoe," relaxing and resting against the leaf at intervals. One cluster of 6 eggs was formed in 16½ minutes, and another moth laid 34 eggs in 8 minutes.

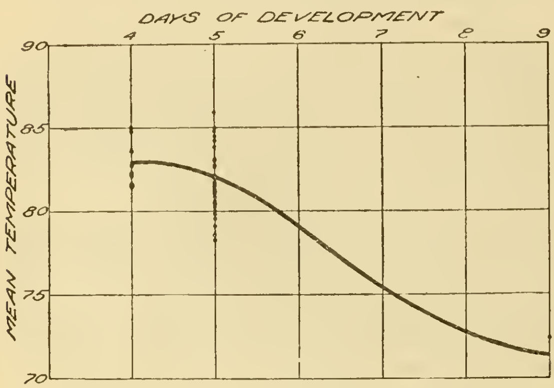

FIG. 6.—Diagram showing relationship of mean temperature to length of egg period of the sugar-cane moth borer, and indicating line of calculated means. The dots represent period means of individuals.

Oviposition is begun at dusk and continues throughout the night, the female flying and walking occasionally. Many clusters of different numbers of eggs may be formed in the same night. Individuals deposit eggs during one, two, three, or four nights, never longer. Oviposition is extended over several nights in cooler weather. Males in the same cage with egg-laying females are indifferent, paying no attention to their mates.

EGG.

DURATION OF THE EGG STAGE.

The duration of the egg stage has been found to be from 4 to 9 days, depending on the temperature, with the average for the year a trifle over 5 days. These results have been obtained from experiments in the insectary, but it is probable that greater variations between the minimum and the maximum periods occur in the field. The period of incubation has been lengthened to 12 days by placing the eggs in an ice box and it is likely that they will stand even greater retardation without being killed. The temperature in the ice box was not very low and eggs laid in the early spring or late fall would probably require as long to hatch. The average length of the egg stage at the prevailing temperatures during the different months is shown in Table III and is graphically illustrated in figure 6.

TABLE III.—*Relationship of mean temperature to the developmental period of the sugar-cane moth borer in the egg stage.*

Period.	Average mean temperature.	Number of records.	Period.	Average mean temperature.	Number of records.
Days.	° *F.*		*Days.*	° *F.*	
4	82.8	10	7	75.2	1
5	81.7	41	8	72.1	1
6	78.9	7	9	72.4	1

DEVELOPMENT.

When the eggs are first deposited they are creamy white, and in a field of cane are practically invisible against the light green of the cane leaves. They gradually darken until they are reddish brown, with the eyes of the embryo showing through as two small black spots. Later the head turns black and the eyes can not be distinguished, but the segments of the larva are discernible. The head seems to fill the whole egg cavity and gives to the egg mass a bluish-black cast. Just before hatching the larva can be seen moving within the eggshell.

HATCHING.

Hatching usually occurs in the early morning during the summer, and later in the day in cooler weather. Observations indicate that all eggs in a given cluster hatch within a few hours. The larva emerges from the egg by rupturing the upper surface, leaving it torn and ragged but without altering the arrangement or position of the egg in the cluster. The empty eggshells are papery and almost transparent, but they show a slight marking under the microscope. The cluster of eggshells adheres to the leaves for some time before being washed away by rains, and is more conspicuous at this period than it is before hatching.

While no definite record has been maintained of the percentage of eggs which hatch, it is only occasionally that one or two in a cluster from a fertilized female fail to produce larvæ. Eggs from unfertilized females do not hatch.

LARVA.

FOOD HABITS.

The larvæ are active from the time of hatching and almost immediately begin their search for food. Those from a single group of eggs congregate in the terminal buds of two or three plants in the immediate vicinity of the place where hatched and begin feeding at once. They are active and can move about and lower themselves with silken threads, but they do not seem to travel far from the place of hatching. They go well down into the "bud" or whorl of the plants, where they are protected from bright light and from possible enemies, and they suffer no harm if, as is frequently the case, the bud is full of water. Young larvæ have often been observed to crawl down into a bud which was completely submerged and feed for several hours under water without any apparent discomfort. Some of them at first eat only the epidermis from one side of the leaf, causing a yellowish blotch, but a little later they burrow through the leaves while these are still unrolled. As one leaf is thus pierced in a number of places at once a row of holes arranged horizontally will be seen when it expands. Very often the larvæ burrow into the midrib, following a zigzag course for several inches along its length. They can be seen very plainly by holding the infested leaves up to the light. The larvæ usually leave the buds or the midribs after the first molt and crawl down between the leaf sheaths and the stalk, some of them entering the stalk immediately and others feeding for a day or two, or until after the second molt. It seems that the larvæ feed longer outside the stalks on old cane than on young plants. The species of Diatraea which occurs at Phoenix, Ariz. (*D. lineolata*), has been observed to spend its entire larval and pupal periods in the midrib.

The larvæ feed either up or down from the place of entrance, but usually upward, producing a winding burrow or tunnel a foot or more up the stalk. The burrows may be branched or two or more may unite, forming a network of tunnels in a badly infested stalk. The tunnels are quite small at first, but they are enlarged as the larvæ increase in size until they are one-eighth to one-fourth inch in diameter, allowing the larvæ to move about and turn round with freedom. The frass is packed loosely behind the larvæ, seldom completely closing the passages. The burrows usually become infested with the red-rot fungus within a short time, causing the surrounding tissue to turn red, the discoloration often extending for several inches beyond the burrow (see frontispiece).

CANNIBALISM.

When larvæ are confined in cages in the insectary they are cannibalistic, especially in the smaller stages. If 200 or 300 newly hatched larvæ are left together they will be reduced to 40 or 50 within two or three days. The smaller ones are usually eaten by the larger when larvæ of different stages are confined together, though full-grown ones also are attacked. It seems that the larvæ usually are attacked when they are weak or inactive, especially just before or after molting. Three or four larvæ often are found living in the same stalk of cane, but in these cases they are more or less separated by their burrows, and it is not likely that large larvæ are eaten by others under field conditions, where they have freedom of action, whereas the habit of small larvæ of congregating in the terminal buds of the plants is very conducive to cannibalism, and many doubtless are destroyed by their companions.

GROWTH.

The rate of growth is dependent upon many external conditions, the temperature and kind of food being the most important factors,

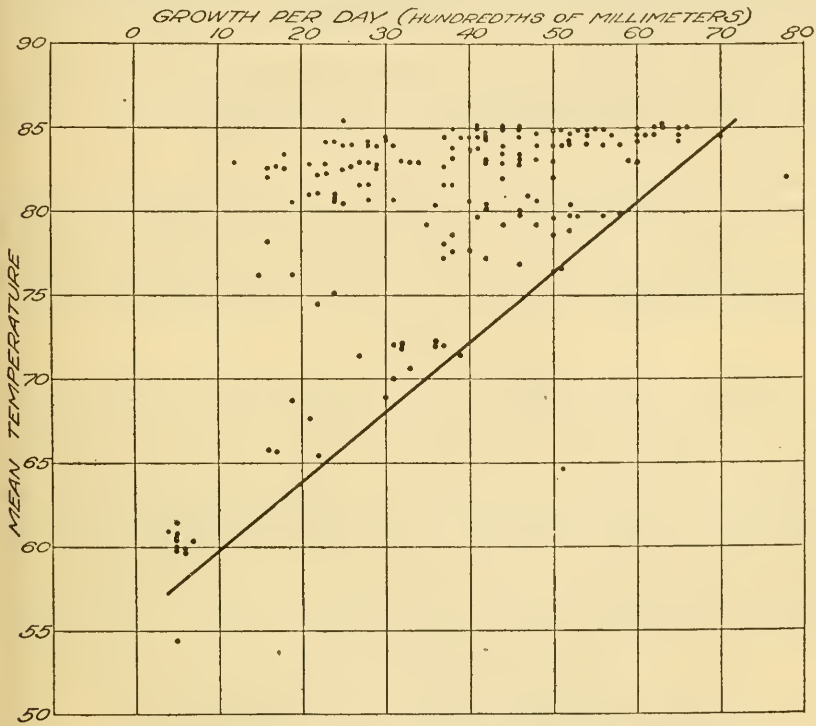

FIG. 7.—Diagram showing relationship of mean temperature to larval growth of the sugar-cane moth borer per day in hundredths of millimeters, showing line of maximum growth of normal individuals. The dots represent growth of individuals in hundredths of millimeters.

but larvæ feeding under similar conditions show a great variation in the rate of development and in the length of the larval period, as is shown by figure 7. Under favorable conditions the rate of increase in body length is about 0.75 mm. per day, but it is often much less. Larvæ are from 1.5 to 2 mm. long when hatched and from 25 to 30 mm. long when fully grown.

MOLTS.

Before molting the larvæ stop feeding for a few hours or sometimes longer and appear stiff and helpless. The skin then ruptures just back of the head, and by a series of contractions and contortions it is worked back over the body. Sometimes the head capsule is cast before the skin and at other times not until afterwards, but usually it is cast during the process of molting. The capsule is worked loose by the movements of the body and is deposited at one side.

The freshly molted larvæ are white and almost colorless, or show faintly purplish markings running the length of the body. The head is white and soft when first molted, but it turns mahogany brown in a few hours and the markings deepen. Rosenfeld and Barber (137) say that the color of the protective fluid secreted by the larvæ is determined by the color of the head and that the fluid is white in freshly molted larvæ.

The whole process of ecdysis requires about 15 minutes. The larvæ then turn, eat the discarded skin, and recommence feeding on the cane.

Ordinarily there are 5 molts, but sometimes there are only 4 in rapidly-developing larvæ. More than 5 are fairly common, as many as 14 having been observed in hibernating larvæ. When the larval period is prolonged by low temperature or other conditions, the larvæ continue molting, with little or no increase, or even a decrease, in size.

INSTARS.

The period from hatching until the first molt is called the first instar. Between the first and second molts the period is known as the second instar, and so on until the larva reaches the pupa stage. The last instar is the period between the last larval molt and the beginning of the pupal period. The number of instars has been found to be from 3 to 10, with 5 as the most common number. The number in relation to mean temperature is shown in Table IV.

TABLE IV.—*Relationship of mean temperature to the number of instars of the larva of the sugar-cane moth borer.*

Number of instars.	Average mean temperature.	Number of records.	Number of instars.	Average mean temperature.	Number of records.
	° *F.*			° *F.*	
3	74.8	14	7	78.9	18
4	80.3	65	8	69.8	11
5	81.1	102	9	68.8	8
6	82.2	50	10	65.5	4

DURATION OF LARVAL PERIOD.

The larval period is the most variable of all the stages in the life history of this insect, as it is this stage which is prolonged by hibernation or adverse conditions. The first molt takes place from 3 to 6 days after hatching, when the larvæ are from 2 to 4 mm. long. From 4 to 8 days are spent in the second instar, and during this period the larvæ attain a length of from 6 to 9 mm. The third instar is somewhat longer and requires from 6 to 9 days, the larvæ reaching 10 to 15 mm. in length, while the fourth instar lasts from 4 to 6 days, at the end of which the larvæ are 15 to 20 mm. long. From 3 to 6 days are spent in the fifth instar, and the larvæ attain a length of from 20 to 30 mm.

The usual time required for the larva stage under favorable conditions is from 25 to 30 days in summer and from 30 to 35 days in the cooler weather, but it may be much longer. Larvæ from the same mass of eggs and reared under exactly the same conditions vary a great deal, and some of them require two or three times as long as others to pupate. Under the most favorable conditions the larval period has been as short as 18 days, and has varied from this to 276 days for hibernating larvæ. The larvæ are very adaptable in this

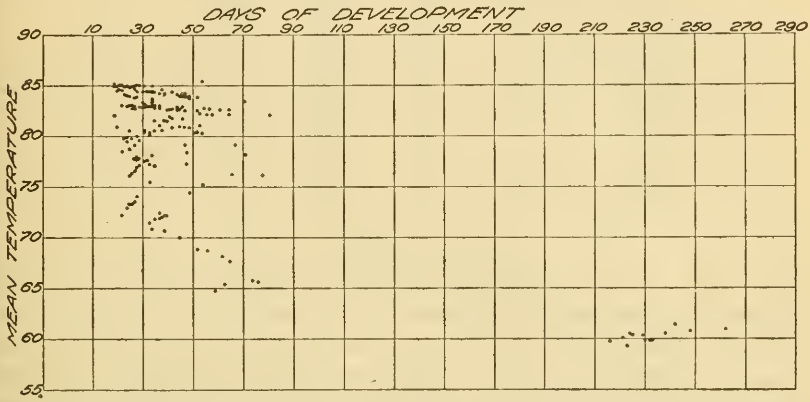

FIG. 8.—Diagram showing relationship of mean temperature to length of larval period of the sugar-cane moth borer. The dots represent period means of individuals.

way and can pass over periods of cold or food shortage without serious inconvenience. Typical life histories at different seasons of the year are shown in Table V and figure 8.

TABLE V.—*Relationship of mean temperature to developmental period in larva stage of the sugar-cane moth borer.*

Mean temperature.	Average period.	Number of records.	Mean temperature.	Average period.	Number of records.
°*F.*	*Days.*		°*F.*	*Days.*	
59.4	246.5	2	78.7	25	1
59.6	216	2	79.1	42	4
59.8	232.5	5	79.5	24	1
60	221	1	79.6	29	1
60.3	225	1	79.7	26	1
60.4	224	1	79.8	23.5	2
60.5	233	2	79.9	23	1
60.7	248	1	80	28	1
60.9	262	1	80.1	33	1
61.4	242	1	80.3	48.5	2
65.3	63	1	80.4	31	1
65.6	76	1	80.5	57	3
65.7	74	1	80.6	38	1
67.6	65	1	80.7	49	1
68.7	56	1	80.8	42	1
68.8	52	1	80.9	46	1

TABLE V.—*Relationship of mean temperature to developmental period in larva stage of the sugar-cane moth borer*—Continued.

Mean temperature.	Average period.	Number of records.	Mean temperature.	Average period.	Number of records.
°*F.*	*Days.*		°*F.*	*Days.*	
70	45	1	81	45	2
70.6	39	1	81.5	35.1	7
70.8	34	1	81.7	46	1
71.4	33	1	82	50	2
71.7	35	1	82.1	65	1
71.9	37	1	82.2	54.5	2
72	38	2	82.4	52	1
72.1	38.5	2	82.5	57.6	3
72.2	22	1	82.6	42.5	6
72.3	37	2	82.7	40.4	5
72.9	24	1	82.8	36	12
73.3	25.8	5	82.9	31.1	19
73.5	27	1	83	24.3	6
73.9	28	1	83.1	31	1
74	39	1	83.3	71	1
74.4	49	2	83.4	34	1
75.1	54	2	83.7	34	2
75.4	33	1	83.8	32.8	7
76.1	60.3	2	83.9	38.8	10
76.2	66	2	84	24	3
76.3	26	1	84.1	45.5	4
76.5	27	1	84.2	29.7	8
76.8	28	1	84.3	38.5	2
77.1	32	2	84.4	29.6	9
77.2	38	2	84.5	20.5	9
77.5	31	1	84.6	25.5	5
78	34	1	84.8	25.5	2
78.1	71	1	84.9	26.2	13
78.2	28	3	85	25	8
78.3	48	1	85.1	19	1
78.5	22	1	85.4	54	1

PUPAL CELLS.

When the larvæ are fully grown they construct a kind of pupal cell before pupating. The larval tunnel is cleaned, enlarged, and extended to the rind of the cane, where a small circular opening 4 to 5 mm. in diameter is made. The rind is not completely cut out, but it is eaten away from the inside until only a thin paperlike section, lightly attached at the edges, remains. This is held in place by threads of silk fastened to the inside so that the moth can easily escape, but other insects can not enter. The lower end of the cell is closed with frass and silk, and the whole cell is lightly lined with silk. In the rearing tubes in the insectary the pupal cell usually is formed on the side of the cane between it and the sides of the glass.

PREPUPA.

As the pupal cell nears completion the larva merges into the prepupa stage. No molt occurs, but the larva ceases feeding and becomes sluggish and helpless. The body contracts longitudinally, especially the thorax, while the use of the legs is lost and the insect thrashes about as do the pupæ. From 1 to 3 days are spent in the prepupa stage, but it often happens that this stage is not noticed by an observer, as it is not very distinct from the larva stage.

PUPATION.

After resting for a short time as a prepupa the pupa is disclosed by the casting of the last larval skin in the same manner as the others are cast.

PUPA.

The pupa at first is dirty white, about the same color as the hibernating larva, with faint purplish longitudinal stripes. It gradually hardens and darkens, and in an hour or two becomes mahogany brown. As the time for emergence approaches the pupa darkens more and may become almost black.

ACTIVITY.

The pupa is quite active when disturbed, being able to thrash about with its abdomen, which gives it a rolling, squirming motion. A touch or a jar will cause this action, as will also the placing of the pupa in direct sunlight in summer. Placed in the sun, a pupa squirmed about till it reached a shady place.

DURATION OF PUPAL PERIOD.

The first pupæ in the spring are formed from overwintering larvæ in April or May, and pupæ may be found from this date to December. Few larvæ pupate after the middle of November, those which have not pupated prior to this time hibernating as larvæ. Nearly 200 larvæ were collected in cane cut for the mill on December 2–4, 1915, but no pupæ were found in all the stalks cut open. Adults have emerged from pupæ in the insectary as late as December 5, but a large percentage of those which did not pupate until late and had the pupal period prolonged by cold did not emerge.

The pupal period, like that of the larva, has a wide variation, from 6 to 22 days being required for the emergence of the adult, with an average of 8½ days throughout the year. The pupæ which produced male moths required on an average 8.8 days for emergence, and those which produced females 8.4 days. Often there is a variation of 2 to 3 days among pupæ which transform on the same date. The data are presented in Table VI and figure 9.

TABLE VI.—*Relationship of mean temperature to the developmental period in the pupal stage of the sugar-cane moth borer.*

Period.	Average mean temperature.	Number of records.	Period.	Average mean temperature.	Number of records.
Days.	° *F.*		*Days.*	° *F.*	
5	77.1	3	13	71.6	1
6	82.3	27	14	79.7	7
7	81.1	153	15	73.9	5
8	81.3	92	16	77	5
9	80.9	42	17	72	1
10	76.6	19	18	69.8	1
11	76.1	12	19	84.6	3
12	74	4	22	63.7	1

DURATION OF THE LIFE CYCLE.

The length of the life cycle varies considerably with the temperature. Taking the minimum of each immature stage, the sum of 28 days is obtained, while in the same way a maximum of 293 days is secured. The sum of the periods required by most individuals in the various stages is 43.1 days, which may be regarded as an average. The maximum larval period is 262 days and only occurs in hibernating larvæ.

SEASONAL HISTORY.

SEASONAL ABUNDANCE.

NUMBER OF BROODS OR GENERATIONS.

The variation in the time required for the development of the moth borer is so great that there are no distinct broods or generations. It is found that some larvæ require three or four times as long to reach the adult stage as others hatching from eggs laid at the same time,

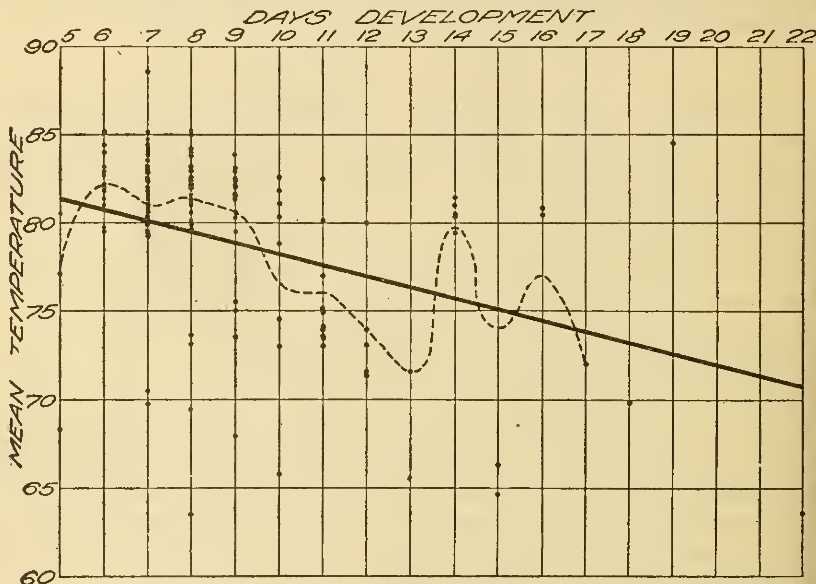

Fig. 9.—Diagram showing relationship of mean temperature to length of pupal period of the sugar-cane moth borer, showing line of calculated means (dashes) and general trend of means (solid line). The dots represent period means of individuals.

and this causes such an overlapping that the broods can not be distinguished.

The time of emergence of the moths in the spring varies from year to year, depending on the season. The earliest record is of a first-instar larva collected on cane in the field on May 5, 1914, and as the eggs require from 6 to 7 days incubation at this season the moth must have emerged during the last few days of April. The first emergence in the insectary was not until May 8, and emergence continued until May 25. Adults emerged from cane planted in boxes of soil as late as June 21. A pupa from the spring brood of borers was found in a "dead heart" on June 2, 1914. Thus adults from the hibernating larvæ and adults from the first spring generation are emerging at the same time. This overlapping continues until by midsummer the broods can not be separated.

The maximum number of generations may be computed by taking the first eggs laid by each generation and assuming that they would develop under optimum conditions, thus reaching the adult stage in the shortest time possible at the prevailing temperature:

The first eggs in the spring, laid by adults from the hibernating larvæ, would hatch by May 1 and the adults appear by June 10.

Adults of the first generation would lay eggs June 11, and these would produce adults on July 24, after 43 days.

Adults of the second generation would lay eggs on July 25, and these would produce adults on September 1, after 38 days.

Adults of the third generation would lay eggs September 2, and these would produce adults on October 8, after 36 days.

Adults of the fourth generation would lay eggs on October 9, and these would produce adults on November 18, after 40 days.

Adults of the fifth generation would lay eggs on November 18, and the larvæ would hibernate and emerge in the spring.

On the other hand, it is equally possible for two generations to span the entire year, if we take the last to emerge from hibernation and allow them the maximum time for completing their life cycle. The latest record of emergence is June 21, 1914, and a moth emerging then would not oviposit before June 22 or 23. Eggs laid in the insectary June 25, 1914, required 90 days to complete their cycle, the adults not emerging until September 23. Larvæ hatching the latter part of August or in September frequently hibernate, so it is evident that the whole year could easily be taken up by two generations.

These data are based on rearing notes in the insectary and on observations in the field. While first-instar larvæ have been found in the fields from May 5 to the middle of December, and adults have emerged in the insectary in December, it is seldom, if ever, that the maximum number of generations are produced in the field. Most of the larvæ reared in the insectary have required from one and a half to two or more times the minimum length of time necessary to complete their life cycle, and there are usually only four, seldom five, generations. If the spring is early and other conditions favorable, there may be five generations, but if the spring is late and cold, as it was in 1915, there will be only four. In the Rio Grande Valley there is no true hibernation, although the stages are prolonged somewhat in winter, and in Cuba they are more nearly the same all the year around.

POSSIBLE ANNUAL PROGENY OF ONE PAIR.

It is on account of its rapid rate of reproduction that the borer is able to inflict enormous damage. As almost all the larvæ are killed in the fall by grinding the cane, and as there is a high mortality among those which escape and hibernate, it is evident that comparatively few emerge in the spring. Yet there is always a heavy infestation by fall. The rapidity of reproduction during the warm months is the only factor which can account for this high infestation.

The record of oviposition for 56 moths at various times during the season of activity shows that each female moth deposits on an average 210 eggs. The sexes are produced in equal proportions. Allowing 200 eggs for each female and four generations a year as a conservative estimate, it is found that each pair surviving the winter is capable of producing the following numbers:

Generation.	Borers.
First	200
Second	20, 000
Third	2, 000, 000
Fourth	200, 000, 000
Total	202, 020, 200

Of course this maximum number will never be produced, because of the numerous checks which control the insect, but something of its enormity may be realized by considering that if the offspring of one female were confined to 1 acre there would be over 10,000 borers per stalk of cane, about 20,000 stalks being the average per acre. Under average conditions about 50 per cent of the stalks are infested and about 25 to 30 per cent of the infested stalks contain borers when cut for the mill, giving from 2,500 to 3,000 borers per acre. Considering the possibilities, it is only surprising that the infestation is not much higher.

PROGRESS OF INFESTATION.

The moth borer is late in developing in the spring. The first "dead heart" at New Orleans is usually found about the 1st of May, which indicates that moths have emerged from hibernation several weeks previously. Not much injury can be found through the summer, but the numbers of borers gradually increase. When the cornstalks become dry in July and August the emerging moths undoubtedly migrate to sugar-cane fields in large numbers. The infestation increases rapidly from about this time until the cane is cut for grinding.

STATUS EXAMINATIONS.

Field examinations to determine the annual status of the moth borer and other sugar-cane insects have received considerable attention from the writers. The best and practically the only time to determine borer injury to sugar cane is during the grinding season when the cane is cut, as the infestation increases up to this time and as the examinations necessitate the removal of the leaves from the stalk—a rather undesirable proceeding when the plant has still to make considerable growth. The plan adopted has been to examine at least 100 stalks in a field, sometimes many more. The uninfested and the infested stalks in these groups have been counted, and the percentage of infestation is determined from the data thus obtained. In actual practice this procedure has been modified. The number of fields examined in one vicinity seldom has been less than four, and often many more, depending upon the amount of time at the disposal of the inspector.

The infestation by the moth borer has been rather accurately determined year by year for the six years 1912 to 1917, inclusive, but the prevalence of other insect pests, which are not so important, has been only estimated.

To facilitate the inspections a card form was devised, which is reproduced here.

Form of card for field notes.

Sugar-cane Status, 191.... State.......................... Plantation..................................

Locality...................... Date...................... Parish or county...............................

Group examinations.	1	2	3	4	5	Total.	Per cent.	Owner, Location of field,
Stalks,								Year of crop,
Clean,								Variety, Soil,
Diatraea,								Cultivation,
								Sugar-cane condition,
Joints,								Stalks cut? Stalks standing? Trash burned?
Clean,								Aphis, Weevil,
Diatraea,								Lachnosterna, Ligyrus,[1]
								Ants, Pseudococcus,
Remarks:								Sugar-cane diseases,
								Environment,

Notes by..........

[1] *Ligyrus*=*Euethcola rugiceps* Le Conte.

AVERAGE ANNUAL INFESTATION IN LOUISIANA.

Observations have been made annually from 1912 to 1917, inclusive, on the infestation of from 6 to 13 localities in the borer-infested area of the Louisiana sugar-cane belt, with the result that the average annual infestation has been determined to be 58.2 per cent, or over half the canes infested. In 1912 the general average was 50.4 per cent, in 1913 it was 52.4 per cent, in 1914 it reached the high figure of 73.9 per cent, while in 1915 the average sank to 51.5 per cent. The average was again high in 1916, being 75.5 per cent, but in 1917 it was 48.8 per cent, the lowest during the six years. In some localities an infestation of 100 per cent is sometimes reached, or all canes infested, while in others the damage may be 30 per cent or lower.

Continuous observations have not been made in Texas, but in the lower Rio Grande Valley, to which the borer is limited at present, casual inspections usually reveal an infestation of nearly 100 per cent.

VARIATIONS IN INFESTATION.

The infestation of different fields of sugar cane in the sugar-producing region varies from a low percentage to 100 per cent, or every cane infested. Conflicting opinions are held by different planters as to the infestation of the different varieties of cane and the infestation in different years of growth. It has not been found that one common variety is more resistant to the moth borer than another, or that plant cane is more infested or less infested than first or second year stubble.[1] Another popular belief is that cane grown on sandy land is likely to be more heavily infested than cane grown on heavy soil. Examinations do not show that this is true, but the belief may have some basis, because it has been found that moths can emerge more readily from canes planted in sandy soil than from those planted in clay soil. The idea is also held that land treated with stable manure or cottonseed meal will be more heavily infested, but the data on the subject are insufficient to warrant any conclusion.

MANY LARVÆ CRUSHED IN THE MILL.

The greater number of moth borers in the larva stage in the late fall and early winter which would otherwise hibernate remain in the stalks of cane after they are cut. An examination of bored stalks at Audubon Park just before grinding yielded the information that 38 per cent of the stalks contained borers. When the stalks are ground in the mill these larvæ are crushed with the cane, leaving only such borers as may be in the stubble, seed cane, scraps of cane left about the plantations, cane tops, and Johnson grass and other grasses to start the infestation the following year.

[1] In 1918, however, 10,000 stalks of cane were examined on a group of six plantations, the examinations being well distributed and evenly divided between plant and stubble cane. It was found that the general average for plant cane on each plantation was invariably higher than for stubble, though there were wide variations among certain fields and parts of fields, both of plant and stubble cane. Examinations on a much smaller scale, made in previous years, did not indicate any difference in favor of either plant or stubble.

Because the species is so prolific, it is easily possible for a very few borers which remain alive in the spring to cause a high infestation over a whole plantation by the following grinding season.

NATURAL DISSEMINATION.

The moth borer has not been found to extend noticeably the limits of the area infested by it, as the cotton boll weevil does. The insect has never been found at Bunkie, La., though it has been observed at Melville, some 30 miles southeast, since 1914, and has probably been there for a much longer time.

ARTIFICIAL DISSEMINATION.

It is apparent that the infestation of new territory is caused principally through shipments of sugar cane, both for grinding and planting. The mature canes, if infested, contain larvæ or pupæ or both, and if left in a freight car on a railway siding, or if planted and imperfectly covered, the resulting moths can easily emerge. It is then an easy matter for the species to become established on such food plants as may be available at the time of year, and the infestation of adjacent cane fields may be expected within the next few years.

Infested seed cane was planted about 1909 above Baton Rouge on property which had previously been devoted to cotton farming and undoubtedly was not infested by the moth borer. In 1914 practically every stalk of cane was bored.

Introduction of new varieties of sugar cane should be left to experiment stations, and the cuttings should be subjected to special treatment and inspection (see "Immersion and fumigation," p. 49).

If cane is needed for planting or grinding by persons outside the infested area, great care should be taken to secure uninfested cane. Freight cars used for hauling cane may contain infested scraps which should be collected and destroyed at frequent intervals.

HIBERNATION.

STAGE OF INSECT THAT HIBERNATES.

The moth borer passes the winter in the larva stage. As fall approaches some of the larvæ go into hibernation, while others enter the pupa stage and emerge shortly as moths. There is nothing to indicate which of these two classes will hibernate and which will become moths. During the summer of 1913 some of the larvæ from eggs laid as early as August 13 went into hibernation, while others from the same mass of eggs completed their development as usual. Other larvæ from eggs laid August 18 and September 8, 22, and 27 died or hibernated, but larvæ from eggs laid September 1 and 18 completed their development and emerged in October and November.

One adult emerged in December from eggs laid as late as September 25, although the others from this mass of eggs hibernated. In general, it seems that most of the larvæ from eggs laid after the middle of September hibernate if they are not killed in the mill, but this depends somewhat on the season, as more will develop in a late fall. All instars of the larvæ hibernate. Small first and second instar larvæ have been seen as late as the middle of December crawling over the cane tops, and these would hibernate if they found suitable places. Hibernation is not what may be called complete, since the larvæ remain active on warm days and continue to feed to some extent. When infested cane is windrowed in the fall it is often badly damaged by the borers continuing their feeding throughout the winter, destroying many eyes and tunneling the stalks until they become brittle and break with handling. The well-grown larvæ continue molting at irregular intervals throughout the winter, but do not increase in size; in fact, they are even smaller and more flabby in the spring than they are in the fall. The small larvæ increase slowly in size and all hibernated larvæ are of a very uniform size in the spring.

PLACES OF HIBERNATION.

The larvæ hibernate in scraps of cane, tops of the cane plant, stalks of large grass, cane stubble, and planted and windrowed cane. Very few are to be found in stubble and grass stalks, however. No larvæ have been found in cornstalks during the winter, for these dry out and become unattractive to the moth borer long before cold weather begins. The usual place of hibernation of the closely related species *D. zeacolella*, however, is in the taproots of corn.

The favorite places of hibernation are scraps of cane left after grinding, and windrowed and planted cane. The windrow forms an ideal place for hibernation, the larvæ being well protected by the earth and the quantity of leaves covering the stalks.

EMERGENCE FROM HIBERNATION.

The hibernating larvæ pupate in the spring and emerge as moths when the cane is from a few inches to a foot or more in height. Though planted cane is covered with earth, this is often washed away by a heavy rain, exposing or partially exposing the seed cane. Moths have been found to emerge from cane under one-half inch of packed soil so that it is often possible for them to emerge from planted cane. There is of course no obstacle to their emergence from grass or cane stubble.

The times of emergence from planted cane under observation were May 7, May 21, and June 1, 1914, and the earliest emergence in the insectary was on May 8. A first-instar larva, however, was collected in the field as early as May 5, indicating that the parent moth must have emerged during the last few days of April.

SURVIVAL OF HIBERNATED LARVÆ.

Only a small proportion of the larvæ which go into hibernation survive the winter and emerge as adults. They die from time to time during the winter and those which have been in the larva stage for a long time seem to have trouble in pupating and often die in the attempt. Then, too, the mortality is higher among the pupæ from hibernated larvæ than from others, and the adults that emerge are not so vigorous.

Not more than 10 per cent of the larvæ kept under insectary conditions emerged, and as those pupating in the field often have the additional trouble of emerging through some depth of soil, it is evident that only a small percentage survives. On account of their rapid increase in numbers it requires only a few moths in the spring to produce a large number of borers during the summer and fall.

LONGEVITY OF HIBERNATED LARVÆ.

The usual larval period is greatly prolonged by cold weather or other adverse conditions, and the larvæ can survive great hardships. It is not at all uncommon for them to live for a month or two without food, and Stubbs and Morgan (152) have kept them for 75 days without food and had them pupate afterwards. Rosenfeld and Barber (137) kept a larva for 200 days without food and it pupated, while E. R. Barber records placing a larva in the photographic dark room on October 19, and finding it alive June 9, a period of 231 days, during which it did not feed on the piece of sugar cane provided. The larva stage of overwintering individuals is generally about 7 or 8 months, and during this time there are 10 or 12 molts, but in the authors' experiments some required 276 days and 14 molts to reach the pupa stage.

NATURAL CONTROL.

CLIMATIC CONTROL.

EFFECT OF RAINFALL.

Mr. George N. Wolcott, while entomologist of the Insular Experiment Station, Rio Piedras, Porto Rico, made a number of observations which tend to prove that the moth borer is adversely affected by rainfall. The following is an abstract of Mr. Wolcott's conclusions:

A large number of careful observations made in Porto Rico during the past grinding season, confirmed by the evidence from other countries, indicates that there is a constant relation between the amount of rainfall and the abundance of Diatraea. The table, which gives the percentage of infestation of cane by Diatraea in conjunction with the total annual rainfall in inches for 1914, shows that the abundance of Diatraea is in inverse proportion to the amount of rainfall. (The table mentioned shows that the infestation varies from 6 per cent, where there were 101 inches of rain, to 66 per cent, where there were only 21 inches.) . . .

It is comparatively easy to demonstrate the effect of an abundance of rainfall in lessening the numbers of Diatraea, but much more difficult satisfactorily to account for this effect. The eggs of the borer are deposited on the leaves of the cane, and when the young larvæ hatch, a considerable interval elapses while they crawl about on the cane before they enter the stalk or the midrib of the leaf. It is quite probable that this is one of the most crucial periods in its life history, and that considerable numbers of borer larvæ were killed in young cane by the more rapid growth of the central shoot of a cane plant than of the outer leaves. Also, larvæ were found which had been drowned in a mixture of water and decaying cane juices which had collected in their tunnels after rains. To avoid danger from these causes, many larvæ were found living outside the shoot, where they were exposed to the attacks of predators or parasites.

The rainfall over the sugar belt of Louisiana does not vary to any great extent, and while there are annual differences both in infestation and rainfall at various points, a careful study of the subject has failed to prove that these variations correspond as they do in Porto Rico.

Below is given the infestation by the moth borer at various places in 1916 as compared with the annual rainfall.

Infestation by the moth borer compared with annual rainfall at various places in Louisiana.

Place.	Annual rainfall. *Inches.*	Canes infested in fall. *Per cent.*
Donaldsonville	61.51	91
White Castle	50 to 60	99
Thibodeaux	50 to 60	79
Mathews	50 to 60	97
Palmetto	50 to 60	37 [1]
Franklin	58.89	53.5
New Orleans	55.37	38
Napoleonville	54.96	95
Lafayette	54.68	99
Melville	51.98	22
Abbeville	50.39	98
Morgan City	47.69	93.5

The period during which the growing cane is attacked by the borer in Louisiana is, roughly, from the month of April to the month of October, inclusive. A graphic comparison of the rainfalls during these months for the years 1912, 1913, 1914, 1915, and 1916 with the average infestations by the borer in the fall of each year is shown in figure 10. In some years the line representing infestation descends as the line representing rainfall ascends, but there were exceptions, especially in 1916, which the authors can not explain. Mr. Wolcott suggests that the small variation in the rainfall at different points

[1] Probably, flooded.

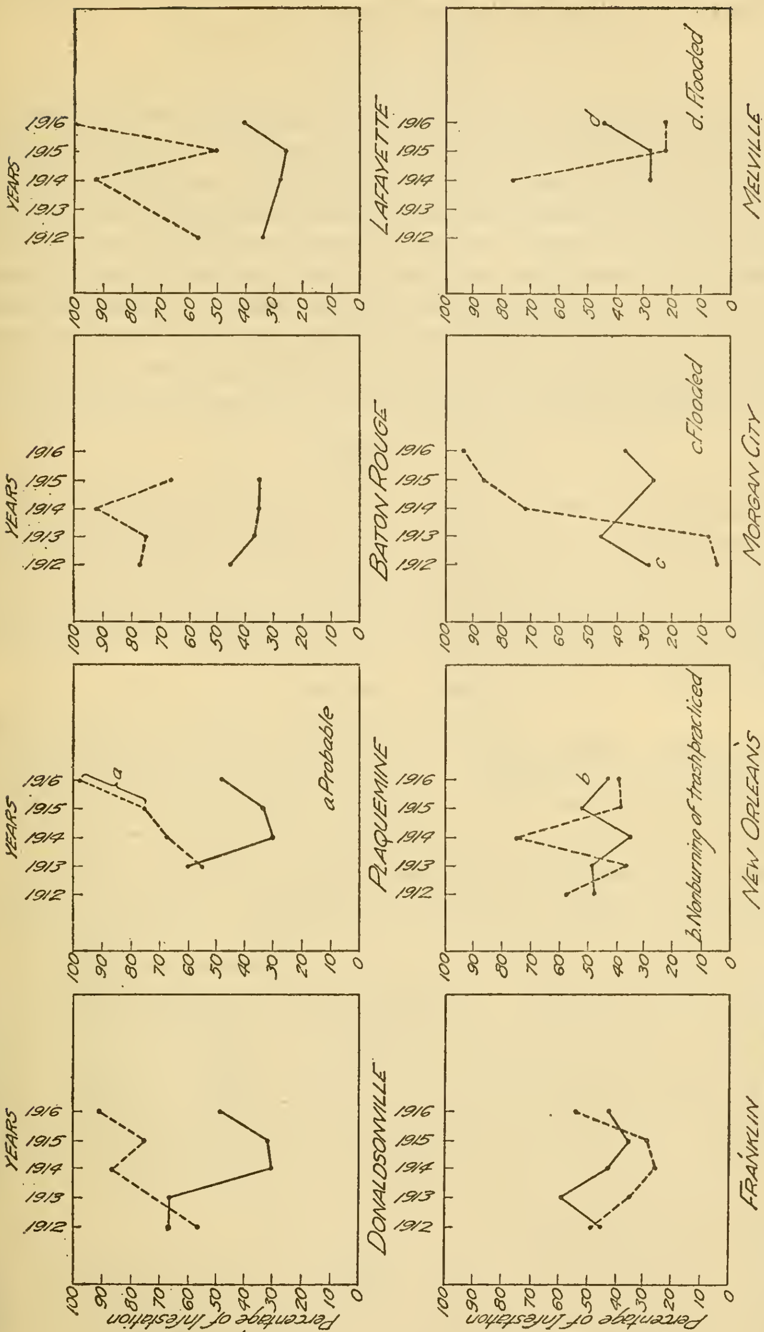

FIG. 10.—A series of graphs showing the nonrelationship of rainfall to infestation by the sugar-cane moth borer in Louisiana. Dash lines represent percentages of infestation and solid lines inches of rainfall from April to October, inclusive, the months of greatest activity.

in Louisiana as compared with Porto Rico makes it more difficult to determine its effect on the moth borer.

EFFECT OF FLOODS.

Complete flooding of cane fields for long periods seems to have a great influence on the infestation of the moth borer. For four years observations have been made on a plantation near Morgan City, which was under water for some weeks in the spring of 1912. In the fall of 1912 the infestation on this plantation was 4 per cent. In the fall of 1913 it was 6 per cent, only slightly higher than in the year of the overflow. In the fall of 1914, however, the infestation had reached 68 per cent, while in 1915 it was 87 per cent. It seems that the moth borer was much reduced in numbers by flooding, but that the numbers increased rapidly the second year after the inundation.

EFFECT OF IRRIGATION.

Though floods seem to reduce the percentage of infestation, it has not been observed that irrigation has any effect. Observations have been made on the nonirrigated plantations of Louisiana and on the irrigated properties of the lower Rio Grande Valley of Texas. No difference in the infestation which can be traced to irrigation has been noticed.

FUNGOUS DISEASES.

Although a fungous disease on the larvæ of *Diatraea saccharalis* was studied by J. R. Picard (120) at the Louisiana State University in 1903, its occurrence under natural conditions is very rare. Larvæ are sometimes attacked in the insectary, especially when kept in tin boxes, but all attempts to inoculate healthy larvæ have failed and it is probable that the fungus is only saprophytic. One such diseased larva of *D. zeacolella* sent in by Mr. A. G. Davis from Chipley, Fla., was submitted to Mr. Alden T. Speare, Mycoentomologist of the Bureau of Entomology. He reported that "the fungus seems to be very close to *Aspergillus parasiticus*, which I found to be parasitic upon the sugar-cane mealybug in Hawaii. There is no doubt that the fungus is an Aspergillus, but I would venture no specific name at present. *A. flavus* has been found to be parasitic upon sugar-cane mealybugs in Louisiana and in Porto Rico, but this is the first record to my knowledge of an Aspergillus on Diatraea, hence I can not vouch for its parasitism."

The fungus parasite *Cordyceps barberi* is recorded by Van Dine (169) from Porto Rico, and by Bodkin (17) from British Guiana on both the larva and the pupa of Diatraea. The present writers planned to experiment with this disease but they were unable to obtain cultures or diseased specimens.

PARASITES AND PREDACIOUS ENEMIES.

MOTH-BORER ENEMIES IN THE UNITED STATES.

Four parasites of species of Diatraea have been found in the United States, but three of them are extremely rare. The chalcis-fly *Trichogramma minutum* Riley is universally distributed in the sugar-cane fields of Louisiana and of the lower Rio Grande Valley of Texas, and is a very important factor in the control of the moth borer. It is a minute wasplike insect, the female of which deposits her eggs within the eggs of the borer, in the course of a few days numbers of adult parasites emerging from the moth-borer eggs.

A similar insect is the black parasite *Ufens niger* Ashmead, found near Brownsville, Tex., by the senior writer in 1912. This has not been found a second time, although Mr. George N. Wolcott made a special search for it extending over about two months in the summer of 1917. Vickery[1] records it as a common parasite of eggs of the leafhopper *Draeculacephala mollipes* Say, and it may attack Diatraea only rarely.

Parasites of the larvæ have not been found in Louisiana, but a braconid, *Microgaster* sp., has been reared from larvæ of *Diatraea zeacolella* Dyar, collected in corn by Mr. E. R. Barber at Bennettsville, S. C. A thorough search for larval parasites was afterwards made in South Carolina, Georgia, and Florida by Mr. A. G. Davis and the junior writer, but none was found.

Another braconid has been reared by Dr. A. W. Morrill, State entomologist of Arizona, from the species of Diatraea (probably *lineolata*) which occurs in that State.

Stubbs and Morgan (152) record a telephorid beetle, *Chauliognathus marginatus* Fabricius, as feeding on the larvæ. This is occasionally found in considerable numbers in sugar-cane fields in Louisiana.

During 1916 Mr. A. G. Davis found earwigs (Dermaptera) consuming larvæ of Diatraea in Florida, and in 1917 Mr. George N. Wolcott, in Texas, observed them feeding on eggs of *Diatraea saccharalis* which had previously been parasitized by *Trichogramma minutum*. It is unlikely that the work of earwigs is of any importance in control, and in feeding on parasitized eggs they would, of course, do more harm than good.

The Argentine ant (*Iridomyrmex humilis* Mayr) has been observed feeding occasionally on eggs, larvæ, and pupæ of the moth borer, but it can not be considered a factor in repression. The ants seem to attack only those eggs which have been parasitized, and while they may sometimes attack larvæ they will not ordinarily molest a

[1] Gibson, Edmund H. The sharpheaded grain leafhopper. U. S. Dept. Agr. Bul. 254. 16 p., 1 fig. 1915.

larva or a pupa unless it has been injured in some manner. The damage produced by ants in increasing the number of mealybugs, and as sugar-house and household pests, more than offsets any good which may come from their destruction of insects.

THE EGG PARASITE, TRICHOGRAMMA MINUTUM RILEY.

On account of its economic importance *Trichogramma minutum* (fig. 11) deserves more extended consideration. It is almost microscopic, and belongs to the large order of Hymenoptera, which includes the bees and wasps. Under the microscope its wings are found to be fringed with delicate hairs and to have lines of these hairs running across their surfaces.

The adults are about one-fiftieth of an inch long, with a wing expanse of a little more than the length of the body. On account of their minute size they are practically invisible in a sugar-cane field, even though they may be present in great numbers. The best way to find them is to search for a cluster of moth-borer eggs which have turned black (indicating parasitism). During the summer, and especially in the fall, an experienced person can sometimes find these clusters in considerable numbers on the leaves both of corn and of sugar cane. If the eggs are put in a small tube and observed for a few days, many light yellow Trichogramma adults may be found to emerge.

In the fields the females of these parasites search for moth-borer eggs very soon after emergence. Finding a cluster, the female inserts her own eggs into the borer eggs, and in the course of eight days or longer, depending on the season, a new generation emerges, the parasites having developed from egg to adult within the moth eggs.

The parasites are scarce at the beginning of the season, and in fact eggs destroyed by them were never found earlier than June 18 in Louisiana. As the season progresses they become more and more abundant, until at last they destroy almost every egg cluster of the moth borer.

If the parasites could be so controlled that they would start their beneficial work earlier in the year, great good would result in limiting the ravages of the moth borer. Low temperatures retard the development of insects, and in an experiment to keep them over the winter parasitized eggs were placed in a refrigerator having a uniform temperature of about 50° F. Some of the parasites emerged even at this temperature, however, and all of them died during the winter.

Under natural conditions they undoubtedly hibernate in the cane trash left on the fields of the sugar plantations, at least until the trash is burned, when many of them are probably destroyed. This practice is probably to blame for their scarcity during the following spring and early summer. To avoid the destruction of these beneficial parasites experiments have been conducted for the last five years in conserving the cane trash. The trash may be raked to the headlands or to waste land, or it may be plowed under. This subject is thoroughly discussed under the heading "Not burning cane trash," page 55.

MOTH-BORER ENEMIES IN FOREIGN COUNTRIES.

The minute egg parasite *Trichogramma minutum* occurs almost universally, having been recorded from Cuba, Porto Rico, Trinidad, British Guiana, Barbados, and elsewhere, as noted below. Another egg parasite, *Telenomus* sp., is recorded from British Guiana by Bodkin (17), who also records a braconid, a tachinid fly,[1] and a large chalcidid, *Heptasmicra curvilineata* Cameron. Two species of ants are mentioned by Bodkin as destroying the eggs. Predators in British Guiana are an elaterid and the histerid *Lioderma quadridentatum* Fabricius. From the same country Moore (104) lists *Iphiaulax medianus* Cameron, *Iphiaulax* sp., *Cremnops parvifasciatus* Cameron, and *Cremnops* sp. (all braconids), and the ichneumonid *Mesostenoideus* sp. From Trinidad Urich (164) records a sarcophagid fly[2] (probably parasitic) and a hymenopteron, *Cyanopterus* sp. The tachinid *Euzenilliopsis diatraeae* Townsend was found in Cuba by the junior author, as well as a species of Apanteles. *Tachinophyto* sp.[1] is recorded by Van Dine (170) from Porto Rico. Rosenfeld and Barber (137) record an intestinal worm, the braconid *Microdus* sp., and a dipteron[2] from Argentina. Van der Goot (58) states that in Java Diatraea is parasitized by *Phanurus beneficiens* Zehntner, *Trichogramma minutum* Riley, *T. nanum* Zehntner, *T. australicum* Girault, in the egg stage, and by a braconid and a tachinid[3] in the larva stage. He also records two species of ants attacking the pupæ and the eggs, and a small carabid feeding on the larva. De Charmoy (51) notes *Telenomus* sp., (*Ophion*) *Stauropodoctonus mauritii* Saussure, *Trichogramma australicum* Girault, *Ophion*

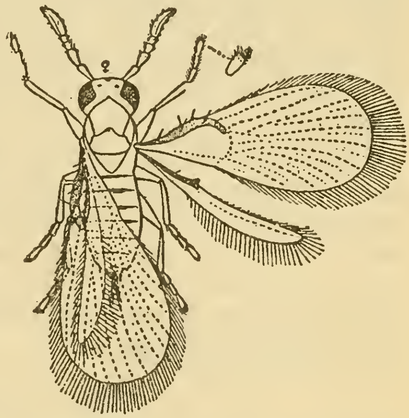

FIG. 11.—*Trichogramma minutum*, an egg parasite of the sugar-cane moth borer. Highly magnified. (Riley.)

[1] These flies are thought by Dr. C. H. T. Townsend to be probably his *Euzenilliopsis diatraeae*.

[2] According to Dr. Townsend Rosenfeld and Barber's "dipteron," and probably Urich's "sarcophagid fly," are *Oxysarcodexia peltata* Aldrich.

[3] According to Dr. Townsend this is *Diatraeophaga striatalis* Townsend.

(*Henicospilus*) *antankarus* Saussure, *Apanteles simplicis* Viereck, and a tachinid fly from Mauritius. Jarvis (83) states that *Diatraea saccharalis* "appears to be under effective natural control in Queensland," while Mr. Frederick Muir has told the writers that this is the case in the Philippine Islands also.

REPRESSION.

EXPERIMENTS AND OBSERVATIONS IN ARTIFICIAL CONTROL.

DESTRUCTION OF SCRAPS OF CANE LEFT AFTER GRINDING.

One of the chief places of hibernation of the moth borer is in scraps of cane left about the plantation. The wise manager will therefore collect such scraps as soon as possible after the grinding season and destroy them. On a plantation on which many scraps had been left about the mill and the derricks from one season to the next the infestation was practically 100 per cent over the whole plantation.

After the scraps are collected they may be disposed of by a very thorough burning with oil or some dry material. Throwing the scraps into a lake or other body of water is not to be recommended, as some of the moths may emerge from the floating stalks or from those which are washed ashore. Passing the scraps between the rollers of the mill has been recommended, but this would hardly be practicable on the ordinary plantation.

CUTTING OUT "DEAD HEARTS."

The dead plants, or "dead hearts," which follow the work of the moth borer in the spring, contain for a few weeks the larvæ which have killed them. A familiar recommendation has been to cut out these dead plants and burn them, care being taken to cut to or even below the surface of the ground so as to secure the larvæ.

The writers had an opportunity of observing this work in progress on a large scale at the State penitentiary farm at Angola, La., in the spring of 1917. The cutting of the "dead hearts" was being done very efficiently by convicts. They collected the dead plants in bags and burned them on the headlands. It was the opinion among the foremen that the "dead hearts" should be cut out of each field three times during the early growing season. One man was said to cover 4 acres per day.

The writers made a point of revisiting the penitentiary farm in the fall to ascertain the results of the work. It was found that the average infestation of the whole plantation was 31.5 per cent, which for 1917 was not extraordinarily low. Around Port Allen, La., for instance, the average infestation was 30.7 per cent, and the "dead hearts" had not been cut out at that place. Individual fields at Angola ran from 6 to 85 per cent, and at Port Allen from 9 to 94 per cent.

It is possible that the different fields at Angola did not all receive exactly the same treatment as to cutting out the "dead hearts," especially as the plantation is divided into a number of farms or sections, each of which has its separate manager. As far as the authors could ascertain, however, the treatment had been uniform over the whole plantation.

It was the opinion of several of the farm managers that cutting out the "dead hearts" would not be practicable on a plantation where free convict labor is not available.

Moore (104) records the collection of 15,285,960 larvæ and pupæ of the moth borer on 17 estates in Demerara, British Guiana, in 1912, and 13,632,655 in 1911. He then remarks:

> The effect upon the pest of all this terrific slaughter has not as yet been very marked, but will increase more and more rapidly if the destruction be kept on persistently, systematically, and relentlessly. The insect propagates at such a very rapid pace, in spite of the counter-activity of a variety of natural enemies, and in spite of whatever may be the weather conditions, when its seasons come round, that to overtake it and bring it under proper control must needs be a rather long undertaking.

POISONING YOUNG PLANTS.

By covering the young plants with an arsenical in powdered form, which was suggested by the junior author, it was hoped to present a poisoned leaf surface to the first young borers of the year. Before gnawing into the plants the newly emerged larvæ feed among the leaf whorls for a limited time. It was thought that if they could then be poisoned much damage later on could be prevented.

A small preliminary experiment gave what seemed to be promising results, and in 1916 a large plantation experiment was planned. Fields on a typical plantation were poisoned one, two, and three times, powdered arsenate of lead being used, and the applications being made at many different dates in the spring. After nearly every application, however, there was a heavy rain, and the following fall no benefit could be observed. About 2 pounds of poison per acre were applied, a special horse machine being used.

The experience gained in 1916 had proved that the machine, which was designed for cotton, was not well adapted to sugar-cane fields. In 1917 the framework was strengthened and a gasoline engine added. This gave a much more uniform distribution of the poison, and an application of 2 pounds per acre covered the plants rather thoroughly. One man and a 2-horse team with this machine could cover 35 acres per day at a total cost for labor and material of

64 cents per acre. The apparatus used in the test is illustrated in Plate VII.

A 125-acre field at Belle Alliance Plantation near Donaldsonville, La., which was naturally divided into approximately 5-acre plats by drainage ditches, was selected for the experiment. One plat was poisoned once a week during the nine weeks from April 19 to June 14, while other plats received from one to four applications of 2 pounds per acre at weekly and fortnightly intervals, beginning at different dates during the nine weeks' period. The season was rather dry and rain did not interfere with the work any more than might be expected under Louisiana conditions.

Borer eggs and "dead hearts" were observed throughout the spring and summer in the various plats, and in October, when status examinations were made, considerable variation was found in the different plats, but no relationship between the poisoning and borer infestation could be established, the treatment evidently having no effect whatever. This is probably due to the fact that the poison did not enter the central whorl or "throat" of the plants, where the young larvæ were feeding.

These experiments will indicate to the reader just how difficult is the control of the sugar-cane borer, and how inefficient are the usual methods of repression when used against it. For a long time the application of poison to sugar cane was regarded as hardly practicable, but when tried it was found to be not prohibitive as to cost or labor, although of absolutely no benefit.

REACTION OF ADULTS TO HONEY AND OTHER BAITS.

In the control of certain pests of vineyards in Europe, baits composed of fermenting molasses and other substances have been reported as successful in attracting the adults. In fact the use of these baits appears to be a well-established practice in some communities. It is also well known that collectors often make use of a mixture of stale beer or rum and brown sugar for attracting certain night-flying moths. It was thought worth while, therefore, to test the attraction of various chemicals and mixtures to borer moths.

Five modified flytraps were hung in cane and corn fields known to be infested. All the traps were baited with the same substance at a time, and were left in the fields for at least 24 hours. The following mixtures and chemical compounds were experimented with: (1) Honey; (2) honey, water, and alcohol; (3) 1 part honey dissolved in 3 parts alcohol; (4) stale beer, low-grade sugar, and alcohol; (5) stale beer and sugar; (6) oil of anise; (7) imitation strawberry sirup; (8) orange-flower sirup; (9) cedar oil; (10) solution of citric acid; (11) pyridin; (12) xylene; (13) vanilla extract; (14) oil of

POISONING YOUNG CANE PLANTS WITH POWDERED ARSENATE OF LEAD.

Poison was found to be unsuccessful in controlling the moth borer.

citronella; (15) oil of wintergreen; (16) oil of cinnamon; (17) formaldehyde solution; (18) pennyroyal; (19) fluid extract of valerian. No borer moths and very few other insects were captured.

REACTION OF ADULTS TO LIGHTS.

Attracting the adults to lights has been proposed occasionally as a means of controlling the moth borer. It seems evident, however, that lights can exercise little attraction for them. The moths avoid the sunlight and remain concealed during the day in dark places, such as between the leaves and the stalk of a sugar-cane plant. If disturbed they fly for a short distance, seeking another place of concealment. As dusk approaches, however, they become very active, but daylight finds them motionless again.

Experiments have been conducted with insect light traps, which are so constructed that insects which fly to the light will be killed by a poisonous gas and fall into a jar, from which they may be removed at the convenience of the collector. A commercial moth trap was used. Some of the traps were fitted with glasses of various colors, so that they would throw colored lights, and they were equipped with electric lights of high candlepower in addition to the kerosene lamps with which they were furnished by the manufacturers.

In September, 1914, a light trap was placed about 20 feet from a plat of young corn which was heavily infested by the moth borer. A clear light of about 60 candlepower was used. The trap was run on 16 nights between September 16 and October 13. The catch of borer moths was as follows:

Sept. 16	4 males, 1 female.
Sept. 17	13 males.
Sept. 18	18 to 20 males, 4 females.
Oct. 6	1 male.
Oct. 9	4 males.
Oct. 10	1 male.
Total males	41 to 43.
Total females	5

Borer moths were caught on only about one-third of the nights during which the trap was operated, and practically no females were secured. The few females caught apparently had deposited their eggs already.

A much more elaborate series of experiments was conducted in 1915. From May 12 to June 18 five traps were operated with kerosene-oil lamps, the traps being fitted to throw lights of the following colors: Green, yellow, clear (uncolored), red, blue. As no borer moths were caught, the traps were provided with carbon-filament incandescent electric lights, 100 watts, 120 volts, candlepower about 80. A mottled brown and yellow glass was substituted for the yellow, which had been broken. The traps were operated during July, August, and September, with the following results:

Clear glass	58 males, 2 females.
Mottled	26 males.
Green	18 males.
Blue	15 males.
Red	0
Total males	117
Total females	2

Neither of the females which were attracted to the clear light contained eggs.

The lights were arranged so that they were about 6 feet from a field of sugar cane. Observations were made to determine whether the number of canes infested by the moth borer had been lowered by the proximity of the lights, but this was not found to be the case, the infestation being as high as usual.

In 1916 more experiments were conducted, larger traps made on the same principle as those previously employed being fitted with glasses of standardized colors prepared for railroad semaphore lights. The colors used were purple, blue, red, green, brown, and clear. The electric globes were of the same type as those used in 1915. The lights were operated on 54 days from May 9 to September 4, the results being as follows:

Purple	5 males, 4 females.
Blue	5 males.
Red	0
Green	6 males.
Brown	1 male.
Clear	44 males, 2 females.
Total males	61
Total females	6

Experiments were conducted also on three nights in September with a 750-watt light taken into a cane field and operated by means of a long extension wire. This was suggested by Mr. E. R. Barber. It was observed that the moths would rise and then settle on the plants again, not continuing to fly around the light. Two males and five females were caught. There was some doubt as to whether two of the females had deposited their eggs, but the remaining three were certainly gravid.

The operation of lights was also observed on a certain Louisiana plantation on a much larger scale, gasoline torches being pulled about over the plantation. One was equipped with a gasoline engine and other apparatus which caused a powerful suction of air back of the light, the insects being sucked into an inner chamber. The other arrangement was a train drawn on the plantation railway, consisting of a locomotive pulling a tank car filled with gasoline and a flat car bearing two huge gasoline burners, which produced flames 5 or 6 feet high. The lower parts of the flames were about 10 feet above the ground. The plantation management makes a practice of operating the train on favorable nights during the summer, and the expense in 1916 was said to be about $7 per night. On the night of August 25 the senior author saw both machines in operation and caught a total of 21 borer moths, of which 5 were males and 17 were gravid females. The moths would fly near the flame, their wings would be singed, and they would drop to the ground, or, in the case of the suction or vacuum outfit, they would be drawn with great force into the inner chamber. The fact that these machines were drawn through the midst of the cane fields may account for the variance of the results with those obtained with the light traps. As the lights were moved from one spot to another, group after group of insects was observed to rise. As soon as the insects had either settled or been captured or burned at one point the machines were moved a few yards farther on and a new group would start up.

It was expected that this plantation would have a low infestation in the fall. Fields were examined near which the lights had been operated and compared with other fields which had not been reached by them. The average infestation of canes was 96.7 per cent for the treated fields, while it was 97.3 per cent for the untreated fields, a difference of less than 1 per cent. The average infestation of all the fields examined as compared with the average infestation of other plantations in that part of the State not using the lights was higher rather than lower.

Even with the high percentage of females taken at the plantation lights it is apparent that with regard to percentage of canes infested the lights have no effect on the moth borer.

FALL PLANTING.

Windrowing seed cane for spring planting is a practice which affords the borer an ideal place to spend the winter. The insects can crawl from one stalk of cane to another in the windrow, killing many eyes which otherwise would germinate. The covering of earth and leaves protects the borer as well as the cane from the severities of winter.

Planting the cane in the fall instead of in the spring does away with the necessity for a windrow altogether, and is to be preferred. This is one of the recommendations of Stubbs and Morgan (152). Fall planting is practiced as far as labor and time will permit on most Louisiana plantations.

DEEP PLANTING OF SEED CANE.

To determine whether moths would emerge from planted seed cane, infested stalks were buried under various depths of soil in boxes which had been raised from the ground and isolated from ants. The soil used the first year was ordinary black soil found at the Sugar Experiment Station, Audubon Park, New Orleans, technically called "Yazoo clay." The cane was buried at the following depths: One-half inch, 1 inch, 2 inches, 3 inches, 4 inches, 5 inches, 6 inches. The soil was packed on the cane and the depths of earth were accurately determined. By covering the boxes with wire screen the capture of any emerging insects was assured. One female moth emerged from the cane buried under one-half inch of soil, while no moths emerged from cane buried at other depths.

This experiment was repeated the following year, using river sand as well as black soil (Yazoo clay) as before. The cane was buried at depths of one-half inch, 1 inch, 2 inches, and 3 inches. Three moths emerged from cane buried under one-half inch of river sand, while no moths emerged from cane buried at other depths. No moths emerged from any of the cane buried in the black soil.

The experiment indicates that the moths can emerge from cane under one-half inch of either clay soil or sand, more moths emerging from sand. Planters would, therefore, do well to keep the planted cane well covered with soil, especially in sandy land.

PLANTING BORER-FREE SEED CANE.

The old recommendation to plant borer-free seed cane is a very good one, providing borer-free seed cane can be obtaind. Ordinarily, however, it is not possible or practicable to obtain uninfested seed cane. The tendency among planters, too, is to grind the best cane and to plant the cane that is not too greatly injured, more cane being planted to a given area if it is somewhat inferior.

Planting borer-free cane has been found to give a better stand as compared to planting infested cane, but at least on a small area the subsequent infestation can not be expected to be reduced.

To determine the effect of planting selected cane, four rows were planted with borer-free cane and the adjoining four rows were planted with infested cane. The details of the experiment are shown in Table VII.

TABLE VII.—*Results from planting borer-free seed cane.*

Kind of seed cane.	Number of eyes at planting.	Plants on June 19.	"Dead hearts" on Sept. 1.
Borer-free	2,125	1,720	8[illegible]
About 38.5 per cent infested	2,004	1,343	6[illegible]

The senior writer was told by a reliable plantation manager of the planting of borer-free cane at Pharr, Tex., in 1916. Although there were no borers in the seed cane, which had been procured from a section known to have none, the cane was badly infested at the grinding season.

A field of cane planted with borer-free seed somewhat resembles a field of corn in its relation to borers. Undoubtedly there are often no borers in the cornfield when the seed is planted, yet there may be a heavy infestation later. The borer moths evidently fly into the cornfield during the early spring, and they can as easily fly into a field planted with borer-free seed cane.

SHAVING CANE STUBBLE.

Some sugar planters believe that "shaving" the cane stubble in the spring reduces the subsequent infestation by the moth borer. This operation is done with a "stubble shaver," a wheeled instrument having a straight or disk blade set horizontally, which cuts away the upper inch or so of the stubble. Borers are supposed to be in the upper portion, and when it is removed they are believed to be killed.

The authors' observations show, however, that few borers can be found in the stubble. Many stubble shavings have been examined, and no borers have been found in any of them.

It is apparent, therefore, that shaving the stubble can not be regarded as an effective measure for the control of the moth borer.

IMMERSION AND FUMIGATION OF INFESTED SEED CANE.

Various entomologists who have made a special study of insects injurious to sugar cane have experimented with hydrocyanic-acid gas and various liquids in attempts to disinfect seed cane before planting. In these experiments, the seed cane has been subjected to the gas in various strengths, and has been soaked in different solutions from one minute or less to at least three hours. The consensus of opinion at present seems to be that treatment of infested stalks is neither practicable on a large scale nor efficient as a means of controlling insects on an infested plantation.

At the Sugar Experiment Station at Audubon Park, New Orleans, all cane cuttings sent out are subjected to a rigid inspection and washing in fish-oil soap solution ($\frac{1}{2}$ pound soap to 1 gallon of water). Only cane not bored by the moth borer is sent out, and this is thoroughly washed in fish-oil soap solution to kill the mealybugs (*Pseudococcus calceolariae* Maskell), and afterwards is inspected to ascertain whether any mealybugs have escaped. This procedure results in the distribution of absolutely insect-free seed cane, which is highly desirable, as otherwise the experiment station would become a center of insect distribution.

On a plantation scale, however, such a treatment, even in a modified form, would be impossible. Experiments have shown that treatment of cane cuttings on a plantation already infested with the moth borer and the mealybug has little or no effect in reducing the subsequent infestation. In the season of 1911–12, a very great effort was made to eliminate sugar-cane insects from a small property in Louisiana. The trash on the fields was burned in the fall, the entire farm was given over to plant cane, no cane was windrowed, all cane was planted in the fall after having been dipped in a fish-oil soap solution (to kill the mealybugs), nearly all the stubble was removed from the fields (according to the plans *all* the stubble was to be removed, but the work was so difficult and expensive that some of the stubble was plowed under to a depth of 4 or 5 inches), and, finally, the planting of corn was delayed in the spring of 1912 so that any possible hibernated moths of the borer would not find corn as an early food plant. While the work may not have been done in an absolutely ideal way, the experiment was much more thorough than ordinarily would have been possible.

Even the weather seemed to cooperate to render the experiment a success. The winter of 1911–12 was cold, and the cane was late in sprouting in the spring, so that it seemed that there was no cane during the winter to serve as a food plant for the borers. Small borers were found, however, as early as May 24, 1912, and by October 17 the infestation ran as high as 75 per cent, with an average of 59 per cent. As to the mealybug, practically all the plants were infested. The experiment was evidently entirely negative in its results.

More exact experiments have been conducted to indicate the actual effect of fumigation and immersion on both the insects and the sugar-cane cuttings. Table VIII gives the results of dipping cuttings in various insecticides and fungicides and also of soaking the cuttings in the solutions for one hour, the borers afterwards being cut out to ascertain whether they were yet alive. The borers were kept and fed for about two weeks after the treatments.

TABLE VIII.—*Effect on moth-borer larvæ of immersion of infested cane cuttings.*

Solution.	Exposure.	Number of larvæ.	Condition of larvæ immediately after treatment.	Penetration of solution in cane cutting.	Condition of larvæ two weeks after treatment.
Bordeaux mixture 6-4-50	Dip	9	All alive	Penetrated, and was deposited on sides of holes.	7 alive.
	1 hour.	6	do	Some of the stalks were evidently full of the solution.	All dead.
Fish-oil soap, ½ pound per gallon water.	Dip	9	do	Evidently penetrated the stalks.	8 alive.
	1 hour.	11	All alive, 4 had emerged from cane and were in the solution.	do	9 alive.

TABLE VIII.—*Effect on moth-borer larvæ of immersion of infested cane cuttings*—Continued.

Solution.	Exposure.	Number of larvæ.	Condition of larvæ immediately after treatment.	Penetration of solution in cane cutting.	Condition of larvæ two weeks after treatment.
Nicotine sulphate (40 per cent nicotine), 1 part to 500 parts water.	Dip...	10	9 alive, 1 small one dead between stalk and leaf sheath.	Probably penetrated the stalks.	4 alive.
	1 hour.	7	6 alive, 1 dead	......do	All dead.
Potassium sulphid, 3 pounds per gallon water.	Dip...	7	All alive	......do	4 alive.
	1 hour.	10	......do	......do	1 alive.
Potassium sulphid $1\frac{1}{2}$ pounds per 10 gallons water.	...do ..	10	All alive, 1 emerged from cane and in the solution.	......do	4 alive.

Soaking the cuttings for 1 hour in either Bordeaux mixture or nicotine sulphate solution was found to kill all the larvæ within 2 weeks. Only 1 larva was killed immediately, however, even after an immersion of 1 hour.

Eggs, larvæ, and pupæ were next subjected to immersions of 1 minute and 1 hour in the various solutions, with results as shown in Table IX. The larvæ and pupæ had previously been removed from the stalks of cane. A cluster of eggs, 5 larvæ, or 5 pupæ were used in each exposure.

TABLE IX.—*Immersion of eggs, larvæ, and pupæ of the moth borer in various solutions.*

Solution used and stage of insect.	Exposure.	Effect within 2 days.	Effect within 10 days.
Bordeaux mixture:			
Eggs	1 hour	Did not kill	All hatched.
Larvæ	1 minute	......do	2 dead out of 5.
Do	1 hour	......do	None dead.
Pupæ	......do	......do	All emerged.
Fish-oil soap:			
Eggs	......do	......do	All hatched.
Larvæ	1 minute	......do	1 dead out of 5.
Do	1 hour	......do	2 dead out of 5.
Pupæ	......do	All killed	
Nicotine sulphate (40 per cent nicotine):			
Eggs	......do	None hatched	All dead.
Larvæ	1 minute	Did not kill	1 dead out of 5.
Do	1 hour	......do	Do.
Pupæ	......do	......do	All emerged.
Potassium sulphid, 3-100:			
Eggs	......do	......do	All hatched.
Larvæ	1 minute	......do	None dead.
Do	1 hour	......do	1 dead out of 5.
Pupæ	......do	......do	All emerged.
Potassium sulphid, $1\frac{1}{2}$-100:			
Eggs	......do	......do	All hatched.
Larvæ	1 minute	......do	1 dead out of 5.
Do	1 hour	......do	All healthy.
Pupæ	......do	......do	All emerged.

Untreated eggs used as a check hatched as usual. Of 5 untreated larvæ, 1 died within 10 days. All of the 5 untreated pupæ were alive at the end of 10 days.

It will be noted that pupæ immersed for one hour in fish-oil soap solution were killed, while eggs immersed for one hour in nicotine-sulphate solution did not hatch. The other solutions were ineffective. It is evident that larvæ and pupæ are more seriously affected by these two dips when in the cane stalks than when they are first taken out and then immersed. The reason for this is that a certain amount of fluid remains in the tunnels after the stalks are removed from the solution, and continues to affect the insects.

To test the effect of immersion and fumigation on the germination of cane cuttings, a number of tops and bottoms of the varieties D74 and Louisiana purple were treated in the fall and planted in the experimental fields. Table X shows the number of healthy plants on May 13 and at the grinding season. The "dip" was a very thorough immersion of the cuttings. Fish-oil soap solution apparently increased the percentage of germination, while no treatment can be regarded as injurious. Table XI shows the weight of cane in pounds of cane from the treated seed at grinding. The fish-oil soap solution appears to have increased the tonnage, though this result is doubtful.

TABLE X.—*Germination of treated seed cane.*

Treatment.	D74.		Louisiana purple.	
	Tops.	Bottoms.	Tops.	Bottoms.
Check (not treated)	[1] 18–73	20–79	44–89	36–71
Bordeaux mixture, dip (6–4–50 formula)	21–81	22–82	45–88	42–87
Bordeaux mixture, 1 hour immersion (6–4–50 formula)	26–94	28–88	46–86	29–81
Fish-oil soap, dip (one-half pound per gallon of water)	34–94	26–91	37–95	39–72
Fish-oil soap, 1 hour immersion	44–119	31–89	49–94	38–91
Check (not treated)	14–85	21–90	45–93	51–79
Tobacco extract (40 per cent nicotine as sulphate), dip (1 part to 500)	26–73	21–74	36–95	53–86
Tobacco extract (40 per cent nicotine as sulphate), 1 hour immersion (1 part to 500)	39–100	31–86	55–88	48–85
Potassium sulphid, 3 pounds to 100 gallons of water, dip	d2=100	29–91	46–123	51–90
Potassium sulphid, 3 pounds to 100 gallons of water, 1 hour immersion	43–108	34–87	53–108	37–70
Potassium sulphid, 1½ pounds to 100 gallons of water, 1 hour	35–118	26–91	45–112	42–94
Hydrocyanic-acid gas, 1 hour fumigation (1 ounce, 20 cubic feet, 1–2–4 formula)	39–103	[2]	53–96	41–77

[1] Number of healthy plants on May 13 (first figure) and number of stalks at the grinding season (second figure), the seed cane having been subjected to various treatments before planting.
[2] Seed cane taken by unknown person.

TABLE XI.—*Weight of cane grown from treated seed cane.*

Treatment.	D74.		Louisiana purple.	
	Tops.	Bottoms.	Tops.	Bottoms.
Check (not treated)	[1] 160	192	230	160
Bordeaux mixture, dip	154	208	208	194
Bordeaux mixture, 1 hour immersion	188	164	214	184
Fish-oil soap, dip	224	204	226	176
Fish-oil soap, 1 hour immersion	238	220	212	214
Check (not treated)	158	238	214	188
Tobacco extract (40 per cent nicotine as sulphate), dip	142	138	168	158
Tobacco extract (40 per cent nicotine as sulphate), 1 hour immersion	168	158	178	138
Potassim sulphid, 3 pounds to 100 gallons of water, dip	158	158	228	148
Potassium sulphid, 3 pounds to 100 gallons of water, 1 hour immersion	178	164	188	134
Potassium sulphid, 1½ pounds to 100 gallons of water, dip, 1 hour immersion	166	164	154	184
Hydrocyanic-acid gas, 1 hour fumigation	204	[2]	212	156

[1] Weight of cane in pounds at the grinding season is indicated by the numbers, the seed cane having been subjected to various treatments before planting.
[2] Seed cane taken by unknown person.

After the development of vacuum fumigation by Mr. E. R. Sasscer, of the Bureau of Entomology, a method which has proved highly efficient in the destruction of insects in seed and cotton bales, it was planned to fumigate cane by this system. It was a matter of general surprise that larvæ of the moth borer came out uninjured, even when subjected to a strong fumigation (6 ounces sodium cyanid, 9 ounces sulphuric acid, and 18 ounces of water to 100 cubic feet) for 1 hour, a vacuum of 25 inches being applied for 15 minutes and a normal air pressure for the succeeding 45 minutes, the combination of reduced air pressure followed by normal pressure having been found very satisfactory for most species.

DESTROYING OLD CORNSTALKS.

Some sugar planters believe that if it were not for the growing of corn on the plantations there might be little damage from the moth borer in sugar cane. They reason that the borer finds an acceptable food plant in corn before the sugar-cane plants are large, and that if corn were eliminated the emerging moths in the spring presumably would die.

Careful observations, however, show that the young cane plants are attacked as early as corn in the spring, if not before. In fact, the authors have always found borers in cane before they have observed them in corn. It is true that the moths emerge from the cornstalks in summer and fly to cane fields to deposit their eggs, the dry corn plants no longer being attractive. But if there were no corn the borers could, and many of them do, reach maturity just as easily in sugar cane.

Corn is not grown in Porto Rico, except in one isolated locality, according to Mr. George N. Wolcott, formerly entomologist of the Insular Experiment Station of Porto Rico. Yet a very high infestation is often found in sugar cane.

It is probable that the elimination of cornfields from Louisiana sugar plantations could have little or no effect on the numbers of borers, but if the cornstalks could be destroyed before the borer moths leave them a large number might be killed and the subsequent infestation reduced. Borers have not been found in the dry stalks at harvest, however, and the destruction of the stalks earlier than midsummer would be impracticable, unless a specially early-maturing variety of corn should be developed. The suggestion has been made that the cornstalks be destroyed during the winter; but the moths leave them many months before cold weather.

In this connection it is worth noting that very late corn is often ruined by the ravages of the larvæ, the moths from the earlier corn and from cane depositing their eggs on the young corn plants as well as on the cane.

BURNING CANE TRASH.

In the process of harvesting sugar cane the tops of the plants and the lateral leaves are cut off and left in the fields, forming a quantity of fibrous vegetable matter almost universally called "the trash." (Pl. VIII, fig. 1.) A common recommendation has been to burn this débris as soon as it is dry enough, which is within a few weeks after the cane has been cut. Apparently burning would tend to decrease the subsequent infestation by the moth borer, but this has not been found to be the case. Examinations of the trash indicate that comparatively few borers are usually to be found in it, most of them being in the stalks of the cane, which are carted from the field and ground in the mill, thus disposing of the greater number. On the other hand, the trash is a favorable hibernating place for numbers of dipterous and hymenopterous insects, many probably of beneficial species. The eggs of the moth borer are deposited on the leaves of the cane plants, and these are attacked by the egg parasite *Trichogramma minutum*. It is probable that these minute beneficial insects are destroyed in great numbers when the trash is burned.

Louisiana sugar-cane planters have been burning over their sugar-cane fields for many years (Pl. IX, fig. 2), and it has not been found that any reduction in the number of canes infested by the moth borer results. Trash burning and other methods of control formerly recommended were thoroughly tried out on a plantation in Louisiana some years ago (see "Immersion and fumigation of infested seed cane," p. 49), but without beneficial effect. It is the opinion of the authors, after having made many field observations, that trash burning can not be expected to diminish the number of canes infested, while it may increase the infestation by destroying beneficial insects. An objection to trash burning, admitted even by its advocates, is that ordinarily it is not thoroughly done. The dry leaves which burn readily are consumed, and in the fields are left short scraps of cane, which sometimes contain living borers, even though they have been considerably heated and charred by the fire. It is evident that trash burning, while unquestionably destroying many beneficial insects, frequently fails to destroy the few borers left in the field, because of their protected situation in scraps of cane which do not burn readily.

When it is remembered that there are four or five generations of borers per year, that about half of the adults are females, and that each female lays an average of 200 eggs, it will be realized that a very few borers passing the winter successfully are sufficient to infest a whole plantation, especially if their parasites have been destroyed.

NOT BURNING CANE TRASH.

To protect the egg parasite the senior author some years ago began experimenting in disposing of cane trash by plowing it under and by raking it to the headland.

On one plat at the Sugar Experiment Station, Audubon Park, New Orleans, the cane trash was burned in the fall of 1912 as usual, while on another plat of about the same size the trash was raked to the headlands in the spring before cultivation. Through the growing season of 1913 careful examinations were made to ascertain the infestation in the two plats, and even in the spring and early summer the results were promising. For a long time no borers were found in the unburned plat, whereas borers and "dead hearts" were found in the burned-over plat, but when the cane was cut in October, the difference was most striking. In the burned-over plat 67.5 per cent of the canes were infested by the borer, while in the unburned plat only 15.5 per cent were infested.

On a plantation in the lower Rio Grande Valley of Texas no cane trash was burned in the fall and winter of 1912–13, while on neighboring plantations under the same management the trash was burned in the fall as usual. When examinations were made in the fall of 1913 the difference in infestation was easily discernible. The average infestation of the unburned fields was 30.6 per cent, while the average infestation of the burned-over fields was 76 per cent. In 1912 the average infestation of these plantations was 50.5 per cent and in a field a few miles away it was 86 per cent.

In 1914 various experiments were conducted at Audubon Park. Trash was burned in the fall, burned in the spring, raked to the headland in the spring, and plowed under in the spring. The results of these experiments are recorded in Table XII.

TABLE XII.—*Nonburning experiments, Audubon Park, New Orleans, La., 1914.*

Kind of treatment.	Number of plants infested by borer, May 29 to June 2, 1914.	Number of plants killed by borer, Oct. 28 to Nov. 2, 1914.	Per cent of canes infested by borer, Nov. 2 to 5, 1914.
Trash left on field in winter and plowed under in spring	3	3	45.73
Trash left on field in winter and raked to headland in spring	6	12	63.31
Trash burned in fall as usual in Louisiana	5	38	83.79
Trash left on field in winter and burned as soon as possible in spring	20	6	69.44

NOTE.—The plants infested May 29 to June 2 ("dead hearts") were cut out and destroyed about June 10, so that the plants killed by October 28 to November 2 were different plants which had been infested later in the season. The dates refer to the times examinations were made.

In each of these plats there were about 20 rows of cane. Three plats were in one field, not separated in any way, while the plat on which the trash was burned in the spring was separated from the plat on which it was burned in the fall by a plantation roadway about 20 feet wide. Needless to state, these conditions were not of the best for the experiments. It would have been better if each plat had been comparatively isolated from other plats of cane so that there would have been no danger of the insects going from one plat to another.

It will be noted that the infestation at the end of May was almost negligible in all plats, but even then the least injury was in the plat where trash was plowed under in the spring. By October 28 the most conspicuous injury ("dead hearts" and large plants killed) was small, but the difference between the plats subjected to different treatments is notable. Again, the smallest number of killed plants (3) was found in the plat where trash was left on the field in the winter and plowed under in the spring. Fall burning gave as many as 38 plants killed. In the plats where the trash was raked to the headland in the spring, and where it was burned in the spring, there were 12 and 6 dead plants, respectively—several times more than where the trash was plowed under in the spring. A few days later, when the cane was cut, a careful examination was made of over 600 canes in each plat. Where the trash was burned in the fall the infestation was nearly 84 per cent, but where the trash was plowed under in the spring it was only about 46 per cent. The experiments in raking the trash to the headland, and in burning it in the spring, gave about 65 and 69 per cent, respectively. From these experiments spring burning seems to be better than fall burning, and plowing the trash under in the spring better than either. (Pl. VIII, fig. 2.) Raking the trash to the headland, for some unknown reason, did not give as good results in 1914 as it did in 1913.

Extensive experiments on plantations in Louisiana were carried on in 1915, 1916, and 1917. During 1915 and 1916 the results were negative, the infestation being about the same on fields where trash was not burned as where it was burned. The fields not burned were usually in the midst of other fields which had been burned over. Yet in 1916, when the trash was not burned except on one field at Audubon Park, the infestation was much lower there than anywhere else in the State, with the exception of two places which had been flooded. The average infestation in Louisiana for 1916 was 75.5 per cent, while the infestation at Audubon Park was only 38.3 per cent.

The reason for the difference between the results on plantations and those at Audubon Park was not understood until it was suggested in 1917 by Mr. W. G. Taggart that the relative isolation of the fields at Audubon Park had prevented the reinfestation of the unburned fields by moths flying from other plantations. This explanation seems to be correct, and the latest results tend to confirm it. The average infestation in Louisiana in 1917 was 45.8 per cent,

FIG. 1.—SUGAR-CANE FIELD AFTER THE CANE HAS BEEN CUT AND REMOVED, SHOWING HEAVY COVERING OF LEAVES OR "TRASH."

FIG. 2.—SUGAR-CANE FIELD SHOWING LEAVES OR "TRASH" PLOWED IN. THE STUBBLE WAS PLOWED UP IN THE SAME OPERATION.

CONTROL OF THE SUGAR-CANE MOTH BORER.

FIG. 1.—PARTIALLY COVERING CANE TRASH WITH TWO FURROWS TO A ROW TO HASTEN DECOMPOSITION DURING WINTER.

FIG. 2.—BURNING CANE TRASH.

CONTROL OF THE SUGAR-CANE MOTH BORER.

as compared with 20.3 per cent at Audubon Park, where the trash was not burned on any of the fields but one. Comparing this burned-over field with an average of the other stubble fields, we have an infestation of 38 per cent for the burned-over field, while the average infestation of eight unburned stubble fields was 20.2 per cent, with 36 per cent as the highest infestation on an unburned field.

The plantation results in 1917 are in accord with the theory that isolation of fields influences the results of nonburning, using the term "isolation" to mean not only a situation detached from other cane plantings, but one separated from plantations where the trash is burned. In a locality in the midst of the sugar parishes, a typical plantation (designated *A* on the diagram, fig. 12), fronting on the Mississippi River and running back to swamp land was not burned over, the trash being plowed under in the fall. This plantation was bordered on the north by a burned-over plantation (*B*), and on the south by a much smaller plantation (*BB*), a long and narrow strip of land which had also been burned over. But bordering these plantations was one on the north (*C*) in which only part of the trash had been burned, the rest having been plowed under, and one on the south (*CC*) treated in the same way. Plantation *A*, where the trash had not been burned, while bordered on each side by burned-over areas, was yet the center of a district where much of the trash had been saved. The infestation at *A* was 22.5 per cent, and at *C* and *CC* it was 56.9 per cent and 53.6 per cent, respectively. At *B*—burned over, but between *A* and *C* and undoubtedly influenced by the trash saved at those places—it was 49.5 per cent. Plantation *BB* was over-

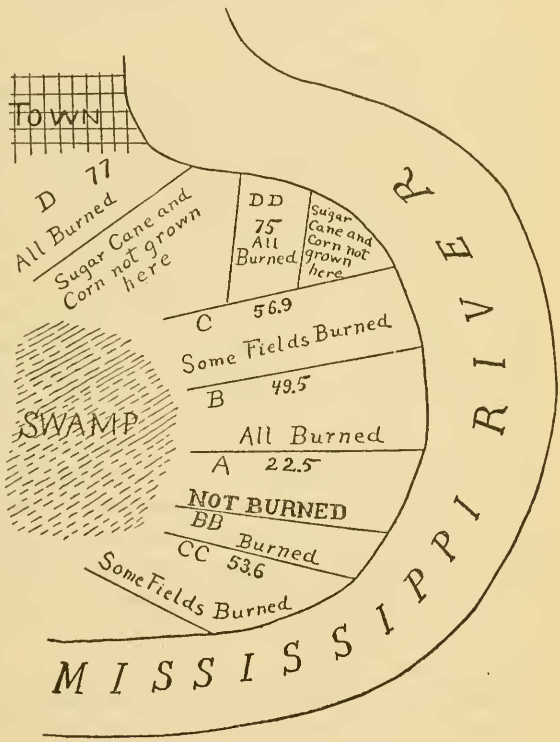

FIG. 12.—Diagram of plantations showing percentages of infestation by the sugar-cane moth borer in relation to nonburning of cane trash.

looked and the infestation is not known, but at two places in the vicinity, *D* and *DD*, both burned over, the infestation was 77 per cent and 75 per cent, respectively. The map will convey a more accurate idea of the situation than any further explanation, but the following points should be noted: At the two burned-over plantations, *D* and *DD*, farthest away from unburned fields, the infestation was high, about 75 per cent. At the two partly burned plantations, *C* and *CC*, it was medium, about 55 per cent. At the burned-over plantation *B*, bordered on each side by unburned or partly burned fields, it was also medium, 49.5 per cent. At plantation *A*, not burned and the center of a nonburning region, the infestation was the lowest of all, only 22.5 per cent.

It is evident that a plantation must be considered as a unit in determining the infestation. The former custom was to consider a field as a unit, to which there is the objection that the moths of the borer can fly readily and doubtless reinfest areas in which the parasites have gained the ascendency. Although a comparison of fields at Audubon Park is not unsatisfactory, it is true that the fields there are small, and they are not surrounded by vast stretches of cane and cornfields which are typical of the sugar parishes.

The results in 1917 indicate that nonburning will be effective on isolated areas of any size and on nonisolated areas so large that the bordering burned-over fields will have little effect on the general infestation. An illustration of nonburning on a single narrow plantation surrounded by burned-over areas was obtained in 1917. In this case nonburning was apparently of no benefit, the infestation being slightly, if any, lower than at a neighboring place. Yet the benefit to the land of plowing under the trash is considerable, and as it is only by degrees that the new practice will become established no planter should hesitate to practice nonburning because his neighbor refuses to do so.

A planter who has plowed under his trash tells us that it maintains the tilth of the soil from year to year, and the difference between the condition of the soil where trash has been plowed under and where it has been burned is immediately perceptible. Where the trash is plowed under the soil is left open and porous and is enriched by the nitrogen and other fertilizing elements of the decaying vegetation. (See Pl. IX, fig. 1.)

The work of plowing out the trash in the spring is regarded by some planters as so great that they refuse to leave it on the fields unburned. At the Sugar Experiment Station the process of caring for the trash, quoting Mr. W. T. Taggart, assistant director, is as follows:

In plowing under cane tops, especially on land where stubble is to be held for the following year, the work must be done in such a manner as not to injure the ratoons, and at the same time to hasten decomposition of the trash. The last object can be best attained by covering the tops with two furrows by the turning plow, before the green material has dried out. If the labor and teams are not available at the time, it is next best to do the plowing when the tops are as wet as can be handled without danger of damaging the mechanical condition of the soil. We find that two furrows, run as far away as possible from the old ratoon, and at the same time just deep enough to cover the trash lightly, are satisfactory. This practice practically allows all trash to be held continuously in a moist condition with free access to air, thereby hastening oxidation and decomposition. The partially decomposed vegetable matter is thoroughly and deeply buried at the usual time in early spring when cane is off-barred. Under average conditions of tonnage and winter rainfall we have found that cane trash treated according to this method will decompose sufficiently to allow cultivation of the middles without undue cost or inconvenience. However, when a heavy crop of tops has been turned under considerable difficulty may be experienced in throwing out the middles, unless the job is undertaken in two operations. First, whatever implement is assigned to this task should be run in such manner as to skim over the main layer of trash; the second furrow can then go deep enough to undermine any trash which has not been decomposed, and divide it along the side of the two rows where the following cultivation, preferably with a disc cultivator, will completely mix all this organic matter, with its humus and nitrogen, into the seed bed.

Practically the same method is used on the large plantations where the trash was left in 1916 and 1917. The labor of the first cultivation was said by one plantation manager to be about doubled and to cost about $1 more per acre than cultivation after burning. A plantation owner estimates an additional cost of $1.50 per acre. This is a very small amount to spend for the possible control of the moth borer, and is slight as compared with a maximum loss of nearly $50 per acre. Stubbs (151) calculates that for every ton of cane there are left in the trash 1.9 pounds of nitrogen, equal to the nitrogen in 27 pounds of cottonseed meal, while Mr. Taggart has told the writers that there are 556 pounds of organic matter in the trash per ton of cane. All this nitrogen and organic matter is lost in the burning of the trash, but preserved when it is buried. Considering the chemical and mechanical benefit to the soil, the possible insect control really costs nothing at all.

On the subject of nonburning, Prof. F. S. Earle (46), formerly director of the Cuba Experiment Station, writes as follows in the *Cuba Magazine:*

To the general burning of the trash in the fields after cutting there are, however, many valid objections under conditions existing in Cuba and Porto Rico. On many soils this trash is badly needed to keep up the supply of humus, but more particularly it is needed as a mulch to protect the soil from excessive drying out during our long periods of winter drought. Aside from this, the universal burning of the trash would involve an amount of summer cultivation to keep down weeds and grass that would be entirely beyond the present equipment and labor supply of most of our plantations. In other words, it is impracticable. The best we can hope in the direction of ratoon cultivation is to move the trash and cultivate alternate middles. Nor is there any reason to suppose that burning the trash would give us any real protection from the borer. Cultural conditions in Louisiana are so different from ours that the burning of the trash is practically a necessity and it is universally practiced.[1] We do not, however, find that this gives them any immunity from the borer. On the contrary, they suffer fully as much as we do. This very likely may be due to the fact that burning destroys borer parasites as well as borers. There is good reason to believe that here in the West Indies borer parasites of one kind or another are sufficiently abundant to play an important part in holding this pest in check. There is no point more urgently in need of careful investigation. Until it is fully determined it will be impossible to outline a really satisfactory campaign against the cane borer. * * * On certain fields it becomes advisable to burn the trash in order to be able by thorough cultivation to kill out pernicious grasses that would otherwise ruin the fields. When and where and how much to burn are questions that must always tax the best judgment of the administrator. If judiciously done on a small scale it is often an advantage, but if universal burning of the trash should be adopted on the advice of our scientific friends it would surely result in the financial ruin of the majority of the plantations in Cuba and of many in Porto Rico.

It is believed that Prof. Earle will be proved correct in concluding that burning or not burning trash is a matter for the mature judgment of the plantation manager, in Louisiana as well as in other countries.

EXPERIMENT WITH THE HAWAIIAN BEETLE BORER PARASITE.

The work of the entomologists of the Hawaiian Sugar Planters' Association Experiment Station is too well known to need any extended description. Suffice it to say that under the auspices of the very progressive sugar planters of Hawaii the world was searched for parasites of insects destructive to sugar cane; that they found many parasites; and that they succeeded in establishing many of them in the cane fields of Hawaii. The injury from insects has been greatly reduced and millions of dollars' worth of sugar is being saved annually.

The parasite which contributed largely to the control of the weevil borer (*Rhabdocnemis* [*Sphenophorus*] *obscurus* Boisduval) was a tachinid fly (*Ceromasia sphenophori* Villeneuve) which was brought from New Guinea. As the habits of this beetle borer in boring through the cane stalks are much the same as those of the moth borer in Louisiana, the junior author suggested that Ceromasia be tried against the moth borer. The same suggestion was made later by Dr. L. O. Howard and Dr. W. D. Hunter, of the Bureau of Entomology. Mr. Frederick Muir, of the Hawaiian Sugar Planters' Experiment Station, who had discovered the parasite and introduced it into Hawaii, was consulted, and gave his opinion that it would not attack the moth borer. He stated that he had seen the moth borer (*Diatraea* sp.) and the beetle borer working together, and that Ceromasia confined itself to its beetle host.

[1] Prof. Earle is writing of conditions in Porto Rico and Cuba, with which he is more familiar, and takes it for granted that burning the trash in Louisiana, at that time universally recommended, is a necessity.

The writers were prevented from introducing parasites known to attack the moth borer in Cuba, however, and it seemed worth while to give Ceromasia a trial. A cage isolated from ants was arranged, and in 2 feet of soil at the bottom of this cage a number of cane plants were set. Later nearly 200 stalks of cane containing tunnels of the moth borer and probably many borers were secured and put into the cage, one end of each stalk being pushed into the ground. Mr. Otto H. Swezey, entomologist of the Hawaiian Sugar Planters' Experiment Station, in September, 1917, kindly gave directions for the preparation of this cage and caused puparia of Ceromasia collected in Hawaii to be sent to the writers, who placed the adults in the cage as soon as they emerged. Eighty-seven puparia were received, from which 23 flies emerged. About half of the adults were small, but many were of normal size. Mr. Swezey's instructions were followed closely, ants were kept out of the cage, the plants were sprinkled daily, and honey and overripe fruit were provided as food for the flies.

It was found that the infestation by the moth borer in the cage was far higher than that usually found in the field. The growing plants were so heavily infested that they did not make any appreciable growth throughout the remainder of the season. Though provided with possible hosts in such numbers, the parasites did not attack the borer. Some of the cane stalks were cut open at the end of six weeks, the length of a generation of the parasite in Hawaii, but no evidence was found that they had parasitized any borers, although many live borers were found. More cane was examined later with the same negative result.

EXPERIMENT WITH A PARASITE FROM CUBA.

In 1915 the junior author went to Cuba to obtain, if possible, a tachinid parasite of the moth borer which had been reported by Mr. George N. Wolcott. It was found that while the moth borer was present, it was by no means as injurious as in Louisiana, and that the tachinid parasite *Euzenilliopsis diatraeae* Townsend evidently had much to do with its comparative control.

Living puparia of the tachinid parasite were obtained and forwarded to the senior author in New Orleans from time to time during the summer of 1915. Cages of many kinds were utilized, although none of the type which had been found satisfactory in Hawaii with tachinids was used. In every experiment the parasites died without attacking the host larvæ provided for them. Finally it was decided to release the adults in the fields at Audubon Park as soon as they emerged from the puparia. Following this action, during the next grinding season one puparium was recovered in a stalk of cane, and an adult of the species introduced from Cuba emerged from it.

No other parasites were found during the succeeding two years, and it would appear that they have died out, but the discovery of the single puparium proves that they will successfully parasitize the sugar-cane moth borer in Louisiana. It is believed by the writers that the parasite might be of much benefit in controlling the borer if it were introduced in larger numbers. If this had been possible, much might have been accomplished, but conditions in 1916 and 1917 prevented further experimental work.[1]

If the introduction of beneficial parasites can be undertaken later, it would seem advisable to station two men in Cuba to collect the parasites and one in Louisiana to receive them and ultimately to release them on the plantations. In 1915 investigations were conducted from February to September, but it appears that the most favorable season is from April to September, inclusive.

RECOMMENDATIONS.

1. Scraps of cane left about the factories and derricks after the grinding season should be destroyed by burning or otherwise. Cars in which cane is shipped, especially if they go into noninfested territory, should be kept free of such scraps.

2. Seed cane should be planted in the fall, if possible, and kept as deeply covered as practicable. Extraordinarily deep planting is not advocated, but as borer moths fail to emerge from cane under more than one-half inch of compact soil care should be taken to keep the seed cane well covered to that depth as a minimum. A heavy rain will sometimes wash the earth from the seed cane from one end of a row to the other, and in this case it is important to cover the cane again as soon as possible, especially in the spring, when the moths are emerging.

3. Cane for shipment to points beyond the infested area should be selected so as to obtain it sound and free of borers, or if this is impossible it should be soaked, previous to shipment, for at least an hour in Bordeaux mixture[2] or a solution of nicotine sulphate.[3]

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[1] Since the manuscript for this bulletin was submitted a number of sugar planters in Louisiana have agreed to contribute a small amount each to enable work in Cuba to be done. This action made it possible for the senior author to spend some time in Cuba in 1918. He collected and sent to New Orleans about 650 puparia of the tachinid *Euzenilliopsis diatraeae*, which were received and cared for by Messrs. E. R. Barber and W. G. Taggart. Several generations were reared during 1918, and it seems that the parasites will become established if they can stand the Louisiana winter.

The junior author, who was in Cuba in 1915, is no longer connected with the investigation, having accepted a position under the Federal Horticultural Board.

[2] The formula for Bordeaux mixture is as follows:

Sulphate of copper	pounds	6
Quicklime	do	4
Water	gallons	50

Dissolve the sulphate of copper in 1 gallon of hot water and slake the lime in another vessel with an equal quantity; reduce the latter to a creamy milk of lime and add slowly to the copper solution, stirring constantly. Finally, add water to make up the 50 gallons.

[3] One part nicotine sulphate (40 per cent nicotine) to 500 parts water.

4. The "trash," leaves, or "shucks" left on the fields after cutting should not be burned, but should be lightly covered with earth in the fall and plowed out in the spring. This practice has never been found to increase the borer infestation, and it has often diminished it. The soil is fertilized by the buried trash and its mechanical condition is greatly improved.

5. Cutting out "dead hearts" or dead plants and destroying them is theoretically sound, and with an abundance of cheap labor it might be recommended.

6. The introduction of parasites of the moth borer from Cuba and other tropical countries is recommended.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 766

Contribution from the Bureau of Entomology
L. O. Howard, Chief

Washington, D. C. PROFESSIONAL PAPER July 10, 1919

A STUDY OF COMPSILURA CONCINNATA, AN IMPORTED TACHINID PARASITE OF THE GIPSY MOTH AND THE BROWN-TAIL MOTH.

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CONTENTS.

INTRODUCTION.

Compsilura concinnata Meigen (Pl. I, fig. 1), one of the imported tachinid parasites of the gipsy moth and the brown-tail moth, was introduced into Massachusetts first in 1906, at which time these moths were so abundant and destructive, particularly in eastern Massachu-

[1] The writer wishes to express his appreciation of the help given by the various assistants at the Gipsy Moth Laboratory as well as by the field men, both at the laboratory and in collecting host material; to Mr. A. F. Burgess and Dr. John N. Summers for their helpful suggestions and advice; to Mr. R. T. Webber for furnishing rearing records, the bulk of the native host list being the results of his experiments; to Mr. C. F. Muesebeck for assisting in the dissections and drawings of some of the figures in this bulletin; and to Mr. A. M. Wilcox, who furnished large quantities of parasite-free host material for use in the reproduction experiments on Compsilura.

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setts, that enormous areas of forest and shade trees were defoliated annually. In some residential sections life was rendered almost unbearable by the presence of enormous numbers of caterpillars. Although the history of the introduction and destructive work of these two pests has already been published,[1] few except eye witnesses could realize the serious conditions that existed at the time parasite introduction was begun.

Since 1891, when the gipsy moth covered an area of approximately 200 square miles, it has spread until in 1916 it involved 20,715 square miles, and is found in all of the New England States. In some localities in Massachusetts, where it was once accounted a plague, the severity of the infestation has been reduced to such an extent that the pest is more easily controlled.

The brown-tail moth was first regarded as a serious problem in 1897, when it was found in 15 towns close to Boston. Since then it has spread until now (1916) it covers a territory of 38,118 square miles, occurring in all of the New England States. Both sexes of the brown-tail moth are strong fliers. This important factor helps to explain why this insect is found over a larger area than the gipsy moth, the female of the latter species being unable to fly.

The life cycle of both the gipsy moth and the brown-tail moth is such that all stages, with the exception of the imago, are attacked by parasites. The internal-feeding parasite *Compsilura concinnata* is parasitic only upon the larvæ of these two hosts, and, while it has been reared occasionally from the pupæ, it will not complete its life cycle if the attack is delayed until the host pupates. These two hosts form an ideal combination for Compsilura, as the brown-tail moth larvæ occur in the field a short while after the parasite emerges from

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hibernation. The gipsy-moth larvæ are a little later, and the bulk of the Compsilura reared at the gipsy-moth laboratory come from this host.

HISTORY OF COMPSILURA CONCINNATA MEIGEN.

DESCRIPTION.

Compsilura concinnata is larviparous, the eggs hatching in the uterus and the young being injected into the host by means of a larvipositor, which is inserted in an opening of the host integument made by a grooved, curved piercer, resembling a V in shape. When parasites were first imported there were among them certain tachinid puparia, some of which were not specifically identified at that time. It is probable that in this lot of unidentified puparia were some of the *Compsilura concinnata*, although, if such was the case, no record was kept.

Compsilura concinnata was first described in 1824 by Meigen, in "Systematische Beschreibung des bekannten europäischen zweiflügeligen Insekten," Volume IV, page 412, under the name of *Tachina concinnata.* Following is a translation of the original description:

Length 7½ mm. Face white, both sides to above the middle with vibrissæ; palpi orange. Vertex rather narrow, white, with a deep black stripe; bristles reaching up to the hypostoma. Antennæ somewhat shorter than the hypostoma, brown, with a larger bristle, which is thickened for about one-third of its length. Thorax whitish; the dorsum with blackish iridescence and four deep black stripes; the outer somewhat broader. Abdomen cone shaped; the first segment and a dorsal line and band on the hind edge of the next segment polished black; venter of abdomen carinate, black, with whitish incisions. Legs black, alulæ white; wings almost glossy transparent; apical cross vein straight, with rounded corners; the veins converge closely on the edge of the wing before its apex, the usual cross vein somewhat curved. The above description was from a female.

The larva and puparium (Pl. I, fig. 2) of Compsilura were both described in 1834 by Bouché in "Naturgeschichte der Insekten . . .", printed in Berlin, page 57. A translation of the descriptions follows:

The larva is elliptical, somewhat narrower anteriorly, roughish, fleshy, soft, variable, with swollen outlines and very finely grooved. The thoracic incision is black, as are also the articulation pieces of the abdomen, armed with little sharp points. The spines are arranged more or less in wavy rows. The black, short, and stout mouth hooks are almost straight. The antennae are wartlike, double, clear brown. The prothoracic stigmata are short, yellow, and parted. The hind part (last segment) is small, rounded, shallowly excavate posteriorly. In this depression are the two round, black stigmata bearers, provided on the inner side with white, round, transparent spots and brown three-divided stigma. Length 7½ mm.

The pupa is dark brown, elliptical-stout. Almost a smooth barrel. The segments are linked together, a little muricate at the abdomen. The prothoracic stigmata of the coming fly forms short blunt points. The blackish-brown posterior stigmata bearers are close together, and are provided with trifoliate stigmata. Length, 6½ mm.

In the description of the larva Bouché neglected to speak of a very important point, the anal hooks of the first-stage larvæ. This character has been found only in one other tachinid first-stage larva, that of the closely allied genus Dexodes. It is very easy to determine this stage by these hooks and to verify the fact that Compsilura parasitizes early-stage brown-tail moth larvæ in the fall, as has been found from various dissections. Pantel describes and illutrates these hooks in "La Cellule." (Fig. 1.) There are three of these peristigmatic hooks; two prestigmatic and one retrostigmatic. It is with these hooks that the larva attaches itself to the peritrophic membrane just previous to molting into the second stage. As the larva grows, the molt skins are pushed down on to this funnel until just previous to emerging, when the full-grown third-stage maggot breaks loose and forces itself out of the dead host. This is done in the following manner: The anterior end of the parasite, assisted by the mouth hooks, makes a small opening in the integument of the host and by a gradual process of extending and retracting the anterior part of the body the larva finally succeeds in passing out. If the host is one that has spun a cocoon, the parasite larva will pupate within this, but if not, it will drop to the ground or pupate near the host. The time between emergence of the larva and pupation is governed by such things as temperature and location, whether on a tree trunk, in soil, or elsewhere.

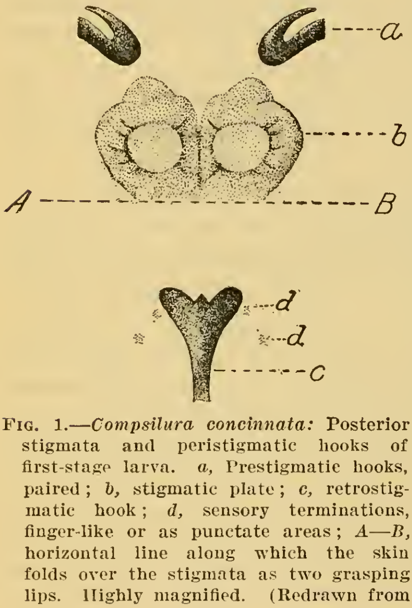

FIG. 1.—*Compsilura concinnata:* Posterior stigmata and peristigmatic hooks of first-stage larva. *a*, Prestigmatic hooks, paired; *b*, stigmatic plate; *c*, retrostigmatic hook; *d*, sensory terminations, finger-like or as punctate areas; *A—B*, horizontal line along which the skin folds over the stigmata as two grasping lips. Highly magnified. (Redrawn from Pantel.)

DISTRIBUTION IN EUROPE.

Compsilura concinnata is found in Europe in practically all of the territory covered by the brown-tail moth. It has been imported into the United States from 10 European countries and possibly from Japan. Very little work has been done with the parasite in Europe beyond Pantel's investigations. Compsilura has been described under a number of synonyms by various authors, and reference to these synonyms can be found in the "Katalog der Paläarktischen Dipteren," Volume III.[1]

[1] See also "Bibliography," pp. 25–26.

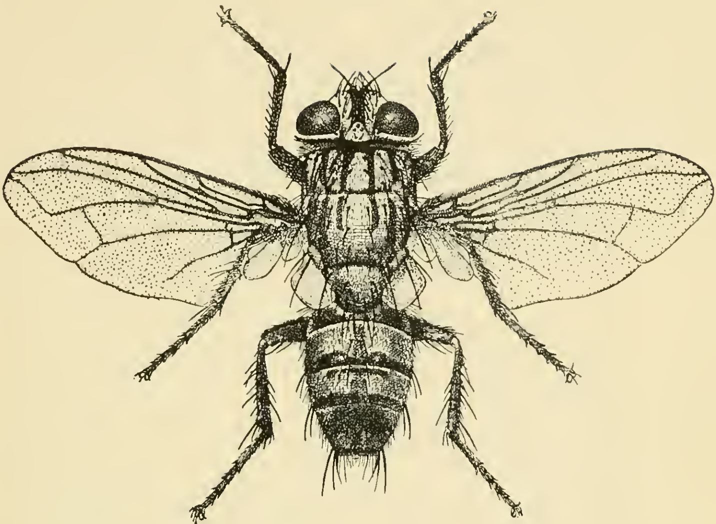

FIG. 1.

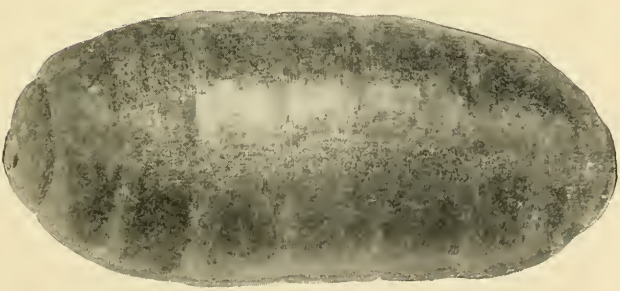

FIG. 2.

ADULT AND PUPARIUM OF COMPSILURA CONCINNATA.

FIG. 1.—Adult female. FIG. 2.—Laterial view of puparium. Fig. 1, 6½ times natural size; fig. 2, about 10 times natural size.

HOSTS, EUROPEAN AND AMERICAN.

This parasite attacks a large number of both nocturnal and diurnal hosts in Europe, the host list comprising 58 different species. In the United States it does not attack so many, probably due to its recent importation to this country. In time the host list for Compsilura in the United States will, no doubt, surpass that in Europe, for within the few years it has been established in New England a host list comprising 33 species already has been compiled,[1] and undoubtedly it attacks more than are known at the present time. All of the records given in the list of native hosts of Compsilura were secured at the gipsy moth parasite laboratory, Melrose Highlands, Mass. In a few instances these records have been duplicated by investigators at other places.

Table I gives the European host list.

TABLE I.—*Foreign hosts of Compsilura concinnata; records from the "Katalog der Paläarktischen Dipteren" and from the Bibliography.*

Abraxas grossulariata L.
Acronycta aceris L.
Acronycta alni L.
Acronycta cuspis Hübn.
Acronycta megacephala F.
Acronycta rumicis L.
Acronycta tridens Schiff.
Araschinia levana L.
Araschinia prorsa L.
Arctia caja L.
Attacus cynthia L.
Catocala promissa Esp.
Cimbex humeralis Fourcr.
Craniophora ligustri Fab.
Cucullia lactucae Esp.
Acronycta verbasci L.
Dasychira pudibunda L.
Dilina tiliae L.
Diptcrygia scabriuscula L.
Drymonia ruficornis Hübn.
Euproctis chrysorrhoea L.
Heteromorpha caeruleocephala L.
Hyloicus pinastri L.
Libytha celtis Laich.
Macrothylacia rubi L.
Mamestra brassicae L.
Mamestra oleracea L.
Mamestra persicariae L.
Malacosoma neustria L.
Oconistis quadra L.
Papilio machaon L.
Phalera bucephala L.
Pieris brassicae L.
Plusia festucae L.
Plusia gamma L.
Poecilocampa populi L.
Pontia rapae L.
Porthetria dispar L.
Porthetria monacha L.
Porthesia similis Fussl.
Melalopha anachoreta Fab.
Pyrameis atalanta L.
Smerinthus populi L.
Spilosoma lubricipeda L.
Stauropus fagi L.
Stilpnotia salicis L.
Taeniocampa stabilis View.
Thaumetopoea processionea L.
Thaumetopoea pityocampa Schiff.
Timandra amata L.
Trichiocampus viminalis Fall.
Trachea atriplicis L.
Vanessa antiopa L.
Vanessa io L.
Vanessa polychloros L.
Vanessa urticae L.
Vanessa xanthomelas Esp.
Yponomeuta padella L.

The following is the American host list:

TABLE II.—*American hosts of Compsilura concinnata.*

Apatela hasta Guen.
Arctiid sp.
Autographa brassicae Riley.
Callosamia promethea Dru.
Cirphis unipuncta Haw.
Cimbex americana Leach.
Deilephila gallii Rott.
Diacrisia virginica Fab.
Deidamia inscripta Harris.
Ennomos subsignarius Hübn.
Estigmene acraea Dru.
Euchaetias egle Dru.
Geometrid sp.
Hemerocampa leucostigma S. & A.
Hyphantria cunea Dru.
Malacosoma americana Fab.
Malacosoma disstria Hübn.
Mamestra adjuncta Boisd.
Mamestra picta Harris.
Melalopha inclusa Hübn.
Noctuid sp.
Notodontid sp.
Notolophus antiqua L.
Papilio polyxenes Fab.
Plusiodonta compressipalpis Guen. (By Reiff, at Forest Hills, April 7, 1913.)
Pontia rapae L.
Phlegethontius quinquemaculata Haw.
Rhodophora florida Guen. (By Reiff, at Forest Hills, Sept. 8, 1913.)
Schizura concinna S. & A.
Vanessa antiopa L.
Vanessa atalanta L.
Vanessa huntera Fab.
Xylina sp. Ochs.

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[1] This covers all records, including those of the year 1916.

IMPORTATIONS TO UNITED STATES.

Compsilura was first imported into the United States in 1906, though it was not determined as such, being included in the general classification of Tachinidae. In 1907, from shipments of brown-tail moth larvæ and gipsy moth larvæ and pupæ there were secured 104 puparia which were determined as *Compsilura concinnata*. These came from France, Germany, and Austria. Most of the Compsilura imported in 1907 were found free in the boxes of brown-tail moth larvæ, and a few in the gipsy moth shipments. In 1908 an experiment was tried in shipping live puparia from Europe to Melrose Highlands, Mass., but it was not successful, as the puparia were nearly all broken. That year 220 Compsilura were received. The year 1909 was the banner year in importations of Compsilura, a total of 6,626 being secured from foreign shipments, about 50 per cent of these coming from gipsy-moth material. This was the first time that Compsilura was accepted as more than an occasional parasite of *Porthetria dispar*. During the year 1910 the majority of the 1,859 Compsilura received were secured from gipsy-moth shipments in the late larva and early pupa stages. No puparia shipped as such were received, as those sent the previous year came in such poor condition. The season of 1911 was the last during which Compsilura was imported. In this year 1,233 were received, about 75 of which came as puparia, practically all of the others being secured from brown-tail moth shipments. In the period between 1906 and 1911 Compsilura was received from nine European countries as well as a few possibly from Japan, a grand total of 10,042 being received at the Gipsy Moth Laboratory.

COLONIZATION.

There is no record of the number of Compsilura colonized in 1906 or 1907, but in Bulletin 91 of the Bureau of Entomology, page 220, reference is made to efforts along this line.

In 1907 a large colony was liberated at the location of one of the colonies of 1906, in the town of Saugus, Mass. No colonization was attempted in 1908, but in 1909 several colonies were established throughout eastern Massachusetts in the gipsy-moth area. Very little colonization was done in 1910 and 1911, a total of 1,304 being colonized during that time. It was in 1910 that a colony of this parasite was put out in Washington, D. C., to combat the white-marked tussock moth (*Hemerocampa leucostigma* S. & A.). In 1912 colonization of Compsilura in New England was again resumed on a larger scale than at any previous time, and this has been continued until the entire gypsy-moth area has been covered. This parasite does not appear to be so firmly established in the brown-tail moth area where the gypsy moth is not found, though colonization has been made there. It is true that it will perpetuate itself without the gypsy moth, but not in such large numbers, as collections made from these outlying towns have shown.

During the years 1912 to 1916 the entomological branch of the Dominion of Canada collected in New England and shipped for colonization to New Brunswick and Nova Scotia 32,824 Compsilura to combat the brown-tail moth. In 1914 and 1915 assistants of the branch of Cereal and Forage Insect Investigations of the United States Bureau of Entomology collected and sent Compsilura to Arizona and New Mexico to be used in the fight against the range caterpillar *Hemileuca oliviae* Ckll., a total of about 4,000 of these parasites being divided between the two States. During the years 1915 and 1916 about 3,000 Compsilura were sent to Florida to be used against the fall army worm (*Laphygma frugiperda* S. & A.). Compsilura has not proved as successful in the West and South as it has in New England up to the present time. In Arizona and New Mexico the conditions are so radically different from those in New England that even though the parasite becomes established it will take some time for it to became climatically adjusted. It has been too recently colonized in the South to justify predictions as to the results that will be accomplished. In Canada it more nearly approaches its standing, as an effective parasite, in the outskirts of the brown-tail moth infestation in New England and in time should prove a valuable aid in the control of this pest.

SPREAD.

The rate of spread of Compsilura has been determined in two ways: (1) By scouting, which consists of carefully examining gipsy moth and brown-tail moth infestations in localities just outside the area previously recorded as covered by Compsilura, and (2) by collections of various lepidopterous larvæ from towns beyond the known spread of the parasite. This rate of spread has been found to be approximately 25 miles per year, and this is taken into consideration in colonizing the parasites, the colonies having been put out in most cases about 25 miles apart in all directions. This proves that the insect is a strong flier, for there are no artificial means worth considering that will assist in its dispersion.

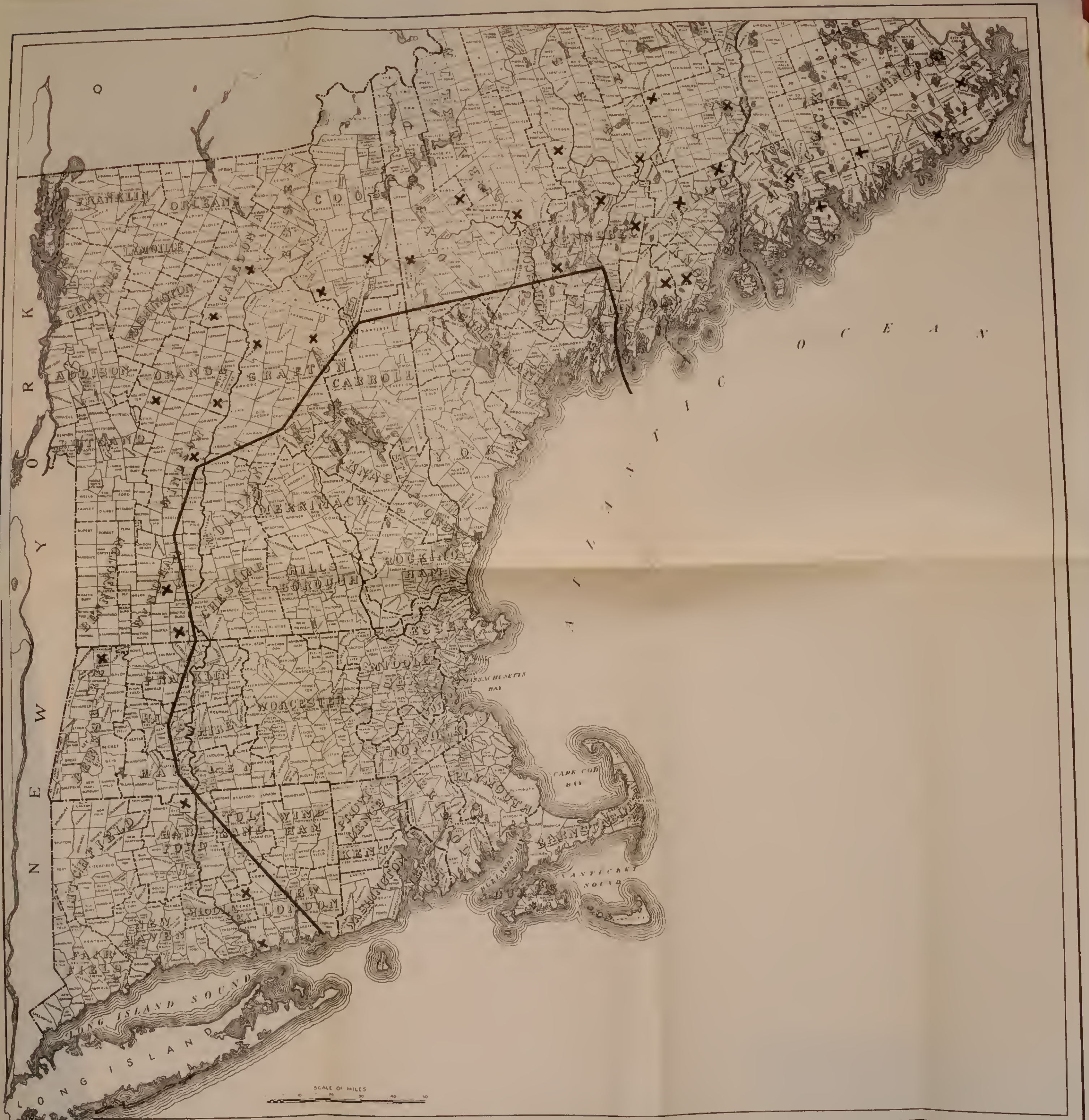
RECOVERY.

The first recovery of Compsilura was made in New England in 1907, a single specimen reared from a field collection of gipsy-moth larvæ. Attempts to recover this parasite failed in 1908, but in 1909, soon after colonization, several puparia were reared from collections of both brown-tail moth and gipsy-moth larvæ, which proved that the parasite had become established from the colonies of 1906 and 1907. It was in 1909 that assistants from the laboratory, in scouting for larvæ of *Calosoma sycophanta* L., found numbers of Compsilura puparia in the field. Since the first substantial recovery in 1909 the parasite has been recovered from 303 towns in New England. These towns are scattered throughout the entire gipsy-moth area, with very few outside. (See map, Pl. II.) An interesting recovery of Compsilura was made in 1915, from the Island of Nantucket, Mass., 25 miles from the mainland, where the nearest colony of the parasite is located.

Compsilura is scattered over so wide a territory that it is usually possible to collect it in almost any part of New England within the gipsy-moth area. This is especially so where the gipsy moth is abundant in a locality not far distant from where Compsilura has been colonized any length of time. The general method is to make trial collections of 100 fourth-stage larvæ and maintain them in feeding trays.[1] These trays are small and rectangular, the bottoms being covered with thin cloth and a narrow band of tanglefoot applied near the top to prevent the escape of larvæ. If this trial collection shows a parasitism of 8 to 10 per cent, the location is considered a good field for bulk collections to secure parasite material for colonization. In a few instances where both trial and bulk collections showed a very high percentage of parasitism the first year, it has not been considered necessary to make trial collections from a given locality the following year. This is not always relied upon, however, as Compsilura may be present in a locality in fairly large numbers one year, while the following year collections from the same locality will give a low percentage of parasitism. This is particularly true of places where the brown-tail moth is scarce and which may have a good infestation of gipsy moths. Compsilura seems to be more prevalent where there is a rather heavy infestation of both brown-tail moths and gipsy moths.

All of the collections are sent by mail or brought into the laboratory in wooden boxes 3½ by 5¼ by 9½ inches. These boxes have a hole in one end through which the larvæ are put as they are collected, about 350 to 400 larvæ in each box; this hole is then covered by a piece of tin or zinc, which is secured by four tacks. Fresh food is placed in the boxes as the larvæ are collected; this keeps them separated in transit. As soon as these boxes are received at the laboratory they are opened, the location recorded and filed under a number, and the larvæ counted and placed in a feeding tray, the size of which is governed by the number from a single locality.

[1] These trays have been described in Department of Agriculture Bull. No. 250, July, 1915.



Map Showing Distribution of Compsilura concinnata in New England. The Area Inclosed by the Heavy Line is the Territory Covered by Compsilura. The Crosses Show Where it Has Been Colonized Outside This Area, But Has Not Yet Been Recovered.

These trays are carefully examined and all of the Compsilura puparia removed and counted every two or three days, records being kept under the locality number. As these puparia are removed they are kept in a cool place until a sufficient number, 500, is secured, when they are ready to be sent to some point for colonization.

DISCUSSION OF CLASSIFICATION OF COMPSILURA CONCINNATA.

The parasitic Diptera, which include Tachinidae, are classified according to structure and method of attack. Method of attack is governed by the structure of the insect, and J. Pantel, in "La Cellule," Volume I, has classified these parasites, grouping them in the form of a key, according to structure. As this entire classification is too lengthy for reproduction here, the writer will give merely an extract of the group containing Compsilura.

FIG. 2.—*Compsilura concinnata:* Ovariole of adult female at hatching. Greatly enlarged. (Pantel.)

Group VII. Species which, by means of distinct perforating and laying instruments, insert hatched larvæ, or those about to hatch, in the body of the host.

Enumeration of species.	*General host index.*
Compsilura concinnata Meig. *Dexodes nigripes* Fall. *Vibrissina demissa* Rond.	A very long list of caterpillars and false caterpillars. (Pantel here notes that he has bred them from 12 (species) bombycid caterpillars (Townsend).)

While Compsilura is moderately fecund, each female deposits larvæ singly beneath the skin of the host. The ovaries, at the time of hatching, form an obconic bundle consisting, on an average, of 14 ovarioles or strings of developing eggs, and each ovariole containing, on an average, 8 developing eggs. (Fig. 2.) These averages were arrived at from dissections of 50 sexually mature females. This would make the reproductive capacity of Compsilura approach 225, but this total is not reached, as a general thing, as dissections of adults, which were three to four weeks old, have shown. A series of dissections have shown that the average reproductive capacity of Compsilura is from 90 to 110 larvæ.

The paired oviducts leading from the ovaries into the anterior uterus, the three spermathecæ, and the accessory glands are shown in the illustration of the reproductive system of an unfertilized female (fig. 3). The posterior uterus in an unfertilized female is a short, nearly straight passageway which is empty, but which, when the female becomes gravid, elongates, as the developing young descend, into a long intestine-like incubating organ leading to the larvipositor. These developing larvæ are arranged transversely for about halfway down the posterior uterus, causing this organ to resemble a flat, more or less coiled ribbon, gradually enlarging toward the external organs of reproduction. As the developing larvæ are forced downward their axes gradually change until the axis of the posterior uterus and the larvæ is the same. (Fig. 4.)

At the distal termination of the posterior uterus is the "laying organ" or larvipositor. This is slightly chitinized and has a small tubelike opening just large enough for the passage of one larva. This organ, as well as the anus, arises in the venter of the sixth abdominal segment and is curved forward when at rest, fitting into the carinate venter of the fifth abdominal segment. The larvipositor fits into a curved chitinous hook or piercer, which is grooved, reresembling a V in structure. Beneath this hook is a supporting organ arising from the fifth segment, which is strongly spined on both sides in such a manner that it reinforces the piercer while the female is in the act of attacking the host caterpillar. The parasite larvæ, as they are forced down the posterior uterus, are turned in some manner and are injected into the host, with the anterior end first. This was the conclusion the writer reached after making a number of dissections of females after they had deposited part of their young. In these dissections some of the larvæ were found to be inclosed in a very thin membranous sheath, which fitted the body very closely, while others were found naked. This leads to the inference that Compsilura deposits both bare and inclosed larvæ. Pantel suggests that this might be possible on account of a prolongation of the egg stage, due to the absence of an appropriate host.

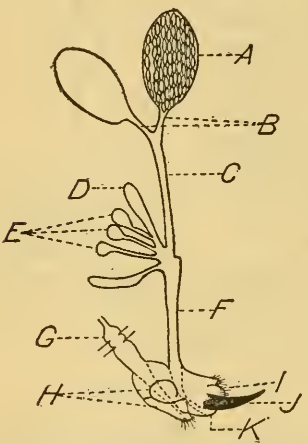


FIG. 3.—*Compsilura concinnata:* Reproductive system of unfertilized female. *A*, Ovary, showing ovarioles; *B*, paired oviducts; *C*, anterior uterus; *D*, accessory glands; *E*, spermathecæ; *F*, posterior uterus; *G*, rectum, showing rectal papillæ; *H*, lateral lobes of dorsum of sixth abdominal segment; *I*, reinforcement of piercer, from dorsum of fifth abdominal segment; *J*, piercer; *K*, larvipositor. Greatly enlarged. (Original.)

DISCUSSION OF LARVA STAGE OF COMPSILURA CONCINNATA.

Compsilura larvæ pass their entire life within the body of the host. The young larva is introduced generally into the intestines, where it is motile, floating free until just previous to molting into the second stage, when it becomes attached to one of the stigmata or vesicles of the branching trachea. This is done by means of the three anal hooks which are found in the first-stage Compsilura maggot. (Figs. 1 and 5.)

Respiration takes place through the anal stigmata of the larva, air being furnished by the stigma or trachea of the host. A tracheal funnel is formed by the maggot pushing itself backward against the

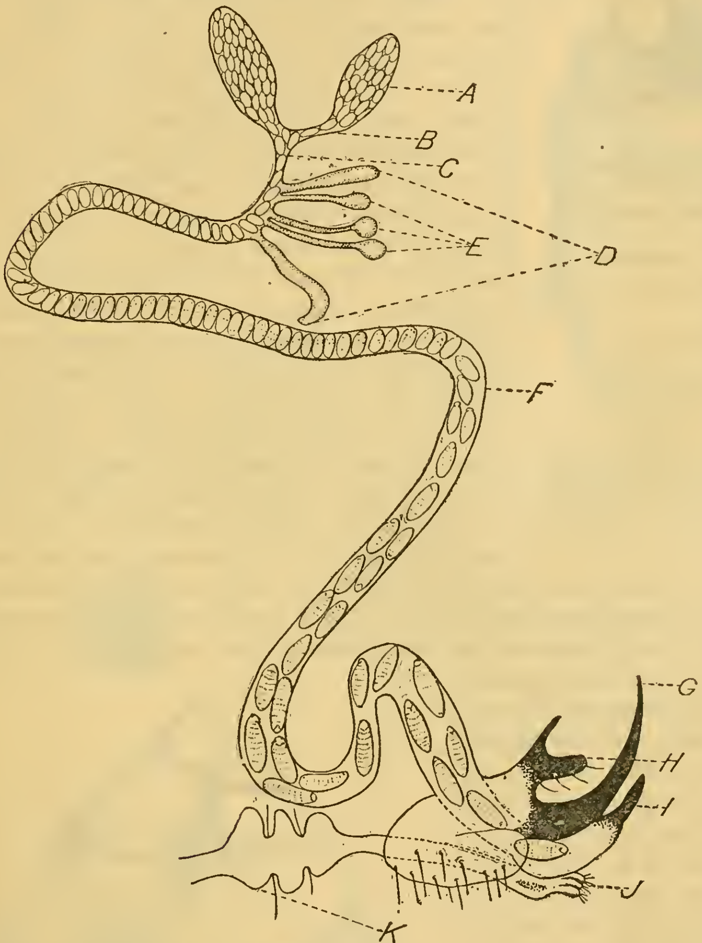


Fig. 4.—*Compsilura concinnata:* Reproductive system of fully developed fertilized female. *A*, Ovary; *B*, oviduct; *C*, anterior uterus; *D*, accessory glands; *E*, spermathecæ; *F*, posterior uterus; *G*, piercer; *H*, support for piercer; *I*, Larvipositor; *J*, anus; *K*, rectum, showing rectal papillæ. Greatly enlarged. (Original.)

place of attachment. This leaves the anterior end of the parasite larva free for feeding. As the larva molts, it pushes the exuvium down on the funnel, and it is possible to locate both the first and second stage mouth-hooks upon dissection of the host. The larva remains in this funnel until just previous to emergence from the host, when it breaks loose and emerges ready for pupation.

The larvæ differ somewhat in appearance in the three stages. In the first-stage larvæ the mouth-hook is single pointed, being heavily chitinized throughout with the exception of the inside areas of the divided posterior part. This posterior end is membranous and serves as a place of attachment to hold the hook in position, this being true of all three stages. The first segment has a row of heavy spines around its base, while the second segment is thickly studded with the same kind of spines. The ventral part of the remaining segments is also fitted with the same spiny structure, in this case the spines extending upward laterally along the anterior border of each segment. All of the segments are more or less covered with what, under the high-power microscope, appear to be very small granulations. On the last abdominal segment there is a peculiar set of hooks that make possible the determination of first-stage Compsilura. These are for the purpose of attachment to the stigma of the host. (Fig. 5.)

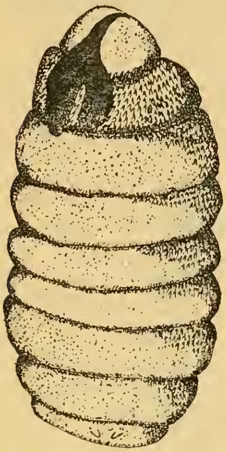


FIG. 5.—*Compsilura concinnata:* First-stage larva, right lateral view. Greatly enlarged. (Original.)

The second-stage larva of Compsilura differs from the first in three main points: (1) The mouth-hook is double throughout, the halves being jointed by a chitinous structure, and is jointed in one place (fig. 6); (2) the chitinous part of the hook extends farther basally, the whole outline of the hook being more uneven; and (3) the heavy spines on the integument are lost in this stage, while the anterior border of each abdominal segment has two or three rows of lighter spines, which extend completely around the body. The first segment is more contracted on the ventral surface, grading off at a gradual angle to its junction with the second segment. The anal hooks are wanting in this stage and the permanent structure of the anal stigmata is clearly shown.

FIG. 6.—*Compsilura concinnata:* Anterior end of second-stage larva, left lateral view. Greatly enlarged. (Original.)

The third and last stage of the larva differs slightly from the second in the structure of the mouth-hook and spines on the body. The mouth-hook is still divided into two parts, but there are two joints in it. (Fig. 7.) The heavy chitinous structure does not extend so far basally, but the membranous portion is larger than in the second stage. The spiny armature is even less than in the second stage, only a thin sprinkling of spines being present on the anterior end of each segment. The anal stigmata are black and much larger than in the second stage, appearing as they will be found in the puparium (fig. 8).

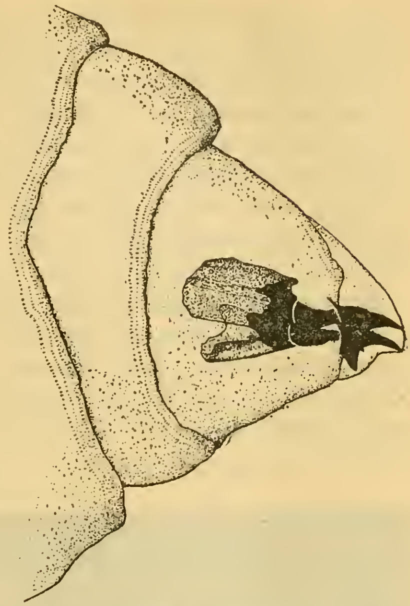


FIG. 7.—*Compsilura concinnata:* Anterior end of third-stage larva, right lateral view. Greatly enlarged. (Original.)

LIFE HISTORY.

METHOD OF HANDLING.

The collection and handling of host material in the laboratory has been referred to in the preceding pages. The methods of handling the parasite in determining its life history follow.

In the fall of 1914, when the life-history work on Compsilura was begun, the notes at the laboratory were thoroughly reviewed and all of the information concerning this parasite assembled. All of the available literature was studied, and, while several authors had written of Compsilura, very little could be found concerning the actual life history of the parasite. At this time experiments were being carried on to investigate the life history of *Apanteles lacteicolor* Vier., and it was from the type of tray then in use that the present "reproduction tray" (fig. 9) for Compsilura was evolved. This tray measured 12 by 12 by 5 inches, with a groove around three sides, in which a sliding glass cover could be fitted. The bottom of the tray was of muslin, which permitted of partial ventilation and could be replaced. In two opposed

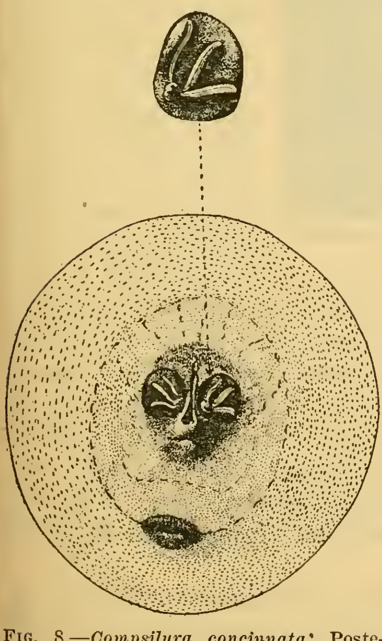


FIG. 8.—*Compsilura concinnata:* Posterior end of puparium, showing characteristic structure of the stigmata and anal opening. Greatly enlarged. (Original.)

sides were holes covered with fine copper screen, affording good ventilation. In the center of the front of the tray was a hole 3 inches in diameter, in which was fitted a round plug having a 1-inch hole through the center for inserting a vial containing foliage; by this arrangement the stem of the foliage could be kept in water. The experiment number label, with the number and species of hosts, number of both sexes of Compsilura, and the date begun, was also pasted on the front. In the right side of the tray was a smaller hole for the purpose of placing the parasites in the tray, this being closed with a cork.

During the summer of 1915 sugar water was used as food, being sprayed on the leaves and on the sides of the tray. This was found to be unsatisfactory, first, because sugar water was not heavy enough food for the flies and they did not live for any length of time, and, second, when this sticky substance was sprayed over the leaves and the sides of the tray the flies frequently would become stuck to it. During the season of 1916 honey water in the proportion of one part honey to three of water was used very satisfactorily. This was fed to the flies by the use of an atomizer, with which it was sprayed on a sponge placed in a watch glass. In the bottom of the tray was kept a small dish of sand, which was moistened each day, thus keeping the humidity constant. Temperature records were kept with a self-recording thermometer placed near the reproduction trays. The experiments were conducted in a house which had three screened windows on one side and the opposite side built so that about half of it was open and well screened. One end was closed and the other had a screen door in it. The three sides being thus open, good ventilation was afforded. The reproduction trays were arranged on two sides of this shed on shelves which were constructed of narrow strips to facilitate ventilation in the trays.

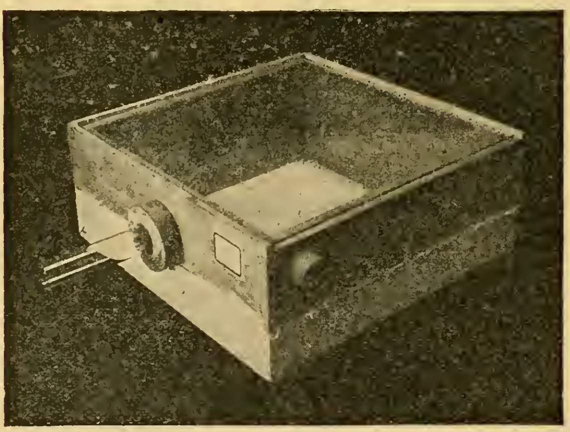


FIG. 9.—Reproduction tray used in life-history experiments on *Compsilura concinnata.* (Original.)

During the summer of 1915 difficulty was experienced in securing parasite-free hosts, the only material of this nature that could be had in large numbers being the brown-tail moth larvæ. These were reared from the hibernating webs collected the previous fall. A large number of gipsy-moth larvæ were hatched for this purpose, but owing to the high percentage of mortality, due to the so-called wilt disease, few survived long enough to be used in the experiments. In the spring of 1916 efforts were made to secure more of the parasite-free material, with the result that the writer was more successful than before. A large number of brown-tail moth larvæ were reared from the webs, and several thousand gipsy-moth larvæ were hatched out. These hosts were kept in large "tanglefooted" trays, which were covered with fine screen cloth, to prevent any possibility of parasitism being effected from outside sources. Through the cooperation of the assistants of the Bureau of Entomology at the Bussey Institution an abundance of parasite-free material was secured of the species *Bombyx mori* L., *Hemerocampa leucostigma* S. & A., and *Callosamia promethea* Drury, which had been reared in a greenhouse, where it was impossible for parasitism by Compsilura to take place.

LARVA AND PUPA STAGES.

The conditions under which the life history of Compsilura was studied were so different from the normal that no doubt it varies from that actually obtaining in the field. Nevertheless, as nearly the normal environment of the fly as was possible under laboratory conditions was simulated.

The length of the larva stage in Compsilura varies with the season, being unaffected by temperature to any appreciable extent. Tables III and VI indicate the length of the larva stage under laboratory conditions. As shown, the adult flies were of varying ages at the beginning of each experiment, this apparently affecting the length of the larva stage. The length of the stage for each larva was computed from the time the experiment was begun, for it was impossible to note the time at which each adult attacked the host larva. The length of the pupa stage is also shown in Tables III and VI. The puparia used in these experiments were removed from the various trays as soon as they had hardened and become the characteristic dark-brown color.

TABLE III.—*Length of larva and pupa stages of Compsilura concinnata under laboratory conditions, Melrose Highlands, Mass., 1916.*

Experiment begun.	Age of female Compsilura when experiment began.	Number of Compsilura larvæ secured.	Average number of days in larva stage of Compsilura.	Number of puparia that emerged.	Average length of pupa stage.	Proportion of sexes.		Number and stage of hosts.	Species and stage of host.
						Male.	Female.		
1916.	*Days.*				*Days.*				
July 13	3	28	16.64	24	12	13	11	100, fourth stage	Brown-tail moth, larvæ.
17	17	6	9.83	3	14.50	2	1	50, fourth stage.	Do.
6	6	19	13.57	15	10.40	7	8	60, third and fourth stages.	Gipsy-moth, larvæ.

The pupa stage of Compsilura is passed in two ways. In the field, puparia will be found both in the crevices of the bark and in the webs of prepupal brown-tail moth larvæ or "spin-ups." They will also be found about 1 inch beneath the surface of the soil at the base of trees. The average length of the pupa stage in the soil is from two to four days greater than above ground.

ADULT STAGE.

The length of the adult stage under laboratory conditions varies with the temperature and methods of handling. The methods of handling have been previously mentioned. The average length of the adult stage of Compsilura is shown in Table IV.

TABLE IV.—*Average length of adult stage of Compsilura concinnata, Melrose Highlands, Mass., 1916.*

22 days for 35 mated males in glass-covered trays.
18 days for 35 mated females in glass-covered trays.
13.5 days for 22 unmated males in glass-covered trays.
4.5 days for 22 unmated females in glass-covered trays.

GESTATION.

The period of gestation varies with the temperature, an increase in temperature tending to shorten the period. A new supply of hosts was added every two days and close watch for the emergence of Compsilura larvæ was maintained. The time required for the period of gestation was reckoned from the time of mating to the time the adults and hosts were separated; then, to get accurately the length of the larva stage, each maggot was isolated as it emerged from the host and the larva stage was reckoned from the end of the period of gestation. (See Table V.)

TABLE V.—*Gestation period of Compsilura concinnata: Single females in each experiment, Melrose Highlands, Mass., 1916.*

Date experiment began.	Age of fly at copulation.	Number of Compsilura larvæ secured.	Average length of larva stage.	Number and stage of hosts.	Host.	Gestation period.
	Days.		*Days.*			*Days.*
July 13	1	3	9.5	30, fourth stage	Brown-tail moth larvæ	4.5
14	2	13	7.42	70, fourth stage	do	5
16	2	8	7.23	60, fourth stage	do	3
31	2	1	10	70, fourth stage	do	6
Average						4.5

PARTHENOGENESIS.

Since it was thought that Compsilura might, at times, be parthenogenetic, a series of experiments was conducted to determine whether this is the case. In each case 5 unfertilized females were placed in trays with 25 third and fourth stage gipsy-moth larvæ which had been reared under screen from hatching. Attempted larviposition was noted, but in no case were Compsilura larvæ secured and none were found upon dissecting the hosts. This same false larviposition was noted with larvæ of *Bombyx mori*. The piercer punctured the integument of the host, for each time an attack was made the caterpillar bled at the point of attack. A number of the Compsilura used were dissected, but none showed uterine eggs or developing maggots in the uterus. In several of these females the posterior uterus had become lengthened as is the case after fertilization.

COPULATION.

When union was successfully accomplished, copulation lasted from 26 minutes to 1 hour and 50 minutes, and while a number of records were secured, the foregoing represents the extremes. Attempted coition was noted at times which occupied several seconds, but in cases of such short duration these attempts were unsuccessful. The results of observations on copulation seem to be more or less contradictory. In some cases Compsilura were confined in glass jars, screen cages, or glass-covered trays for several days, and did not copulate; whereas in one case a male, which was 16 days old and had been mated previously, copulated for 1 hour and 50 minutes with a female which was only 24 hours old. Another pair that were only 18 hours old copulated for 1½ hours. In cases where copulation occurred soon after emergence from puparia the temperature and humidity were quite high. It was observed also that the flies will copulate more readily if the male is from 2 to 4 days older than the female.

LARVIPOSITION.

Compsilura will attempt larviposition in confinement when only one day old and before copulation takes place. It is physically impossible that this attempted larviposition can be effective, as Compsilura is viviparous and young larvæ have not had sufficient time to develop within the mother in that length of time.

The method of larviposition is as follows: The female approaches the host, stopping within about an inch of it and, after surveying the victim carefully, strikes quickly. The host makes a quick movement of the entire body and the Compsilura flies off, only to return immediately until she is finally satisfied. If larviposition is successful at the first attempt, the parasite seems satisfied for a few moments. Records were secured of Compsilura attacking one gipsy-moth larva as many as seven or more times in rapid succession, the whole occurring within 1½ minutes. Larviposition will be attempted shortly after copulation, as records show that this occurs within 26 minutes after coition has been completed.

The host larva will be attacked in almost any portion of the body, as larviposition was attempted on the head capsule, the middle part of the body, and the posterior segments. Although the middle portion seems to be preferred, this may be due to the host's inability to disturb the parasite as easily in this portion as it does on either the anterior or posterior end.

ACTION ON HOSTS OTHER THAN THE GIPSY AND BROWN-TAIL MOTHS.

In working out the life history of Compsilura various hosts were used, all, with one exception, being indigenous to this country. Sixteen native species were utilized, and while Compsilura had been reared from most of these, attempts at reproduction in the laboratory failed on all but four. A matter of interest in connection with reproduction on *Callosamia promethea* and *Bombyx mori*, which had been reared parasite-free beneath screen, was the high percentage of superparasitism. This was particularly true of *Bombyx mori*, in several instances as many as 10 Compsilura puparia being secured from a single host; and of *Hemerocampa leucostigma*, it being a very common occurrence for from 3 to 4 Compsilura puparia to be reared from one host. In Table VI are given the results of reproduction upon these three hosts.

TABLE VI.—*Development of Compsilura concinnata in various hosts, Melrose Highlands, Mass., 1916.*

Date.	Age of flies when experiment began.	Number of Compsilura larvæ.	Average length of larva stage.	Number of puparia secured.	Length of pupa stage.	Proportion of sexes.		Number and stage of host.	Host.
						Male.	Female.		
	Days.		*Days.*		*Days.*				
July 19	3	30	14.76	26	12	19	6	50, third[1] and fourth stages.	H. leucostigma.
15	18	5	17.20	3	17.33	1	2	15, third stage....	C. promethea.
18	2	23	22.27	17	16.25	8	9	25, third and fourth stages.	Do.
19	2	5	19	5	15.80	3	2	25, fourth stage...	Do.
19	3	59	15.60	30	11.60	17	13	35, fourth stage...	Bombyx mori.
24	4	60	19.05	....	....	......	......	50, fourth stage...	Do.

[1] These stages refer to each molt of the host larva.

Pontia rapae is a splendid intermediate host for Compsilura, this pest being found in New England wherever cabbage is grown, and because of the overlapping of its broods, which makes it possible to find nearly all stages of larvæ in the field from spring until winter, Compsilura is assured of at least one host upon which to perpetuate itself. Fortunately, however, Compsilura is not compelled to rely solely upon *Pontia rapae* for existence, as a glance at the native host list will show.

EFFECT OF TEMPERATURE UPON VARIOUS STAGES OF COMPSILURA CONCINNATA.

Temperature, under laboratory conditions, appears to exert little influence in the development of larvæ within the host. This is particularly true during the summer season. In the late summer the larva stage is lengthened, but in averaging the whole season when Compsilura larvæ were secured, July 13 to August 24, it was found that the larva stage was lengthened at a time when there was very little variation in average temperature. (See Table VII.)

TABLE VII.—*Effect of temperature upon length of larva stage of Compsilura concinnata under laboratory conditions, Melrose Highlands, Mass., 1916.*

Number of individuals.	Larva stage.	Average temperature.	Number of individuals.	Larva stage.	Average temperature.
	Days.	° *F.*		*Days.*	° *F.*
1	6	72	2	11	71
4	7	74	1	14	74
4	8	73	1	15	71
8	9	72	1	16	71
2	10	72			

This average temperature, as noted in Table VII, was secured by taking four readings a day and averaging the whole.

The effect of temperature upon the pupa stage is shown in Table VIII.

TABLE VIII.—*Effect of temperature upon length of pupa stage of Compsilura concinnata under laboratory conditions, Melrose Highlands, Mass., 1916.*

Number of individuals.	Pupa stage.	Average temperature.	Number of individuals	Pupa stage.	Average temperature.
	Days.	° *F.*		*Days.*	° *F.*
3	7	71	9	15	66
2	9	67	4	16	64
13	10	72	4	17	64
5	11	71	2	18	66
46	12	72	3	19	63
13	13	69	1	20	63
7	14	68			

Temperature averages shown in Table VIII were secured in the same way as for the larva stage. The shorter pupal periods were observed in the middle of the summer and those of longer duration in the late summer and early fall. All of these records were made from puparia above ground, the length of the pupa period in those below the surface of the soil being from two to four days greater.

The effects of temperature on adult Compsilura are shown in figure 10. The temperature was determined by readings at noon each day, when observations were made on the activity of the adults. It is practically impossible to rate terms of activity in either degrees or percentages, so the following terms were adopted: (1) *Very active.*

Constantly flying; copulating; larvipositing freely and feeding. (2) *Active.* Flying a little; larvipositing some; crawling around and feeding. (3) *Inactive.* Crawling around; no copulation or larviposition; very little feeding. (4) *Very inactive.* Practically dormant, sluggish.

SEASONAL HISTORY.

PRESENCE IN FIELD AND NUMBER OF GENERATIONS.

Compsilura occurs in the field, as shown by collections of adults in 1915, on May 1. It was on this date that two male specimens were collected. The latest that adults were taken in the field was October 28 and 29, 1915. This represents the extremes of collections of adults of this parasite. The earliest collections of puparia in the field were made June 16, 1915, from brown-tail moth "spin-ups," and the latest record, from a collection of *Pontia rapae*, made September 30, 1915. Among collections of host material for Compsilura is that of brown-tail moth "spin-ups" and the time of occurrence of these in the field varies from year to year, the average being about June 25. Immediately following these is begun the collection of gipsy-moth larvæ for this parasite. Figuring on the foregoing basis of collections, and allowing a range of 28 to 30 days for completion of life history in the field, it will be found that three full generations are passed during the season.

In the laboratory the period from adult to adult averages 24 days, and with a "gestation period" of 4.5 days, the life cycle involves about the same length of time as is required under natural conditions in the field. It was found possible to secure more than three generations annually in the laboratory by supplying hosts later than they could be found in the field.

The most accessible host in the spring is the brown-tail moth larva, which is attacked soon after emergence from the hibernating web. The growth of the parasite in this host during the early part of the larval period is more or less retarded owing to the slow spring development of the young brown-tail moth larvæ. Just previous to pupation of the host, while the brown-tail moth larva is spinning its cocoon, the parasite larva emerges and pupates within the loosely woven web. A short time after this the appearance of adult Compsilura is noted, and puparia are to be found in the early gipsy-moth larvæ, some few coming from the late fourth and early fifth stage hosts. These are evidently part of the same generation as those from the brown-tail moth larvæ. The early issuing adults emerge from the brown-tail moth hosts in time to attack the later stages of the gipsy-moth larvæ together with native hosts, which are prevalent at this time, and this constitutes the beginning of the second generation of Compsilura. Those issuing from this second generation the last of August and first of September constitute the third generation and furnish the adults which attack the hosts in which the Compsilura larvæ later hibernate.

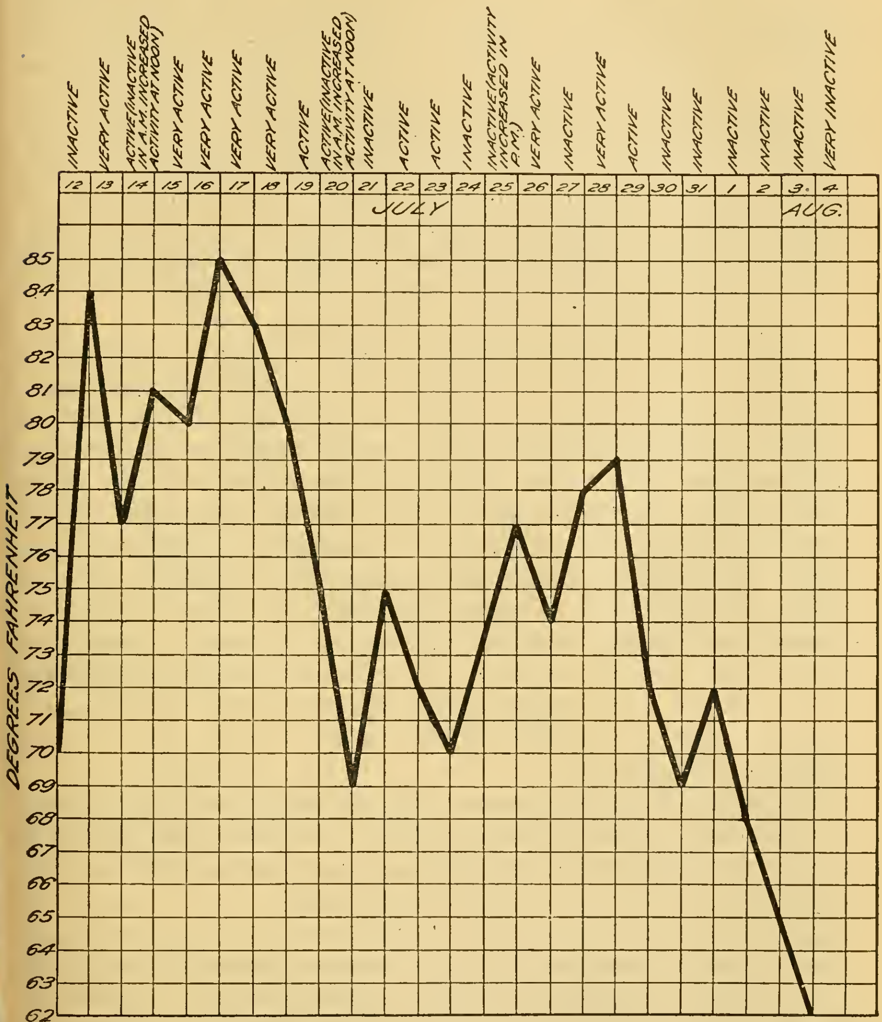


FIG. 10.—Diagram illustrating relation of temperature to activity of adult *Compsilura concinnata*, July and August, 1916. (Original.)

HIBERNATION.

Hibernation of Compsilura is the point in the life history of the parasite which has not been completely worked out, although enough has been accomplished in this line to warrant its discussion here. Several cases of hibernation of Compsilura have been recorded, but only six hosts have given absolute records. These are

Papilio polyxenes Fab., *Diacrisia virginica* Fab., *Deilephila gallii* Rott., *Deidamia inscriptum* Harris, *Callosamia promethea* Drury, and an unidentified geometrid. In all of these cases the parasites passed the winter as larvæ, emerging and pupating in the spring. No doubt when the host material lately in hibernation at the laboratory is fully examined the list of hosts in which Compsilura passes the winter will be materially increased. A single record of hibernation was noted in a chrysalid of *Pontia rapae* that was kept inside during the winter, the Compsilura emerging January 18, 1915. While it would seem that this host is ideal for the hibernation of Compsilura, in no other case has the parasite been recorded as passing the winter in it, although several thousand chrysalids of *Pontia rapae* have been collected from localities where Compsilura has been recovered in the fall and placed in hibernating quarters.

Attempts which have been made to carry Compsilura through the winter in the adult and pupa stages, under laboratory conditions, have proved unsuccessful. In the early fall of 1916 a number of puparia were divided into two lots, one of which was placed in an ordinary glass vial and the other in a box of leaf mold and loam. Both lots were then put in an ice chest where the temperature varied from 40° to 42° F., and where the humidity was high and constant. A month later some of the puparia were taken from the vial and opened, disclosing well-developed, healthy nymphs. A few were opened from time to time until November 15, when the last were found dead. The last puparia found alive had been confined in the ice chest for 49 days, and it would appear that under natural conditions the puparia might hibernate, although attempts made in this direction have failed.

In Bulletin 91 of the Bureau of Entomology, published in 1910, is found the only plausible explanation of the failure of Compsilura to hibernate within the overwintering brown-tail moth larvæ. On pages 219 and 220 is the following paragraph:

> Larvæ, which are almost certainly *Compsilura concinnata*, have been occasionally found in living brown-tail moth caterpillars during the winter months. It is presumed if these larvæ were able to mature under these circumstances, that they would have been reared before now from some among the hundreds of thousands of brown-tail caterpillars which have been carried through their first three or four spring stages in the laboratory. None having been reared under these circumstances, the only logical conclusion is that they start into activity so early and develop so rapidly as to cause the death of the host before they are sufficiently advanced to pupate successfully.

This, no doubt, is true, for the writer conducted experiments under ideal conditions for the hibernation of Compsilura, if this were possible, in hibernating brown-tail moth larvæ. From several places where Compsilura was prevalent during the summers of 1914 and 1915, hibernating webs of brown-tail moth larvæ were collected during the following fall and spring, and when the season began they were placed in feeding trays which were kept covered with fine mosquito screening. These were fed until the hosts pupated, and although this experiment was repeated for two years, the trays being carefully examined at least once a week during the time of feeding, no Compsilura were secured.

The results of these experiments substantiate the statement referred to in the foregoing bulletin, that it is impossible for Compsilura larvæ to hibernate in overwintering brown-tail moth larvæ. Dissections during the fall of 1915 showed conclusively that Compsilura attacks the young brown-tail moth larvæ and will live through part of the first larval instar in this host, but that the small size of the host prevents the parasite larva from maturing sufficiently to pupate.

SECONDARY PARASITISM.

Secondary parasites of Compsilura play an important part in the spread and effectiveness of the tachinid parasite. These secondaries attack the Compsilura maggot immediately following its emergence from the host, or the fresh puparia, and before it has hardened. From no puparia secured from beneath the surface of the soil have secondary parasites emerged, only those found above ground being attacked. During the seasons of 1915 and 1916 1,164 Compsilura puparia were collected in various parts of New England over the entire area covered by this parasite, and from 10.31 per cent of them secondary parasites issued.

SUPERPARASITISM.

To ascertain the effectiveness of Compsilura, a series of experiments was conducted from 1912 to 1916, with gipsy-moth larvæ collected on the border towns of Compsilura dispersion for the years 1909 to 1913, five towns being selected in which the parasites were first recovered in the five-year period mentioned. These border towns have furnished the host material each year for the last four years, and the collections yielded an average parasitism of 10.21 per cent. These results were secured by making collections of from 10 to 20 fifth-stage gipsy-moth larvæ and feeding them singly, either in small trays or in screened boxes, care being exercised to safeguard them from any parasitism after reaching the laboratory.

It was from these same experiments that the highest parasitism by Compsilura was gained, and in several cases three puparia were secured from a single host larva. Data were also obtained from the foregoing experiments on the effect of wilt on Compsilura parasitism. If the parasite larva is ready to molt into the last larval instar, although the death of the host occurs from wilt, it will not prevent further development of the parasite larva, but pupation will be accelerated. The larva can not remain in its tracheal funnel after the body contents of the host become flaccid, but it will be seen moving slowly about, and will emerge from two to five days after the death of the host.

Similar experiments were conducted during the years 1915 and 1916 with brown-tail moth larvæ, treated in the same manner as were the gipsy-moth larvæ, with the average result of two parasites per larva, at times as many as four puparia being secured from one host.

SUPERNUMERARY PARASITISM.

The fight for ascendancy between some of the tachinid and hymenopterous parasites is well illustrated by a study of Compsilura parasitizing brown-tail moth larvæ. When two internal feeding parasites of different orders occur in a single host larva and complete that part of their existence which is passed within the host, parasitism is described as "supernumerary." This is illustrated by Compsilura and *Meteorus versicolor* Vier. in their occurrence in brown-tail moth larvæ. It was noted, in an experiment where brown-tail moth larvæ were isolated and fed in single boxes, that *Meteorus versicolor* was present to quite an appreciable extent. The hosts did not die immediately after emergence of this hymenopterous parasite, and in from two to four days, in some cases, Compsilura would emerge. In no case were any Compsilura secured previous to emergence of Meteorus.

ECONOMIC IMPORTANCE.

The white-marked tussock moth, *Hemerocampa leucostigma*, which a few years ago was a serious pest in many localities in New England, has practically disappeared since Compsilura was established. The saturniid *Callosamia promethea*, which in past years was very common in the area covered by Compsilura, is now quite rare. While the cabbage worm, *Pontia rapae*, is still a serious pest, its numbers have been materially lessened in some sections, Compsilura, no doubt, playing an important part in this decrease. The celery worm, *Papilio polyxenes*, is not so common now as it was previous to the importation of Compsilura. The fall webworm, *Hyphantria cunea*, which could be found in eastern Massachusetts in large numbers in 1910, is scarcely noticed now. The writer does not claim that Compsilura is the sole cause of the disappearance of these pests, but this parasite has been reared from all of them, and it is significant that the decrease has occurred since the advent of Compsilura. Outside of the area in which this parasite occurs, many of these caterpillars will be found in considerable abundance. The gipsy moth and brown-tail moth infestation has been materially lessened in sections where this parasite has been firmly established for some time, but spraying, hand-suppression work, and the effects of predacious enemies, disease, and other parasites have all had their parts to play in causing the decrease, not only of the gipsy moth and the brown-tail moth, but of other native pests as well.

From the foregoing it will be seen that *Compsilura concinnata* is the most important tachinid parasite brought into this country for combatting the gipsy moth and the brown-tail moth, and that it attacks both freely. Judging from its increasing list of native hosts in the United States, it bids fair to become one of the most important economic parasites in this country. Compsilura has been established in the United States only 10 years, and during that time it has been recorded from a large number of native hosts, and no doubt this host list is much longer than is known at the present time.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 771

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER February 21, 1919

A STUDY OF THE EFFECT OF STORAGE, HEAT, AND MOISTURE ON PYRETHRUM

By W. S. Abbott, *Scientific Assistant*

CONTENTS

INTRODUCTION

It has been generally accepted by entomologists that pyrethrum powder deteriorates rapidly under ordinary conditions of storage, but few or no data have been advanced to support this theory or to show under what conditions or how rapidly such deterioration takes place. The following experiments, made at the testing laboratory of the Insecticide and Fungicide Board of the United States Department of Agriculture, Vienna, Va., were conducted to ascertain the effect of exposure to heat, moisture, and the weather, and of storage in sealed glass containers, on whole and ground flower heads of *Pyrethrum cinerariaefolium* (Trev.).

METHODS OF TESTING

Two methods of testing the pyrethrum powder were used: (1) By dusting and (2) by dipping.

In the dusting tests small potted nasturtium plants, grossly infested with aphids (*Aphis rumicis* Linnaeus), were thoroughly dusted by means of a small hand dust gun.

In the dipping tests large specimens of the German roach or Croton bug (*Blattella germanica* Linnaeus) were dropped into a beaker containing a small amount of the pyrethrum powder to be tested, and the beaker was given a shake so that the insects were thoroughly covered with the powder. Each roach was then placed in a separate 8-ounce bottle and observed at frequent intervals, the time when the insect became inactive, i. e., unable to walk, and the time of death

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being recorded. With each set of experiments checks, consisting of 10 roaches dipped in fresh pyrethrum powder and 10 untreated, were used. The average mortality for the untreated roaches was found to be less than one roach in 108 hours, which is so small that the untreated series were omitted from the following tables.

EFFECT OF EXPOSURE TO WEATHER AND IN A ROOM

Table I shows the killing effect on roaches of whole and ground flower heads that had been exposed to the weather or in a room for various periods of time.

TABLE I.—*Effectiveness against roaches of whole and ground pyrethrum flower heads exposed to the weather or in a room. Ten roaches dipped for each test*

No.	Material.	Exposed—	Number of weeks.	Hours required to kill.		
				First roach.	Last roach.	Average.
1	Whole flower heads	To weather	2	19.3	43.3	31.2
2	....do	....do	12	19.6	92.1	34.6
3	....do	....do	21	23.2	3 active at end of 120 hours.	
4	Ground flower heads	....do	2	19.5	64.5	35
5	....do	....do	12	19.6	47.6	29.8
6	....do	....do	21	23.4	4 active at end of 120 hours.	
7	Whole flower heads	In room	2	24.	64.8	43.1
8	....do	....do	12	19.8	92.3	39
9	....do	....do	21	[1] 4.5	71.9	31
10	....do	....do	34	22.4	67	40.7
11	....do	....do	150	18	44.5	22
12	Ground flower heads	....do	2	19.5	64.5	39.5
13	....do	....do	12	19.7	43.9	26
14	....do	....do	21	[1] 6.1	27.5	22
15	....do	....do	34	22.1	46.5	36.4
16	....do	....do	136	26.1	1 active at end of 120 hours.	
17	....do	....do	150	42.1	8 active at end of 120 hours.	
18	Whole flower heads	In sealed jars	150	17.5	41.5	25.2
19	Ground flower heads	....do	2	19.3	43.3	36.2
20	....do	....do	12	19.9	44	27.4
21	....do	....do	21	23.5	47.5	30.7
22	....do	....do	34	18.3	46.9	35.2
23	....do	....do	136	22.3	46.3	28
24	....do	....do	150	17.9	44.1	21.9

[1] Probably injured in dipping.

The material used in these experiments was received as whole flower heads in April, 1915, when it was divided into six lots which were treated as follows:

No. 1. Whole flower heads, in a large open glass cylinder, were placed out of doors where they were fully exposed to the sun, wind, and rain.

No. 2. Powdered flower heads, sifted to 80 mesh, were exposed as in lot No. 1.

No. 3. Whole flower heads were placed in a shallow dish and allowed to stand on a shelf in the laboratory.

No. 4. Powdered flower heads (80 mesh) were exposed as in lot No. 3.

No. 5. Whole flower heads were kept in a tightly sealed fruit jar in the laboratory.

No. 6. Powdered flower heads (80 mesh) were kept as in lot No. 5.

At the times indicated in the table portions of these six lots were ground, sifted to 80 mesh, and tested against roaches by dipping the insects as described on page 1.

This table shows that an exposure to the weather for 12 weeks does not noticeably injure ground or whole flower heads, but that an exposure of 21 weeks materially reduces the efficiency of both, since at the end of this time they killed, in 120 hours, only 60 and 70 per cent, respectively.

When whole flower heads were exposed in an open dish in the laboratory for 150 weeks, they retained their full efficiency. Under the same conditions the powdered flower heads showed some deterioration in 136 weeks, and were of almost no value at the end of 150 weeks. Both flower heads and powder showed no loss of efficiency when kept in tightly closed jars for 150 weeks.

EFFECT OF STORAGE IN SEALED GLASS CONTAINERS

Tables II and III give a comparison of the effectiveness against aphids and roaches of whole and ground pyrethrum flower heads stored in glass containers for 5½ years.

The materials considered in these tables were received as whole flower heads in 1911. A portion of each sample was ground early in 1912 and stored in a tightly stoppered bottle. The remaining flower heads were stored in sealed fruit jars under the same conditions until March, 1918, when a portion of each lot was ground and tested in comparison with the powders prepared in 1912.

TABLE II.—*A comparison of the effectiveness against aphids of whole and ground pyrethrum flower heads stored in glass containers for 5½ years. One nasturtium plant, grossly infested with aphids, dusted in each test*

No.	Material.	Number of tests.	Ground in spring of 1912; tested March, 1918.	Number of tests.	Ground and tested, March, 1918.
1	California flowers	4	Ineffective	4	80–90 per cent killed or repelled.
2	Montenegrin flowers	4	do	4	80–95 per cent killed or repelled.
3	Dalmatian flowers	4	do	2	90 per cent killed or repelled.

TABLE III.—*A comparison of the effectiveness against roaches of ground and whole pyrethrum flower heads stored in glass containers for 5½ years. Ten roaches dipped for each test*

No.	Material.	Ground in spring of 1912, tested March, 1918—Hours required to kill roaches.	Ground and tested in March 1918—Hours required to kill—		
			First roach.	Last roach.	Average.
1	California flowers	7 killed in 120 hours	18.5	44	32
2	Montenegrin flowers	5 killed in 120 hours	18.9	72.8	36.7
3	Dalmatian flowers	6 killed in 120 hours	19.5	72	40.3

As will be noted in Table II, the powders ground in 1912 were ineffective in 1918, when tested against nasturtium aphids. Whole flower heads from the same stock, which had been kept in sealed fruit jars for 5½ years and were ground in 1918, killed from 80 to 90 per cent of the treated aphids. Fresh pyrethrum tested at the same time killed 90 per cent.

Table III gives the results of dipping tests against roaches with the same materials as used in Table II. In every case the powders ground in 1918 were found to be effective, all of the roaches being killed in from 32 to 40.3 hours, while in no case did the powders ground in 1912 kill all of the dipped roaches in 120 hours. Fresh pyrethrum, used at the same time, required on the average 31.3 hours to kill 10 roaches. These tests show that pyrethrum powder kept in tightly stoppered bottles for 5½ years loses practically all of its effectiveness, but that the unground flower heads stored under the same conditions for the same length of time are practically unhurt.

Table IV shows the effect, on powdered flower heads, of 5½ years' storage in tightly stoppered bottles or sealed glass fruit jars.

TABLE IV.—*A comparison of the effectiveness against nasturtium aphids of freshly ground Dalmatian closed flower heads and of the same powder after it had been stored in tight glass containers for 5½ years. One nasturtium plant, grossly infested with aphids, dusted for each test*

No.	Material.	Crop of—	Dalmatian closed flower heads ground in spring of 1912.					
			Tested November, 1912.			Tested March, 1918.		
			Number of tests.	Length of tests.	Results.	Number of tests.	Length of tests.	Results.
				Days.			*Days.*	
1	Wild flowers	1908	1	1	98 per cent killed	4	7	Ineffective.
2	......do	1909	2	2	95-100 per cent killed.	2	7	Do.
3	......do	1910	2	4	99 per cent killed	2	7	Do.
4	Cultivated flowers	1908	2	2	100 per cent killed.	4	7	Slightly effective.
5	......do	1909	2	2	......do	2	7	Ineffective.
6	......do	1910	[1] 2	1	......do	2	7	Do.

[1] The cabbage aphis (*Aphis brassicae* Linnaeus) was used in these tests.

The materials used in these tests were received in 1911 as whole flower heads, which were ground and sifted in the spring of 1912, and stored in sealed fruit jars or tightly stoppered bottles. These powders were tested against nasturtium aphids in November, 1912, and again in March, 1918.

As will be noted, all of these powders were found to be effective in November, 1912, and of almost no value in March, 1918. It is therefore evident that pyrethrum powder stored in sealed glass containers for 5½ years will lose practically all of its efficiency.

In connection with the deterioration of unground flower heads, it is of interest to note that, in the 1912 tests, practically no difference in effectiveness was found between the 1908, 1909, and 1910 crops, which indicates that the flower heads are not noticeably injured in four years under the commercial conditions of storage.

EFFECT OF SOAKING IN HOT OR COLD WATER

Table V shows the effectiveness against roaches of pyrethrum powder which had been soaked for 24 hours in hot or cold water.

TABLE V.—*Effectiveness against roaches of pyrethrum powder soaked for 24 hours in hot or cold water. Ten roaches dipped in each test*

No.	Treatment.	Hours required to kill.		
		First roach.	Last roach.	Average.
1...	Check, untreated	21.7	35.9	25.9
2...	Soaked in cold water	21.9	48.2	38.9
3...	Soaked in hot water	[1] 2.5	1 living at end of 94 hours.	

[1] Probably injured in dipping.

The material used in test No. 1 was prepared by soaking 20 grams of pyrethrum powder (80 mesh) in 100 c. c. of cold water for 24 hours. The water was then filtered off and the powder dried at room temperature and resifted to 80 mesh.

The material used in test No. 2 was prepared in the same way, boiling water being used.

This table shows that pyrethrum soaked for 24 hours in cold water killed all of the dipped roaches in 48.2 hours, but required on the average 13 hours longer to kill than did the untreated powder. The pyrethrum treated with hot water killed only 9 roaches in 94 hours. It is therefore evident that cold water removes some of the active ingredients from pyrethrum powder, but not as much as is removed by hot water.

EFFECT OF EXPOSURE TO DRY HEAT

Table VI shows the effect on ground flower heads of exposure to dry heat for 18 hours.

TABLE VI.—*Effectiveness against roaches of pyrethrum powder exposed to dry heat for 18 hours. Ten roaches dipped in each test*

No.	Temperature.	Hours required to kill.		
		First roach.	Last roach.	Average.
1	Check, unheated	20.5	39.6	31.0
2	120° C.	19.6	43.6	30.9
3	120° C.	21.1	47.4	27.8
4	130° C.	1 dead in 48 hours.		
5	140° C.	None dead in 48 hours.		

The materials used in these tests were placed in open tubes and heated for 18 hours at the temperature given. The results show that an exposure to a temperature of 120° C. (248° F.) for 18 hours does not noticeably injure pyrethrum powder, but that a temperature of 130° C. (266° F.) or 140° C. (284° F.), for the same length of time, either destroys or drives off the active principle.

SUMMARY

1. Whole and ground flower heads kept in sealed fruit jars for 150 weeks were not injured.

2. Ground flower heads kept in tightly closed glass containers for 5½ years lost practically all of their effectiveness.

3. Whole flower heads kept in tightly closed glass containers for 5½ years were practically unhurt.

4. Whole flower heads exposed in an open dish in a room for 150 weeks were not injured.

5. Ground flower heads were not injured by an exposure for 34 weeks in an open dish in a room. Their value was materially reduced by an exposure of 136 weeks and they were practically worthless at the end of 150 weeks.

6. Whole and ground flower heads were uninjured by an exposure to the weather of 12 weeks, but an exposure of 21 weeks greatly reduced their efficiency.

7. Powdered flower heads heated at 120° C. for 18 hours were practically uninjured, but a temperature of 130° or 140° C. for the same length of time destroyed practically all of their effectiveness.

8. Ground flower heads were slightly injured by soaking for 24 hours in cold water, and materially injured by soaking for the same length of time in hot water.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 774

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER April 28, 1919

LIFE HISTORY AND HABITS OF THE MEALY PLUM APHIS.

By W. M. DAVIDSON, *Scientific Assistant, Deciduous-Fruit Insect Investigations.*

CONTENTS.

The mealy plum aphis (*Hyalopterus arundinis* Fabricius) has been recognized for many years as an enemy of plums, prunes, and to a lesser extent apricots in California. Since 1913 it has been especially severe in some regions, notably those in which artificial control for the pear thrips (*Taeniothrips pyri* Daniel) was not practiced.

ORIGIN.

The insect is European in origin, having been first described in 1794 by Fabricius. In North America it is widely distributed. According to Lowe (3)[1] it is present in Australia and New Zealand, Van der Goot (2) reports it from Java, while the United States Bureau of Entomology has records of its occurence in Japan. Specimens in the writer's collection taken on Arundo in Peru, by Mr. E. W. Rust, late of the Bureau of Entomology, appear to belong to this species but the lack of winged forms prevents certain determination.

HOSTS AND MIGRATORY HABITS.

In California plums and prunes of the *domestica* type are the favorite hosts, but apricots and Asiatic types of plums and rarely

[1] Figures in parenthesis refer to "Literature cited" on the final page of the bulletin.

almonds are attacked also. In Europe grape, peach, and nectarine are also attacked (Lowe).

From the deciduous-fruit hosts mentioned the mealy plum aphis migrates in early summer to plants of the genera Phragmites, Typha, and Arundo, and in the late fall there is a return migration to the fruit trees. This is the normal process of migration. Occasionally the writer has seen generations of aphids persist on plum until September, a habit that Lowe (3) records as not unusual in New York State.[1] The migratory forms are winged aphids and there are strong indications that they traverse long distances in passing from host to host, as summer colonies have been found in June many miles from the nearest winter hosts. Vast numbers of migrants are produced both in spring and fall, and the production of considerable numbers of summer migrants serves to distribute the species among the summer hosts. In California Phragmites and Typha are the known alternate hosts.

INJURY.

In the early summer months the aphids occur on the foliage, often crowding together in great quantities. (Pl. I.) The lower surface of the leaf is the preferred location, but the petioles and upper surface are frequently infested. The young fruit is less commonly attacked. The infested leaves are generally curled and discolored and glisten with honeydew deposits. (Pl. II.) The ground beneath the tree is often sprinkled with the whitish shed skins dropped by the aphids. The combined effect of myriads of aphids feeding simultaneously on the tree produces fruit of small size and an early drop. In the years 1915 and 1916 an unusual midsummer apical cracking of green prunes developed in California. Morris (4), after making observations in the Santa Clara Valley in 1915, opined that this cracking was due to aphis action. In 1916 the writer made some observations in Contra Costa County. He found that whereas on the whole cracking was more general on trees that previously in the season had been heavily infested with the aphis, it occurred also in other cases on trees which had escaped infestation. He could not conclude otherwise than that the aphis was not more than a contributing, or at least not the sole cause of the apical cracking in the prunes.

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[1] Blakey (1), conducting his observations at Redditch, England, found no certain migration from the winter hosts, the aphids remaining the year around on fruit trees. In this connection it is of interest to note that he found the active cycle (from hatching of stem mother to oviposition) to extend in England from the beginning of May to the middle of October, 5.5 months, whereas in California the writer found the cycle to cover a period of 9 months (Mar. 1 to Nov. 30). The longer growing period enjoyed by the trees in California is of course responsible for this condition, and it is possible that the much dryer climate of California is concerned in the summer migration of the species to plants of a semiaquatic nature. The writer has observed that the aphids tend to remain on the fruit trees later into the summer in the more humid than in the more arid localities of California, while the occurrence on May 15 of large colonies on a summer host at Salton Sea (a very arid region) suggested that the aphids were living on this host the year around.

SYNONYMS.

1794. *Aphis arundinis* Fabricius, Ent. Syst., v. 4, p. 212.
1794. *Aphis pruni* Fabricius, Ent. Syst., v. 4, p. 213.
1886. *Aphis phragmiticola* Oestlund, List Aphid. Minn., p. 44.
1911. *Hyadaphis umbellulariae* Davidson, Jour. Econ. Ent., v. 4, p. 559.

BIOLOGY.

THE EGG.

Size 0.55 by 0.27 mm. The newly laid egg is pale green, covered with conspicuous silvery filaments excreted by the oviparous female. It darkens rapidly and after about 5 days is shining black; the threads, however, remain silvery.

LOCATION ON TREES.

The eggs are laid almost invariably in the axils of lateral buds of year-old or 2-year-old wood. Rarely more than three eggs are to be found to a single bud group. Occasionally eggs are placed in small scars or wrinkles in the bark of twigs.

HATCHING.

In 1916 hatching commenced about March 4, and continued for about two weeks. At this time most prune varieties were just starting to leaf, but the Myrobalans were in full leaf; nevertheless hatching was no earlier on the latter trees than on other plums and on apricots.

THE STEM MOTHER.

DESCRIPTION.

Newly hatched.—Pale green; eyes dark red; antennæ and legs pale gray; dorsum of head with a median longitudinal narrow pale green stripe; beak gray. Form oval.

Antennæ one-fourth the length of the body, 5-jointed. Comparative lengths: I, 0.03 mm.; II, 0.035; III, 0.045; IV, 0.05; V, 0.11 (0.060 plus 0.050); beak reaching to third abdominal segment, 0.21 mm. in length; cornicles minute raised pores. Style rounded. Length of body 0.63 mm.; width of body 0.39 mm.

During the first and second instars the color darkens and the dark markings on the head gradually disappear. The characteristic longitudinal stripes of darker green appear during the third and fourth instars. There are 3 of these, 1 mediodorsal and 2 dorsolateral. The tarsi, apices of tibiæ, cornicles, tip of beak, and distal third of the antennæ of the growing nymph become gray.

After the second molt the nymph assumes an elongate shape, and there appears on the sides and at the abdominal sutures a pruinose "meal." This "meal" is much more scanty and less conspicuous in the stem mother than in later forms.

Adult.—Yellowish-green with three longitudinal green stripes on dorsum; eyes dark red; antennæ pale green, distal joint dark gray; cornicles pale, dusky at apex; tarsi dark gray; style pale yellowish green; apex of beak blackish. Form elongate oval, comparatively flat; newly molted individuals carinate.

Antennæ on very short frontal tubercles, barely one-third the length of the body, 5-jointed. Comparative lengths: I, 0.075 mm.; II, 0.06; III, 0.30; IV, 0.14; V, 0.22 (0.08 plus 0.14). Beak, length 0.26 mm., reaching to second coxæ; cornicles, 0.045 mm.; style, 0.17 mm. Cornicles wartlike, style ensiform. Prothorax and all abdominal segments bearing small, pale, lateral tubercles. Body bearing a sparse, inconspicuous clothing of granular "meal," most abundant at the sutures. Length of body (style included), 2.39 mm.; width of body, 1.06 mm.

HABITS AND LENGTH OF NYMPHAL LIFE.

After hatching, the young aphids seek out buds, often massing on those most advanced, and contrive to penetrate to the inner portions. On unopened buds they feed on the tender apical portions and numbers of them die in such situations. Newly-hatched aphids move awkwardly on rough spiny leaf surfaces and frequently fail to make headway. This was observed especially in connection with Myrobalan plum leaves, and perhaps explains the fact that the stem mothers on this tree have a high percentage of mortality in their early stages.

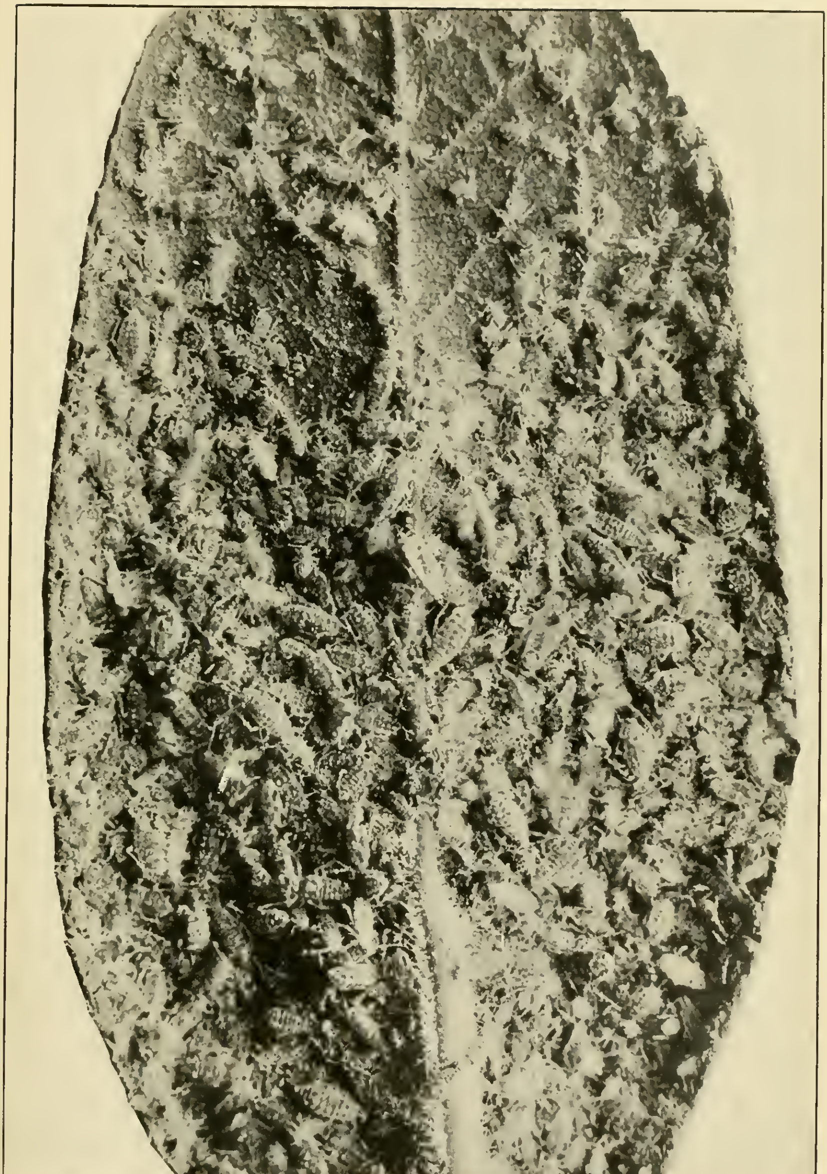
After the blossoms shoot out the aphids feed on the petioles or on the outside of the sepals. In the leaf bud they feed generally on the under (outer) surface of the unfolding foliage and less abundantly on the reverse side. A favored point is that at the junction of sepal and petiole on the flower stalks.

The first stem mothers matured on the plums at time of full bloom (March 19, in 1916), their growth being the more rapid on forward trees. On March 25 it was estimated that on the most advanced trees 85 per cent of the aphids were mature, while on the most backward only 20 per cent were full grown. At this time the mature stem mothers were on the underside of the leaves; none were remaining on the fruit stalks. On March 28 virtually all stem mothers on forward trees were mature; on most backward trees 50 per cent were still immature. By April 5 no more immature stem mothers were found.

Five stem mothers raised on potted Myrobalan seedlings developed in from 13 to 17 days. This time is perhaps less than in the average orchard, since the quality of food available for the newly-hatched aphid is often poor, while the seedlings were well in leaf at the time the experimental eggs hatched. It should be stated that the temperature in 1916 during the first part of the development of the stem mother was higher than usual for that time of year.

REPRODUCTION.

The stem mothers deposit on an average about 4 young a day during a period of from 3 to 5 weeks. The rate of fecundity rises rapidly at first, maintains an even zenith for some three weeks, and then rapidly declines. Stem mothers may live for as long as three weeks after they have deposited their complement of young.



THE MEALY PLUM APHIS (HYALOPTERUS ARUNDINIS).

Colony of aphids on lower surface of leaf. Enlarged.

THE MEALY PLUM APHIS.

Infested plum foliage.

THE SPRING FORMS.

Six wingless generations, in the maximum-generation series, were bred from April to June during 1916. An unusually hot wave occurred June 6, and killed all of the individuals of the seventh and eighth generations in the cages. It has been determined, however, that wingless generations may persist on the winter hosts through the summer as late as September, but apparently they can not produce true sexes. In the maximum series all second-generation individuals were wingless, in the third generation 1 out of 29 was winged, none of the fourth or fifth generations were winged, while the majority of the sixth and seventh generations were wingless. All the individuals in this series were bred on Myrobalan plum.

SPRING WINGLESS FORMS.

Description.

Newly hatched.—Pale yellowish-green; eyes dark red; rims of cornicles dusky. Appendages hyaline greenish-white. Form elongate oval.

Antennæ 5-jointed, half as long as body. Comparative measurements as follows: I, 0.03 mm.; II, 0.025; III, 0.11; IV, 0.06; V, 0.175 (0.05 plus 0.125). Beak reaching third coxæ. 0.22 mm. long; cornicles wartlike, 0.025 mm. long. Style rounded. Length of body, 0.50 mm.; width of body, 0.22 mm.

In the first instar the general color darkens, but it is never as dark as that of the stem mother; the tarsi, last antennal joint, and tip of beak become dark grayish-black. After the first molt a conspicuous "meal" is secreted in four longitudinal rows of circular areas on the body dorsum. This "meal" is more abundant on the first and fifth abdominal segments than elsewhere. The three longitudinal green stripes described in the stem mother appear less distinct in later generations. After the second molt the body is elongate oval. The aphids have a carinated appearance following each molt.

Adult.—Light green; eyes dark red to black; antennæ pale hyaline green, apex gray; legs hyaline greenish-white, tarsi and tibial apices gray; cornicles somewhat dusky in apical half; cauda light greenish-white. Beak pale, tip blackish. "Meal" as in larva, increasing with age of insect. Form elongate oval.

Antennæ on frontal tubercles, 6-jointed, two-thirds as long as body; comparative measurements as follows: I, 0.085 mm.; II, 0.075; III, 0.39; IV, 0.24; V, 0.225; VI, 0.445 (0.105 plus 0.340). In later generations filament of VI is longer in proportion than in earlier. Beak reaching second coxæ, 0.30 mm. long. Cornicles imbricated rather inconspicuously, constricted near base, somewhat enlarged in middle, mouth not flaring; length, 0.115 mm. Cauda ensiform, 0.17 mm. long. Body length, 2.2 to 2.8 mm.; width, 1.2 mm. Small, pale, blunt lateral tubercles occur on the prothorax and on each abdominal segment. Body armed with very few hairs.

Duration of Nymphal Stages.

Records of the development of the wingless forms were made both on caged trees and in the orchard. Myrobalan and Agen (*French*) prunes were used for hosts. The development was similar on both hosts, the aphids being retarded on weaker trees. The instars occupied, on the average, equal periods of time, except that the fourth was slightly shorter than any one of the others.

Forty-five individuals of the second generation were observed during the period March 27–May 4, the majority developing during the period March 30–April 22. The average growing period was 12.6 days, the maximum 18, and the minimum 10.

Between April 11 and May 30, 34 third-generation wingless individuals developed in an average of 11.8 days, the maximum and minimum periods being, respectively, 18 and 9 days.

Individual records of generations 4 to 7 were made chiefly from the maximum-generation series and might be grouped best in tabular form as follows:

TABLE I.—*Development of spring wingless generations of the mealy plum aphis. Walnut Creek, Cal., 1916.*

Generation.	Dates included.	Number of individuals.	Developmental period.		
			Average.	Maximum.	Minimum.
			Days.	*Days.*	*Days.*
IV....	Apr. 23–May 16	10	9.9	14	9
V.....	May 3–May 18	27	11.1	14	10
VI....	May 14–May 27	30	12.7	16	11
VII...	May 26–June 3	10	[1] 10	11	9

[1] June 7, five fourth-instar wingless individuals died because of an excessive heat wave. Had these matured, the average developmental period would have been slightly lengthened.

MAXIMUM AND MINIMUM GENERATIONS.

A maximum-generation series of first-born aphids (wingless) is shown in the table following:

TABLE II.—*Development of maximum-generation series of the mealy plum aphis. Walnut Creek, Cal., 1916.*

Generation of individual.	Date of birth.	Date of fourth molt.	Developmental period.
			Days.
I.......	Mar. 11	Mar. 28	17
II......	Mar. 30	Apr. 11	12
III.....	Apr. 11	Apr. 23	13
IV......	Apr. 23	May 3	10
V.......	May 3	May 14	11
VI......	May 14	May 26	12
VII.....	May 27	June 6	9

Thus in the space of 11½ weeks seven complete generations occurred. Had it been possible to have continued the series until winter, certainly 10 more generations would have been produced. The adults usually deposit young within a very few hours after shedding the final skin.

A minimum-generation series of last-born aphids is indicated below:

Table III.—*Development of minimum-generation series of the mealy plum aphis. Walnut Creek, Cal., 1916.*

Generation of individual.	Date of birth.	Date of fourth molt.	Developmental period.
			Days.
I		Mar. 31	
II	Apr. 21	May 3	12
III	May 29	June 11	13
IV	July 1	July 12	11

These four generations were completed in about four months, or over a month longer than the seven generations of the first-born series.

The period of reproduction as indicated in the foregoing table varied from 20 to 26 days.

Reproduction.

Observations were made on the reproduction of individuals of wingless generations 2 to 5 inclusive. Adults of the second generation, for a total reproductive period of from 4 to 5 weeks, averaged about 4 young daily, producing the first three weeks a daily average of 6 young. The later generations were less prolific, fourth and fifth generation individuals not averaging above 2¼ young per day. Ten young were deposited within 24 hours on several occasions, but on no occasion was this number exceeded. The rise and decline in fecundity was in the main similar to that found in the case of the stem mother.

Habits of Spring Generations.

The aphids of the second generation, when newly born, dispose themselves in groups, close by the parent, on the underside of the leaf. After the first molt many remove to other leaves and this is the beginning of the migration from leaf to leaf and branch to branch. Second-generation larvæ and adults prefer to suck the rib tissues of the leaf. Owing to the rapidity of reproduction and consequent crowding, the aphids of later generations have little choice of location and feed at any point on the lower surface of the leaves or on petioles. If the lower surface of a leaf is entirely occupied many larvæ will be found feeding on the upper surface, in some cases apparently in preference to seeking other less crowded leaves.

In 1916 infested prune leaves began to curl at the beginning of April, such leaves having one or more colonies of adult stem mothers and first-instar young. As April progressed the leaf-curl became more and more pronounced and the colonies increased rapidly. About the middle of the month the most heavily infested leaves began to have a yellowish appearance in the form of blotched areas at the points where the aphids were most abundantly settled. On April 21 a few leaves were found to have their under surfaces quite covered with feeding aphids, and at the end of the month such leaves were abundant, while twigs and limbs were covered with a sticky "honeydew," and here and there young fruits were coated with this substance. During May and June this condition was greatly aggravated in the orchards examined.

The spring winged form first appeared April 21, and throughout May and June increased in numbers, and after the middle of May there was a corresponding decrease in the numbers of wingless adults produced. By July 1 the mature wingless individuals had diminished greatly in quantity and thereafter their numbers dwindled so that by the middle of August none were to be found. In no instance in 1916 was an infestation prolonged beyond this date, but in 1914 in the same locality a small but vigorous infestation occurred throughout September, later becoming annihilated by natural enemies.

In the rearing cages it was found that the transfer of newly born young was very frequently attended by the loss of the insect, and in most cases the adult was transferred when it was desired to make observations on a new plant. Several transfers of larvæ and adult wingless individuals from plum to apricot failed, while others resulted successfully. Infested apricot leaves did not curl as badly as those of prune and plum.

THE SPRING MIGRANT.

Description.

In the first three instars the nymphs of the migrants do not differ from those of the wingless spring form, except that the third-instar individuals are somewhat narrower.

Pupa.—Light green; eyes dark red; tarsi and apex of beak dark gray. On the body ground color is superimposed a narrow dorsomedian stripe of darker green. Thorax broadened to twice the width of the prothorax. Wing pads yellowish white. Body with pruinose covering as in wingless nymph.

Adult.—Light green; eyes red; antennæ light gray, basal portion of third joint hyaline yellow; head, thoracic lobes, and sternum dark grayish black; scutellum yellowish brown; prothorax, sides of thorax, and wing insertions greenish yellow; wings hyaline, stigma and veins gray; legs pale greenish yellow, apices of tibiæ and the tarsi dusky gray; abdomen and style pale green or greenish yellow; cornicles pale at base, dusky at apex. Beak pale, extreme tip dusky.

Form elongate, the abdomen with parallel sides.

The dorsum and sides are covered with white pruinose "meal," on the abdomen the "meal" occurring in transverse bars.

Antennæ four-fifths as long as body, on frontal tubercles. Comparative measurements as follows: I, 0.08 mm.; II, 0.06; III, 0.405; IV, 0.26; V, 0.21; VI, 0.48 (0.10 plus 0.38). Beak reaching a little beyond anterior border of mesosternum, 0.26 mm. long. Wings 2.5 mm. long. Cornicles faintly imbricated, shorter than in wingless female, barely twice as long as broad at base, slightly constricted near base, in length 0.08 mm. Style ensiform, 0.15 mm. long. Length of body, 1.61 to 2 mm.; width, 0.66 mm.

Lateral tubercles as in wingless form; first antennal joint somewhat gibbous.

Sensoria.—On III, 23 to 30; on IV, 4 to 10; on V, 1 to 2; on VI, usual apical group. Sensoria of unequal size, not at all arranged in longitudinal rows, but rather in spirals.

Duration of Nymphal Stages.

Eight winged spring migrants developed in an average of 14½ days, the developmental period ranging from 13 to 18 days. The winged form therefore develops more slowly than the wingless, due to the increased duration of the fourth instar.

Reproduction.

The migrants commenced to reproduce on the cat-tail rush (Typha) a few days after they settled. In many cases migrants were found to settle, remain for several days, and finally die without reproducing and only a small percentage of those settling reproduced. Most of them remained a few days and then departed. Spring migrants in only one instance out of 76 deposited young on caged plums. In this instance the three young born refused to feed on the plum (Myrobalan). In this connection it might be said that all attempts to induce wingless forms of earlier generations to settle on Typha failed. Migrants placed in small dishes and provided with plum and cat-tail foliage in no instance deposited young and in extremely few instances did migrants placed on cat-tail deposit young. Unfortunately it was not possible to obtain Phragmites for similar tests.

The migrants may remain on the winter host foliage for several days before taking flight, especially if the weather be cool and cloudy.

Field observations indicated that the migrants produced young at the rate of about five every two days at first, and later at a slower rate. On Typha it appeared that the maximum number of young per migrant rarely exceeded 20 and, discounting all migrants which failed to deposit, averaged not much over five. This must have been abnormal, as examination of individuals disclosed the presence of many more embryos than were extruded. It is possible that Typha does not prove an invigorating food for the migrant and this point is perhaps elucidated below in the paragraphs on migrations.

Migrations.

Phragmites and Arundo have long been known as alternate hosts of the mealy plum aphis; in fact the species has been described as new from both of these hosts. In California enormous infestations have been observed on the former in swampy regions, sometimes removed many miles from any winter hosts. On the other hand, Typha grows in abundance close to prune orchards and yet, considering the enormous production of spring migrants throughout May, June, and July, the later infestations on near-by Typha are in the aggregate exceedingly small. The writer has seen clumps of *Typha latifolia*, growing not 30 feet from prune trees on each of which thousands of winged forms were being developed, receive only a few dozen migrants and perhaps have not over 6 out of 100 blades colonized by their progeny. It is true that when once established a colony on Typha increases rapidly, but it is also evident that the migrant fails to do justice to her reproductive capabilities on this plant.

That the migrants fly long distances to seek their alternate hosts, especially Phragmites, is the conviction of the writer.

The spring migrants settle on Typha near the apex of a strongly-growing blade and station themselves parallel to its long axis. The wingless forms later take up this same position. After the migrants have extruded a few young the whitish meal is excreted in greater abundance. On Phragmites the colonies are similarly disposed. On three occasions the writer observed heavy summer infestations on the reed *Phragmites communis* L. On July 5, 1917, along the banks of the San Joaquin River about 15 miles west of Stockton, Cal., this plant was heavily attacked. Among the colonies occurred a few pupæ and winged forms of a winged summer form. *Typha latifolia* growing among the infested reeds was not attacked. On August 13, 1917, at Benicia, Cal., clumps of reeds growing in swampy ground near San Francisco Bay bore heavy infestations of the aphis and the summer winged form was abundant. Plants of Typha growing among the clumps of Phragmites were sparingly infested. On May 15, 1918, heavy infestations were observed on *Phragmites communis* growing on the west shore of the Salton Sea, in southern California.

These observations indicate that Phragmites is the preferred summer host plant.

The summer winged aphids serve to distribute the species among the reeds. They do not differ in appearance or structure from the spring migrants produced on the winter hosts.

Fall migrants appeared both in 1915 and 1916 on Typha about October 15, and continued until the end of November. Males appeared the last week of October and throughout November. The small yellowish pupæ of the latter are easily distinguishable on the cat-tails from the green pupæ of the fall migrant. Mature fall migrants remained on the summer host for a day or two before departing.

Although migrations from Typha were traced with apparent certainty in the fall of 1915, in the following year so few fall migrants were produced on local Typha under observation that they were out of all proportion to the great numbers of winged forms which began to appear in the prune orchards near Walnut Creek toward the end of October, and it was certain that the great majority of migrants were coming from a considerable distance.

THE SUMMER WINGLESS FORMS.

DESCRIPTION.

Newly hatched.—Similar to that of spring wingless form, but more yellowish. Form elongate.

Adult.—In color similar to those of spring wingless, but smaller in size and narrower in shape.

Antennæ about two-thirds body length. Comparative measurements as follows: I, 0.08 mm.; II, 0.045; III, 0.26; IV, 0.16; V, 0.155; VI, 0.40 (0.08 plus 0.32). Beak reaching second coxæ, 0.26 mm. long. Cornicles more cylindrical than in spring wingless form, inconspicuously imbricated, 0.07 mm. long. Style 0.135 mm. long, shaped as in spring wingless form. Length of body, 1.6 to 2 mm.; width of body, 0.65 mm.

Measurements from specimens of what appears to be *H. arundinis* collected in April on Arundo in Peru by Mr. E. W. Rust were noticeably greater, but similar in proportions.

The lateral tubercles are inconspicuous.

DURATION OF STAGES.

Eighteen first-generation (progeny of migrant) individuals in the period May 29–August 20 matured on Typha in an average of 14.6 days, the period of growth ranging from 12 to 18 days. Between June 17 and July 30, 15 aphids of the second and third summer generations developed in an average of 15.8 days, with a range of from 9 to 18 days, while 17 fourth-generation individuals developing between July 26 and August 27 averaged 12.2 days, with a range of from 9 to 16 days. Aphids maturing in September developed in an average of 14 days. All the individuals recorded above were wingless. There is apparently a maximum of as many as 10 wingless summer generations and a mimimum of 3. Molts occurred about as in the spring wingless forms.

HABITS OF SUMMER WINGLESS FORMS.

Colonies are located on both sides of the blades, chiefly on the outer half, occasionally on the basal half of the leaf. In September, 1915, several colonies of over 200 wingless individuals were observed on single blades of Typha at Walnut Creek, and about the end of this month the aphids reached their maximum abundance. This latter condition was repeated in 1916, although the colonies were never as large as the year previous. As has been noted, the aphids lie parallel to the length of the blade. They move off at slight disturbance and much difficulty was experienced in transferring individuals, owing to their failure to settle on a new plant.

Toward the end of October the blades frequently turn yellow, causing the aphids resident thereon to assume a straw-colored appearance.

The aphids frequently deposit a little circle of "meal" around them on the surface of the blade, a habit similar to that practiced on the same host by a species of white fly. On leaves of Phragmites the aphids congregate in large masses on both surfaces, lying parallel to the long axis of the leaf. The central portion of the leaf is colonized first and as the colony increases in numbers the infested area approaches the margins.

THE FALL FORMS.

There are three fall forms—the fall viviparous migrant, the male, and the sexual oviparous female. The first two fly to the winter hosts, after which the viviparous migrants deposit the sexual oviparous females.

FALL MIGRANT.

Description.

The immature stages do not differ materially from those of the spring migrant.

The adult insect, aside from being slightly smaller and having the antennæ, legs, and style more dusky, is similar to the spring migrant. Form elongate.

Antennæ on somewhat gibbous frontal turbercles, about two-thirds as long as the body. Comparative measurements as follows: I, 0.07 mm.; II, 0.06; III, 0.39; IV, 0.235; V, 0.175; VI, 0.48 (0.10 plus 0.38). Beak reaching a little beyond anterior border of mesosternum, 0.26 mm. in length. Wings 2.6 mm. in length. Cornicles shaped as in spring migrant, 0.075 mm. long. Style ensiform, 0.16 mm. long.

Sensoriation and tubercles as in spring migrants.

Reproduction and Habits.

The migrants normally locate on the underside of the leaves (of the winter host), but those that arrive latest in the season often find the leaves blown off by winds and perforce settle on the twigs. Frequently they feed for several days before producing young. In experimental cages inclosing Agen (*French*) prunes and Myrobalan plums 14 was the highest number of young laid by a single migrant, and the average was about 8 (excluding about 20 per cent of the individuals which died without bearing progeny). The migrants were more prolific on Agen (*French*) prunes than on Myrobalan plums. In the field it appeared that from 12 to 35 young sexual females are produced normally, with an average of about 20, on French prunes.

The young were produced within about 12 days (in the cages mostly within 7 days) and at a rate of from 2 to 3 a day. The migrants, after they had extruded their complement of young, remained settled for as long as two weeks.

MALE AND OVIPAROUS FEMALE.

Male.

DESCRIPTION.

Pupa.—Noticeably smaller than that of the fall migrant, light yellow in color; eyes dark red; tarsi and distal antennal joint dusky gray. Form elongate.

Adult.—Light clay yellow; head, antennæ, prothorax, thoracic lobes, scutellum, legs, cornicles, and style brownish-black; eyes dark red; stigma light greenish-gray; veins of wings brown; abdomen with a dorsomedian longitudinal row (segments 1 to 5 inclusive) of subcircular gray spots, similar lateral spots on segments 1 to 3 inclusive, and with cross bars of similar color on segments 6, 7, and 8; genital plate and organs dark gray; beak pale yellow, tip brownish black. The male is almost devoid of "meal."

Antennæ on gibbous frontal tubercles, three-fourths the length of the body; comparative measurements as follows: I, 0.08 mm.; II, 0.07; III, 0.38; IV, 0.25; V, 0.23; VI, 0.46 (0.09 plus 0.37). Wings 2.3 mm. long. Cornicles vase-shaped, narrowed close to base, faintly imbricated, 0.085 mm. in length. Style conical, 0.10 mm. long. Beak reaching a little beyond anterior mesosternal border, 0.30 mm. long. Length of body, 2.05 mm., width, 0.68 mm.

Circular sensoria are distributed along the antennal joints much as in the spring and fall migrants. They are much more numerous, there being from 38 to 53 on III, 19 to 29 on IV, 9 to 18 on V, and the usual apical group on VI.

Oviparous Female.

DESCRIPTION.

Newly hatched.—Light green, appendages hyaline; eyes red. Form oval.

The immature females are bright green with a very scant covering of "meal."

Adult.—Greenish yellow; eyes dark red; distal half of antennæ, cornicles, and tarsi gray; beak pale yellow, tip brown. The coating of "meal" is not so conspicuous as in the earlier forms, in this respect resembling the stem mother. Form elongate oval, rather flat.

Antennæ not quite half as long as body, comparative measurements as follows: I, 0.06 mm.; II, 0.035; III, 0.145; IV, 0.06; V, 0.085; VI, 0.245 (0.05 plus 0.195). Beak reaching second coxæ, 0.25 mm. long. Cornicles cylindrical, twice as long as wide at base, faintly imbricated, 0.05 mm. long.

Style conical, 0.08 mm. long. Length of body, 1.18 mm.; width, 0.52 mm.

The thickened hind tibiæ bear a large number of small circular sensoria.

Nymphal Stages.

For the male the nymphal stages were not observed closely, this form having been very rare on the cat-tails in 1916. From such observations as took place it appears safe to say that both males and fall migrants develop in about three weeks. The development of oviparous females was observed in 1916 on both Agen (*French*) prunes and

Myrobalan seedlings. Within the period October 20–November 23, 40 oviparous females matured in an average of 19.1 days, the period of development ranging from 16 to 22 days. On Myrobalan plum the development was slightly slower than on Agen (*French*) prunes.

Habits and Oviposition.

The females feed normally on the under surface of the leaves, but occasionally also on tender stalks, especially of sucker growth. The males frequently arrive before the females are mature and settle down beside the immature aphids. Copulation takes place very soon after the female casts her fourth skin, and a male may copulate with more than one female. As the males are much less abundant than the females this practice is probably common and was often noticed in the cages. Toward the middle of November, 1916, large numbers of immature females were blown off the trees by winds and perished. In some orchards this only thinned out the infestation to a small degree, as plenty of mature females had been observed previous to the coming of the high winds, but in others wherein the sexes were not so advanced it destroyed the majority of the aphids. The oviparous females bear only a scant coat of "meal" and may be easily confused in the orchard with those of *Phorodon humuli* Schrank and *Aphis cardui* Linnæus, both of which are contemporaneous with *arundinis*. They are less likely to be confused with the plump reddish-brown oviparous form of *Rhopalosiphum nympheae* Linnæus.

As a rule the female commences oviposition within 24 hours of copulation, but this was delayed in some cases as long as 5, and in one instance 10 days. In cages never more than 2 eggs, and more often only 1, were laid in one day by a single aphid.

Sixteen females laid an average of 4.1 eggs in the period November 9–December 18. In the early part of this period the average was 6, while toward the end it was 3.5. Not over 7 eggs were deposited by one female. There was a marked tendency to deposit the eggs over a long period—as much as three weeks—and the females after depositing an egg or eggs on the stems generally returned to the leaf, remaining there until the time for the deposition of the next egg. The females usually died within a week of depositing their last egg, but in some cases lived longer, and one aphid lived beyond three weeks. It appeared, however, that those that persisted had not rid themselves of all their ova, as they did not have the shrunken appearance of sterile aphids.

NATURAL ENEMIES.

The mealy plum aphis, both on winter and summer hosts, is preyed upon by a large series of natural enemies. As early as March 17, 1916, a few eggs of Syrphidae and Chrysopidae were observed deposited near the growing stem mothers on plums. Throughout April lampyrid beetles (*Podabrus comes* Le Conte, *P. binotatus* Le Conte var., and *Telephorus divisus* Le Conte) appeared locally. During May syrphus-fly larvæ (especially *Catabomba pyrastri* Linnæus) and ladybird adults and larvæ (especially *Hippodamia convergens* Guérin) abounded, as did also a few hemerobiid larvæ. Nevertheless these predators made little apparent headway in reducing infestations.

Observations made in June, 1915, indicated that *Hippodamia convergens* was by far the most beneficial of the ladybirds.

The Typha colonies were preyed on by the larvæ of Syrphus; those on Phragmites by beetles of the Hippodamia group and by Leucopis larvæ; and late in the fall the sexual females were attacked by syrphids and Triphleps.

Internal parasitism in the writer's opinion is of very rare occurrence. Occasionally he has observed parasitized specimens in nature.

CONTROL SUGGESTIONS.

There are two especially vulnerable periods in the annual life cycle of the mealy plum aphis—one in early spring when the stem mothers are growing and the other in late fall when the sexual females are developing on the winter hosts. Unfortunately at these two periods the enemies of the aphis are very scarce, but the aphis itself is more easily destroyed than at other times by artificial substances. Both the stem mothers and the oviparous females have a scant protective covering of "meal" and both live for the most part on exposed surfaces of the plant, whereas the aphids of the spring and summer generations bear a comparatively thick coating of meal and live in great part in curled foliage. Contact insecticides, which have little effect on aphids of the intermediate generations, easily destroy the stem mothers and the egg-laying females.

SUMMARY.

The mealy plum aphis in California is a decided pest of plums, prunes, and, to a lesser degree, apricots. Besides devitalizing the trees it causes small-sized fruits and early drops, and is probably concerned in a measure with apical cracking of prunes.

In 1916 winter eggs hatched between March 4 and 18 and early stem mothers began reproduction about March 20. It appeared that normally from 3 to 5 generations were raised on the winter hosts, but rarely series of wingless generations persisted until the fall. The aphids of the earlier generations were mostly wingless like the stem mothers, and the individuals of the later generations mostly winged, and after the middle of June virtually all the insects produced developed wings.

Migration to the summer hosts, Phragmites and Typha, began the last week in April and continued until August, the great body traveling in early June. On these hosts about 10 generations took place, continuing up to November. The vast majority of aphids to be found during the summer were wingless, but winged parthenoparous individuals were also produced on the summer host plants and these served to distribute the species among these plants. About the middle of October and for six weeks succeeding, winged sexuparous migrants and winged males were produced and these flew to the fruit trees whereon the sexuparae proceeded to deposit sexual females. The sexes were most abundant during the forepart of November, and were to be found as late as the middle of December.

Oviposition took place throughout November and December. the majority of ova having been placed before December 10.

The foregoing data are based on observations made at Walnut Creek, Cal., between August, 1915, and December, 1916.

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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

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THE ROSE MIDGE.

By E. R. SASSCER, *Collaborator*, and A. D. BORDEN, *Scientific Assistant, Tropical and Subtropical Fruit Insect Investigations.*

CONTENTS.

INTRODUCTION.

The rose midge, *Dasyneura rhodophaga* (Coq.), an insect related to the Hessian fly, is often the cause of considerable injury to roses grown under glass. In 1912 Davis (3)[1] estimated that the loss due to this pest in two Chicago greenhouses would approximate $10,000 annually. Subsequently this insect was reported by various entomologists as being especially injurious to the flower and leaf buds of the rose, distorting their growth and eventually causing them to turn brown and die.

In the fall of 1916 an infestation was located at Colgate, Md., which, according to the owner, caused an annual loss of from $4,000 to $6,000. Although the house was generally infested, the infestation was limited to the following varieties of roses: Radiance (pink), Hadley (red), Russell (pink), and Killarney (white). The Hadley and Radiance varieties were most severely infested, scarcely a leaf or flower bud escaping attack.

This infestation offered an excellent opportunity for determining a satisfactory means of controlling this pest in a commercial greenhouse, and, in collaboration with Prof. E. N. Cory, entomologist of the Maryland Agricultural Experiment Station, the investigation was begun in October, 1916. Results of these experiments are given on pages 6 and 7.

[1] Figures in parentheses refer to "Literature cited," p. 8.

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HISTORY AND DISTRIBUTION.

This rose pest, together with a closely related species, *Diplosis rosivora* Coq., was first collected in New Jersey, in 1886 (1). It was collected later in New Jersey in 1889, in New York in 1890, in the District of Columbia in 1891, 1894, and 1896, in Massachusetts in 1894, and in Chicago, Ill., in 1897 (2, p. 15). In 1903 specimens were sent to the Bureau of Entomology from Cleveland, Ohio, infesting the Meteor variety, with the report that as many as 35 larvæ had been taken from a single bud. Apparently the same insect was received from Cincinnati, Ohio, in 1905, where it was seriously damaging the buds and tips of the La France and Duchess of Albany. Notwithstanding the fact that in the houses containing both varieties the heat was turned off throughout the entire winter, the correspondent reported that the hibernating midge was not killed.

In 1911 a heavy infestation of the variety My Maryland was reported from Rhode Island, and in 1915 Hewitt (5) recorded the occurrence of this midge in a garden at London, Ont., infesting shoots of the variety Mrs. J. Laing. In 1916 Gibson (8) reported it from the same locality and also in greenhouses at Toronto, Ont. Snodgrass (7) includes the rose midge among the important insect pests of Indiana, and Crosby and Leonard (6) state that it attacks roses grown in the open in New York.

Although the rose midge has been reported frequently from several States, it does not necessarily follow that these infestations are still in existence, since some of the varieties subject to infestation have been given up for more resistant and profitable varieties, and in others the insects may have been exterminated by the use of insecticides. Rose houses in the District of Columbia were repeatedly inspected during the past two years, and no infestations were located.

DESCRIPTION.[1]

EGG.

FIG. 1, A.

Egg elongate ovoid, yellowish, about 0.32 mm. long and 0.075 mm. in width.

LARVA.

FIG. 1, C.

Full-grown larva about 1.8 mm. in length, 0.45 mm. in width, reddish in color, obtuse and tuberculated on posterior segment, tubercles bearing minute apical spines, lateral margins distinctly compressed, attenuated anteriorly, breast-bone distinct, with distinct black spot on upper side immediately in front of breast-bone.

PUPA.

FIG. 1, E.

Length of pupa 1.6 mm., width 0.53 mm.; color varying from reddish to reddish yellow, eyes black at time of emerging from cocoon, legs and antennæ approaching black with head and prothorax dusky; all segments except first

[1] The descriptions of the egg, larva, and pupa are compiled from Webster (2, p. 21–23); that of the adults is copied verbatim from Felt (4).

bearing a transverse spinulose ridge on dorsal surface, ventral surface without these ridges; bases of antennæ produced with usual pair of bristles immediately posterior to them and with two large respiratory tubes protruding through cocoon.

ADULT.

Male [Fig. 1, F]. Length 1 mm. Antennæ short, 9 subsessile segments, the fifth with a length only a little greater than its diameter, the last segment greatly produced, with a length about four times its diameter. Palpi; the first

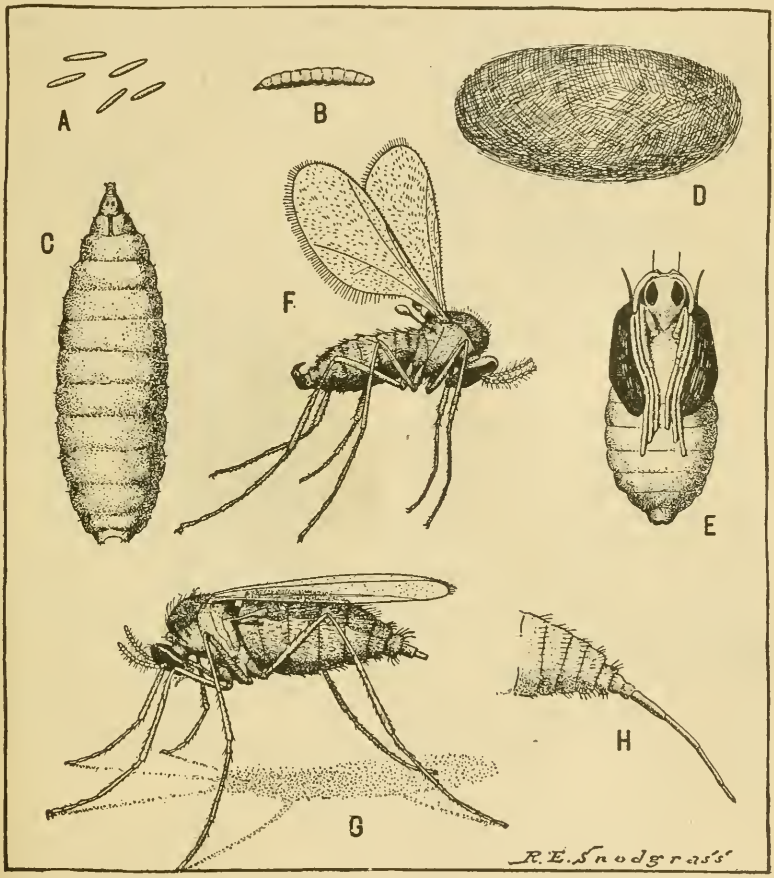

FIG. 1.—The rose midge (*Dasyneura rhodophaga*), enlarged about 27 diameters: *A*, eggs; *B*, young larva; *C*, full-grown larva; *D*, cocoon; *E*, pupa; *F*, adult male; *G*, adult female; *H*, female ovipositor. (9th Ann. Rept. State Ent. Ind.)

segment short, the second broadly oval, the third one-half longer, dilated, the fourth as long as the third, slender. Head and thorax brown, the abdomen, in alcoholic specimens, yellowish. Wings hyaline, costa dark brown, third vein curving forward. Claws long, slender, the pulvilli a little shorter than the claws. Genitalia; basal clasp segment slender; terminal clasp segment long, slightly swollen basally; dorsal plate broad, deeply and narrowly incised, ventral plate long, broadly and roundly emarginate. Harpes long, subtruncate and irregularly tuberculate.

Female [Fig. 1, G]. Length 1 to 1.25 mm. Antennæ short; 9 subsessile segments, the fifth with a length nearly twice its diameter, the terminal segment greatly produced, with a length about five times its diameter. Ovipositor nearly as long as the abdomen, the terminal lobes narrowly oval, tapering. Other characters presumably as in the opposite sex.

LIFE HISTORY.

The female midge, with her long ovipositor, places small yellowish eggs just under the sepals of the flower buds or between the folded leaves of the leaf buds. Under favorable temperature conditions these eggs hatch in 2 days, and the young larvæ or maggots immediately attack the buds, extracting the sap and eventually causing the petals and leaves to dry up and die. (Fig. 2.) They grow very rapidly, reaching maturity in from 5 to 7 days, and, when full grown, work their way out of the buds and fall on and enter the ground where they construct small silken cocoons (fig. 1, D) in which they pupate. Adults appear in from 5 to 7 days, and shortly after deposit eggs for the next generation of larvæ or maggots. In confinement the life of an adult is from 1 to 2 days. The total cycle, therefore, under greenhouse conditions, is from 12 to 16 days. About 85 per cent of the adults reared in cages were females.

SEASONAL HISTORY.

Although larvæ or maggots have been observed injuring buds as early as February 22, under normal conditions they do not appear in injurious numbers until June or July. In Washington adults were reared in early May from larvæ which pupated in November. During the warm summer months the generations may mature every two weeks, and overlapping of broods probably takes place. Larvæ were especially injurious at Colgate, Md., during two periods of the year, namely, from the latter part of May to early July and from early September to November 1. On the approach of cold weather the stages are slightly prolonged, and about the latter part of November the larvæ enter the ground and construct overwintering cocoons. No injury has been reported during winter.

FOOD PLANTS.

Roses, especially the hybrid teas, are apparently the only plants attacked by this insect. It has been recorded as infesting the Radiance, Hadley, Russell, Killarney, Ophelia, Hoosier Beauty, Shawyer, My Lady, American Beauty, Uncle John, Joe Hill, Kate Moulton, Bridesmaid, Liberty, Richmond, Mrs. John Laing, Meteor, Madam Chatenay, Ivory, Golden Gate, Wooten, La France, and a sport of the latter, the Duchess of Albany.

EXPERIMENTS IN CONTROL.

At the suggestion of Prof. E. N. Cory a series of experiments, in which the following combinations were used as sprays, was conducted to determine the value of molasses in catching the larvæ, thus preventing their entrance to the soil where pupation takes place: (1) Two pounds (by weight) of molasses, 3 gallons of water, 200 cc. of nicotine sulphate (40 per cent nicotine), and ½ ounce (by weight) of lead arsenate; (2) 1½ pounds (by weight) of molasses, 3 gallons of water, 30 cc. of nicotine sulphate (40 per cent nicotine), and ½ ounce (by weight) of fish-oil soap; (3) 2 pounds (by weight) of molasses,

FIG. 2.—Young leaves and flower buds of roses injured by larvæ of the rose midge.

2½ gallons of water, 25 cc. of nicotine sulphate (40 per cent nicotine), ⅘ ounce (by weight) of neutral soap, 1⅗ ounces (by weight) of lead arsenate, and 6⅖ ounces of Bordeaux mixture; (4) 2 pounds (by weight) of molasses, 2½ gallons of water, 25 cc. of nicotine sulphate (40 per cent nicotine), and 1⅗ ounces lead arsenate; (5) 2 pounds (by weight) of molasses, 2½ gallons of water, and 1⅗ ounces (by weight) of lead arsenate; (6) 2 pounds (by weight) of molasses and 2½ gallons of water.

All of the foregoing experiments were conducted in a commercial greenhouse, and each test represents a 50-foot bed of roses. For the most part the killing results of all six experiments were satisfactory. Unfortunately, however, the molasses served as a medium for the development of sooty mold, and, moreover, where lead arsenate was used an objectionable white deposit developed. The presence of either on cut flowers necessarily would reduce their value and in some instances would eliminate them from the market. As the rose midge usually is present at a season when the grower can ill afford to have objectionable deposits on his cut flowers, it is evident that any of the foregoing combinations will be unsatisfactory, unless some method of counteracting these objectionable features is developed. In addition to the foregoing, 1 part of nicotine sulphate (40 per cent nicotine) to 400 parts of water, with the addition of enough soap to produce suds, was tested. The results of this experiment were very unsatisfactory, fully 95 per cent of the larvæ being uninjured.

To determine the value of tobacco dust in preventing the full-grown larvæ, or grubs, from entering the soil, the following cage experiments were conducted: (1) Soil around caged plants covered with dry tobacco dust; (2) same as former except that the dust was wet. Full-grown larvæ which were placed in the cage containing dry dust were active for 24 hours, but did not go below the surface, whereas the larvæ similarly placed in cage 2 were exceedingly active upon coming in contact with the wet dust, acting as if they were burned, and after from 5 to 8 hours they were all dead. All larvæ used in the check immediately entered the soil.

Having determined a satisfactory method of preventing the entrance of the full-grown larvæ into the soil, all of the rose beds in the infested houses at Colgate, Md., were covered on October 12, 1916, with tobacco dust averaging from one-fourth to one-half inch deep. To prevent the larvæ from entering the dirt walks of the houses, all walks were sprayed with 5 per cent kerosene emulsion. Simultaneously nightly fumigation with tobacco stems was inaugurated and continued until October 30, inclusive, and from that date until November 8 the houses were fumigated every other night. The object of this fumigation was to kill all adults before eggs were deposited.

Although this control work was not undertaken until October 12, its effectiveness was soon apparent, and by the latter part of October it was very difficult to locate an infested bud. Not only was the midge under control, but the owner was enabled to bring on his fall crop earlier than was the case in 1915. On May 7, 1917, these houses were carefully examined, and only 6 larvæ were located, 2 in the buds of the Hadley and 4 in the buds of the Radiance. All plants at this time were in excellent condition and gave promise of producing a full crop of flowers. These houses were again carefully examined on June 19, and no injury was to be found on any of the plants which had been infested so severely during the fall of 1916. Moreover, the owner reported that up to June 19 more than twice as many blooms had been cut as during the entire previous year.

The rapid elimination of this pest was due no doubt to two causes, (1) nightly fumigation, which killed off the adults before egg-laying took place, and (2) the application of tobacco dust, which prevented the larvæ from entering the soil. Moreover, the tobacco dust served a dual purpose, since it prevented the larvæ from entering hibernating quarters and at the same time fertilized the soil.

METHODS OF CONTROL.

It is evident from the experiment described above that a severe infestation of the rose midge can be controlled, if not entirely eliminated, in a comparatively brief period by the careful application of tobacco dust on the soil and by persistent nightly fumigation with tobacco, in the form of stems, nicotine papers, or one of the volatile nicotine preparations.[1]

Where earth walks are present, it is advisable to spray the walks also with a 5 or 10 per cent kerosene emulsion.[2]

In the case of light infestations, the midge can be controlled by systematic nightly fumigations with tobacco fumes, which should be continued until all adults disappear; or by a careful application, at the proper season, of tobacco dust. Inasmuch as the broods probably overlap during the summer, there is a possibility that frequent syringing of the plants would cause much of the dust to wash down into the soil before all larvæ matured; hence there is a chance that some would fall on and enter earth where the dust had lost its effectiveness. It would seem, therefore, that the most opportune time to apply the dust, if not accompanied with nightly fumigation, is

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[1] Although tobacco stems have been used in greenhouses from time immemorial they are being replaced rapidly by nicotine paper and the volatile nicotine extract, owing to the fact that the nicotine content of the stems is so variable. Tobacco stems in the proper condition (those which have not been allowed to become wet and dry out) will yield good results. As there is no satisfactory and easy method by which the florist can determine accurately the nicotine content of tobacco stems, however, it will probably be a saving of time and money to use the nicotine papers or the volatile nicotine extracts, in which case the directions on the label of the container should be followed.

[2] Kerosene emulsion (stock solution, 66 per cent oil) is made after the following formula:

Kerosene (coal oil, lamp oil)	gallons	2
Soap (fish-oil or laundry) (or 1 quart soft soap)	pound	½
Water (soft)	gallon	1

First dissolve the soap in boiling water, then remove the vessel from the fire and immediately add the kerosene, thoroughly agitating the mixture until a creamy solution results. The stock solution may be more conveniently made by pouring the mixture into the tank of a spray pump and pumping the liquid through the nozzle back into the tank for five minutes. A 10 per cent solution can be made by adding to each gallon of the stock solution about 5⅝ gallons of water. In some regions the water is "hard," and in such cases it should be broken with a little lye, or rain water should be used.

during the latter part of October or the first three weeks of November, at which season the last generation of larvæ leaves the plants, enters the ground, and constructs overwintering cocoons. If dependance is placed on the dust alone, it is imperative that the application be so timed as to be on the soil before the larvæ seek winter quarters. No hard and fast rule governing the date of this application can be recommended for all localities, since temperature naturally influences the final disappearance of the larvæ.

PRECAUTIONARY MEASURES.

The rose midge can be kept out of greenhouses if proper precautions are exercised. Under no condition should infested plants be taken into a house free from this pest. Plants should not be purchased knowingly from firms which carry infested stock, and should be bought with the understanding that they are free from the midge either in the buds or in the soil. Before new stock is placed in a house, all plants should be examined carefully, and suspicious ones destroyed or returned to the shipper.

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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 780

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER June 12, 1919

NOSEMA-DISEASE

By

G. F. WHITE, Specialist in Insect Diseases

CONTENTS

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CONTENTS.

INTRODUCTION.

Nosema-disease is an infectious disease of adult honeybees. It causes the death of many individual bees, tending thereby to weaken the colonies infected. Many colonies die of the disease, but the percentage of deaths is comparatively small and entire apiaries are rarely, if ever, destroyed by it. It is not to be considered, therefore, as a particularly serious disorder. This is shown by the results recorded throughout the present paper. It is to be thought of rather as a disease the losses from which are less to the infected apiary than the losses from either of the foulbroods, although greater than those from sacbrood. The disease is one, however, of considerable economic importance.

The fact that Nosema-disease is not a new disease deserves emphasis. The knowledge of the disease and its name only are of recent origin. Nosema-disease, like the brood diseases, has probably existed among bees longer than history records the keeping of bees by man. Since the disease is not a new one, fear regarding additional losses from it would not be justified. On the other hand, as we know of the disorder, we may entertain the hope that the losses due to it may now be lessened.

Until 1909 the existence of Nosema infection among bees was not generally known to beekeepers, although it had been studied somewhat by Dönhoff (1857) about a half century earlier. Zander began his studies a decade ago and since the appearance of his first paper (1909) a number of investigators have made studies on the disorder. In the papers which have been written concerning the infection, widely differing views regarding certain points have been expressed. To discuss these different views would be to go beyond the scope of the present bulletin.

The writer began the study of Nosema infection in 1910 following the demonstration by him that the disorder exists in the United States. In pursuing these investigations the object has been not to devise a treatment for the disease, but rather to ascertain such facts concerning the disorder that the beekeepers might be able to devise methods for its treatment with the assurance that they would be not only efficient but also economical. While there is yet much to be learned about the disease, this object has been fairly well attained. Relations which the results obtained bear to practical apiculture should be borne in mind, therefore, in reading the paper.

During the studies the effect of the disease on colonies and on apiaries, the transmission of the disease, the resistance of the infecting germ to heat, drying, sunlight, fermentation, putrefaction, and disinfectants, and the effect of drugs on the disease are among the problems which have been considered.

An earlier paper (White, 1914) refers briefly to the nature of the results obtained from these studies. The present bulletin gives all the results obtained from them which are believed to be of direct practical value to the beekeeper or otherwise of particular interest to him. The nature of the bulletin is similar, therefore, to the one on sacbrood (White, 1917) recently published.[1]

[1] As in the sacbrood paper, so in the present one, technical discussions have been purposely avoided. The semitechnical points which could not well be omitted are briefly explained in the sacbrood paper. Unless the reader is familiar with the nature of such investigations, the sacbrood bulletin will probably be found helpful in following the present one.

NAME OF DISEASE.

About 60 years ago Dönhoff (1857, March) discovered small oval bodies upon examining microscopically the stomachs from adult bees which he supposed had died of exposure. He sent some of the bees to Leuckart, who after an examination of them expressed the belief that the oval bodies were the spores of a fungus ("Pilz"). The disorder was referred to by Dönhoff (1857, August) by the term "Pilzsucht" (fungous disease).

These observations apparently had been practically forgotten at the time Zander (1909) reported his studies on a disease of adult bees in which he found small oval bodies in the walls of stomachs taken from affected bees. These were in fact the parasites that cause the disease. To the germ Zander (1909) gave the name *Nosema apis* and for the disease he (1911) used the name "Nosema-seuche."

The disorder studied by Dönhoff and the one studied by Zander are almost without question one and the same condition. It will be noted that each of these men in referring to the disorder used a term containing a reference to the parasite considered by each, respectively, as being its cause. The term "Nosema-disease,"[1] which the writer (1914) has suggested as the common name[2] for the disease, is not a new one, it will be observed, but simply an English translation of the term "Nosema-seuche" used by Zander.

In Switzerland "Nosemakrankheit" (Nosema-disease) (Nussbaumer, 1912; Angst, 1913) is the term commonly used in referring to the disease. In Denmark Bahr (1915) used the term "Nosema-sygdommen" (Nosema-disease).

The name "Nosema-disease" possesses certain features which commend it: (1) It is definite, as it can refer only to the disease caused by *Nosema apis*; (2) it suggests the nature of the disease by referring to its cause; (3) it is readily understood; and (4) it is not long.

Care should be observed that Nosema-disease is not confused with dysentery. Leuckart (1857, March) early raised the question regarding its relation to dysentery. The question was soon afterwards

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[1] It will be observed that there are two parts to the name and that the name of the disorder is not "Nosema," but "Nosema-disease." It is suggested, therefore, that the name be written, for the present at least, as a compound word. By so doing the difficulty which has been experienced by some will be avoided.

[2] While working on a disorder which had received the common name "Isle of Wight disease," Fantham and Porter (1911), in England, encountered a protozoan parasite belonging to the group Microsporidia which they identified as being *Nosema apis*. In selecting a technical name for the disorder caused by the parasite they chose the term "Microsporidiosis," derived, as will be observed, from the group name Microsporidia, under which the parasite is classified. The name is, therefore, an appropriate one. The term has received some criticism on account of its length and possibly on account of its not being readily understood.

As the parasite is now believed to belong to the genus "Nosema," the writer begs to suggest that as a technical name for the disorder the term "nosemosis" would have some arguments in its favor. This is not to be interpreted as proposing a substitute for the earlier term "Microsporidiosis." It is meant, rather, as an explanation of it.

taken up by Brotbeck (1857). Zander (1909) in his first paper referred to Nosema infection as a (malignant) dysentery. Other discussions have appeared from time to time in regard to such relationship (Maassen and Nithack, 1910; Beuhne, 1911; Maassen, 1911).

In fact the two disorders are very different and should be considered, for the present at least, as having no direct relation to each other. As both conditions are widely distributed and occur most frequently in the spring of the year, it is to be expected that not infrequently both of them may be encountered together in the same colony.

Efforts have been made to determine the name by which Nosema-disease has been known to beekeepers in the past. In these studies it was found (p. 16) that the highest percentage of Nosema-infected bees occurred in weak colonies. Consequently in asking beekeepers for samples bees from weak colonies were requested. In response to the request made approximately 150 samples were received. Fully half of these contained *Nosema apis.* Nine representative beekeepers located in different sections of the country that sent Nosema-infected bees were asked concerning the name by which the colonies showing the weakened condition were known. Three replied spring dwindling; two, not spring dwindling; two, weak colonies; one, bad queen; and one, "Don't know." None suggested paralysis and none dysentery.

In reply to requests for bees from colonies showing spring dwindling 38 samples were received from 14 beekeepers located in different sections of the country. Out of the 38 samples 15 upon examination revealed the presence of *Nosema apis.* From these 15 samples 314 bees were examined, of which 70 were found to be Nosema-infected.

Samples have been received from five beekeepers who diagnosed the condition in the colonies from which the bees were taken as paralysis. *Nosema apis* was not found in any of them.

The facts indicate, it would seem, that beekeepers had not learned to recognize the disease produced by *Nosema apis* by any one name.

DIGESTIVE TRACT OF ADULT BEES.

In Nosema infection the parasite *Nosema apis* enters, infects, and leaves the bee by way of the digestive tract. It is well, therefore, to know something of the location, arrangement, appearance, and structure of the organs of the alimentary canal of the healthy adult bee in order that the disease when encountered may be recognized and more fully understood.

The following description is an abbreviation of a general survey of the alimentary tract by Snodgrass (1910). The part of the alimentary canal (fig. 1) immediately following the mouth forms an enlargement called the pharynx (*Phy*). Succeeding this is the œsophagus (Œ), a slender tube traversing the entire thorax. In the anterior part of the abdomen the œsophagus expands into a large thin-walled sac which is known as the honey stomach (*HS*); next is the short neck-like portion, the proventriculus (*Pvent*); then comes the large U-shaped portion, the stomach or ventriculus (*Vent*), an organ with thick walls and many annular constrictions. Following the stomach is the short, narrow and coiled, small intestine (*SInt*) having a circle of about one hundred long, greatly coiled, blind, thread-like tubes opening into its anterior end. These tubes are the Malpighian tubules (*Mal*). Following the small intestine is the large intestine or rectum (*Rect*). When bees have been confined for some time this latter portion of the canal is found distended with material to be voided.

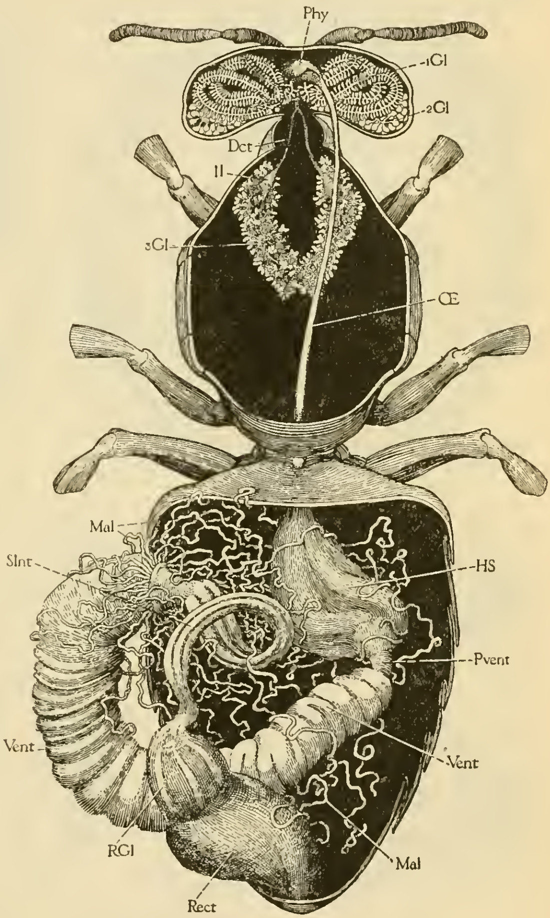


Fig. 1.—Alimentary canal of worker bee: Pharynx (*Phy*), œsophagus (*Œ*), honey stomach (*HS*), proventriculus (*Pvent*), stomach or ventriculus (*Vent*), small intestine (*SInt*), and large intestine or rectum (*Rect*), rectal glands (*RGl*), Malpighian tubules (*Mal*). Salivary glands of head (*2Gl*) and thorax (*3Gl*), and pharyngeal glands (*1Gl*) are also shown. (Snodgrass.)

Since the stomach is always invaded by the parasite in Nosema-disease, and the Malpighian tubules occasionally are, a further description of the structure of these organs seems warranted.

The stomach (fig. 1, *Vent*) is a relatively thick-walled organ lying U-shaped within the abdomen. When removed and straightened it is seen to be in general cylindrical but somewhat spindle-shaped in form. (Pl. I.) Circular constrictions present give to it a segmented appearance. The number and distinctness of these transverse markings vary somewhat. The size of the organ and its color vary also. The color varies within wide limits, being usually some shade of brown. It may be quite light, approaching a yellow, or it may be dark, approaching the red observed in the flesh of the ox. Stomachs of the lighter shades especially are translucent.

The rather thick walls of the stomach (fig. 2) consist of an inner epithelial and an outer muscular portion. Between these is the

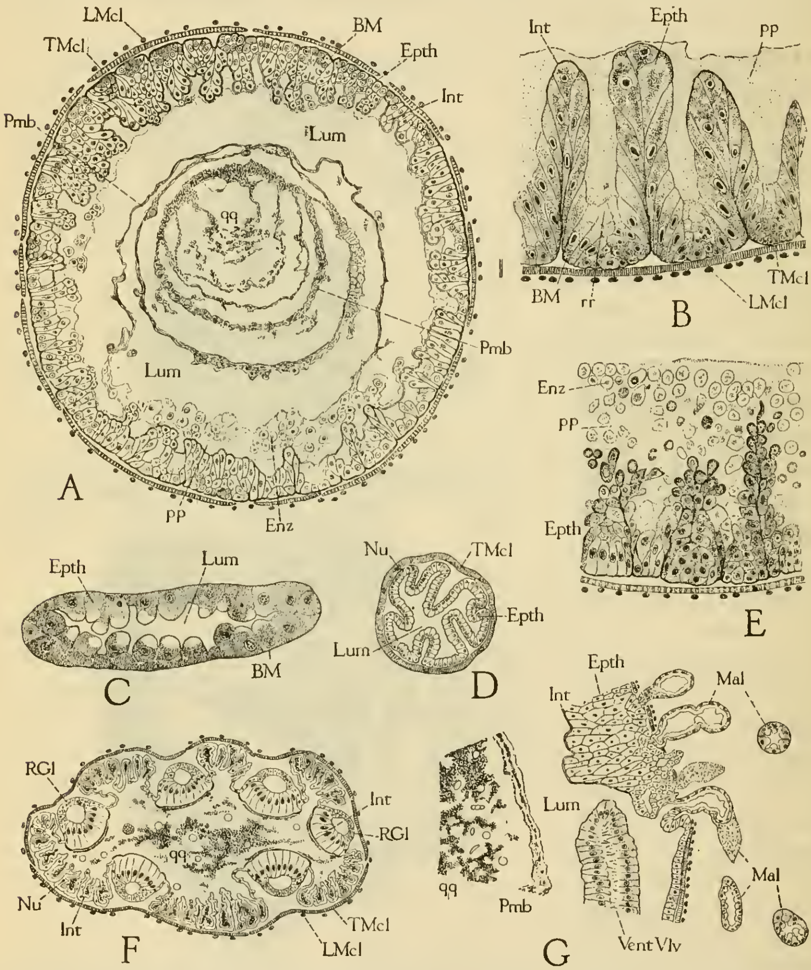


FIG. 2.—Microscopic anatomy of alimentary canal of worker bee: *A*, cross section of stomach showing peritrophic membranes (*Pmb*); *B*, wall of stomach, more highly magnified, showing epithelial layer (*Epth*), basement membrane (*BM*), and muscular portion; *C*, section of Malpighian tubule showing epithelium (*Epth*) and basement membrane (*BM*); *D*, cross section of small intestine. This portion of the canal, the rectum, and the œsophagus have a heavily chitinized intima. (Snodgrass.)

basement membrane. Both surfaces of the epithelial layer are irregular. This consists of epithelial cells (*Epth*) varying in size and outline. Closely associated with the outer surface of the epithelial layer is the basement membrane (*BM*). In connection with its inner surface is the more or less indefinite intima (*Int*) which possibly bears some relation to the peritrophic membranes (*Pmb*). Outside the basement membrane is the muscular portion of the stomach wall consisting of three (White, 1918) muscular layers (Pl. II, D; and Pl. III, L). The outer and inner ones are made up of longitudinal and the middle one of circular fibers (fig. 3). Each layer is made up of a single layer of branched fibers.

Digestion and absorption, comparable to some extent to those obtaining in the human stomach, are functions which have been attributed to the stomach of the bee.

The Malpighian tubules (fig. 2, G *Mal*) empty into the alimentary tract at or very near the juncture of the stomach and small intestine. Microscopically their structure is seen to consist of a single layer of

FIG. 3.—Longitudinal section of stomach of honeybee showing infection with *Nosema apis: ep*, Epithelial portion, containing the spores of the parasite stained black. (The younger parasites, not differentiated so easily by staining, are not shown; they are found toward the base of the cells reaching the basement membrane (*BM*), but do not extend beyond it. Younger spores sometimes show an unstained area at one end and occasionally at both ends.) *m*, muscular portion of stomach wall showing an outer and an inner longitudinal muscular layer and a middle circular one. (Author's illustration.)

epithelial cells (fig. 2, C, *Epth*) and a basement membrane (*BM*), but no pronounced intima. The function attributed to these tubules is one comparable in a measure to that of the kidneys of the vertebrates.

CAUSE OF NOSEMA-DISEASE.

THE EXCITING CAUSE.

On December 4, 1856, Dönhoff (1857, August) inoculated a colony of bees with the oval bodies he had found in the stomachs of adult bees. The inoculation was made by feeding the colony the crushed stomachs of the infected bees in a honey suspension diluted with water. Upon examining stomachs from adult bees taken from the inoculated colony in eight days following the inoculation no spores were observed. In 11 days, however, they were found to be teeming with the parasites. A second colony was then similarly fed on December 16. On the twenty-ninth of the same month all of the bees examined from the colony were found to be infected. The results of these experiments strongly indicated that the disorder in which the oval bodies were found was an infectious one and that the bodies were parasites which bore a causal relation to the disease. Other studies made by Dönhoff (1857, September) indicated that the parasite was quite prevalent in Germany but that there were colonies apparently free from infection.

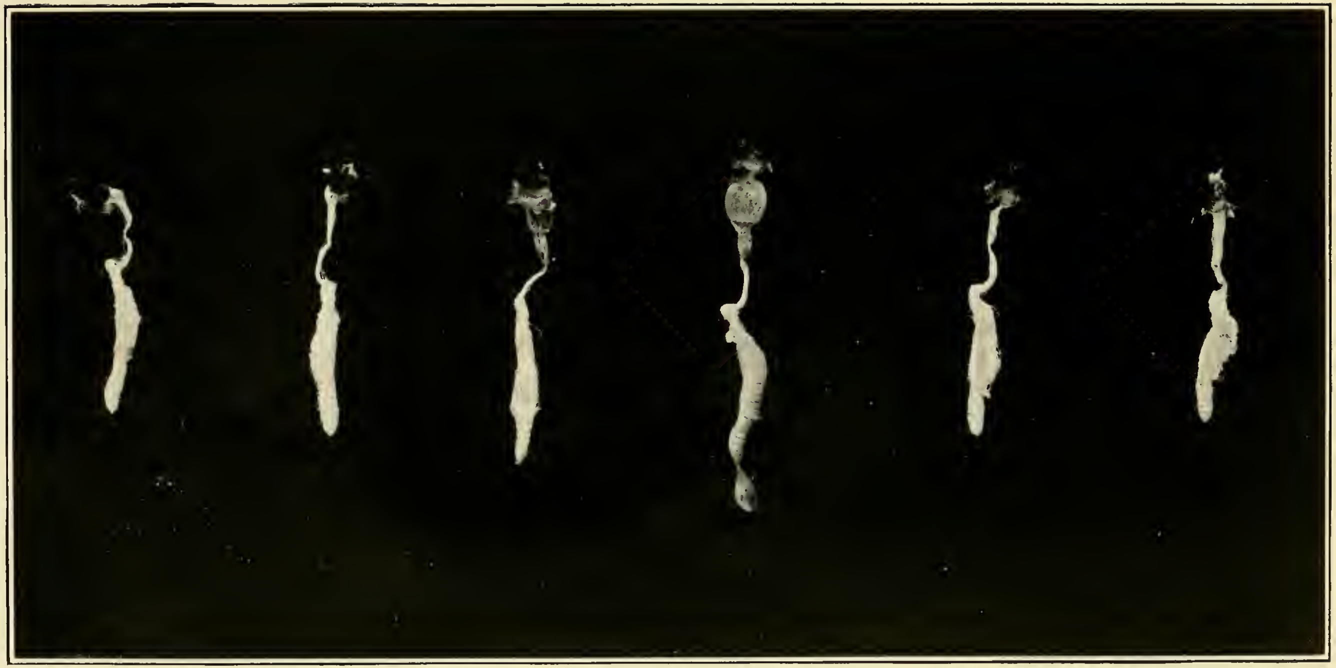
About 50 years later Zander (1909) inoculated colonies experimentally by feeding material containing the oval bodies he had encountered in his studies. In bees from the colonies inoculated he demonstrated that the oval bodies were in the walls of the stomach. This fact showed still more conclusively that there was an infectious disease of adult bees in which the oval bodies were parasites bearing a causal relationship to the disease.

The oval bodies studied by Zander and those studied by Dönhoff in all probability are the same. To Zander, however, is due the credit for having determined their true nature. Together with Döflein he (1909) classified the germ as a protozoan (a one-celled animal parasite) belonging to the group Microsporidia and to the genus Nosema. Zander gave the name *Nosema apis* to the species he found in the honeybee.

The parasite *Nosema apis* grows and multiplies for the most part in the epithelium of the stomach (fig. 3; Pls. II and III) of the adult bee. Occasionally, but rarely, it is found within the epithelial cells of the Malpighian tubules (Pls. II and III). When *Nosema apis* is encountered in making an examination for the parasite it is the spore form (fig. 4; Pl. III, G, H) that is most often encountered and most readily recognized. Viewed microscopically the spore in unstained preparations is seen to be a small, refractile, more or less oval body varying somewhat in size but measuring about 2/10,000 of an inch in length and about 1/10,000 of an inch in width. Its width seems, however, to be slightly greater than one-half its length.[1] The spore is surrounded by a somewhat resistant coat which tends to maintain for it a constant form. It is not, however, a rigid structure, since, when studied in fresh preparations, it will be seen to bend to and fro as it is carried along by a current under the cover glass.

The manner in which a bee becomes infected with *Nosema apis* is in general as follows: Spores which have left the body of an infected bee with the excrement are ingested by the healthy adult bee. The environment within the stomach of the bee is favorable for the

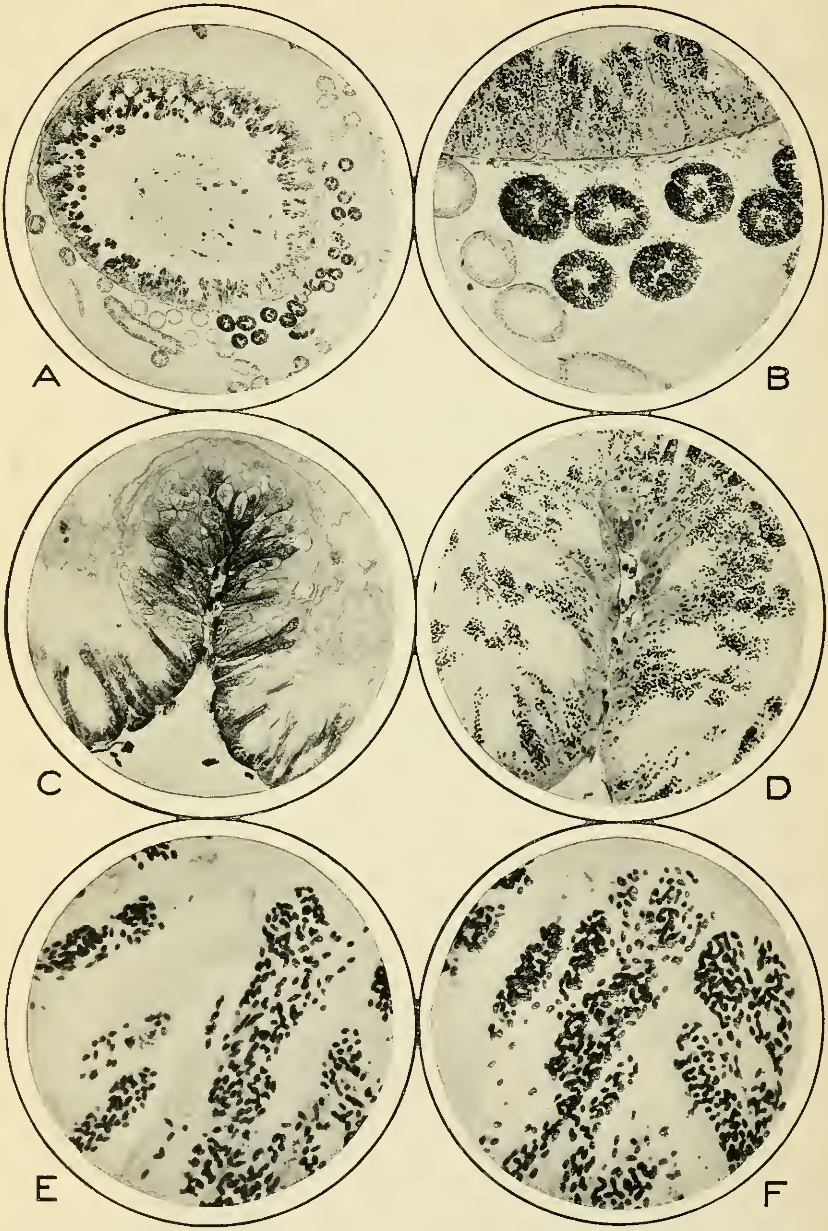
[1] Measurements were made of spores in smears stained with iron hematoxylin and of others in preparations made by an India-ink method. In making the latter preparations thin smears of the spore containing material were made and allowed to dry, and over these smears a thin film of undiluted India ink was spread. The average length of the spores measured in the stained preparations was 4.15 μ and the average breadth 2.06 μ; the average length in the India ink preparations was 4.46 μ and the average breadth 2.44 μ.



1 2 3 4 5 6

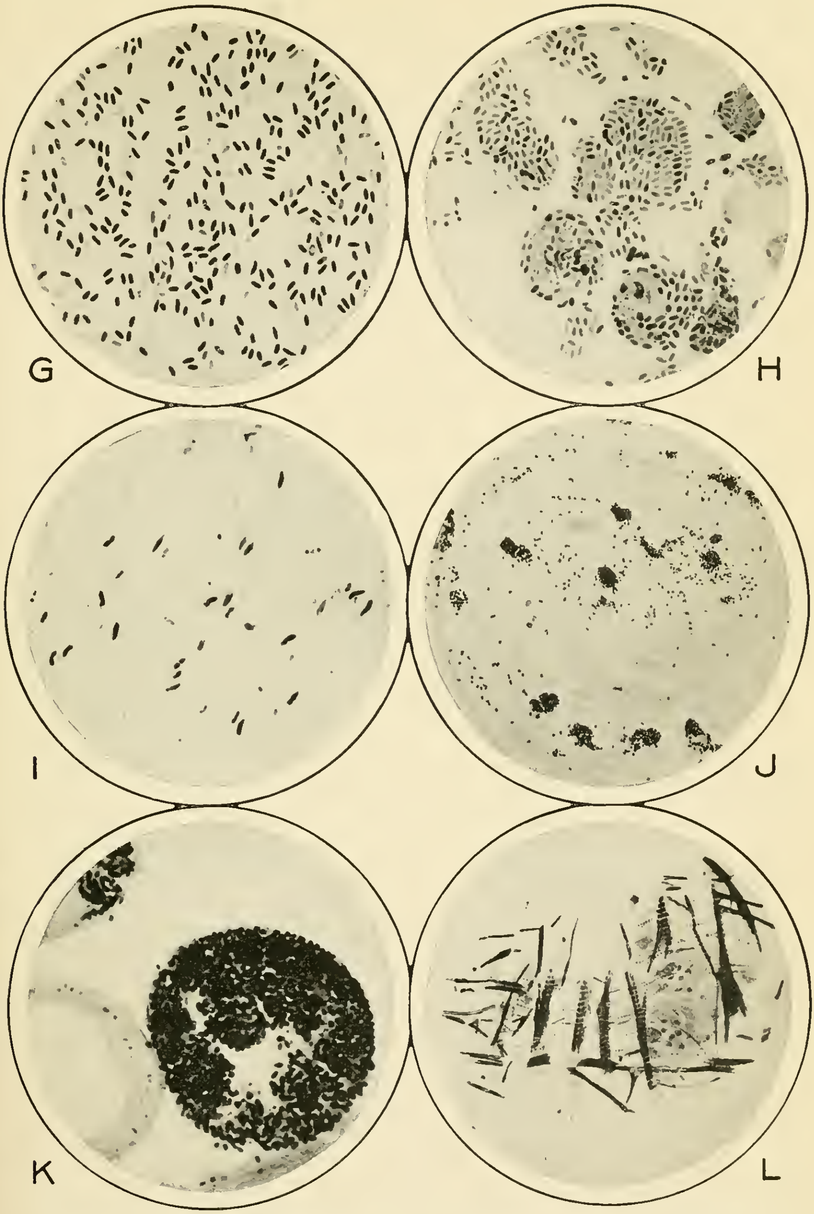
STOMACHS OF WORKER BEES REMOVED FOR EXAMINATION.

The tip of the abdomen, the large intestine, the small intestine, and, in one instance, the honey stomach also are shown. From left to right (1) a healthy stomach, (2) one recently Nosema-infected, (3) one infected for a longer period, and (4), (5), and (6) each respectively infected for a period longer than the one preceding it. (Original.)



PHOTOGRAPHS OF SECTIONS OF THE STOMACH OF THE HONEYBEE AS SEEN THROUGH THE MISCROSCOPE.

A, entire cross section of stomach (queen) and Malpighian tubules, showing infection of these organs with *Nosema apis*; *B*, a portion of *A* more highly magnified; *C*, a small portion of a longitudinal section of a stomach from a healthy bee; *D*, similar to *C*, but from a Nosema-infected bee; *E*, infected epithelium highly magnified, the disease as seen in America; *F*, similar to *E*, but from a preparation made by Zander in Germany. (Original.)



FURTHER STUDIES ON NOSEMA APIS AS REVEALED BY THE MICROSCOPE.

G, *Nosema apis* as seen in a stained smear preparation; *H*, a stained smear preparation showing within the groups how closely the cells are packed with parasites (note the nucleus of an epithelial cell below and to the right of the center); *I*, smear showing young forms (note the paired appearance); *J*, portions of epithelial cells are shed into the lumen of the stomach, carrying with them the contained parasites, accounting for the groups in this photograph; *K*, cross sections of Malpighian tubules highly magnified (the epithelial cells of the one to the left are not infected, some of those of the one above contain parasites, while all of those of the one to the right are heavily infected); *L*, tangential section of stomach wall showing the three muscular layers, the fiber of all of them being branched and striated. The inner and outer layers are made up of longitudinal fibers while the middle one consists of circular ones. (Original.)

growth and multiplication of the parasite. The digestive fluids are believed to assist in removing the spore coat. The liberated young parasite finds its way to the walls of the stomach and invades the epithelial cells. Within this epithelial tissue it grows and multiplies with great rapidity, giving rise finally to numerous spores. The cells of the epithelium at times seem to become virtually filled with the parasites (fig. 3; Pls. II and III). That portion of an epithelial cell that is normally shed into the lumen of the stomach in case of infection bears with it many spores. These are liberated gradually from the fragments, become mixed with the partially digested food of the stomach, and are carried onward first into the small and then into the large intestine and finally pass out of the alimentary tract with the excrement. Other bees ingesting these spores become infected. This in brief is the life cycle [1] through which the parasite passes.

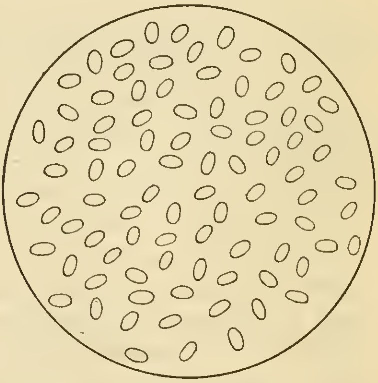


FIG. 4.—Spores of *Nosema apis* as seen in a fresh preparation, indicating their general oval form. (Original.)

Nosema apis reaches the tissues of the bee by way of the alimentary tract. In infecting the stomach the parasite reaches the basement membrane but does not penetrate it (Pls. II and III). The muscular part of the organ is therefore uninvolved (fig. 3). Likewise when the infection is found in the Malpighian tubules the germ does not proceed beyond the basement membrane (Pls. II and III). Furthermore the germ does not infect (fig. 1) the pharynx (*Phy*), the œsophagus (*Œ*), the honey sac (*HS*), the proventriculus (*Pvent*), the small intestine, or the large intestine (*Rect*)—organs which possess a pronounced chitinized intima. Infection with the parasite seems, therefore, to be confined to the epithelium of the stomach and of the Malpighian tubules. So far the writer has not encountered the germ in the blood, musculature, or any of the other tissues of the body.

Nosema apis has not been cultivated in pure cultures by artificial methods. The nature of the organism makes the accomplishment of such a task at the present time especially difficult. Direct proof obtained by the inoculation of bees with cultures of the parasite has not, therefore, been obtained. Fortunately such direct proof is not

[1] Fantham and Porter (1911 and 1912) encountered a parasite in bees taken from colonies affected with Isle of Wight disease which they have identified as *Nosema apis*. Their studies on the morphology of the parasite are interesting.

The morphology of *Nosema apis* and of *Nosema bombycis* are apparently quite similar and studies made by Stempell (1909) on the latter parasite may be referred to with profit in studying *Nosema apis*.

always necessary to establish the causal relationship between the germ and the disease.

Because of the absence of any of the higher animal parasites and of fungi in bees suffering from Nosema-disease these groups of parasites naturally can be eliminated as possible causal factors. Malden (1912, 1913) studied the bacteriology of Nosema-infected bees. He found that the number of bacteria in the diseased bees was much greater than in normal ones, the proportion being as 12 to 1. He found, however, no evidence of a direct etiological relation existing between these bacteria and the disease. Whether they play a secondary rôle is a question which admits of much discussion but one which is somewhat foreign to the present paper.

Some preliminary experiments were made by the writer in regard to the possibility of the presence of a filtrable virus in Nosema-disease. The results obtained indicate that no such virus is present.

By thus eliminating, at least tentatively, the higher animal parasites, the fungi, the bacteria, and the filtrable viruses—groups of parasites which cause diseases in animals—there remains another group, the protozoa. Of this group there is only one species, *Nosema apis*, that is constantly present in Nosema-disease. Other protozoa are occasionally encountered in adult bees, but when found are present usually in small numbers only. The conclusion is naturally reached, therefore, that *Nosema apis* is the cause of Nosema-disease. Such a conclusion is in harmony with views generally accepted at the present time in regard to proof necessary to establish the causal relation of such a germ to the disease.

PREDISPOSING CAUSES.

AGE.

Experimental inoculations have shown that in general adult bees of all ages are susceptible to Nosema infection. In nature it is found that the youngest bees are always free from infection and that the old shiny bees usually are. The absence of *Nosema apis* in the younger ones may be attributed simply to the fact that they have not yet been infected through the taking of food containing the germ. In the case of the shiny bees it seems probable that they have escaped infection, although it is possible that some of them might have been infected at one time and later recovered.

The brood does not seem to be at all susceptible to infection with *Nosema apis*. In heavily infected colonies the larvæ and pupæ apparently remain healthy. In these studies larvæ were inoculated more or less directly by means of a pipette and examinations [1] were made daily following the inoculation. The spores were found mixed with

[1] The examinations were made through fixing and sectioning inoculated larvæ.

the food within the stomach for from 1 to 3 days after the inoculation, but there was no evidence that the parasite had increased in numbers or that it had invaded the tissues.

SEX.

Nosema infection is encountered most frequently in workers, although drones and queens are susceptible. In nature it is not unusual to find from 10 to 20 per cent of the workers of diseased colonies infected. Frequently a much higher percentage is encountered. In no instance has the writer found Nosema infection in drones taken from colonies in which the disease occurred in nature. In a few instances only were the queens that were examined from such colonies found to be infected.

As a result of artificial inoculation practically 100 per cent of the workers of the experimental colony become infected. If drones are present a very large percentage of them also become infected.

Queens in experimental colonies may or may not be found infected. To obtain data relative to queens a number of inoculations were made. Table I summarizes the experiments together with the results obtained.

TABLE I.—*Nosema infection in queens in experimental colonies.*

Date of inoculation.	Period before examination.	Workers infected.	Results of inoculation.
	Days.	*Per cent.*	
Mar. 11, 1913	8	100	Queen not infected.
July 12, 1913	13	100	Do.
Do	16	100	Do.
Mar. 3, 1914	19	100	Do.
Oct. 5, 1914	22	40	Do.
Oct. 19, 1914	23	50	Do.
Oct. 29, 1914	48	100	Do.
Do	53	100	Do.
Feb. 4, 1915	23	....	Queen Nosema infected.
Sept. 16, 1914	42	100	Do.
Nov. 20, 1912	48	100	Do.
Oct. 29, 1912	53	100	Do.
Aug. 6, 1914	162	100	Do.

It will be seen from the foregoing table that out of the 13 experimental colonies 9 of the queens upon examination were found to be free from infection while the other 5 were infected. Infection in the queen occurs less frequently, apparently, when the inoculations are made in the spring and summer than when made in the autumn or winter. Queens in colonies inoculated and kept at room temperature were found infected in some instances and not in others although practically 100 per cent of the workers in all of them became infected.

RACE.

In experiments recorded in the present paper the bees used have been largely hybrids, being for the most part grade Italians. Two each of tested Carniolans and Caucasians and a few common blacks have been among the colonies used. The bees were found to be susceptible to Nosema infection in all instances. It is not unlikely that future studies will show a difference among the races as to their relative immunity to the disease, but sufficient data are yet wanting to justify a definite statement in regard to the point.

CLIMATE.

Nosema infection has been reported from Australia (Price and Beuhne, 1910), Brazil (Zander, 1911), Canada (White, 1914), England (Fantham and Porter, 1911), Germany (Zander, 1909), and Switzerland (Nussbaumer, 1912). Studies have not yet been made in Denmark on the disease (Bahr, 1916). The writer (1914) has found it in samples of bees received from 27 different States of the United States. Out of 120 samples examined 40 contained the parasite. Samples showing infection were received from the coast plains and mountains of the East, from the plains of the Mississippi Valley, from the plateaus and plains of the West, and from the South and the North.

The infection was found in bees received from Florida and southern California, but in 15 samples received from Texas it was not found. The data thus far obtained indicate that less infection occurs in the southern portion of the United States than farther north. Whether it is found in the Tropics or in the coldest climate in which bees are kept is not yet known.

Laidlow (1911) reports that heavier infection was encountered in some parts of Australia than in others. Nussbaumer (1912) reported the infection from 14 of the cantons of Switzerland.

The practical import of these observations in connection with the climate, to the beekeepers of the United States at least, is that the presence of the disease in a region can not be attributed entirely to the climatic conditions present. It is possible, however, that the climate of a particular region may affect somewhat the occurrence and the course of the disease in that locality.

SEASON.

Infection in apiaries has been found to occur at all seasons of the year, but is greatest during the spring. In the studies reported in the present paper (p. 20) infection was greatest in April and May, being greater in these months than in March. Very little of a definite character is known of the infection as it occurs in nature during the winter. Experimentally it has been found that bees are susceptible to infection with *Nosema apis* at all seasons of the year.

FOOD.

As is pointed out under the heading "Climate," Nosema-disease occurs in a wide range of localities. The food and water obtained in these localities naturally differ as to quality and quantity. Infection is found in colonies having an abundance of stores and in others having a scarcity. The disease is produced readily by experimental inoculations in colonies with much and in colonies with little stores. From these observations the conclusion seems to be justified that the rôle played by food in the causation of Nosema-disease is slight, if indeed it contributes at all appreciably to it.

A THREE-YEAR STUDY OF NOSEMA INFECTION IN AN APIARY.

The presence of Nosema infection among bees in the apiary of the Bureau of Entomology was discovered in May, 1910 (White, 1914) In April, 1912, a more or less systematic study was begun on the prevalence and persistence of the infection in the apiary and was continued until June, 1915, As the apiary was being used for other purposes than these studies, it was not possible to follow all of the colonies throughout this entire period. In Table II are summarized observations made during the first year of the study.

TABLE II.—*Results obtained from April, 1912, to March, 1913, inclusive, in a study of Nosema infection in an apiary.*

Colony No.	1912																												1913		
	April.		May.				June.		July.			August.		September.			Per cent.	Experiment No. 1.	October.								December.		March.		
	12	20	2	10	23	28	2	28	2	24	30	2	14	9	13	18			5	8	11	16	18	21	28	30	17	17	12	25	
1	0e		2e	2p		2e		1p		3p				0p			14					0p			0e					0e	
2																1p				0p					2e	0e				0e	
4																0p									0e						
5	3e		1e	3p				2p		2p							22		0p			0p			0e					0e	
6	9e		D														90														
6a															1p			1	6p		5p		S		8e		3f	M	D		
7	3e		3e		3p			1p		3p							26		0p					1p	3e					0e	
8																				0p		6p			0e					0e	
10																						0p			0e						
11	0e		1e		4p			1p		R																					
12	0e		0e		2p			0p		2p				1e			8	2	7p		4p		S		9e		7f	M	4f	8f	D
14	10e		10e		D												100														
18																								7p		0e					
19																			0p						1e					0e	
21	0e		2e		1e			1p									10														
23	1e		0e		5p			4p						1p			22					3p		0e					0e		
25															2p			3		10p	5p	10p	W		10e		10f	W	D		
26																						9p		1e						0e	
28	8e		D														80														
29																						7p		0e							
30																								7p		0e					
31																					4p					0e	0f				
35														0p	1p			4	9p		4p	10p	S		9e	1e	10f		6e		
36		1e	1e		3e			6p			2p						26					7p				1e				1e	
38		3e			1p				0p		1e						12				8p				2e						
40																								7p		1e					
41														1p				5		6p	6p		W		10e	10e	5f	W	D		
42		0e	1e		5p				1p		1p						16														
44		3e	2e		3p												27						8p								
49																							6p			0e				1e	
50		0e	0e		1p				2p								7						8p			2e				0e	
51		10e	10p		1f	D																									
52																							9p			0e					
53												1p	3p												6p	1e					
54																									1e	2p					
55														0p	2p			6			5p		M		3e		3f	W	0e		
56																									5e	6p					

57		5e	D														50														
59		1e	1e			2p	0p										10														
60																								9p	1e	1e					
63		2e				3e			0e				1p				15					1p									
65		0e	0e			1p	1e						1e		0p		5	7			10p		M	8p			4f	M	2e		
66														1p				8	7p		7p	8p	W		8e		5f	D			
67														1p				9				8p	M		9e		0f	W	0e		
68		3e	3e			2p	1e										25								5p	3e			0e		
69													3p												2e	6p			0e		
70														0p	2p			10	5p				S		4e		2f	M	0e	2e	
72																									5p	1e				0e	
73		6e	0e	5h	5p				0e		4p						33								5p	1e				0e	
75																									0e	5p				0e	
77		2e	2e			0p	1e						5p				20														
79		2e	3e			0e	0e										12								1e					1e	

Explanation for Table II.—The number of Nosema-infected bees found in each sample of 10 bees examined is recorded. The colony from which the sample was taken is shown by its number in the first column. The results are given in columns headed by the approximate date on which the examinations were made. Approximate dates are used to abbreviate the table. As a rule they are within two days of the exact dates. The letter accompanying a number indicates the source from which a sample was taken; the letter "e" showing that the sample was taken from among the bees about the entrance of the hive; "p," that the bees examined were carrying pollen primarily when taken; "h," that they were carrying honey or water; and "f," that they were taken from the brood frames. The letter "D" shows that the colony was dead; "R," that it was removed. "S" indicates that the colony was relatively strong; "M," that it was medium in strength; and "W," that it was relatively weak.

From Table II it will be noted that in April there were 24 colonies in the apiary. Out of 240 bees examined from them during the month, 72 (30 per cent) were Nosema infected. The number of bees out of each sample of 10 was found to vary from 0 to 10.

During May, out of 410 bees examined 96 (23 per cent) were found to be Nosema infected.[1]

During June, out of 130 bees taken from 13 colonies 19 (15 per cent) were found to be Nosema infected.

During July, out of 130 bees examined 21 (16 per cent) were found infected.

During September, out of 170 bees examined 14 (8 per cent) proved to be Nosema infected.

Out of a total of 1,140 bees examined in 1912, from April to September, inclusive, 236 (20 per cent) Nosema infected bees were found. The number of infected bees found in the different colonies varied from 5 to 100 per cent.[2]

Five of the 24 colonies died. These were dead by the end of May. It was found that the number of infected bees present in them varied from 50 to 100 per cent. The number of infected bees in the colonies that lived varied from 5 to 33 per cent.

All of the colonies that died were weak when first examined in the spring and dwindled until they disappeared. The colonies that lived gained in strength and behaved as healthy ones.

The colonies that died had sufficient stores. The queen in each of them was apparently in good condition and brood was being reared. At times, indeed, the brood was in excess of the amount that could properly be cared for by the diminishing number of bees present. These and other facts which have been observed justify the belief that the immediate cause of death in each of the five colonies that died was the Nosema infection that was present. These colonies, therefore, may be said to have died of Nosema-disease.

The number of colonies in the spring was increased during the bee season through swarming and by division.

In September an experiment was begun in the apiary in which 10 colonies were inoculated with *Nosema apis*. The results of these inoculations will be referred to later under experiment No. 1 (p. 23).

Examinations were made in 1913 for the prevalence and persistence of Nosema infection in the apiary studied in 1912. Naturally the colonies present were not altogether the same as those of the previous year. Some of them had been lost and some represented the increase. The results obtained are summarized in Table III.

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[1] Fractions are omitted in this paper, as a rule.

[2] As the younger bees and the older ones were avoided in selecting samples for examination, the results recorded in this paper show a higher percentage of Nosema-infected bees in the colonies than actually existed.

Table III.—*Results obtained in 1913 from a study of Nosema infection in an apiary.*[1]

Colony No.	Experiment No. 1.	March. 12.	March. 25.	May. 29.	June. 3.	June. 18.	July. 14.	July. 16.	July. 19.	July. 22.	Experiment No. 2.	August. 9.	August. 25.	September. 23.	October. 13.	October. 18.	October. 28.	Per cent.
1			0^e															
2			0^e			1^e		0^p				0^e						2
5			0^e			1^p			0^p					1^p				5
7			0^e			1^p								2^p				10
8			0^e			0^e			1^e									3
12	2	4^f	8^f	D														60
26			0^e			0^e						0^e	2^e					5
30			1^e	R														
31			1^e	R														
35	4	6^e		0^p	3^h		1^e			1^e		0^e	0^e					16
36			1^e			0^p	3^e				A			6^p			0^e	20
48			1^e			0^p		0^e				1^e		1^p				6
49			1^e			0^e			0^e			1^e		2^p				8
50			0^e			0^e		1^e			B	0^e		2^p		1^e		7
55	6	0^e		3^f														
61											C	0^e		9^p			0^e	30
65	7	2^e		0^e	0^p	0^p	1^e					1^e	0^e					6
66						1^p		1^e			D	2^e		2^p			0^e	12
67	8	0^e		0^e	0^e		0^e			2^h		1^e	0^e					4
68			0^e			0^p	3^e				E	0^e		3^p	0^e			10
69			0^e				0^p	1^e						1^p				5
70	10	0^e	2^e	4^e		0^p	0^e			1^e		1^e						11
72			0^e			1^e	0^e			5^h		0^e	0^e					10
73			0^e			0^e	0^e							0^p				0
75			0^e			0^e	0^e											0
79			1^e			0^e		1^e				1^e		0^e				6
81			0^e															
82											F	0^e		1^p			0^e	3
a						0^p		0^e				1^e	0^e	2^p				6
b						0^p			0^e					3^p				10
c													0^e					
d													0^e	4^e				20
e							1^e							4^p				25

[1] Where the number of bees examined is small, the rate indicating the percentage frequently is not given.

Explanation for Table III.—The method of recording results is the same as in Table II. Colonies examined in 1913 that were examined in 1912 bear the same numbers in Table III as in Table II. Colonies representing the increase in the spring are designated by the letters "a" to "e," inclusive. Colonies in experiment No. 1 are indicated by numbers; colonies in experiment No. 2, by capital letters.

From Table III it will be observed that in March, 1913, out of 270 bees examined from the 25 colonies then in the apiary 28 (10 per cent) were found to be Nosema infected.

During June bees were examined from 21 colonies, and out of 220 bees 8 (4 per cent) were found to be infected.

During July 21 colonies were examined and out of 260 bees 23 (9 per cent) were found to be infected.

During August bees from 18 colonies were examined and out of 240 bees 11 (5 per cent) were found to be infected.

During September, out of 170 bees from 17 colonies 43 (25 per cent) were found to be infected.

During October bees were examined from 6 colonies only, and out of 60 bees 1 (2 per cent) was found to be infected.

Out of a total of 1,270 bees examined during the year 1913, 121 (10 per cent) were infected, being less than the percentage found in 1912, which was 20 per cent. The spring infection was very much less in 1913 than in 1912.

The percentage of infected bees found during the spring and summer remained quite constant, increasing unexpectedly in September. The reason for the increase can not be assigned at present.

Out of the 25 colonies in the apiary in March, 1913, 1 (No. 12) died. As this colony contained a high percentage of Nosema-infected bees, and as it dwindled until it disappeared, it may be assumed that Nosema-disease was the immediate cause of its death. As in the preceding year all of the colonies that lived behaved much as do uninfected ones.

In this year another experiment was begun in the apiary. This one is described as experiment No. 2 (p. 25).

Studies similar to these made in 1912 and 1913 were continued throughout 1914 and until June, 1915. While in the main the colonies of the apiary were those of the previous years, naturally there had been some changes. The results obtained are summarized in Table IV.

TABLE IV.—*Results obtained from May, 1914, to June, 1915, from a study of Nosema infection in an apiary.*

Colony No.	1914													1915				
	May.					June.			July.	September.		November.		March.	April.		May.	
	2	8	12	15	27	5	8	18	15	10	23	5		2	8	25	7	26
1	0^{e}	1^{p}	....	0^{p}	1^{p}	0^{p}	5^{p}	0^{p}	0^{p}	0^{p}	0^{p}	0^{e}	....	0^{e}	0^{e}	0^{p}	0^{p}	0^{h}
2	2^{e}	2^{p}	....	1^{p}	1^{h}	0^{p}	....	0^{p}	0^{p}	0^{p}	0^{e}	0^{e}	....	....	....	....	....	....
3	1^{e}	1^{e}	....	3^{p}	2^{h}	1^{p}	....	1^{p}	0^{p}	0^{p}	0^{e}	....	....	....	....	....	....	....
4	1^{e}	1^{p}	....	1^{p}	2^{h}	0^{p}	....	0^{p}	....	0^{p}	0^{e}	0^{e}	....	....	....	....	....	....
5	0^{e}	1^{p}	....	1^{p}	2^{h}	0^{h}	....	1^{p}	0^{p}	0^{p}	0^{e}	0^{e}	....	0^{e}	0^{e}	0^{p}	1^{p}	0^{h}
6	0^{e}	0^{p}	....	1^{p}	2^{h}	0^{p}	....	0^{p}	0^{p}	0^{p}	....	....	....	....	....	....	....	....
7	1^{e}	2^{p}	....	0^{p}	2^{h}	1^{h}	....	1^{p}	0^{p}	0^{p}	0^{e}	0^{e}	....	....	....	....	....	....
8	0^{e}	0^{p}	2^{p}	....	1^{h}	0^{e}	....	0^{p}	0^{p}	0^{p}	0^{e}	0^{e}	....	5^{e}	0^{e}	D	....	....
9	1	0^{p}	....	0^{p}	4^{h}	0^{h}	1^{p}	1^{p}	0^{p}	0^{p}	....	....	....	....	....	....	....	....
10	0^{p}	2^{e}	....	2^{e}	1^{h}	0^{p}	2^{p}	0^{p}	0^{p}	0^{p}	....	....	....	....	....	....	....	....
11	1^{e}	1^{p}	....	0^{p}	1^{h}	0^{h}	....	0^{p}	0^{p}	0^{p}	....	....	....	....	....	....	....	....
14	2^{e}	2^{e}	....	2^{e}	0^{e}	1^{e}	....	0^{p}	0^{p}	0^{p}	....	....	....	....	....	....	....	....
15	1^{e}	1^{p}	....	2^{p}	2^{h}	2^{h}	....	0^{p}	0^{p}	....	....	....	....	....	....	....	....	....
16	2^{e}	2^{p}	....	2^{p}	1^{h}	0^{h}	1^{p}	0^{p}	1^{p}	....	....	....	....	....	0^{e}	....	....	....
17	2^{e}	4^{p}	....	1^{p}	4^{h}	0^{h}	1^{p}	0^{p}	1^{p}	0^{p}	....	....	....	1^{e}	0^{e}	....	1^{p}	0^{h}
18	0^{e}	1^{p}	....	1^{p}	3^{h}	1^{h}	3^{p}	1^{p}	0^{p}	....	....	....	....	0^{e}	5^{e}	D	....	....
19	0^{e}	0^{p}	....	1^{p}	2^{h}	2^{h}	2^{p}	0^{p}	0^{p}	....	....	....	....	....	0^{e}	0^{p}	0^{h}	0^{h}
20	1^{e}	1^{p}	....	2^{p}	1^{h}	1^{h}	3^{p}	0^{p}	0^{p}	....	....	....	....	....	0^{e}	0^{p}	0^{p}	0^{h}
21	1^{e}	3^{p}	....	0^{p}	2^{h}	1^{h}	1^{h}	0^{p}	....	....	....	....	....	....	0^{e}	1^{p}	0^{p}	0^{h}
22	0^{e}	2^{p}	....	2^{p}	3^{h}	2^{h}	2^{p}	1^{p}	....	....	....	....	....	....	....	....	....	....
"7"	0^{e}	2^{p}	....	2^{p}	1^{h}	0^{p}	1^{p}	1^{p}	0^{p}	....	0^{e}	....	s	....	0^{e}	0^{e}	....	....
"36"	3^{e}	....	....	2^{p}	3^{h}	0^{h}	3^{p}	1^{p}	0^{p}	....	....	....	t	....	0^{e}	0^{p}	....	....
"50"	4^{e}	4^{p}	....	3^{p}	2^{h}	1^{p}	3^{p}	0^{p}	0^{p}	0^{p}	....	....	u	....	6^{e}	2^{e}	1^{p}	0^{e}
"66"	2^{e}	2^{p}	....	0^{p}	....	....	2^{h}	1^{p}	....	....	....	....	v	....	0^{e}	0^{e}	0^{e}	0^{e}
"68"	0^{e}	2^{p}	....	0^{p}	3^{h}	0^{p}	0^{p}	0^{p}	0^{p}	....	....	....	w	....	0^{e}	....	....	....
"73"	7^{e}	5^{e}	....	4^{p}	6^{h}	1^{p}	1^{p}	3^{p}	0^{p}	....	....	....	x	....	0^{e}	....	....	....
"82"	1^{e}	3^{p}	....	1^{p}	....	0^{h}	2^{p}	1^{p}	0^{p}	....	....	....	y	....	0^{e}	9^{e}	9^{p}	1^{e}
													z	....	0^{e}	1^{e}	3^{p}	0^{e}

Explanation of Table IV.—The colonies reported in Table IV for 1914 do not bear the same numbers that were assigned to them for 1913 in Table III except those designated by numbers in quotation marks. The first 9 colonies reported in the table for 1915 bear the same numbers they did in 1914. The identity of colonies numbered by letters "s" to "z," inclusive, had been lost through changes made in the apiary.

Table IV shows that out of 1,050 bees examined during May, 1914, 166 (16 per cent) were Nosema infected.

In June, out of 700 bees examined 60 (9 per cent) were found infected.

In July, out of 240 bees examined 2 (1 per cent) were infected.

In September, 220 bees were examined and no Nosema-infected one was found.

In November, 60 bees were examined and none was found infected.

Out of 2,270 bees examined during the summer of 1914, 218 (10 per cent) were found infected.

It will be noted that during the early months of the active bee season of 1914 there was a higher percentage of Nosema-infected bees in the apiary than during a similar period of 1913.

Two colonies were so weak in May that they were disposed of. In one of these at least (No. 13) the weakness was most probably due to Nosema infection.

During the first week in July the apiary was moved to a new location. It is interesting to note that the amount of Nosema infection after removal was reduced to practically nothing. This is not definitely accounted for by the results obtained by these investigations.[1]

Examinations were made of a portion of the apiary in 1915. In March, out of 50 bees taken from 5 colonies, 6 (12 per cent) were found to be Nosema infected.

In April, out of 280 bees taken from 17 colonies 24 (9 per cent) were found infected.

In May, out of 200 bees taken from 10 colonies 16 (8 per cent) were infected.

Out of 530 bees examined from the apiary during the spring of 1915, 46 (9 per cent) infected ones were found.

Among the colonies that were examined during the spring of 1915 two (Nos. 8 and 18) died by the end of April. Both of these contained a rather high percentage of Nosema-infected bees. Two others containing an equal or greater number of infected bees lived throughout May and had recovered apparently by June. In case of these 4 colonies it can properly be said that the two colonies that died died of Nosema disease, whereas the two that lived recovered from it.

In Table V is given a summary of the results obtained in the study of the apiary from April, 1912, to June, 1915.

[1] That the immediate environment of the apiary determines, to some extent, the presence or absence of Nosema-disease and its transmission seems quite likely. In searching for the cause for such a difference the water supply of the bees, if near by, must not be overlooked (p. 46). In this connection, it may be pointed out that in the experimental apiary (Pl. IV) Nosema infection at no time exceeded 1 per cent, excepting naturally in inoculated colonies, although the source from which these colonies were obtained had been largely the apiary which, it will be seen from Tables II and III, showed Nosema infection in from 10 to 20 per cent of the bees. Here there was no slowly moving body of water used by the bees as the source of their water supply.

TABLE V.—*Summary of results from a study of Nosema infection in an apiary.*

Year.	March.			April.			May.			June.			July.		
	Bees examined.	Nosema infected.	Per cent.	Bees examined.	Nosema infected.	Per cent.	Bees examined.	Nosema infected.	Per cent.	Bees examined.	Nosema infected.	Per cent.	Bees examined.	Nosema infected.	Per cent.
1912	.....	....	....	240	72	30	410	96	23	130	19	15	130	21	16
1913	270	28	10	.....	....	....	50	7	....	220	8	4	260	23	9
1914	.....	....	....	.....	....	....	1,050	166	16	700	60	9	240	2	1
1915	50	6	12	280	24	9	200	16	8	......	....	....	.....	....	....
Total	320	34	11	520	96	18	1,910	285	17	1,050	87	8	630	46	7

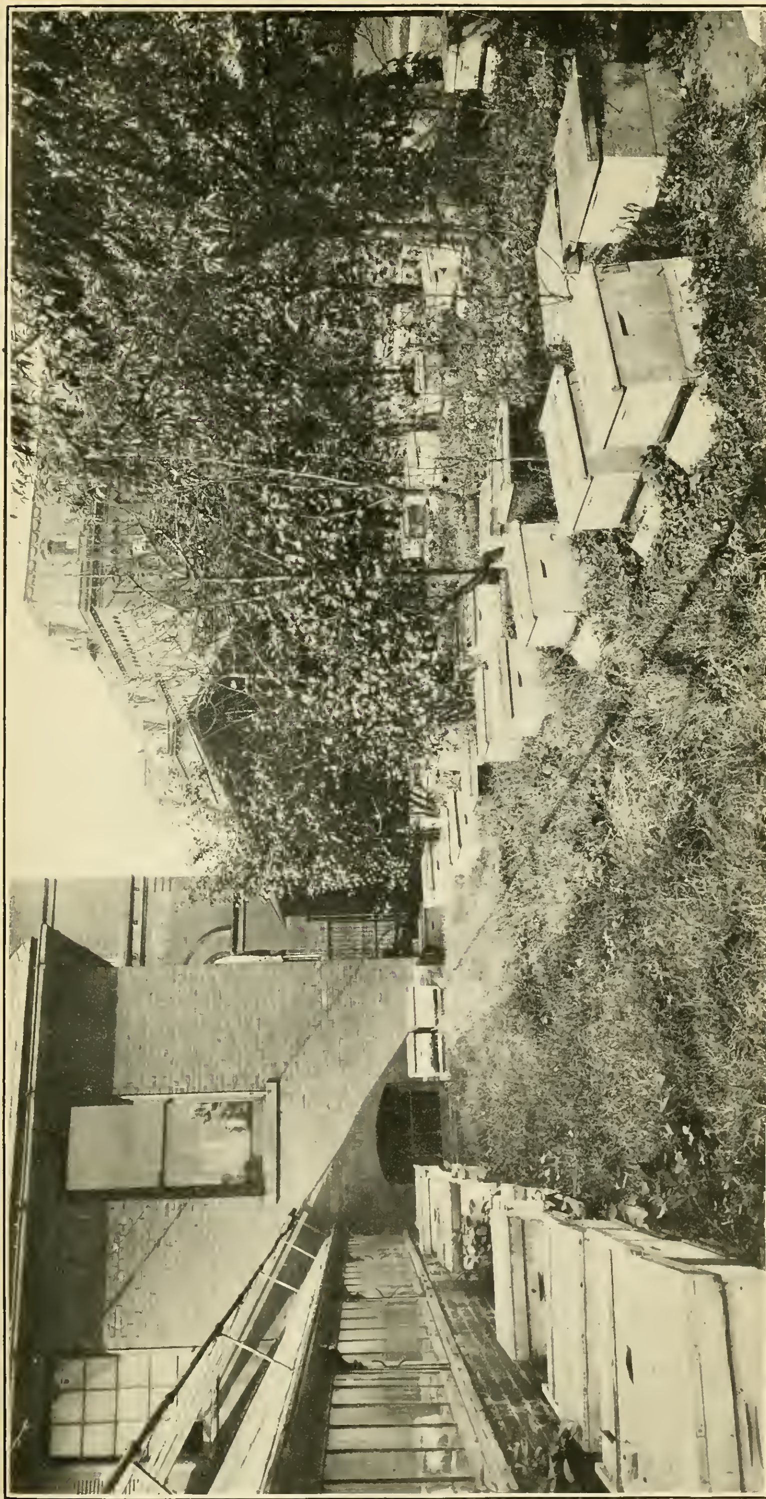
Year.	August.			September.			October.			Total bees examined.	Total Nosema infected.	Per cent.
	Bees examined.	Nosema infected.	Per cent.	Bees examined.	Nosema infected.	Per cent.	Bees examined.	Nosema infected.	Per cent.			
1912	60	14	......	170	14	8	......	......	......	1,140	236	20
1913	240	11	5	170	43	25	60	1	......	1,270	228	10
1914	......	......	......	220	......	......	......	......	......	2,210	121	10
1915	......	......	......	......	......	......	......	......	......	530	46	9
Total	300	25	8	560	57	10	60	1	......	5,150	631	12

From Table V it will be observed that the number of infected bees found at different periods of the year varied considerably. April and May furnished the highest percentage, being 18 and 17 per cent respectively. In March, June, July, August, and September the number of Nosema-infected bees among those examined was 11, 8, 7, 5, and 10 per cent respectively. Out of 5,150 bees taken from the apiary from April, 1912, to June, 1915, and examined, 631 (12 per cent) were Nosema infected.[1]

Laidlow (1911) reports that out of somewhat more than 1,500 bees received from various parts of Australia, 17 per cent were found to be Nosema infected.

From an examination of the foregoing tables it is seen that Nosema infection was found to be present in practically every colony of the apiary. Had further examinations been made of the few colonies in which *Nosema apis* was not found, one could well expect, from what is known of the disease, that these, too, would have revealed the presence of the infection. It is seen also that the infection persisted throughout all seasons of the year, and that it was heaviest

[1] While this three-year study was being made the apiary served for other work. It is likely that the attending manipulations were accompanied from time to time by a certain amount of robbing. From the nature of the disease, however, it is not believed that this fact affected materially the results obtained.



EXPERIMENTAL APIARY IN WHICH THE NOSEMA-DISEASE EXPERIMENTS MADE DURING THE SUMMER OF 1915 WERE CONDUCTED. (AUTHOR'S ILLUSTRATION.)

in the spring. Some colonies died as a result of the disease, while a greater number recovered from the infection, increased in strength, and behaved in all respects as healthy colonies.

The total of all the spring counts, during the period from 1912 to 1915, inclusive, of the apiary under study, was 94 colonies. Out of this number at least 12 (13 per cent) died more or less directly as the result of Nosema disease. An equal or greater loss to the apiary than this colony loss probably is the aggregate loss in strength sustained by colonies weakened by the infection but which recover from the disease.

Naturally it is particularly unfortunate from an economic point of view that the highest percentage of infected bees, and consequently the heaviest loss in strength sustained by colonies from Nosema infection, occurs in the spring.

Beuhne (1916) has reported investigations made on colonies from his own apiary which are similar in nature to the foregoing studies. The results he obtained indicate that Nosema infection in Australia is similar to the infection as it occurs in America.

SYMPTOMS OF NOSEMA-DISEASE.

Nosema-disease presents only a few symptoms. In describing them the colony rather than individual bees should be considered as the unit, since it is the colony as a whole that is of primary interest to beekeepers.

Weakness is a colony symptom which invariably will be manifest if a sufficiently large percentage of the bees of the colony are Nosema infected and if the infection persists for a sufficient period. When only a small percentage of the bees are infected the weakness resulting may never be apparent. The loss in strength may be gradual or sudden.

The behavior of a Nosema-infected colony is similar to that of a healthy one. The stores are sufficient. The queen does her work well. As the colony dwindles the queen usually is among the last handful of bees. The brood in general is normal in appearance, but in colonies weakened by the disease not infrequently it is seemingly in excess of the amount that can be properly cared for by the adult bees present.

In Nosema-disease the workers especially suffer from the infection. An infected bee manifests no outward symptoms of the disease when seen among the other bees of the colony and it performs functions similar to those performed by healthy ones.

When the stomach of an infected bee is removed it may show marked changes which are characteristic of Nosema-disease. The organ pales as a result of infection. The brownish yellow or dark reddish hue of the normal stomach is gradually lost as the disease advances. The organ (Pl. I) is often increased in size, the circular constrictions are less marked, and the transparency is diminished. In late stages of the disease, however, the stomach approaches the normal in size and the constrictions are again well marked. The organ is then white and opaque and the tissues are friable and easily crushed. When crushed the mass presents a milky appearance.

Upon microscopic examination *Nosema apis* is found in very large numbers in the crushed tissues. The presence of the parasite is almost invariably recognized by its spore form. The presence of Nosema-infected bees in a colony is the one constant colony symptom of the disease.

METHODS EMPLOYED IN EXPERIMENTAL STUDIES.

As *Nosema apis* has not been grown in the laboratory by artificial methods, in carrying out these investigations it has been necessary to inoculate a large number of colonies of bees. The use of a few bees in cages was found to be inadequate for experimental purposes. A 4 to 6 frame nucleus in a 10-frame hive body (fig. 5) serves well the purposes of an experimental colony. The experimental apiary (Pl. IV), consisting usually of about 50 colonies, was the same one that was used in the sacbrood studies. During the bee season the colonies were inoculated and kept in the apiary in the open under conditions similar to those occurring in nature. Precautions similar to those observed in the sacbrood studies were followed in the present studies. During the winter colonies to be inoculated were removed to and kept in the laboratory. The top of the hive body was screened and the bees given free opportunity for flight through a hole in the window.

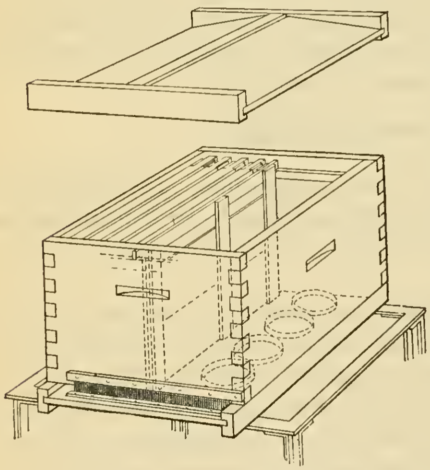


FIG. 5.—Experimental hive, having four Hoffman frames, a division board, Petri dishes as feeders, the entrance nearly closed with wire cloth, and the opening on the side of the hive body occupied by the frames. (Original.)

The manner of obtaining the parasite *Nosema apis* from diseased bees for use in the inoculations is described under "Diagnosis" (p. 48). The stomachs of from 5 to 10 infected bees are amply sufficient for each inoculation. After their removal from the bees they are crushed, suspended in sirup, and fed to a colony free or practically free from Nosema infection. The methods throughout are similar in general to those employed and described in the sacbrood studies. It should be stated in addition that no watering place for the bees was provided at the time of these experiments and none with sluggish water was near by.

The results of an experiment usually can be determined during the second week following the inoculation. The diagnosis is made as described later in the present paper (p. 48). Usually one examination of 10 bees is sufficient for the determination of results. It is advisable sometimes, however, to make others.

As a rule experimental colonies inoculated during the summer recover from the infection and can be used again. The period which must elapse, however, before they can be used for a second experiment varies. An examination of the field bees should show no infection among them or only an occasional infected bee before another inoculation is made. A colony used in the laboratory is good for one inoculation only if by it Nosema-disease is produced. Should the results be negative following an inoculation, however, the colony may be used in a subsequent experiment.

It is not necessary to disinfect a hive which has housed a Nosema-infected colony. The experimental colony may or may not have a queen. If one is present no concern need be felt in regard to whether or not she is infected. No fear need be entertained that drones from infected colonies in the apiary will transmit the infection to the experimental colony.

EFFECT OF NOSEMA INFECTION ON THE COLONY AND ON THE APIARY.

To determine the effect which Nosema infection in a colony produces on the colony, and on the apiary of which the colony is a part, is a problem in the study of Nosema disease which is of vital interest to the beekeeper. Some observations have been made bearing directly upon this point.

EXPERIMENT NO. 1.

On September 13, 14, 15, and 18 ten colonies were fed a sirup suspension of the crushed intestines of Nosema-infected bees. These colonies (Table II, Nos. 6*a*, 12, 25, 35, 41, 55, 65, 66, 67, and 70) were in the apiary mentioned on page 13. Those selected for inoculation were not especially strong, the bees being easily accommodated on six or seven brood frames and being about an average for the apiary. Examinations show that about 10 per cent of the pollen-carrying bees of these colonies were Nosema infected at the time of the inoculation. The 32 uninoculated colonies in the apiary served as checks.

It will be seen from Table II that after inoculation 50 to 100 per cent of the pollen-carrying bees in the inoculated colonies were Nosema infected. Out of the 100 bees examined from these colonies during the period from October 5 to October 16, inclusive, 132 (70 per cent) were found infected. These colonies when examined on October 28 showed that, out of 100 bees examined, 78 (78 per cent) were infected. It will be noted, therefore, that following the feeding inoculations there was a marked increase in the percentage of Nosema-infected bees in each of the 10 colonies inoculated.

In the experiment sufficient precautions were not taken to prevent robbing at the time the inoculations were made. This resulted in an increase also of Nosema-infected bees in some of the uninoculated colonies (Table II) of the apiary—the checks. The increase in the number of infected bees disappeared more readily from the check colonies, however, than from the inoculated ones, suggesting that probably a comparatively small amount of the contaminated sirup was obtained by the robbing bees.

On December 17, out of 100 bees taken from the 10 inoculated colonies 49 (49 per cent) were found to be Nosema infected, showing that the percentage of infected bees had decreased.

From comparison of the inoculated colonies in October and in December, it was observed that their strength had decreased and that they were relatively weaker than the checks. Toward the last of December one of the 10 inoculated colonies died. During the last week of the year the remaining 9 were packed for the winter as were also the check colonies. Some of the weaker check colonies were united, giving them a slight advantage in strength over the inoculated ones.

The winter 1912–13 being a favorable one for bees, the winter losses were low. In March, 1913, when the first examination of the apiary was made, 4 of the 10 colonies that had been inoculated had died out. Four of the six inoculated colonies that were still alive showed 4, 6, 2, and 2 Nosema-infected bees respectively in samples of 10 bees examined. Neither of the other two inoculated ones showed at the time the presence of Nosema infection. All of the 19 uninoculated colonies packed in December were alive in March, 1913. Out of 190 bees caught from the entrance of these check colonies during March only 6 (3 per cent) were Nosema infected.

By the middle of May another of the inoculated colonies (No. 12) had died, making 5 in all. Of the 10 colonies that had been inoculated in September, 1912, the 5 that lived through the winter and the following spring continued to gain in strength during the summer of 1913 and by autumn were apparently as strong and healthy as any in the apiary.

By experiment No. 1 it is shown that when colonies are inoculated with *Nosema apis* a high percentage of adult bees of each colony becomes Nosema infected—results which confirm similar ones previously obtained by Dönhoff (1857), Zander (1909), and others.

Such results, together with facts which are recorded on the foregoing pages, are sufficient to demonstrate that Nosema-disease is an infectious disease of adult bees.

It is shown also by the results of this experiment that there is a tendency for the infected colonies to become weakened. It is further shown that when inoculated in September colonies do not die out readily as a result of the inoculation. Furthermore the results indicate that the infection is not readily transmitted from the infected to the healthy colonies of the apiary. It is further shown that colonies inoculated in September may die as a result of the infection during the winter that follows, or they may survive the winter, gain in strength during the brood-rearing season, and by the following autumn present the appearance of healthy colonies.

EXPERIMENT NO. 2.

Beekeepers are always desirous of knowing whether combs from diseased colonies can be used in healthy ones without causing a spread of the infection. To obtain data relative to this point experiment No. 2 was begun in July, 1913 (Table III). In the experiment, brood combs from diseased colonies were inserted into colonies comparatively free from Nosema infection and kept under observation for more than a year afterwards.

Combs from the 5 colonies of experiment No. 2, which died during the winter and spring following their inoculation with *Nosema apis* in September, 1912, were inserted into the 6 colonies (Nos. 36, 50, 61, 66, 68, and 82, numbered by capital letters "A" to "F," respectively) used in the present experiment, each colony receiving from two to four combs. The colonies from which the inserted frames were obtained had been dead for from seven weeks to five months before they were given to the colonies. None of the 6 colonies were strong, the bees being easily accommodated on from four to six brood frames, a strength representing about an average for the apiary.

Out of 110 bees examined from the 6 colonies of the experiment prior to the insertion of the combs 10 (9 per cent) were found to be infected; and out of 170 bees examined after they were inserted 26 (15 per cent) were found to be infected. This increase in Nosema-infected bees can not be attributed to the introduction of the combs, since a similar increase is noted in the other colonies of the apiary serving as checks.

All of the colonies of the experiment lived through the winter and spring except one (No. 61). This colony was dead when examined in May, 1914. Dead bees taken from the bottom board of the hive showed a high percentage of Nosema-infected bees. The 5 colonies that survived gained in strength, behaved as healthy colonies, and contained a percentage of Nosema-infected bees approximating that of the other colonies of the apiary (Table IV, colonies numbered 36, 50, 66, 68, and 82).

The results obtained indicate, therefore, that by inserting combs from Nosema-infected colonies, as was done in experiment No. 2, the infection is not transmitted appreciably. An explanation for this is easily seen from results recorded throughout the present paper. Further experiments on the point are summarized in Table XXVI.

EXPERIMENT NO. 3.

In this experiment 7 colonies free from Nosema infection were inoculated by feeding them sirup to which *Nosema apis* had been added. The bees from which the parasites were obtained for this experiment were from various sources (p. 12). They had been dead and drying in the laboratory at room temperature for at least three months. All of the 7 colonies received the first inoculation feeding on October 8. On each succeeding day for four days the feeding was repeated. Each of the inoculated colonies of the experiment was examined from time to time, but no Nosema-infected bees were found. The final examination in connection with this experiment was made on October 28. Out of 70 bees examined from the 7 colonies only one Nosema-infected bee was found. The infection in this instance probably did not result from the inoculations.

In this experiment it is shown that *Nosema apis* drying in the abdomen of bees at room temperature for three months does not produce infection when fed to healthy bees. This result suggested the interesting fact that the parasite of the bee resisted drying for a comparatively short time only (see other experiments, p. 40).

EXPERIMENT NO. 4.

In experiment No. 4, four of the colonies used in experiment No. 3 were inoculated on October 29, 1912, with *Nosema apis* taken from infected bees recently killed. Nine days after the inoculation samples of bees were examined from each of the four colonies inoculated. Nosema infection was found in nearly all of the bees examined. Two weeks after inoculation 50 bees were examined from each of the 4 colonies. All of the 200 bees were found to be infected. At the end of three weeks a similar condition prevailed. On December 16, 48 days after inoculation, all of the 4 inoculated colonies were alive. A large number of bees were now found on the bottom board of the hive. By this time the colonies had become very much weakened. The bees were uneasy, the cluster being easily disturbed. During the following week 1 of the colonies died out completely. The remaining 3 were chloroformed. Another colony inoculated in November gave like results, and died in January, 1913.

Each of the 5 colonies of the experiment were four-framed nuclei. As the inoculations were made late in the autumn there were no young bees emerging. All of the bees of the colonies were exposed, therefore, to infection by the inoculation.

It is seen from this experiment that during the autumn workers infected with *Nosema apis* live, as a rule, for more than one month, but that most of them die during the second month after infection. These results led to the conclusion that heavy infection in a colony when no brood is being reared will destroy the colony, but that it may live for two or three months following the infection.

Although 100 per cent of the workers in each of the 5 colonies were infected, the queens from 3 of them were free from infection at the death of their respective colonies. The other 2 were found to be infected.

NOSEMA INFECTION WEAKENS THE COLONY.

There is good evidence at hand indicating that Nosema infection weakens the colony. The fact that the epithelial layer of the stomach is filled with parasites (fig. 3; Pls. I and II) at once suggests that the functions of the organ, digestion and absorption at least, would be decidedly impaired thereby. Likewise, when the Malpighian tubules are invaded (Pls. II and III), it is to be expected that the bee suffers impaired functions. The abnormal condition argues strongly that such a bee is less efficient as a member of a colony than an uninfected one. Further evidence that infection weakens a colony is seen in the fact that in nature the heaviest infection is encountered in the weaker colonies. Still further evidence is seen in the results obtained in experiments Nos. 1, 3, and 4, just recited, and from inoculations made in 1913, 1914, 1915, and 1916, now to be referred to.

On June 4, 1913, a colony was inoculated by feeding it *Nosema apis* in a sirup suspension. On the 13th it was found to be heavily infected. At this time the inoculation was repeated. When examined on July 12 the colony had not increased in strength as the uninoculated ones had done. On this date it was reinoculated. By the middle of August it had not gained in strength. No reason could be assigned for the failure of the colony to become strong other than the presence in it of Nosema infection resulting from the inoculation.

On June 9, 1914, a colony was inoculated with *Nosema apis*. On the 22d it was found to be heavily infected. On July 8 it was reinoculated, at which time it was weaker than the check colonies. On August 6 the colony was still relatively weak and was reinoculated. On the 17th it was still weak. The failure on the part of the colony to become stronger is attributed to the Nosema infection.

On August 6, 1914, a colony was inoculated with *Nosema apis*. It became heavily infected and on September 9 it seemed to be weakened as a result of the infection. It was reinoculated on this date. On December 1 it was found to be heavily infected and on January 15, 1915, it was dead.

On March 30, 1915, a colony was inoculated, resulting in heavy infection with *Nosema apis*. On June 17 the inoculation was repeated. Later a swarm was cast. Inoculations were repeated on July 3, 9, 17, 24, 31, and August 13. The colony became much weakened and later in the autumn died.

Beginning on March 22, 1916, a colony was inoculated at irregular intervals thereafter until September. Much brood was being reared in it throughout the season, but its strength in September was about equal to its strength in March.

The evidence obtained, it will be observed, is sufficient to justify the conclusion that the Nosema infection in a colony tends to weaken it. The weakness resulting does not occur immediately following the infection, however. During the active brood-rearing season the young bees reared may exceed the loss from disease and the colony will then actually gain in strength. On comparison of colonies that are infected with those that are not, however, it will be seen that the infected ones are the weaker. An experimental colony receiving repeated inoculations increases in strength, as a rule, during the first two weeks following the initial feeding through the emergence of young bees, but comparatively little, if any, after the first month.

The question arises as to whether the weakness is the result of infection in workers, drones, or the queen, or in a combination of these different members of the colony. Brood apparently does not become affected with *Nosema apis* (p. 10). The weakness in a colony can not be attributed, therefore, to infection of the brood. Infection among drones is rare (p. 11). Loss in strength, therefore, could not be expected to result from infection in the drones. The queen in an infected colony is more often free from the infection than not (p. 11). Weakness from Nosema infection can result, therefore, when the queen is free from infection. By elimination in this way the conclusion is reached that the weakness produced by Nosema infection in a colony is due primarily to infection among the adult workers.

Other observations made point to the same conclusion. Workers taken from colonies in which Nosema infection had reached a rather advanced stage were confined in the McIndoo wire-screen cages [1] and kept at room temperature. Healthy ones were similarly caged and kept under observation. The relative length of time that the infected and uninfected bees lived under these conditions was noted.

On December 8, 1914, in each of four cages were placed from 15 to 30 bees taken from colonies heavily infected with *Nosema apis*. By the end of one week, out of 79 bees confined 62 (78 per cent) had died. On the same date bees from another infected colony were similarly confined. At the end of a week out of 119 bees confined 108 (91 per cent) had died. On December 15, 1914, the experiments were

[1] Small triangular cages devised by McIndoo (1917, p. 4) in his studies on the honeybee.

repeated. Out of 138 bees in one set of four cages 125 (91 per cent) were dead at the end of one week. In the other set of four cages out of 136 bees confined 98 (72 per cent) were dead at the end of a week.

On December 8 a check experiment was begun. In each of two cages bees taken from healthy colonies were confined and kept at room temperature. At the end of one week out of 59 bees confined 5 (8 per cent) had died.

Out of a total of 472 diseased bees confined 393 (83 per cent) were dead at the end of one week, while out of a total of 59 healthy bees kept under similar conditions only 5 (8 per cent) were dead at the end of a week. Although such experiments are subject to great variation and should be repeated many times for definite results, yet the difference between 83 per cent of loss in the case of infected bees and 8 per cent of loss in the case of healthy ones is sufficiently great to justify the conclusion that the heavily infected bees under the conditions of the experiment possessed less endurance than the healthy ones. These results indicate that weakness in a colony may result directly from infection among the workers.

Throughout the investigations which have been made on the disease, therefore, evidence has been obtained indicating that weakness results not from the infection of the queen, drones, or brood, but of the workers.

RESISTANCE OF NOSEMA APIS TO HEATING.

NOSEMA APIS SUSPENDED IN WATER.

Preliminary results indicating the minimum amount of heating that is necessary to destroy *Nosema apis* were given in an earlier paper (White, 1914). Other experiments have been performed. In conducting the experiments a suspension was made in water of the crushed stomachs and intestines of Nosema-infected bees. This suspension was distributed in test tubes in such a dilution that the amount in each tube contained the infective material of from 5 to 10 bees. The tubes were stoppered and heated at different degrees of temperature by immersing them in water. Colonies free from infection were inoculated with the heated material and the results noted.

Table VI summarizes some of the experiments made with the results obtained.

TABLE VI.—*Experiments to determine the heat required to destroy Nosema apis suspended in water.*[1]

Date of inoculation.	Temperature employed.		Period of heating.	Results of inoculations.
	° *C.*	° *F.*	*Minutes.*	
Jan. 31, 1913	50	122	20	Nosema infection produced.
Jan. 8, 1913	55	131	10	Do.
Oct. 4, 1913	56	133	10	Do.
Oct. 15, 1913	56	133	10	Do.
May 21, 1915	58	136	10	Do.
Oct. 15, 1913	57	135	10	No infection produced.
Feb. 8, 1913	58	136	10	Do.
Oct. 4, 1913	58	136	10	Do.
Aug. 28, 1915	59	138	10	Do.
Nov. 11, 1912	60	140	10	Do.
Nov. 20, 1912	60	140	10	Do.
May 21, 1915	60	140	10	Do.
Aug. 28, 1915	61	142	10	Do.
Nov. 12, 1913	65	149	10	Do.
Jan. 8, 1913	65	149	10	Do.
Oct. 29, 1912	80	176	20	Do.
Nov. 12, 1912	100	212	5	Do.

[1] In omitting fractions of degrees the nearest whole number is given.

From Table VI it will be observed that *Nosema apis* in a water suspension was destroyed in 10 minutes at a temperature somewhere between 135° F. (57° C.) and 138° F. (59° C.).

NOSEMA APIS SUSPENDED IN HONEY.

From preliminary experiments it was learned that the amount of heating that is required to destroy *Nosema apis* suspended in glycerin is approximately equal to that required to destroy it when suspended in water. It was anticipated, therefore, that the minimum amount of heating that would destroy the germ suspended in honey would approximate that required to destroy it when suspended in water.

Experiments were made to determine the approximate thermal death point of *Nosema apis* when it is suspended in honey. In making the experiments the technique used was similar in the main to that of the preceding group of experiments wherein suspensions in water were heated. In Table VII are summarized the experiments performed, together with the results obtained.

TABLE VII.—*Experiments to determine the heat required to destroy Nosema apis suspended in honey.*

Date of inoculation.	Temperature employed.		Period of heating.	Results of inoculations.
	° *C.*	° *F.*	*Minutes.*	
Aug. 28, 1915	58	136	10	Nosema infection produced.
Aug. 27, 1915	59	138	10	Do.
June 9, 1915	59	138	10	No infection produced.
May 21, 1915	60	140	10	Do.
June 8, 1915	61	142	10	Do.
Aug. 28, 1915	61	142	10	Do.
June 9, 1915	62	144	10	Do.
June 8, 1915	63	145	10	Do.
May 5, 1915	65	149	10	Do.
May 21, 1915	70	158	10	Do.
May 21, 1915	80	176	10	Do.

Table VII shows that *Nosema apis* in a honey suspension was destroyed by heating for 10 minutes at a temperature between 136° F. (58° C.) and 140° F. (60° C.), the death point being about 138° F. (59° C.).

RESISTANCE OF NOSEMA APIS TO DRYING.

In experiments relative to the effect of drying on *Nosema apis*, stomachs from Nosema-infected bees were crushed, and the crushed tissues were smeared on slides to the extent of a thin layer. The slides were placed in incubator, room, outdoor, and refrigerator temperatures, respectively. At different intervals after the preparation of the smears an aqueous suspension was made, germs from two slides representing the material from 5 to 20 bees being used. This was added to sirup and fed to a healthy colony. Whether or not the parasite had been destroyed was determined by the presence or absence of Nosema-infection in the colony following the inoculation with the sirup.

NOSEMA APIS DRYING AT INCUBATOR TEMPERATURE.

In Table VIII are summarized the experiments, together with the results obtained, in which the Nosema material was allowed to dry at incubator temperature.

TABLE VIII.—*Resistance of Nosema apis to drying at incubator temperature.*

Date of inoculation.	Period of drying.		Results of inoculation.
	Months.	*Days.*	
July 30, 1915	0	10	Nosema infection produced.
July 14, 1916	0	13	Do.
Oct. 5, 1914	0	14	Do.
July 21, 1915	0	18	Do.
July 29, 1916	0	15	No infection produced.
Sept. 11, 1914	0	21	Do.
Nov. 2, 1914	0	30	Do.
Sept. 29, 1914	0	40	Do.
Oct. 16, 1914	0	56	Do.
July 9, 1915	2	15	Do.
May 24, 1915	7	27	Do.
July 9, 1915	9	19	Do.

From Table VIII it will be seen that *Nosema apis* drying at incubator temperature was destroyed in from 15 to 21 days, that is, during the third week.

NOSEMA APIS DRYING AT ROOM TEMPERATURE.

In Table IX are summarized experiments in which the drying of *Nosema apis* took place at room temperature.

TABLE IX.—*Resistance of Nosema apis to drying at room temperature.*

Date of inoculation.	Period of drying.	Results of inoculation.
	Days.	
July 26, 1916	18	Nosema infection produced.
Sept. 11, 1914	21	Do.
Aug. 11, 1916	35	Do.
Oct. 2, 1914	42	Do.
Sept. 1, 1915	43	Do.
Aug. 26, 1916	50	Do.
Oct. 16, 1914	56	Do.
May 24, 1916	60	No infection produced.
Sept. 1, 1915	61	Do.
June 27, 1916	95	Do.

From results recorded in Table IX it will be observed that *Nosema apis* drying at room temperature remained virulent for from 56 to 60 days, that is, about 2 months.

NOSEMA APIS DRYING AT OUTDOOR TEMPERATURE.

Table X summarizes experiments in which *Nosema apis* was allowed to dry at outdoor temperature.

TABLE X.—*Resistance of Nosema apis to drying at outdoor temperature.*

Date of inoculation.	Period of drying.		Results of inoculation.
	Months.	*Days.*	
Sept. 11, 1914	0	21	Nosema infection produced.
Oct. 2, 1914	0	42	Do.
Aug. 17, 1914	0	46	Do.
Oct. 16, 1914	0	56	Do.
June 7, 1916	0	60	Do.
Sept. 27, 1913	0	60	No infection produced.
July 9, 1915	0	75	Do.
June 27, 1916	0	80	Do.
Aug. 17, 1915	0	85	Do.
July 17, 1916	0	100	Do.
May 25, 1915	9	0	Do.
July 17, 1914	10	10	Do.
July 1, 1914	11	0	Do.

The results recorded in Table X show that *Nosema apis* ceased to be virulent after 2 months of drying at outdoor temperature.

NOSEMA APIS DRYING AT REFRIGERATOR TEMPERATURE.

Table XI summarizes experiments in which *Nosema apis* was allowed to remain dry in the refrigerator.

TABLE XI.—*Resistance of Nosema apis to drying at refrigerator temperature.*[1]

Date of inoculation.	Period of drying.	Results of inoculation.
	Months.	
Dec. 2, 1915	3	Nosema infection produced.
Jan. 3, 1916	4	Do.
Mar. 3, 1916	6	Do.
Apr. 2, 1916	7	Do.
Apr. 22, 1916	7½	No infection produced.
May 3, 1916	8	Do.
July 3, 1916	10	Do.

[1] A few times during the experiments in which the refrigerator temperature was used, the ice became exhausted, allowing the temperature to approach and possibly to reach that of the room. This higher temperature, when present, however, at no time prevailed for more than a day.

It is learned from the results recorded in Table XI that *Nosema apis* drying at refrigerator temperature remained virulent for seven months but that no disease was produced following inoculation with the material after seven and one-half months drying.

From the results obtained in the experiments relative to the resistance of *Nosema apis* to drying, given in Tables VIII–XI, it will be observed that the period the parasite remained alive, or at least virulent, varied, depending upon the environment of the germ. The shortest period for the destruction of spores was obtained under incubator conditions, while the longest period occurred under refrigerator conditions. The death probably was not due to the drying alone but to a combination of factors of which drying was an important one.

RESISTANCE OF NOSEMA APIS TO FERMENTATION.

Experiments have been made to obtain data relative to the resistance of *Nosema apis* to fermentative processes. In conducting the experiments suspensions of the crushed stomachs from Nosema-infected bees were made in a 10 per cent sugar (saccharose) solution and in a 20 per cent honey solution. These solutions were distributed in test tubes. Each tube contained infectious material equal to that present in the stomachs of from 5 to 10 infected bees. To each suspension was added a bit of soil to inoculate it further. Suspensions were allowed to ferment at incubator, room, outdoor, and refrigerator temperatures, respectively. At intervals reckoned in days the fermenting suspension from a single tube was transferred to about one-half pint of sugar sirup and fed to a colony free from the infection. The results were then noted.

FERMENTATION AT INCUBATOR TEMPERATURE.

In Table XII are summarized some of the results that were obtained when a suspension of *Nosema apis* in a 20 per cent aqueous solution of honey was allowed to ferment at incubator temperature.

Table XII.—*Resistance of Nosema apis to fermentation in a honey solution.*

Date of inoculation.	Period of fermentation.	Results of inoculation.
	Days.	
July 25, 1916	1	Nosema infection produced.
July 26, 1916	2	Do.
July 27, 1916	3	No infection produced.
July 28, 1915	4	Do.
July 12, 1915	5	Do.
July 15, 1916	8	Do.
July 17, 1916	10	Do.

From experiments recorded in Table XII it was shown that *Nosema apis* was destroyed by fermentation in 20 per cent honey solution at incubator temperature in three days.

FERMENTATION AT ROOM TEMPERATURE.

In Table XIII are summarized experiments in which colonies were inoculated with a suspension of *Nosema apis* in a 10 per cent sugar (saccharose) solution, which had been allowed to ferment, at room temperature.

TABLE XIII.—*Resistance of Nosema apis to fermentation in sugar solution at room temperature.*

Date of inoculation.	Time of fermentation.		Results of inoculation.
	Months.	*Days.*	
Sept. 8, 1915	0	5	Nosema infection produced.
Sept. 9, 1915	0	6	Do.
June 4, 1915	0	11	No infection produced.
Sept. 10, 1915	0	7	Do.
July 27, 1915	0	8	Do.
July 29, 1915	0	10	Do.
Sept. 13, 1915	0	10	Do.
Sept. 15, 1915	0	12	Do.
Sept. 16, 1915	0	13	Do.
Sept. 1, 1915	0	14	Do.
Jan. 9, 1915	0	18	Do.
Sept. 15, 1914	0	21	Do.
Sept. 29, 1914	0	34	Do.
June 9, 1914	7	12	Do.
June 10, 1914	10	6	Do.
May 13, 1915	18	6	Do.

From Table XIII it will be seen that the parasite was destroyed by fermentation in a 10 per cent sugar solution at room temperature in from 7 to 11 days. The range of variation shown may be attributed largely to variation in the temperature.

FERMENTATION AT OUTDOOR TEMPERATURE.

In Table XIV are summarized experiments made for the purpose of obtaining approximate data relative to the resistance of *Nosema apis* in a 20 per cent honey solution at outdoor temperature.

TABLE XIV.—*Resistance of Nosema apis to fermentation in a honey solution at outdoor temperature.*

Date of inoculation.	Period of fermentation.	Results of inoculation.
	Days.	
July 26, 1916	2	Nosema infection produced.
July 27, 1916	3	Do.
July 28, 1916	4	Do.
Sept. 8, 1915	5	Do.
July 29, 1916	5	Do.
Aug. 30, 1916	6	Do.
July 29, 1916	7	Do.
Aug. 31, 1916	7	Do.
Sept. 2, 1916	9	No infection produced.
Sept. 6, 1916	12	Do.

From Table XIV it will be observed that the parasite was destroyed in 9 days in the presence of fermentation processes taking place in a 20 per cent honey solution at outdoor temperature.

At refrigerator temperature it was found that *Nosema apis* resisted fermentative processes for more than seven and less than nine days.

It will be observed from the results obtained that *Nosema apis* in the presence of fermentative processes is destroyed in a comparatively short time. The period, it will be seen, varies somewhat with the temperature of the fermenting suspension. The experiments tend to indicate, furthermore, that the time element depends slightly upon the nature of the fermenting medium, the germ being destroyed sooner in a honey solution than in a saccharose one. The time element is dependent also upon the strength of the solutions employed.

RESISTANCE OF NOSEMA APIS TO PUTREFACTION.

Experiments have been made for the purpose of obtaining results relative to the resistance possessed by *Nosema apis* to putrefactive processes. The nature of the experiments was similar to those relative to fermentation but instead of sugar solutions used for the suspensions a 1 per cent peptone solution in water was employed. In the experiments, suspensions, after undergoing putrefactive changes at incubator, room, outdoor, and refrigerator temperatures, respectively, were used in the inoculation of colonies.

PUTREFACTION AT INCUBATOR TEMPERATURE.

The experiments summarized in Table XV indicate the resistance of *Nosema apis* to putrefaction at incubator temperature.

TABLE XV.—*Resistance of Nosema apis to putrefaction at incubator temperature.*

Date of inoculation.	Period of putrefaction.	Results of inoculations.
	Days.	
July 25, 1916	1	Nosema infection produced.
July 26, 1916	2	Do.
July 27, 1916	3	Do.
July 28, 1916	4	Do.
July 12, 1916	5	No infection produced.
Sept. 10, 1915	7	Do.
July 15, 1916	8	Do.
July 17, 1916	10	Do.

By the results recorded in Table XV it is shown that *Nosema apis* was destroyed by putrefaction at incubator temperature in five days.

PUTREFACTION AT ROOM TEMPERATURE.

In Table XVI are summarized experiments in which the putrefactive processes took place at room temperature.

TABLE XVI.—*Resistance of Nosema apis to putrefaction at room temperature.*

Date of inoculation.	Period of putrefaction.	Results of inoculation.
	Days.	
July 28, 1915	12	Nosema infection produced.
July 21, 1915	18	No infection produced.
July 28, 1915	25	Do.
Sept. 29, 1914	34	Do.
July 1, 1915	40	Do.
Aug. 20, 1914	52	Do.

From Table XVI it is seen that *Nosema apis* at room temperature resisted the putrefactive processes for about two weeks. As the room temperature varies it is to be expected that the time required for the destruction of the parasite will vary also.

PUTREFACTION AT OUTDOOR TEMPERATURE.

The following table summarizes experiments that indicate the period *Nosema apis* resists putrefaction at outdoor temperature:

TABLE XVII.—*Resistance of Nosema apis to putrefaction at outdoor temperature.*

Date of inoculation.	Period of putrefaction.	Results of inoculation.
	Days.	
July 26, 1916	2	Nosema infection produced.
July 27, 1916	3	Do.
July 28, 1916	4	Do.
July 29, 1916	5	Do.
Aug. 31, 1916	7	Do.
Sept. 2, 1916	9	Do.
Sept. 6, 1916	12	Do.
Aug. 26, 1916	15	Do.
Sept. 2, 1916	22	Do.

In the experiments recorded in Table XVII it will be observed that *Nosema apis* was not destroyed in the presence of putrefactive changes at outdoor temperature in 22 days.

At refrigerator temperature the parasite has resisted putrefaction for more than three months.

The foregoing experiments relative to the effect of putrefactive processes on *Nosema apis* show that the parasite may be destroyed as a result of putrefaction. They show also that the temperature of the suspension is a factor in determining the period of resistance. Furthermore, it is seen that the germ resists the destructive processes accompanying putrefaction longer than those accompanying fermentation.

RESISTANCE OF NOSEMA APIS TO DIRECT SUNLIGHT.

RESISTANCE WHEN DRY.

Petri dishes (fig. 6) which were smeared with the crushed stomachs of Nosema-infected bees were exposed to the direct rays of the sun.

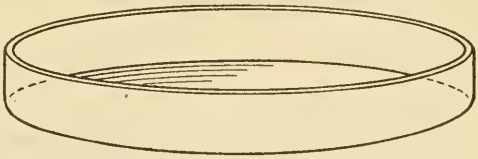


Fig. 6.—Open Petri dish. One-half of the dish, either top or bottom.

After intervals reckoned in hours healthy colonies were inoculated with a suspension made from the dishes which had been exposed. Table XVIII summarizes the experiments and the results obtained.

Table XVIII.—*Resistance of Nosema apis when dry to direct sunlight.*

Date of inoculation.	Period of exposure to sun.	Results of inoculation.
	Hours.	
Aug. 2, 1915	2	Nosema infection produced.
Aug. 21, 1914	5	Do.
Aug. 2, 1915	5	Do.
July 28, 1915	8	Do.
Aug. 27, 1914	10	Do.
Aug. 23, 1915	13	Do.
Aug. 20, 1915	15	Do.
Sept. 2, 1914	15	Do.
Aug. 25, 1915	17	Do.
Sept. 3, 1914	20	Do.
Sept. 14, 1915	29	Do.
Aug. 17, 1915	15	No infection produced.
Sept. 10, 1915	17	Do.
Aug. 19, 1915	18	Do.
Sept. 11, 1915	21	Do.
Aug. 24, 1914	22	Do.
Sept. 13, 1915	32	Do.
Aug. 4, 1914	34	Do.
Sept. 16, 1915	35	Do.

The results in Table XVIII show that *Nosema apis* was destroyed in the experiments recorded in from 15 to 32 hours' exposure to direct sunlight.

It will be readily appreciated that the time that *Nosema apis* will resist the destructive effects of the sun's rays will vary largely according to the intensity of the rays, the heat present, and the thickness of the layer of infective material exposed.

DESTRUCTION IN WATER.

In experiments made for the purpose of determining the time required to destroy *Nosema apis* suspended in water, an aqueous suspension of the crushed stomachs of about 10 bees was poured into each of a number of Petri dishes (fig. 6) and exposed to the direct rays of the sun. The top of the dish was not on during the exposure. After intervals reckoned in hours inoculations were made of healthy colonies, the germs contained in one dish being used.

Table XIX gives a summary of a set of experiments of this kind.

TABLE XIX.—*Resistance of Nosema apis suspended in water to the direct rays of the sun.*

Date of inoculation.	Period of exposure.	Results of inoculation.
	Hours.	
Aug. 2, 1915	2	Nosema infection produced.
July 27, 1915	10	Do.
Aug. 20, 1915	12	Do.
Do	18	Do.
Aug. 26, 1915	20	Do.
Sept. 10, 1915	20	Do.
Aug. 27, 1915	27	Do.
Sept. 11, 1914	27	Do.
Sept. 13, 1915	44	Do.
Do	37	No infection produced.
Sept. 14, 1915	51	Do.
Sept. 16, 1915	58	Do.
Do	65	Do.
Sept. 17, 1915	72	Do.

The results in the foregoing table show that *Nosema apis* was destroyed by the direct rays of the sun in from 37 to 51 hours. It is seen, therefore, that *Nosema apis* when suspended in water shows a considerable amount of resistance. In the question of the transmission of the disease this resistance may be of considerable importance.

At the time these experiments were made the intensity of the rays was, as a rule, quite marked and, therefore, favorable for the destruction of germs. The temperature of the aqueous suspension, however, did not reach 136° F. (58° C.) and, therefore, was not sufficient to destroy the virus through heating. Some of the suspensions stood for more than a week in the Petri dishes, thereby introducing the factors of fermentation and putrefaction. The effect of these factors on the results is not known.

DESTRUCTION IN HONEY.

In performing the experiments crushed stomachs from about 10 Nosema-infected bees were suspended in about 3 ounces of honey in Petri dishes (fig. 7). To prevent robbing by bees the dish was used with the top on. The suspension was exposed to the direct rays of the sun with the dishes resting on a wooden support. After different intervals healthy colonies were inoculated with germs which had been exposed to the sun.

Even when resting on a wooden support it is not unusual during the summer for the honey of the suspension exposed to the sun to reach a temperature beyond the thermal death point of the parasite. To determine facts in regard to the effect of the sun's rays on *Nosema apis*, therefore, this point in regard to heat must be met by the technique employed. This could have been done quite easily but for the lack of time.

In the experiments it was found that *Nosema apis* was destroyed in all instances in which the temperature of the honey reached or exceeded 140° F. (60° C.), a temperature at which the germ is killed by heat (p. 30). Sufficient data, therefore, have not been obtained to warrant a definite conclusion regarding the time required for the

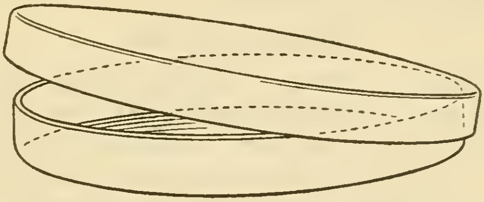


FIG. 7.—Petri dish. The top half is slightly raised. Those used here are 4 inches in diameter.

direct sunlight to destroy *Nosema apis* suspended in honey. The results obtained from the experiments made in which aqueous suspensions were exposed to the sun give some idea as to the probable approximate time which would be required.

PERIOD NOSEMA APIS REMAINS VIRULENT.

PERIOD IN HONEY.

In experiments made to determine the length of time *Nosema apis* remains virulent in honey a suspension of the parasite in honey was distributed in flasks, about one-half pint being poured into each flask. These were placed at room temperature and shielded from the light. After different intervals colonies were inoculated, the suspension from a single flask being used. The results obtained are included in Table XX.

TABLE XX.—*Period Nosema apis remains virulent in honey.*

Date of inoculation.	Period in honey.		Results of inoculation.
	Months.	*Days.*	
Oct. 20, 1914	1	0	Nosema infection produced.
Feb. 4, 1915	1	18	Do.
Feb. 24, 1915	2	0	Do.
Feb. 4, 1915	3	10	Do.
Jan. 16, 1915	3	27	Do.
July 14, 1915	2	6	No infection produced.
July 23, 1915	2	15	Do.
Oct. 21, 1915	2	25	Do.
June 11, 1915	3	5	Do.
Sept. 3, 1915	3	17	Do.
June 24, 1915	3	20	Do.
Oct. 21, 1915	3	21	Do.
July 24, 1916	4	4	Do.
Aug. 14, 1913	5	0	Do.
May 1, 1915	7	17	Do.
June 9, 1914	7	19	Do.
Apr. 27, 1915	9	7	Do.
May 5, 1914	9	19	Do.
July 26, 1916	12	0	Do.

The experiments summarized in Table XX show from the results recorded that *Nosema apis*, when suspended in honey and kept at room temperature, shielded from the light, remained virulent for from 66 to 124 days, that is, from 2 to 4 months. The wide variation noted here probably is due very largely to the variation in temperature of the honey suspension.

PERIOD IN DEAD BEES.

Among the factors tending to destroy *Nosema apis* within the remains of dead bees are drying, putrefaction, and probably fermentation. The temperature also is to be expected to vary the period of resistance. In conducting the experiments, therefore, incubator, room, outdoor, and refrigerator temperatures were used. Infected bees were killed and kept in these different environments. After different intervals suspensions were made in sirup, the crushed bodies of from 5 to 10 of the infected bees being used. Colonies were inoculated with the suspensions.

AT INCUBATOR TEMPERATURE.

Table XXI summarizes the results obtained when inoculations were made with suspensions of Nosema-infected material from bodies of bees kept at incubator temperature.

TABLE XXI.—*Resistance of Nosema apis within dead bees at incubator temperature (37.5° C.).*

Date of inoculation.	Period of drying.	Results of inoculation.
	Days.	
Apr. 9, 1916	2	Nosema infection produced.
Apr. 12, 1916	4	Do.
Apr. 14, 1916	6	Do.
June 27, 1916	7	No infection produced.
July 1, 1916	12	Do.
May 17, 1916	15	Do.
Aug. 4, 1915	16	Do.
Oct. 8, 1914	18	Do.
Aug. 8, 1915	21	Do.
Aug. 17, 1915	28	Do.
Oct. 19, 1915	30	Do.
Aug. 23, 1915	35	Do.
Aug. 6, 1914	38	Do.
Nov. 2, 1914	42	Do.

By the results recorded in the experiments summarized in Table XXI, it was shown that *Nosema apis* in the bodies of dead bees kept at incubator temperature ceased to be virulent in less than one week.

AT ROOM TEMPERATURE.

In Table XXII are summarized the experiments in which dead bees, kept at room temperature, furnished the Nosema-infected material for the suspensions used in the inoculations.

TABLE XXII.—*Resistance of Nosema apis in dead bees kept at room temperature.*

Date of inoculation.	Period of drying.	Results of inoculation.
	Days.	
Aug. 4, 1915	16	Nosema infection produced.
Aug. 10, 1915	21	Do.
July 17, 1916	28	Do.
Aug. 26, 1916	30	Do.
Aug. 17, 1916	28	No infection produced.
June 3, 1916	32	Do.
Aug. 23, 1915	35	Do.
July 26, 1916	36	Do.
Aug. 1, 1916	43	Do.
June 27, 1916	56	Do.
Aug. 20, 1914	111	Do.
Aug. 30, 1914	168	Do.

From Table XXII it is learned that when dead infected bees were kept at room temperature the parasite remained virulent for three or four weeks, but did not produce the disease after one month. Since the temperature of the room was not constant, variations in results obtained at this temperature are to be expected.

AT OUTDOOR TEMPERATURE.

Dead Nosema-infected bees were placed in a hive body standing in the experimental apiary. At different intervals suspensions were made and colonies were inoculated. In Table XXIII are summarized a few experiments indicating by the results obtained the approximate period *Nosema apis* remains virulent in the body of dead bees at outdoor temperature.

TABLE XXIII.—*Resistance of Nosema apis in dead bees drying at outdoor temperature.*

Date of inoculation.	Period of drying.	Results of inoculation.
	Days.	
Oct. 19, 1914	28	Nosema infection produced.
Aug. 23, 1915	35	Do.
Nov. 2, 1914	42	Do.
June 7, 1916	36	No infection produced.
June 27, 1916	56	Do.
July 17, 1916	76	Do.

From Table XXIII it is seen that *Nosema apis* in the bodies of dead infected bees kept dry at outdoor temperature remained virulent for from five to six weeks. These experiments extended over a period from June to November, as shown by the dates. It is to be expected that if they had been conducted throughout the year the results obtained would have shown a much wider range of variation.

AT REFRIGERATOR TEMPERATURE.

In Table XXIV are summarized experiments the results of which indicate the approximate period during which *Nosema apis* remains virulent in the bodies of infected bees kept at refrigerator temperature.

TABLE XXIV.—*Resistance of Nosema apis in dead bees drying at refrigerator temperature.*

Date of inoculation.	Period in refrigerator.	Results of inoculation.
	Months.	
Mar. 4, 1916	2	Nosema infection produced.
Mar. 20, 1916	2	Do.
Mar. 20, 1916	2½	Do.
Apr. 22, 1916	3	Do.
May 6, 1916	3½	Do.
Dec. 7, 1915	3	No infection produced.
Jan. 7, 1916	4	Do.
May 24, 1916	4	Do.
June 3, 1916	4	Do.
Feb. 10, 1916	5	Do.
Apr. 7, 1916	6	Do.
May 6, 1916	8	Do.
July 3, 1916	10	Do.

The results recorded in Table XXIV show that *Nosema apis* in the bodies of dead infected bees remained virulent at refrigerator temperature from two and a half to four months.

ON THE SOIL.

Dead Nosema-infected bees were placed on the soil in the open, but in a somewhat shaded spot. After different intervals of time colonies were inoculated, these dead bees being used as the source for the infective material. Table XXV summarizes the experiments performed, the results of which indicate the approximate period during which *Nosema apis* remains virulent in the bodies of dead bees lying on the soil.

TABLE XXV.—*Resistance of Nosema apis in dead bees lying on the soil.*

Date of inoculation.	Period on soil.	Results of inoculation.
	Days.	
July 16, 1915	13	Nosema infection produced.
Aug. 1, 1916	18	Do.
Aug. 28, 1915	25	Do.
Aug. 12, 1916	29	Do.
Aug. 26, 1916	43	Do.
Aug. 28, 1915	44	Do.
May 14, 1916	71	No infection produced.
Oct. 4, 1915	77	Do.
Oct. 21, 1915	85	Do.
Oct. 21, 1915	94	Do.
Oct. 4, 1915	104	Do.
Nov. 9, 1915	104	Do.

From the results recorded in Table XXV it is seen that when the dead Nosema-infected bees were allowed to remain on the soil exposed to outdoor conditions *Nosema apis* was virulent at the end of 44 days, but the germ had lost its virulence before 71 days. Results of experiments having the nature of those referred to in this table naturally depend largely upon the climatic conditions which prevail.

It was observed that insects, ants especially, fed upon the dead bees lying on the ground. In this way they removed much of the material containing the parasites. This fact must be borne in mind in a consideration of the length of time that bees dead of Nosema disease and lying on the soil might serve as a possible source of infection.

The five foregoing groups of experiments relative to the period during which *Nosema apis* remains virulent in the bodies of dead infected bees show that the period varies with the environment under which the bees are kept, the temperature being an important factor in causing the variation. It is interesting to note that under fairly favorable conditions for its preservation *Nosema apis* remains virulent within the bodies of dead infected bees only three months, while under less favorable conditions its destruction occurs in a much shorter period.

INFECTIOUSNESS OF BROOD-COMBS FROM NOSEMA-INFECTED COLONIES.

Experiments have been made for the purpose of obtaining data relative to the likelihood of the transmission of Nosema disease from colony to colony through the medium of brood-combs. Brood-combs on which colonies had died of the disease and others taken from colonies heavily infected with *Nosema apis* through experimental inoculation were inserted into healthy colonies after different periods of time had elapsed following their removal. Table XXVI gives a summary of experiments made and the results obtained.

TABLE XXVI.—*Results from insertion of brood-combs from Nosema-infected colonies into healthy ones.*

Date combs were inserted.	Period combs were stored.	Number of combs inserted.	Results of inoculation.
Apr. 20, 1915	Inserted immediately.	4	No Nosema infection produced.
Do	do	3	Do.
Apr. 26, 1915	do	3	Do.
July 3, 1915	do	3	Do.
May 19, 1916		1	Do.
Apr. 26, 1915	½ month	3	Do.
Do	do	3	Do.
Apr. 24, 1915	1 month	2	Do.
June 18, 1914	2 months	2	Do.
June 29, 1914	do	2	Do.
Apr. 24, 1915	3 months	2	Do.
May 1, 1915	do	2	Do.
Aug. 22, 1914	4 months	2	Do.
May 19, 1916	6 months	1	Do.

As will be observed from Table XXVI, infection did not occur in any of the experiments in which brood-combs from Nosema-infected colonies were given to healthy ones. The practical import of the results is that brood-combs from Nosema-infected colonies need not be destroyed, but may be inserted without treatment into hives containing healthy bees with practically no fear that losses will result from such manipulation. (See also experiment No. 2, p. 25.)

RESISTANCE OF NOSEMA APIS TO CARBOLIC ACID.

Stomachs taken from Nosema-infected bees were crushed and suspended in aqueous solutions of carbolic acid (commercial). One, 2, and 4 per cent solutions were used. These suspensions, respectively, were distributed in test tubes and were allowed to stand at room temperature. After different intervals healthy colonies were inoculated, the suspension from a single tube being used for each.

A summary of experiments performed with the results obtained is given in Table XXVII.

Table XXVII.—*Effect of carbolic acid on Nosema apis.*

Date of inoculation.	Per cent of carbolic-acid solution.	Period in carbolic acid.		Results of inoculation.
		Hours.	*Minutes.*	
Aug. 18, 1915	1	0	10	No infection produced.
July 16, 1915	1	1	0	Do.
July 2, 1915	1	6	0	Do.
June 9, 1915	1	51	0	Do.
Aug. 18, 1915	2	0	10	Do.
July 16, 1915	2	1	0	Do.
July 2, 1915	2	6	0	Do.
June 8, 1915	2	27	0	Do.
July 16, 1915	4	1	0	Do.
July 2, 1915	4	5	0	Do.
June 8, 1915	4	27	0	Do.

From the preliminary results given in Table XXVII it will be noted that *Nosema apis* is rapidly destroyed in 1, 2, and 4 per cent aqueous solutions, respectively, of carbolic acid, showing that the parasite possesses very slight resistance to the disinfectant.

EFFECT OF DRUGS ON NOSEMA-DISEASE.

It is natural that beekeepers should have thought of drugs and employ them in the treatment of Nosema infection. Preliminary experiments have been made to obtain data relative to the effect of betanaphthol, salol (phenyl salicylate), carbolic acid (phenol), salicylic acid, formic acid, oil of eucalyptus, and quinin (bisulphate of quinin) on this infection. It will be recalled that most of these drugs have been given a trial from time to time by beekeepers in the treatment of one or more of the bee diseases.

In the experiments honey was diluted with an equal quantity of water and medicated.[1] To the medicated solution *Nosema apis* was added. This suspension was fed to a colony, usually within a half hour from the time it was made. On each of four or five days immediately following the inoculation, the colony was fed honey medicated with the drug but free from *Nosema apis.*

In Table XXVIII are summarized the experiments performed, together with the results obtained.

TABLE XXVIII.—*Effect of drugs on Nosema infection.*

Drug.	Experiment 1.		Experiment 2.		Experiment 3.		Experiment 4.	
	Proportion.	Results.	Proportion.	Results.	Proportion.	Results.	Proportion.	Results.
Betanaphthol	2:1,000	No infection.	1: 1,000	No infection.	1: 2,000	No infection.	1: 5,000	Infection.
Salol	2: 1,000	...do.....	1: 1,000	...do.....	1: 2,000	...do.....	1: 5,000	Do.
Salicylic acid	2: 1,000	...do.....	1: 1,000	...do.....	1: 2,000	Infection.	1: 5,000	Do.
Carbolic acid	3: 1,000	...do.....	2: 1,000	...do.....	1: 1,000	...do.....	....	
Formic acid	3: 1,000	...do.....	2: 1,000	...do.....	1: 1,000	...do.....	....	
Eucalyptus	5: 1,000	Infection.	4: 1,000	Infection.	2: 1,000	...do.....	....	
Quinin	10: 1,000	...do.....	4: 1,000	...do.....	2: 1,000	...do.....	....	

The results recorded in Table XXVIII show that the parasite was destroyed by some of the drugs used but that it resisted others. Their relative efficiency as indicated from these preliminary results is shown by the arrangement in the table. Betanaphthol and salol seem to be the most effective of those tried, and eucalyptus and quinin the least efficient.

Experiments were performed in which the inoculation with *Nosema apis* was not followed by feedings with medicated sirup. The results obtained show that under the conditions of the experiments the drugs affected the parasite as seen by the lower percentage of Nosema-infected bees in the colonies inoculated. In colonies receiving subsequent feedings of medicated sirup a still lower percentage of infected bees was found.

While it is thus established that *Nosema apis* is somewhat susceptible to the effects of some of the drugs, the experiments are altogether too few for definite conclusions as to the extent of their action. Statements regarding the effect of the drugs on Nosema-disease, therefore, should be accepted cautiously, for the present at least, unless they are supported by experimental or other good evidence.

[1] In obtaining the desired proportion of the drug, betanaphthol, salol, salicylic acid, and eucalyptus were dissolved in alcohol. In the case of carbolic acid, formic acid, and the bisulphate of quinin aqueous solutions of the drugs were employed.

MODES OF TRANSMISSION OF NOSEMA-DISEASE.

No problem in the study of Nosema-disease is more important than that of its transmission. The problem is at the same time one of the most difficult for complete solution. While further information is still much desired, yet it is possible from the studies which have been made to arrive at certain conclusions concerning the manner in which the disease is spread. The discussions which follow are based chiefly upon observations noted in the foregoing pages.

It is naturally safe to conclude that the transmission of Nosema-disease depends directly upon the transmission of the parasite that causes it. If the course of *Nosema apis* in nature were followed completely, therefore, the problem relative to the spread of the disease would be solved. Such a task is difficult, as the possible sources for the parasite and the accompanying conditions are various.

The fact, determined experimentally, that a suspension of *Nosema apis* in sirup when fed to bees will produce the disease shows quite conclusively that infection takes place through the ingestion of the parasite. At present there is no evidence that it takes place otherwise than by way of the alimentary tract. This leads to the important tentative conclusion that the transmission of the disease is effected through either the food or the water supply of bees, or both.

On reaching the stomach by ingestion the parasite begins its growth, invades the walls of the organ, multiplies enormously, and forms spores which are shed into the lumen and passed out of the alimentary tract with the excrement. The chances that any single parasite once outside the bee will be ingested and cause infection are very slight. The immense number that are produced, however, increases the chances very greatly. Again, the chances of infection are very much reduced by the many destructive agencies in nature encountered by the parasite. Among these are drying (p. 31), heat (p. 29), direct sunlight (p. 37), fermentation (p. 33), and putrefaction (p. 35).

The excrement is voided normally during flight and most often soon after the bee leaves the hive. Should the droppings from infected bees fall into a body of water, such water would become thereby contaminated with the Nosema parasite and the use of it by bees would expose them to infection. Should the body of water be a rapidly flowing one, naturally the chances that other colonies of the apiary might become infected from such a source would be less than if it were a sluggish one. Should such contaminated water be exposed to the sun, the rays of the latter would have a tendency to destroy the parasites. The resistance of *Nosema apis* to the destructive effects of the sun's rays (p. 38) are sufficiently great, however, that there would still remain a strong likelihood that infection might take place from the water supply. While in the water the parasites may be subjected to fermentation or putrefaction or both. These factors would tend to destroy the germ, although its resistance under these conditions is again considerable.

It has been suggested by some writers that drops of water from showers or dew on vegetation about the apiary might become contaminated by excrement present and thus be a source of infection. This would seem to be a possibility. The extent, if any, to which the disease is thus transmitted is not yet known.

Should the excrement of infected bees fall on the soil, the chances, ordinarily, would be slight that the contained parasite would reach a bee and infect it. Should the surface water resulting from rains carry the germ into a water supply used by bees, the chances of infection from the soil as a source would be considerably increased thereby. If the bodies of dead Nosema-infected bees were washed into the water supply, contamination of it might follow.

In estimating the probable danger of infection from the bodies of bees dead of Nosema-disease, the possibility of the parasites being destroyed after the death of such bees through putrefaction (p. 35), drying (p. 31), or other means must be given due consideration.

The facts which are known concerning Nosema-disease indicate that the disease may be transmitted: (1) From the infected bees of a colony to healthy bees of the same colony, and (2) from the infected bees of a colony to healthy bees of another colony. When the infection is transmitted from infected bees to noninfected ones of the same colony, the question arises as to whether such infection takes place while the bees are within or without the hive. The fact that the heaviest infection with *Nosema apis* occurs in the spring of the year, and the further fact that only a comparatively few colonies of the apiary are likely to be heavily infected, support the tentative conclusion that the transmission of the germ takes place within the hive rather than from a source outside of it.

There are facts concerning the disease, however, which indicate that the infection under certain circumstances is not readily transmitted within the hive. For example, colonies which in the spring of the year show less than 50 per cent of Nosema-infected bees are likely to recover from the infection without treatment, showing that under such circumstances the infection is not transmitted within the hive, to any great extent at least. The fact that a colony may contain a small percentage of Nosema-infected bees throughout the year and not become heavily infected at any time furnishes further evidence that Nosema infection does not always spread with rapidity within the hive. It has been found that colonies becoming heavily infected through experimental inoculation in June, July, or August, are practically free from the infection within six weeks from the date of inoculation, showing again that the infection is not always readily transmitted within the hive.

Colonies may die out, or they may only become weakened by the disease. Each of these conditions invites robbing, which in a certain number of cases probably results in the transmission of the disease. The likelihood of the transmission of the disease through robbing, however, seems to be not nearly as great as in the case of the foulbroods.

Uninoculated colonies in the experimental apiary have always remained practically free from infection, although colonies heavily infected as the result of experimental inoculations were present. This fact suggests that very little infection, if any, results either from the visit of healthy bees to flowers previously visited by infected ones, or, furthermore, from the straying or drifting of bees from infected to healthy colonies.

The possibility that the queen may be infected and that infection will be transmitted by her to the other bees of the colony need give the apiarist no uneasiness, and no concern need be felt that drones will spread the disease in the apiary.

Fear that Nosema-infection might be transmitted by hives which have housed infected colonies need not be entertained; neither is it to be feared that the hands or clothing of the beekeepers, or the tools used about an apiary, will serve as means for the transmission of the disease. Furthermore, the spread of the disease is not to be attributed directly to winds.

Theoretically it would seem that combs from Nosema-diseased colonies, if inserted into a healthy colony, would be the means of transmitting the disease and that the danger would extend over a period of a few weeks or months (p. 39). Experimentally it is shown, however, that such combs can be inserted immediately without transmitting the disorder, at least appreciably (p. 43).

Evidence is yet to be obtained to prove that insects other than honeybees are susceptible to infection with *Nosema apis*. A few experiments made in which silkworms, maggots, and ants were inoculated with this parasite gave negative results. At the present time, therefore, there is no cause for fear that Nosema-disease will be transmitted as the result of a similar infection in other insects.

DIAGNOSIS OF NOSEMA-DISEASE.

Nosema-disease usually can be diagnosed from the colony symptoms present together with the gross appearance of stomachs removed from adult bees of the colony.

Weakness, especially in the spring of the year, should cause a suspicion that the disease is present. The suspicion is strengthened if in such a colony the brood in general is normal, if the adult bees are not noticeably different in outward appearance or behavior from bees of healthy colonies, if the queen is present and if stores are abundant.

While the colony symptoms may justify a very strong suspicion that the disease is present, an examination of the stomachs from adult bees of the colony is necessary in making a definite diagnosis. The selection of the proper sample for examination is important. In choosing samples it is advisable to take such bees as are most likely to show a high percentage Nosema-infected. Young workers, old shiny ones, and drones are, therefore, to be avoided. Workers from the field are naturally to be preferred. As bees carrying pollen are most readily recognized as being field bees, these are the ones usually sought. Sometimes it is more convenient to take bees carrying honey or water. Next to the field bees, preference should be had for bees from among those about the entrance of the hive. During the colder seasons of the year it is often necessary to take the samples from the brood-combs.

Ten bees from a colony constitute a satisfactory sample as a rule. Ordinarily these are taken at the entrance with forceps. They are killed by pinching the thorax. All of the bees of the sample should be examined.

In removing the stomach for examination the bee is held by the thorax between the thumb and index finger of one hand and with a pair of forceps held in the other the tip of the abdomen is seized and pulled gently. By this method the organs of the alimentary tract (Pl. I) forward to and including the stomach are easily obtained. Occasionally the proventriculus and honey sac are also removed by this procedure. The stomach is the most prominent of the organs removed and the one that is most readily recognized.

If the stomach upon removal appears swollen and lighter in color than a healthy one, Nosema infection may be suspected; if it is chalk-white and easily torn, infection is very probable; should the tissues of the organ when crushed be milky in appearance, infection is practically certain. Usually the gross examination is sufficient for a definite diagnosis of the disease as encountered in nature. Sometimes it is desirable however, to have such a diagnosis confirmed by a microscopic examination of the crushed tissues of the stomach. This is often the case in experimental studies.

If infection is present in a bee the oval glistening spores of the parasite (fig. 4) usually will be found in very large numbers upon a microscopic examination of the crushed tissues of the stomach. No staining is needed. Addition of water to the mount is not necessary but it improves the preparation, permitting the spores to be seen more distinctly. Stomachs which become dry, after their removal and before the examination is made, can be used readily by the addition of water.

Very few objects are encountered in the microscopic examination of the stomachs that are likely to be mistaken for the spores of *Nosema apis*. Occasionally yeasts are encountered. They occur, however, in small numbers only, as a rule; a variation in size is usually to be observed; and if stained they take the stain readily and intensely. The writer occasionally has encountered small oval bodies resembling spores which escape from pollen grains. They are found in comparatively small numbers when encountered, however, and are smaller than Nosema spores. What these bodies are has not been determined.

In examining bees that have been dead of Nosema-disease for some time a portion of the contents of the abdomen is suspended in water on a slide and examined microscopically. The highly refractive oval spores of the parasite will be found if the bee was Nosema infected at the time of its death. Younger stages of the parasite will not be encountered under these conditions.

Stages of the parasite that precede that of the spores may be recognized at times from fresh preparations. Forms approaching spores in appearance, which have been referred to as young spores, together with growing or vegetative forms appearing frequently as though they were in pairs (Pl. III, I), are seen occasionally. These younger forms are not likely to be recognized in preparations except in those made from bees recently killed and then only in small numbers. They should not be depended upon in the making of the diagnosis.

To determine very early stages of infection with *Nosema apis* the stomach of the suspected bee must be fixed, sectioned, and stained by laboratory methods.[1] The parasite is then found in the epithelial cells of the organ.

Nosema-disease, like sacbrood, is quite prevalent among bees, and like sacbrood a small amount of infection may be present in a colony without producing any appreciable loss. When a diagnosis of the disease is being made in practical apiculture, therefore, considerable caution should be observed. A colony showing only a small percentage of Nosema-infected bees and no other evidence of the disease is practically healthy. In reporting the presence of infection it would seem well to indicate in some way the amount of infection present. The percentage of infected bees among those examined might be given.

[1]As a fixing fluid one containing a strong solution of mercuric chlorid can be recommended in studies on *Nosema apis*. Heidenhain's iron hematoxylin is a very satisfactory stain for much of the work. Other fixers, especially those containing picric acid or formalin, have been used successfully. The spores of *Nosema apis* are not readily stained by all stains. Pyronin sometimes gives good results with methyl green as a counterstain. Alcoholic eosin applied for a considerable period, with methyl blue as a counterstain, used on fixed smears made from fresh tissues, often results in desirable preparations.

In expressing a positive diagnosis the degree of infection could be indicated, for the present at least, by the terms "slight," "moderate," "heavy," and "very heavy." Slight infection by this scheme would indicate that not more than 10 per cent of the bees are infected and that no noticeable loss is to be anticipated from the infection; moderate infection would indicate that from 10 to 35 per cent are infected, that the colony will probably sustain losses from the disease, but that the chances are good for recovery; heavy infection would indicate that from 30 to 60 per cent are infected, that the colony will most likely show weakness as a result of the disease, and that it may or may not die; and very heavy infection would indicate that more than 60 per cent are infected and that the colony will probably die as a result of the disease.

While a definite diagnosis in regard to Nosema infection can always be made by laboratory methods (McCray and White, 1918), beekeepers in most instances can diagnose the disease sufficiently well for practical purposes in the apiary. Weakness should cause suspicion. If there is no other obvious cause for the weak condition a strengthened suspicion is justified. If, upon the removal of the stomachs of a few field bees (at least 10 should be examined), some white stomachs are found among them, the presence of Nosema-disease is quite certain. Should there still exist a doubt the organ should be examined further. If the tissues seem to tear easily and when crushed present a milky appearance,[1] it may be concluded that the colony is Nosema infected.

DIFFERENTIAL DIAGNOSIS.

Dysentery, paralysis, palsy, spring dwindling, Isle of Wight disease, May pest, May sickness, abdominal distension, dry dysentery, dropsy, and disappearing trick are some of the many names which have been applied to disorders among adult bees. The disorders for which the names have been used have not been sufficiently well defined in all instances, however, to insure their positive diagnosis. From the facts at hand it seems probable that the number of adult diseases is small and that each disease, therefore, from time to time has had more than one name applied to it. It seems equally probable that some of the names used have been applied to more than one disease.

Although little of a definite character is known concerning the disorders of adult bees in general, Nosema-disease is such a definite condition that its differentiation from other disorders should not be difficult. It is the only adult disease that can be diagnosed positively at the present time by laboratory methods.

[1] In testing the "milky appearance," crush the suspected stomach between two plates of clear glass.

DYSENTERY.

The term "dysentery" as applied to a disorder among adult bees is found in early beekeeping literature and is still encountered frequently. The spotting of the hive which is so often referred to as a symptom of dysentery and the absence of *Nosema apis* will serve to distinguish it from Nosema-disease.

PARALYSIS.[1]

The term "paralysis" has been widely used to designate a disease of adult bees. In this country the name usually is applied to a condition in which a large number of the bees of the affected colony die suddenly with the result that often a large mass of them is found in front of the hive. When this disorder is encountered usually only a colony here and there in the apiary is affected. Whether or not the disorder is infectious has not yet been determined. Time has permitted the making of only a few preliminary experiments on this disorder by the writer. The few which have been made and the facts as observed by practical beekeepers indicate that if the disease is infectious it is only slightly so. It is not likely, therefore, to spread to any great extent in the apiary. It can be differentiated from Nosema-disease by the absence of *Nosema apis* in the bees that have died of the disorder, and in the bees remaining in the colony.

SPRING DWINDLING.

It is very probable that more than one disorder has been referred to by the term "spring dwindling." When Nosema-disease was encountered by the beekeepers in the past, most likely it was often designated spring dwindling. Other conditions which are called spring dwindling may be differentiated from Nosema-disease by the fact that *Nosema apis* is present in Nosema-disease and is absent in other conditions unless, of course, a mixed infection is present.

ISLE OF WIGHT DISEASE.

There has been encountered in many parts of England a disorder among adult bees from which heavy losses have been reported. The condition was described in 1906 by the beekeepers on the Isle of Wight, where apiaries had suffered heavy losses.

Bullamore and Malden (1912), of England, after studying the symptoms of the disease, arrived at the conclusion "that no one symptom is characteristic of the Isle of Wight disease, the only essential feature being the death of large numbers of bees within or

[1] On account of the shaking or trembling movements sometimes manifested by individual bees affected, the term "palsy" has been used to designate the condition. As this term describes more accurately a marked symptom observed in the individual bee affected, it would seem to be a more appropriate one than "paralysis."

without the hive." They believed that the condition had been endemic in parts of England for many years, and shared with Graham-Smith the belief that a large amount of the losses among adult bees ascribed to it is due to Nosema infection.

From the facts at hand it is not possible to state whether the Isle of Wight disease and Nosema-disease are one and the same disorder. Studies made on the Isle of Wight disease by English workers will most likely result in revealing further valuable facts concerning it (Anderson and Rennie, 1916). The writer examined one sample of adult bees from England taken from a colony suffering from Isle of Wight disease. No spores of *Nosema apis* were found in the sample. The results of the examination naturally prove nothing regarding the disease.

For the present the American beekeeper should bear in mind that when Nosema-disease is given as the diagnosis, a condition having the destructiveness described for the Isle of Wight disease is not meant.

OTHER DISEASES OF ADULT BEES.

It is quite probable that other diseases of adult bees than those referred to here exist. If so, they have not yet been sufficiently studied to make their recognition possible, at least by laboratory methods. Such disorders could be differentiated from Nosema-disease by the absence in them of *Nosema apis*. As Nosema infection is very widely distributed among bees, the fact must always be borne in mind that Nosema infection may occur in a colony together with other bee diseases and be of secondary importance. This caution should never be overlooked.

PROGNOSIS IN NOSEMA-DISEASE.

The prognosis in Nosema-disease varies markedly and is dependent upon the conditions present. Of these conditions the percentage of Nosema-infected bees in the colony, the strength of the colony, the season of the year, and the environment of the apiary are among the more important factors which determine the outcome of the disease.

The percentage of Nosema-infected bees in the colony may be very small, much less than 1 per cent, or it may be very large, reaching practically 100 per cent. Between these limits all degrees of infection are encountered, the prognosis in each instance being different.

As a rule colonies which in the spring of the year show less than 10 per cent of Nosema-infected bees gain in strength and the losses are not detected. This is often true also in cases where the infection is somewhat greater than 10 per cent. When the number of infected bees approaches 50 per cent the colonies become noticeably weakened and in many instances death takes place. When more than 50 per cent are infected they become weakened and usually die as a result of the infection. Generally speaking, therefore, it may be said that when a colony contains less than 10 per cent of Nosema-infected bees the prognosis is excellent; that when it contains more than 10 and less than 50 per cent the prognosis is fair; that when it contains more than 50 per cent the prognosis is unfavorable; and that when the number of Nosema-infected bees present approaches 100 per cent the prognosis is especially grave.

In arriving at a decision as to the probable course and outcome of the infection the strength of the colony must also be considered. This factor, indeed, may be the deciding one. As a rule, the stronger the colony, the more favorable is the prognosis.

In early spring heavy losses among the workers are not replaced and the colony weakens. During the active brood-rearing season, on the other hand, the bees dying of the infection are replaced by young bees. These young bees being free from infection and the transmission of the disease within the hive during summer being slight as a rule, the prognosis at this season of the year is favorable.

Experimentally it is found that a single inoculation early in the spring will cause a colony to die as a result of the infection produced; if inoculated somewhat later, however, the colony will weaken appreciably but will recover from the infection; if inoculated during the active brood-rearing season the weakening effect resulting from the infection may not be appreciable; if inoculated toward the close of the brood-rearing season the weakness resulting will be noticeable, but the colony may winter; and if inoculated later in the autumn or during the winter the colony will die as a result of the infection. It will be seen, therefore, that the prognosis in Nosema-disease in every case is dependent in some measure upon the season of the year, being more favorable in the active brood-rearing season than in any other. Indeed the season may play a major rôle in determining the course and outcome of the disease.

The immediate environment of the apiary may possibly play a rôle in determining the prognosis. Opportunity for reinfection from without tends to vary the course and outcome of the disease. In this connection the nature of the water supply should not be overlooked.

The extent to which the different races of bees vary in their susceptibility to the disease, the extent to which individual colonies vary in their susceptibility, and the extent to which different strains of *Nosema apis* vary as to their virulence are not at all definitely known at the present time. The facts, however, indicate that in no instance is the variation particularly great. Much care should be exercised, therefore, in ascribing variations in losses from the disease to the two phenomena virulence of the germ and resistance of the host.

Whether a bee once infected ever recovers from the infection has not yet been established definitely. From what is known of diseases in man and animals one might expect recovery in a certain percentage of Nosema-infected bees. The data at hand indicate that occasionally recovery does take place in the worker bee. This is suggested by the fact that among the last few workers alive in a colony, following a heavy infection resulting from an experimental inoculation, some have been found upon examination to be only slightly infected and still others to be free from infection. The only conclusion that can be drawn at the present time on this point is that if recovery from the infection ever takes place in the worker bee the cases are comparatively rare.

Whether the prognosis is as grave in the case of an infected queen is not known. The facts at hand suggest that it probably is not. In the writer's experience less than 50 per cent of the queens in experimental colonies were found to be infected (Table I). Whether they had been infected and had recovered was not determined. The queens from colonies which had been inoculated from one to three weeks were found to be free from infection, indicating that infection was infrequent, at least within the period that workers and drones show the greatest percentage of infection.

Death from Nosema infection does not take place for some time after infection. The length of time an infected worker lives depends in a large measure upon the season of the year. During the active bee season death takes place as a rule in less than one month but in more than two weeks. During winter the disease may run a course of two or three months or even more. Infected drones die sooner than infected workers, whereas infected queens probably live longer. This relation is to be expected since in healthy bees a somewhat similar relation exists. It is quite likely that the age of the bee when infected is not a negligible factor in determining the course of the disease.

Finally it should be emphasized that the prognosis of Nosema infection, as it occurs in the United States, is not nearly so unfavorable as has been reported for the Isle of Wight disease in England and for Nosema infection in Bavaria, Germany. It is, however, very similar to that of the infection as it has been reported from Australia (Price, 1910; Laidlow, 1911; and Beuhne, 1916).

SUMMARY AND CONCLUSIONS.

The following statements concerning Nosema-disease seem to be justified from the facts recorded in the present paper:

(1) Nosema-disease is an infectious disorder of adult bees caused by *Nosema apis*.

(2) The disease is not particularly malignant in character, being in this respect more like sacbrood than the foulbroods.

(3) Adult workers, drones, and queens are susceptible to infection, but the brood is not.

(4) The infecting agent *Nosema apis* is a protozoan that attacks the walls of the stomach and occasionally those of the Malpighian tubules.

(5) A colony can be inoculated by feeding it sirup containing the crushed stomachs of infected bees.

(6) One-tenth of the germs present in a single stomach are sufficient to produce marked infection in a colony.

(7) Within a week following the inoculation the parasite can be found within the walls of the stomach.

(8) Before the close of the second week infection can be determined by the gross appearance of the organ.

(9) The disease can be produced at any season of the year by feeding inoculations.

(10) Infected bees may be found at all seasons of the year, the highest percentage of infection occurring in the spring.

(11) Nosema infection among bees occurs at least in Australia, Switzerland, Germany, Denmark, England, Canada, and the United States. This distribution shows that the occurrence of the disease is not dependent altogether upon climatic conditions.

(12) The course of the disease is not affected directly by the character or quantity of food obtained and used by the bees.

(13) A sluggish body of water, if near an apiary and used by bees as a water supply, and the robbing of diseased colonies, must be considered for the present as two probable sources of infection.

(14) The transmission of the disease through the medium of flowers is not to be feared.

(15) The hands and clothing of the apiarist, the tools used about an apiary, and winds need not be feared as means by which the disease is spread.

(16) Hives which have housed infected colonies need not be disinfected and combs from such colonies are not a likely means for the transmission of the disease.

(17) Bees dead of the disease about the apiary are not likely to cause infection unless they serve to contaminate the water supply.

(18) *Nosema apis* suspended in water is destroyed by heating for 10 minutes at about 136° F. (58° C.).

(19) Suspended in honey, *Nosema apis* is destroyed by heating at about 138° F. (59° C.).

(20) *Nosema apis*, drying at room and outdoor temperatures, respectively, remained virulent for about 2 months, at incubator temperature about 3 weeks, and in a refrigerator about 7½ months.

(21) *Nosema apis* was destroyed in the presence of fermentative processes in a 20 per cent honey solution in 3 days at incubator temperature and in 9 days at outdoor temperature. In a 10 per cent sugar solution it was destroyed in from 7 to 11 days at room temperature.

(22) *Nosema apis* resisted putrefactive processes for 5 days at incubator temperature, for 2 weeks at room temperature, and for more than 3 weeks at outdoor temperature.

(23) *Nosema apis* when dry was destroyed in from 15 to 32 hours by direct exposure to the sun's rays.

(24) *Nosema apis* suspended in water was destroyed by exposure to the sun's rays in from 37 to 51 hours.

(25) *Nosema apis* if suspended in honey and exposed to the sun's rays frequently will be destroyed on account of the temperature of the honey which results from the exposure.

(26) *Nosema apis* remained virulent in honey for from 2 to 4 months at room temperature.

(27) *Nosema apis* in the bodies of dead bees ceased to be virulent in one week at incubator temperature, in 4 weeks at room temperature, in 6 weeks at outdoor temperature, and in 4 months in a refrigerator.

(28) *Nosema apis* in the bodies of dead bees lying on the soil ceased to be virulent in from 44 to 71 days.

(29) *Nosema apis* is readily destroyed by carbolic acid, a 1 per cent aqueous solution destroying it in less than 10 minutes.

(30) The time element which by the experiments is shown to be sufficient for the destruction of *Nosema apis* should be increased somewhat to insure their destruction in practical apiculture.

(31) The prognosis in Nosema-disease varies markedly from excellent, in case of strong colonies with a comparatively small percentage of Nosema-infected bees, to very grave, in case of weak ones with a high percentage of infected bees.

(32) From a technical point of view the results here given must be considered as being approximate only. They are, however, in most instances sufficient for practical purposes.

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BULLETIN No. 787

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. June 9, 1919

PROTECTION FROM THE LOCUST BORER.

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CONTENTS.

INTRODUCTION.

The increasing value of black or yellow locust[1] for many purposes, and especially the recent demand for sound locust pins or treenails in the construction of wooden ships, render its protection from insect damage important.

In addition to the natural growth of locust in forests, farmers' woodlots, and abandoned fields, many attempts have been made to grow it on a commercial scale in plantations. These attempts in most cases have resulted in failure, owing to the serious damage to the wood and frequently the destruction of the trees caused by the locust borer.[2] The fact, however, that in natural growth and occasional plantations practically no injuries from the borer are found, while in other cases the trees are ruined for commercial purposes or killed outright, has led the writer to make a thorough investigation of the problem to ascertain the cause of the occasional immunity from borer injury.

As a result of these investigations, it appears practically certain that *plantations of this tree can be protected successfully from*

[1] *Robinia pseudacacia* L.

[2] *Cyllene robiniae* Forst.

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the borer and grown profitably on a commercial scale if the locusts are planted in thick stands or mixed with other trees so as to produce a densely shaded condition and natural pruning during the first 10 to 15 years of growth.

HISTORICAL.

The great variation in the extent of injury by borers to both planted and natural stands of black locust has been noted by many writers. In fact, as early as 1821, Pickering (2)[1] stated that trees of natural growth in groves were much less liable to injury than were transplanted trees. Schwarz (3) in 1890 observed that the insect lives in large colonies affecting all trees of small groves, while long hillsides full of locust are not infested. Cotton (5) observed that in Ohio injury was greater in single trees and plantations of considerable size than in natural forests. Hopkins (6) remarked that "Favorable conditions for the destructive work of the borer appear to be found in the presence of isolated trees and groves in the open. . . . Unfavorable conditions are found in forest growth or large areas of pure stands, or mixed stands where the locust predominates; also, in plantations and groves where resistant varieties prevail, and where there is no goldenrod or other favorite food for the beetles." Dearborn (1), Kellogg (4), and Garman (7) also call attention to this fact.

OBSERVATIONS BY THE WRITER.

In examining locust plantations during the last few years, the writer was greatly impressed with the absolute destruction of some tracts, while others, or parts of the same tracts, were thrifty and unmarred by borers. This was convincing evidence that the trees could be grown so as not to be injured by the locust borer. Many tracts, therefore, both planted and natural, were studied with the idea of securing evidence that might be applicable in a practical way. As far as possible the accurate history of many locust stands, both pure and mixed, was obtained and factors that might be responsible for the presence or absence of injury were weighed. As a result of such study, it was found that the amount of destruction was unquestionably greater in those tracts which had been pruned occasionally, closely grazed, or in which fire had gone through from time to time, killing out the underbrush and destroying the natural shade produced by weeds or shrubbery. The denser the growth, particularly weeds and undergrowth about the stem of the tree, the less was the amount of borer work and vice versa. Pure stands in open fields, where the trees were growing from 2 to 3 feet apart, were seldom injured, while near-by isolated trees were riddled by the borer.

[1] Reference is made by number in parenthesis to "Literature cited," p. 12.

Possible reasons for such immunity in dense stands were discussed with Dr. A. D. Hopkins in several letters during May, 1910. In a letter of May 11 Dr. Hopkins wrote:

Perhaps with the unpruned trees there is more shade and, since the beetles are sun-loving and active during the day, the more open and light conditions found in the pruned groves may serve as the attractive influence. This is the only thing I can think of that would make the difference. Observations should be made during the period of flight to determine the relative number of beetles found on trees under shaded and sunny exposures.

If this should lead to a solution of the problem and shaded conditions are favorable, then mixed planting with some quick growing tree like catalpa might be advisable.

This seems a very plausible theory to account for the immunity of unpruned and natural growths, and it is substantiated in the experiments conducted. No other factors considered seem to cover the conditions in the many localities where trees were examined.

INVESTIGATIONS AND EXPERIMENTS.

Natural growths of locust in the vicinity of Falls Church, Va., and plantations along the Pennsylvania Railroad right of ways were selected and used as experimental plats. Some of these near Falls Church were pruned while others were left as they were found. The history of plantations along the Pennsylvania Railroad as to planting and subsequent management has been furnished by the office of the forester of the railroad, which also provided facilities for the study of these plantations.

NATURAL GROWTH IN THE VICINITY OF FALLS CHURCH, VA.

1. On Miners Hill there is a stand of mixed growth of reproduction averaging 3 to 5 inches in diameter. The aspect is a westerly slope, the trees extending from the crest more than half way down the hill. It contains about an acre and is composed chiefly of oak, chestnut, tulip, persimmon, hickory, sassafras, maple, and locust. It is thickly undergrown with weeds and briers which now are dying out. The locust composed about 5 per cent of the stand. In the fall of 1915 these locusts were from 2 to 3 inches in diameter and contained no borers. In January, 1916, one end of this plot, constituting about one-tenth of the area, was pruned; all trees, except the locust, were cut out. The following fall adult beetles were observed ovipositing on the trees thus isolated, and examination in the spring of 1917 showed from 3 to 10 borers in each tree. Again in 1918 these trees were found to be heavily infested. In the remainder of the stand (that which is still growing naturally) about 1 tree in 10 can be found containing one or rarely two defects made by the borer.

2. Just across a road from the tract described above is an old orchard which is used as a pasture. About two dozen locusts of the

same age are growing here. These trees are gnarly, some broken off, and all heavily infested. In the spring of 1918, 10 to 35 larvæ were found in each of these trees. The cattle have kept down the weeds and underbrush which would otherwise protect the trunks.

3. In the same general locality, about one-half mile north of these tracts, lies an abandoned field covered with an almost pure stand of virgin scrub pine 12 to 14 years old. Mixed in this pine are quite a few locusts. During the winter of 1915–16 about an acre of this pine was cleared. The locusts, then averaging 4 inches in diameter, were left standing. None of the trees were infested, as were none of those in the midst of the remaining pine. All were straight, naturally well-pruned, thrifty trees. In the fall of 1916 these trees were attacked by the beetles, and many larvæ were found in them in the spring of 1917. The land has not been cultivated, so that a dense growth of weeds conceals the trunks for 6 to 8 feet above the ground. Scarcely any adults were found on these trees in the fall of 1918, and very few larvæ are expected in the spring of 1919.

In January, 1918, another part of this pine wood was cleared, leaving 15 trees exposed. In July the trees were examined and no borers found nor any evidence of injury in the past. During August and September, 1918, adults were observed ovipositing on these trees.

4. Another abandoned field on an easterly slope contains a clump of about a hundred small locusts, 2 to 6 inches in diameter, grouped about several large trees. These are closely spaced, averaging 2 feet apart. They are well mixed with sumac, tulip, and sassafras. In the surrounding field are many isolated trees. All these isolated trees are scrubby and badly infested by repeated borer attack, while those in the dense clump are tall, thrifty, and contain no borers or defects from past injury.

5. Another abandoned field one-half mile north of Green Gables station on the Washington and Virginia electric line contains several groups of locust from 6 to 18 years of age and many isolated trees. This field contains about 100 acres. Clumps of sassafras and pine mixed with locust and persimmon occupy much of the remaining area. Broom sedge and goldenrod cover the ground on all open spots. All isolated locusts are heavily infested and have been damaged severely by the borers. Many of these trees have fallen over (Pl. I, fig. 1).[1] Three excellent stands of locust occur here; one group of an almost pure stand is composed of trees 25 to 30 feet high and 6 to 8 inches in diameter. They grew very close together and have now thinned out to an average of 10 feet apart. There are more than 500 trees in this plot; all are thrifty and no evidence of borers can be found. They represent what can be grown in 18 years' time on

[1] The photographs were taken by Mr. R. A. St. George, scientific assistant, Forest Insect Investigations, Bureau of Entomology.

FIG. 1.—NATURAL GROWTH OF LOCUST IN AN OLD ABANDONED FIELD OF SOME 60 ACRES IN EXTENT AT FALLS CHURCH, VA.

Trees badly infested by the locust borer. Several killed and others blown over. Note scattered position. Diameter near base, 2 to 6 inches.

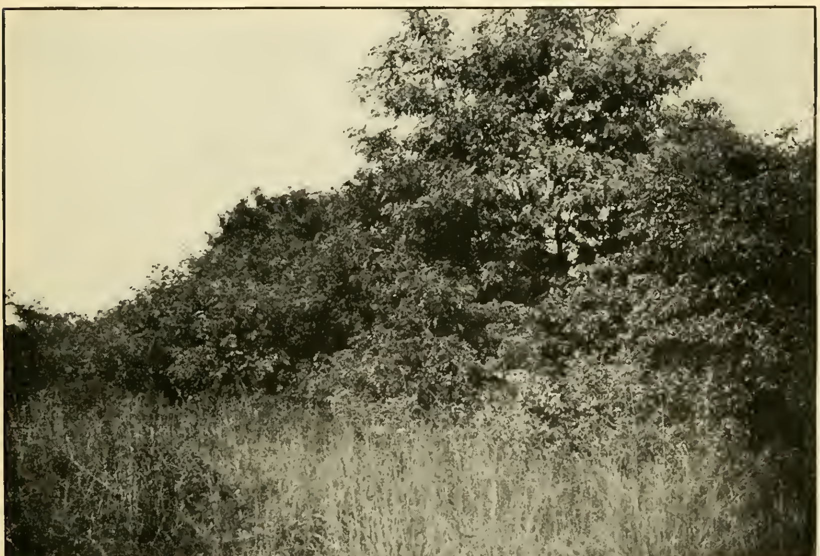

FIG. 2.—NATURAL GROWTH OF LOCUST IN AN OLD ABANDONED FIELD OF SOME 60 ACRES IN EXTENT AT FALLS CHURCH, VA.

Several old seed trees and surrounding root sprouts and seedlings. Note thick growth. None of these trees are infested. Diameter near base, 1 to 8 inches.

FIG. 1.—NATURAL GROWTH OF LOCUST IN AN OLD ABANDONED FIELD OF SOME 60 ACRES IN EXTENT AT FALLS CHURCH, VA.

An isolated clump of some 30 trees, 2 to 4 inches in diameter. These were growing close together and mixed with tall weeds and sassafras bushes. Illustration after clearing the trunks in July when not a single borer was present. In September these were heavily infested.

FIG. 2.—ILLUSTRATION OF A FENCE ROW AT FALLS CHURCH, VA., SHOWING THICK LOCUST GROWTH OF 2 TO 5 INCHES IN DIAMETER NEAR BASE.

None of these trees contained borers in July, 1918, when the underbrush and small branches were cleared from the trees in the foreground. These trees were infested in September.

PROTECTION FROM THE LOCUST BORER.

FIG. 1.—A DENSE GROWTH OF ROOT SUCKERS FROM A FEW OLD TREES THAT WERE REMOVED, ON MINERS HILL NEAR FALLS CHURCH, VA.

This illustrates the type of growth that will not be attacked. In the background to the right of the road are many trees containing 5 to 20 borers each. It illustrates the pruned portion of example 1 (see p. 3).

FIG. 2.—LARGE MATURED LOCUSTS AT VIENNA, VA., SHOWING WHAT CAN BE GROWN IN A LOCALITY WHERE THE BORERS ARE VERY ABUNDANT.

These trees show no evidence of borer injury.

PROTECTION FROM THE LOCUST BORER.

old waste land, the soil of which has been enriched by a thick bed of humus beneath the trees.

Another group (Pl. I, fig. 2) near by contains about 30 trees similar in respect to size and conditions. These have seeded the surrounding soil so that a large clump is formed of dense growth, the outermost being some 6 to 8 feet high. None of these trees have been injured by the borer. A third group (Pl. II, fig. 1), forming a small oval clump, contains 38 trees from 2 to 4 inches in diameter and 15 feet high. They were closely set, averaging 4 feet apart. A few sassafras were intermixed. In July, 1918, not one of these trees contained a borer. August 20, 1918, the plot was thinned, all branches trimmed to 8 or 10 feet, and all weeds and briers removed. The trees were closely watched and many adults were observed ovipositing on them during September.[1] Adults were likewise observed on the isolated trees near by, but none in the dense plats described above.

6. A fence row opposite the eastern field station at Falls Church, Va., is densely matted with wild cherry, honeysuckle, and goldenrod along the sides. Through this grow a dozen locusts (Pl. II, fig. 2) 2 to 4 inches in diameter. None of these trees were infested on or previous to August 15, 1918, on which date all the surrounding growth was cleared from four trees. During September adults were observed ovipositing on these four. Many such fence rows exist wherever locust is grown and explain why so little trouble is experienced on the average farm.

7. Along the south bank of the Potomac River between Difficult Run and Scotts Run many locusts are growing on the wooded slope. This stand is a hardwood mixture composed chiefly of oak, chestnut, hickory, tulip tree, basswood, and butternut. All the locusts are tall, straight poles, reaching to the top of the stand, the trees averaging from 6 to 18 inches in diameter. All show a thrifty condition of growth and no borer defects. A low meadow, sometimes cultivated but now pastured, lies between this river terrace and the water. A few occasional locusts grow here, nearly all of which are infested and badly deformed. No goldenrod occurs in the meadow, and the adult beetles were observed to feed on several species of Eupatorium.

PLANTATIONS ALONG THE PENNSYLVANIA RAILROAD.

From the office of the forester of the Pennsylvania Railroad records have been secured of 42 plantations, comprising nearly 2,000 acres, on which over 1,000,000 trees were planted. These trees were about 2 years old when set out and usually were spaced 8 by 8 or 8 by 10 feet. Many of these tracts were personally examined by the writer, accompanied by Mr. I. T. Worthley, assistant forester. The history of each plantation was ascertained as accurately as possible.

[1] Examination of this plot on Apr. 8, 1919, showed an average of 15 borers per tree.

Some of these tracts are in excellent condition, others almost totally destroyed. It is necessary to describe only a sufficient number of these to give all conditions of culture and past history.

8. Along the line of the railroad, between Philadelphia and Harrisburg, Pa., near Kinzers, are two locust plantations, one on the south side planted in 1904, one on the north planted in 1905. Together they comprise about 25 acres, containing 44,000 trees. As far as can be ascertained, nothing was done in these plots until 1909 and 1910, when thorough prunings took place. The entire tracts were gone over and all the trees trimmed to a single straight stem. All natural growth of other trees or shrubs was thinned out. The writer personally assisted in one of these thinnings in 1910 and at that time noted a few borers in the larger trees. Nothing more was done, but an examination in 1912 showed the borer very abundant and many trees breaking off. At present it is difficult to find a good tree. A few have not been injured sufficiently to cause them to break, but the great majority form a broken tangle. Many root sprouts and suckers are present. These are now meeting the same fate.

9. Near New Brunswick, at Stelton, N. J., are several more plantations in a long strip on the old roadbed comprising some 8 or 10 acres of 13,000 trees. One of these lies along the present roadbed near the station. These trees have been pruned from time to time by the section crews. At present they are badly infested (in the spring of 1918 averaging 10 living borers to a tree) but few broke off until the summer of 1918, when a severe wind destroyed about 5 per cent. These trees average 2 to 5 inches in diameter.

Farther west, some distance from the present roadbed, is a similar stand planted at the same time. No care was taken of it and the trees grew up in thick weeds and other natural, shrubby growth. They are scarcely close enough to produce much natural pruning and all have several large branches. An examination in 1917 and 1918 showed that only a very few trees were infested or ever had been infested. The average diameter is larger than that of those nearer the station.

10. One mile east of Metuchen, N. J., are 10,000 trees planted in 1909, divided into about equal stands, one on the south and one on the north side of the roadbed. The north plot was pruned at two different times, but the years could not be determined. In the spring of 1918 all these trees were badly infested and many were broken off. Many root sprouts and suckers have grown out. The trees on the south side never were pruned or thinned. In the spring of 1918 it was almost impossible to find a borer in the tract; however, a certain amount of old work was present, though not sufficient to mar the trees greatly. These trees were not planted close enough to cause natural pruning and consequently are considerably branched. Very

few root sprouts occur in this tract. They are now producing a more dense shade and natural pruning is taking place. At an earlier date, when the trees were less dense, borers attacked, but as the density increased they probably were repelled before the trees were seriously injured.

The diameter of the stand on the south side averages several inches more than that of the standing trees on the north side. If these trees on the south side had been planted several feet closer, say 6 by 6 instead of 8 by 10 feet, it is the writer's opinion that they would now have unbranched stems with practically no borer defects.

11. On the low-grade freight line between Martic Forge and Columbia, Pa., are five plantations set out in 1906 containing about 150,000 trees. None of these have ever received any attention in the way of pruning. They present conditions varying from such as described at Kinzers (example 8) to almost perfect stands free from borer injury. In no single plantation are the trees all destroyed or all in good condition, but the extremes are found in different parts of each tract. Another factor has been responsible here. A definite correlation exists between those parts of the plantation that have been run over by fire and those parts which were by nature of their position less subject to fire. Where fire has burned over repeatedly, killing the undergrowth, the worst destruction by borers is found. In many places the locusts themselves have been killed. One tract near Shenks Ferry attracted particular attention. It extends from the roadbed across a bottom and up over a hillside. Fire no doubt has gone through the part near the tracks repeatedly, as evidenced by the different ages of scars on the standing trees. Here there is little undergrowth; the locusts are scattered (many have been fire-killed), and all are severely infested. On the hillside and over the crest, fires, for some reason, have not gone through. The locusts have grown up in a dense stand mixed with much underbrush, and oak and chestnut sprouts from the original stumpage. These trees are now in excellent condition; they are tall, straight, thrifty, not branched, and free from borer defects. In some parts the shade of the mixed stand has become so dense that all weeds, briers, and underbrush have been shaded out.

12. Along the railroad between Harrisburg and Huntingdon, Pa., much locust has been planted, and many natural stands occur. The condition of the locust in this region is generally so much better and so much more thrifty that the first examination gave the impression that it is an exceptionally favorable situation for the growth of the tree. It is no doubt true that certain localities are better adapted to the growth of black locust, but the essential factor in this location is considered to be more than purely a favorable situation. The locusts are growing in a narrow belt of river terrace from a few

yards to a mile wide between the foot of the mountain and the Susquehanna and Juniata Rivers. There is much humidity, and all vegetation is vigorous.

It is believed that the good condition of these locusts and the decided absence of injury by borers are due to the fact that the situation is conducive to a rapid growth of underbrush and plants characteristic of river shores which have afforded protection to the locusts. This is further emphasized by the fact that in other localities are found trees of equal size and good appearance, as described at Shenks Ferry (example 11), of the same age. Also in the same locality we find trees deformed and aborted by borer injury, as described in the following paragraph.

13. Along the Juniata River between Newport and Old Ferry, Pa., a continuous plantation of locust set out in 1904 extends for a distance of 2 miles. These trees, especially that part near Newport, show the best stand of all the plantations. After planting no attention was given them until 1914, when they were thinned to afford a view of the river from the trains. At this time most of the stems had reached a sufficient size to be immune from borer attack. The trees nearest Newport now average 5 to 8 inches in diameter. They are straight, free from branches, and about as tall as the telegraph poles near by. The bark is ridged naturally, showing absence of borer injury in the past. Nothing definite as to how these trees grew in the period intervening between planting and first pruning could be ascertained, but from a study of many plots of all ages along the river it is certain that they were intermixed with a dense growth of other shrubs and weeds. Natural pruning and thinning have taken place to such an extent that few living branches are found below the crown, and many trees have been suppressed and killed. Farther back from the railroad, where no pruning at all was done, the dead, suppressed trees and shaded-out branches give a good idea as to how rapidly this process takes place in the tree.

In this 2-mile strip of locusts the borers are serious in two places and have caused many trees to break off or have stunted the growth badly. In one of these places fire has gone through; the other was evidently pruned (as shown by scars) to afford a view of a pond just behind. These last trees were also isolated in the sense that the rows were only two trees deep. These trees average scarcely half the diameter of those in the better parts of the grove.

CONDITION OF TREE NECESSARY FOR BORER ATTACK.

All trees and all parts of the tree are not subject to attack by the borer to the same degree.

Moderately rough bark seems to be an essential condition, since it provides the necessary crevices in which the adults deposit their eggs.

Likewise, until they become $1\frac{1}{2}$ to 2 inches in diameter at the base, trees are not subject to attack unless the bark is rough. On younger trees the borers are found concentrated at the base and near crotches.

For some unknown reason trunks of trees reaching 5 to 6 inches in diameter and over (excepting old brood trees) rarely are found to contain borers. On such trees the larger branches frequently are infested, but such injury is seldom common enough to do much harm or even attract attention. It can be said, therefore, that protection from borer injury is necessary for only a comparatively short period during the tree's growth. Under good growing conditions this time should not exceed 10 years.

In every locust grove that has borers present, certain trees will be found on which they have concentrated. These are called brood trees. The thick, irregularly barked, gnarled appearance and stunted growth will distinguish such individuals. They are often continuously infested until they reach an old age, or 12 to 18 inches in diameter.

HOW TO RECOGNIZE TREES CONTAINING NO BORER DEFECTS.

The larval mine made by the locust borer destroys a certain amount of the growing tissue or cambium and makes a serious defect in the wood. This injury to the cambium accelerates growth to heal it over and produces a swollen or gnarly appearance. Many such defects give the entire stem a roughened, distorted shape. The bark is irregular and scaly. On the other hand, trees that have not been injured by the borer are characterized by very regular bark, which is grooved longitudinally between thick, dark ridges. With a little experience these features can be quickly recognized and until the tree reaches 10 to 12 inches in diameter it is possible to determine accurately whether the borer defect will be found in the wood.

CHARACTER OF GROWTH OF UNINFESTED STANDS.

Not only is the appearance of uninjured individual trees characteristic but pure stands of such trees have a different appearance from those that are damaged. The tops of isolated natural stands have a domelike outline, the innermost trees growing taller and straighter, while root sprouts continuously coming up around the borders form smaller and younger trees which give additional protection to those within. These younger trees are at first too small for infestation, and when they have reached a susceptible size are protected in their turn. The crowns are uniformly shaped and no branches project to break the contours. Planted stands, where the trees are of the same age, are uniform in height, the tops forming a flat outline. No large branches are found on the trunks, but many small, naturally pruned dead branches are seen and many trees are thinned out naturally as the others increase in size. Few root sprouts appear. Infested plantations are very irregular in outline; broken tops, trees of irregular size, and many root sprouts and suckers are characteristic indications of borer damage.

CONDITIONS UNDER WHICH LOCUST CAN BE GROWN.

From the history of the foregoing tracts it is evident that black locust can be grown profitably under circumstances that require little care, or, in fact, better results are obtained without too much attention. After comparing all the data available it seems that *provision for sufficient shade during the period of growth subject to borer attack* is all that is necessary in order that this tree may be grown successfully.

This can be achieved by some system of close and mixed planting. Experiments of such a character should be tried. In nature it is accomplished by close reproduction coming up around the seed tree, by root sprouts from older trees, or often by the mixture of other plants growing with the locusts. Weeds and vines often form the needed shade, as illustrated by trees in old fence rows. It is very essential that this shade be present after the trees reach 1½ to 2 inches in diameter, and that it be continued until they attain 5 or 6 inches. After this time thinning and pruning can be done with little or no subsequent injury by the borers.

Close planting or thick growth of these trees also is necessary to produce straight, unbranched boles. Trees in the open are always much branched and rather crooked, but those grown in forests are tall, straight, and naturally pruned while the branches are quite small.

That difference in site or locality is not the influencing factor in the growing of uninjured trees is evident from the fact that in every locality examined it was possible to find examples of borer-free and destroyed trees growing 100 yards apart. It is also evident that goldenrod is not necessarily associated with greater damage by the borer, for in the same abandoned field, massed with this plant, were found plots of trees absolutely free from injury and near-by isolated trees badly infested. Again, localities where no goldenrod is growing may have borer-infested trees, the adults feeding on other composites, as illustrated by example 7.

The idea has been advanced that the borers are more abundant in some localities than in others and that this will account for the difference in infestation. This difference can not be sustained, as the beetles are present everywhere within the natural range of this tree. Side by side we find stands of badly infested trees and trees containing no borers. It is rather to be believed that in localities where locust was planted the beetles present either remained in about the same numbers or increased enormously, according as the condition of the trees retarded or favored their increase. In no new locality where plantations were put out would there be enough beetles present to infest all the trees. They only attack all the trees as they become sufficiently numerous.

CONTROL.

A METHOD OF HANDLING SEVERELY DAMAGED PLANTATIONS.

Many locust plantations have been abandoned and all hope of ever realizing any commercial product given up because of the severe devastation produced by the borers. Such tracts look hopeless with the greater percentage of the trees broken off or killed, but it is believed that they can be reclaimed after several seasons' care by virtue of the sprouting ability of this tree.

It is recommended that all such plantations be gone over and the broken-down and infested trees removed and burned during the winter. Unless otherwise desired it would be necessary to cut out only the living infested trees, because no beetles will breed in the dead ones. Especial attention should be given to the seriously damaged or so-called brood trees. If the cutting out of the infested trees can be done early in November it is not necessary to destroy or burn the wood. The larvæ require living wood for their early development and will not mature in dead material. This not only will reduce the numbers of the insects, but before the sprouts become large enough to be attacked a sufficiently dense stand will have been developed to provide natural protection, as illustrated in Plate III, figure 1.

TREATMENT OF SHADE TREES.

The locust is widely planted for ornamental and shade purposes. It is very desirable for such planting, because of its ability to succeed well in a variety of soils and situations and its rapid growth and good form of crown in the open. We often hear complaints of serious injury by the borer to locust shade trees; this is because such trees are usually grown in isolated situations most favorable for attack.

It has been found that the young borers can be killed readily by the use of an arsenical spray, applied to the bark when the new growth begins to open at the tips of the twigs in the spring. It is necessary to apply this mixture so thoroughly as to cover all parts of the trunk and reach every spot where a larva is working.[1]

A thorough application will probably be necessary only every two years unless there are badly infested trees near by which are not treated and form centers of reinfestation. As a rule, spraying will

[1] The presence of a young borer can be determined by the oozing of sap and boring dust from a small hole through the bark. This hole is enlarged as the larva grows.

not be necessary after the trees reach 6 inches in diameter or such a size that they are immune from attack. Isolated trees, however, are sometimes exceptions to this and should be watched.

Many spray solutions have been tried by the writer, but by far the most successful has been the combination of a soluble arsenate with an oil emulsion. This provides a penetrative poison which enters the exudation pores made by the larvæ through the bark and poisons the inner bark on which the young larvæ feed. Insoluble arsenates are not so effective, as the exudation pore is usually plugged with a wad of fine granular frass from which the arsenate in suspension filters out. Kerosene emulsion can be used to carry the arsenical, but it has been found that the miscible oils are just as satisfactory and require much less time in preparation.

The formula and preparation are as follows:

Dissolve ½ pound of sodium arsenite or arsenate in 5 gallons of water. Add 1 quart of miscible oil and agitate thoroughly.

With kerosene emulsion, dissolve ¼ pound of the arsenical in 4 gallons of water and add 1 gallon of stock solution of kerosene emulsion, agitating thoroughly.

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[1] Other papers dealing with the locust borer will be found in the bibliography given by Dr. A. D. Hopkins in the bulletin entitled "Some insects injurious to forests: The locust borer." (U. S. Dept. Agr., Bur. Ent. Bul. 58, pt. I.)

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 796

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. October 21, 1919

USE OF TOXIC GASES AS A POSSIBLE MEANS OF CONTROL OF THE PEACH-TREE BORER.

By E. B. BLAKESLEE, *Entomological Assistant, Deciduous Fruit Insect Investigations.*

CONTENTS.

INTRODUCTION.

The study of poisonous gases and their use as a possible means of control of the peach-tree borer, *Sanninoidea exitiosa* Say, of which the present paper is a brief report, was begun in 1915, under the direction of Dr. A. L. Quaintance, in charge of deciduous fruit insect investigations, of the Bureau of Entomology. In this investigation the attempt has been made to develop a method of control by the use of local applications of volatile toxic compounds in the soil at the base of the trees. On account of the intimate association of the insect and its host, any gas fully efficient as a larvicide must necessarily have more or less effect upon the tree. In this respect, however, the problem presents nothing unusual, as the application of insecticides generally and the fumigation of living plants especially is restricted to a greater or less extent by the same limitation. In the case of the peach-tree borer the insect and its host are by no means susceptible to fumigation in the same degree. Also, for various reasons, a much wider margin of safety to the tree is afforded by some gases than by others.

It has been necessary, in regard to fumigation, to take into consideration the manner in which it is affected by soil and atmospheric temperatures, soil type, soil moisture, rainfall, seasonal development of the insect and its host, and their relation to the chemical properties of the materials tested, such as the volatility and solubility of the gas, etc. In 1916 daily determinations of soil moisture and records of soil and atmospheric temperatures and rainfall were obtained in connection with each experiment, but on account of the

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infinite variation of such factors under field conditions it has been found impossible to correlate these data with the results of the experiments except in a very general way. For the most part, therefore, conclusions have been based on the results of fairly extensive field tests with only a general analysis of the conditions involved.

A number of substances have been tested and many data accumulated which it is impossible to include in the present paper. In so far as promise of providing a safe and effective control measure for the insect is concerned, all of the gases tested have given negative results except one, p-dichlorobenzene. The results obtained from the use of this material are so promising that it has seemed best to report upon the present experimental status of the work for the information of others interested in the problem. Also it is hoped that as far as possible useless duplication of work with some of the other less promising gases may be prevented.

EXPERIMENTAL PROCEDURE.

As already stated, the essential idea of the experiments involves application of volatile toxic compounds to the soil at the base of the trees. In one experiment small tents were used to confine the gas, but this method, on account of the mechanical difficulties involved, was never used to any great extent. The soil under all ordinary conditions proved a fairly satisfactory container for the gas. Whether the material was applied in water solution or in its original form depended upon its chemical properties. Whenever possible both methods of application were adopted. When applied either in solution or suspended in water, a trench was dug about the collar of the tree as for "worming" and the required dose, in from 1 to 2 gallons of water, puddled about the trunk, after which the soil was replaced and compacted. When applied in its original state the material, if a liquid, was poured into the soil about the collar, and if a solid, was buried in the surface soil about the trunk.

Two methods of ascertaining results were followed. In the first the treated trees were examined within a short time after application, usually within a few days, the results being judged by the mortality of the larvæ. The interval from application to examination was usually varied sufficiently to determine the toxicity of the fumigation. In the second method the treatments were made either in late fall or early spring and examination made several weeks or several months later, before the infestation of the next season. By this time dead larvæ usually had largely decomposed, and it was necessary to judge the effectiveness of the fumigation by a comparison of the number of active larvæ escaping on the treated trees with the number active on untreated trees in adjoining rows. In all cases the effect of the fumigation on the tissues of the tree was carefully noted, the margin of safety being considered as fully as the larvicidal action of the gas. Injury to the trees has been classified under the following terms: Trace, slight, moderate, severe, and maximum. Maximum injury applies to cases where the tree has been girdled completely by the fumigation, and no doubt remains of its immediate death. Severe injury indicates that the tree has been girdled partially, sufficient to destroy permanently its productive value, but not to cause its immediate death. The other terms, moderate, slight, and trace, represent a gradually diminishing degree of injury, the last term indicating that the effect of the gas was only sufficient for identification. The first two terms, trace and slight, represent injury which is of little or no importance as far as the effect upon the tree is concerned.

EXPERIMENTAL RESULTS.

MISCELLANEOUS GASES.

The principal materials that have been tested are carbon disulphid, carbon tetrachlorid, hydrocyanic-acid gas, naphthalene, and para-dichlorobenzene. In the discussion of the relative merits of these materials the results are given in detail only for the last, p-dichlorobenzene.

Carbon Disulphid.

In 1902 Woodworth[1] recommended the use of carbon disulphid against the western species of peach borer. Under the proper condition of soil moisture and temperature it is a most efficient larvicide. In practice, however, it was found impossible to standardize its use to an extent which would make it both safe and effective. The main difficulty with this material arises from its great volatility at ordinary temperatures, which makes it very sensitive to variations in soil porosity. In very dry or porous soils, large doses of several ounces may be applied with no effect upon the larvæ. On the other hand, in very moist, tight soils, large vigorous 12-year old trees have been entirely girdled by an application of as small a dose as one-fourth of an ounce. Its application in water emulsion was found to standardize soil conditions greatly, and successful treatments by this method with greatly-reduced doses have been made on hundreds of trees without injury. A very slight misjudgment in dosage for a given set of conditions, however, gave results of an opposite character, and after two and one-half years' experience with this gas its use has been entirely abandoned.

[1] Woodworth, C. W. The California peach-tree borer. Cal. Agr. Exp. Sta. Bul. 143. 1902.

CARBON TETRACHLORID.

Carbon tetrachlorid does not differ essentially from carbon disulphid, in so far as its effect upon the tree or its larvicidal action is concerned. To achieve the same result it seemed to require about double the dosage of the disulphid. Its chief merit as a fumigant seems to lie in the fact that the vapor is not inflammable.

NAPHTHALENE.

Naphthalene was tested quite fully in 1916 and 1917. For the greater part of the year it vaporized just fast enough to give the soil about the base of the tree a pronounced odor, but apparently produced no effect upon the insect or the tree. With a soil temperature of 70° F. and over, attained in July and August, there is a very decided larvicidal action, but not sufficient to make this material of value.

HYDROCYANIC-ACID GAS.

Hydrocyanic-acid gas, while a very effective larvicide, proved too dangerous. The great solubility of this gas effectually prevents the standardization of its use. Variation in moisture content and in the type of soil so greatly affect the absorption of this gas by the latter that it has been found impossible to establish any standard dosage that is both effective and safe for any number of conditions. Moist soils required much larger doses than dry soils or soils of low water-holding content. This point has been fully covered by Ong[1] in a recent publication. The great solubility of the gas, furthermore, leads to its rapid absorption by the portions of the tree with which it comes in contact, which probably explains in part the considerable injury resulting from its use.

PARA-DICHLOROBENZENE.

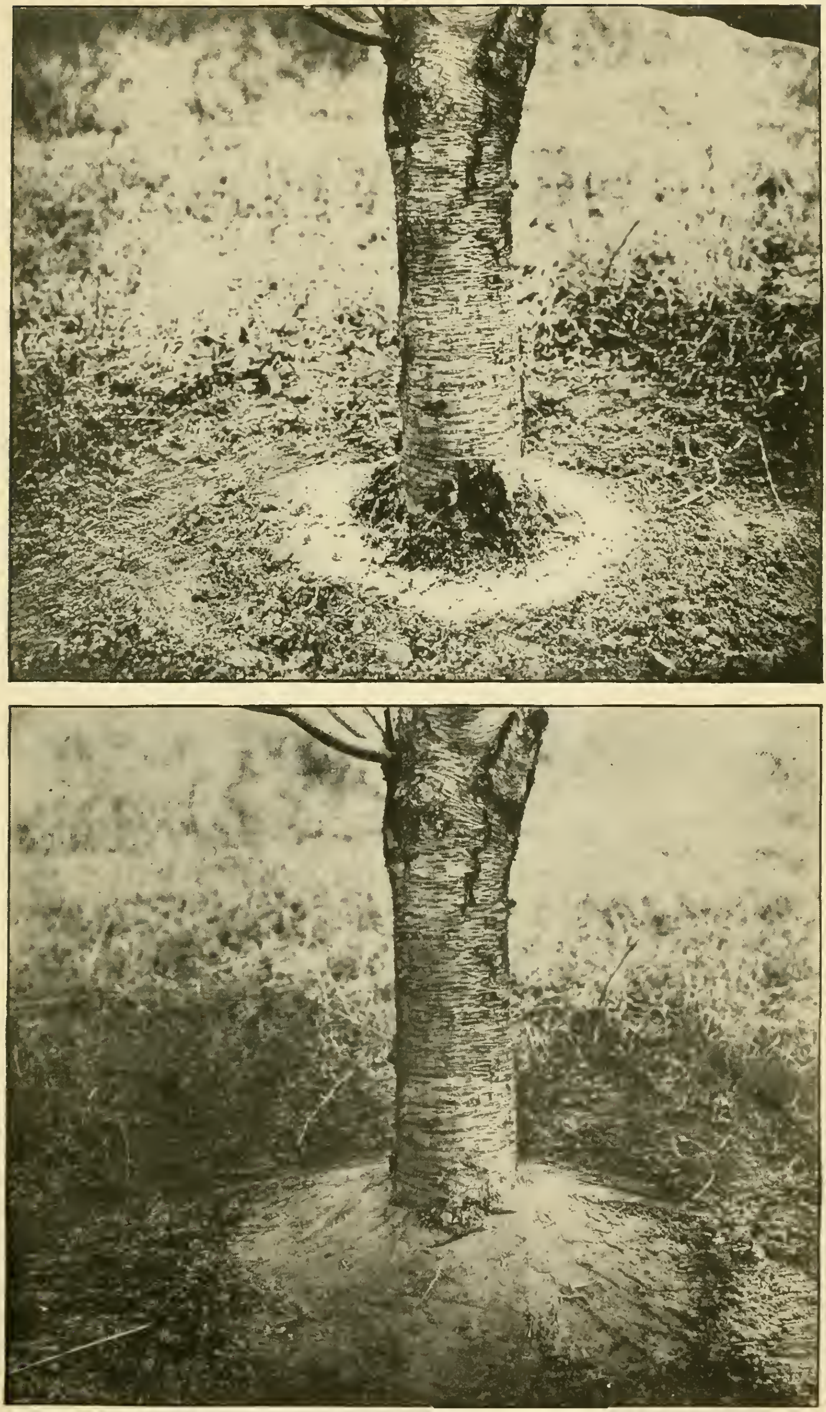
INSECTICIDAL, PHYSICAL, AND CHEMICAL PROPERTIES.

Of the various volatile compounds tested, the merits of some of which have been briefly discussed, para-dichlorobenzene has been by far the most promising. While well known chemically, its value as an insecticide is of comparatively recent discovery.

Of the various volatile compounds tested, the merits of some of which have been briefly discussed, para-dichlorobenzene has been by far the most promising. While well known chemically, its value as an insecticide is of comparatively recent discovery. Duckett,[2] in 1915, published a report on the insecticidal value of its vapor as a fumigant against various insects. Later in the same year Cook,

[1] ONG, E. R. DE. HYDROCYANIC-ACID GAS AS A SOIL FUMIGANT. *In* Jour. Agr. Research, v. 11, no. 9, p. 421–436. 1917.

[2] DUCKETT, A. B. PARA-DICHLOROBENZENE AS AN INSECT FUMIGANT. U. S. Dept. Agr. Bul. 167. 1915.



METHOD OF APPLYING PARA-DICHLOROBENZENE FOR CONTROL OF THE PEACH-TREE BORER.

Above: Tree with soil crust broken about the collar and one ounce of para-dichlorobenzene applied.
Below: Same tree with soil placed over the material and compacted.

Hutchison, and Scales[1] reported rather indifferent results from its use against fly larvæ in horse manure. Moore[2] used it in 1916 in the fumigation of animals to destroy their external parasites and found it less effective for that purpose than nitrobenzene. Its chemical formulæ and physical properties are discussed fully in Duckett's report. It is a crystalline solid at ordinary temperatures, insoluble in water, melting at 53° C., and boiling at 172° C. Like naphthalene it vaporizes much below its boiling point, although only very slowly at ordinary temperatures. Its vapor pressure and rate of volatilization are discussed on page 21. Apparently, however, when vaporization takes place in a closed container of a capacity appropriate to the dose, or under conditions approximate to that, the evolution of gas even at ordinary temperatures is sufficiently rapid to produce eventually an atmosphere of toxic saturation.

Method of Application.

The method of application for the use of p-dichlorobenzene against the peach borer is illustrated in Plate I. The mechanical condition of the material, on account of its relation to the rate of evaporation, is of considerable importance. The action of the gas is quite local and an even distribution about the tree is highly desirable. It was found that p-dichlorobenzene was most convenient and satisfactory for use when pulverized to about the fineness of coarse salt or granulated sugar. The form in which it usually appears on the market may be reduced to this condition by crushing and sifting through a 12-mesh screen. In this condition it does not lump badly, can be evenly distributed, and vaporizes at about the proper rate.

In making application the soil crust is first broken to a depth of 1 or 2 inches with a hoe, or some other suitable tool. The vapor of p-dichlorobenzene is about five times heavier than air and it is not desirable to apply it deeper than is necessary to avoid washing and surface loss of gas. The soil is not scraped away from the collar of the tree unless there is a decided mound. The material is placed as nearly as possible at the level of the uppermost galleries. The soil, moreover, should not be disturbed except to break up the surface crust. The gas will permeate very tight soils readily, and any unnecessary digging up of the soil about the collar only makes more air space to be saturated, and increases the chance of ineffective fumigation. After the preparation of the soil surface the p-dichlorobenzene is sprinkled as evenly as possible about the collar of the tree in a band 1 or 2 inches wide. In practice the material may be con-

[1] Cook, F. C., Hutchison, R. H., and Scales, F. M. Further experiments in the destruction of fly larvæ in horse manure. U. S. Dept. Agr. Bul. 245. 1915.

[2] Moore, Wm. Fumigation of animals to destroy their external parasites. *In* Jour. Econ. Ent., v. 9, no. 1, p. 71–78. 1916.

veniently carried in an open pail and the dose measured in a graduate holding just the desired amount. A little preliminary practice with the graduate and scales enables one to gauge the dosage very correctly. It is probably best to keep the material from actual contact with the bark by perhaps half an inch, although the practical importance of this precaution is not known. Finally, the material is covered to a depth of 2 inches with two or three shovelfuls of soil, and this slight mound compacted by a few sharp blows with the back of the shovel. The soil is the container for the gas, and the success of the fumigation depends upon the vapor being given off faster than it is lost. At best there is considerable surface loss of gas, and the final compacting of the soil is of considerable importance. No lumps or stones are left against the trunk above the surface to furnish a harbor behind which newly-hatched larvæ may begin feeding out of reach of the vapor. No effect, of course, can be produced upon larvæ feeding in galleries above ground.

Larvicidal Action.

To determine the actual larvicidal value of the vapor of p-dichlorobenzene, a series of applications were made to trees in the field at Springfield, W. Va., in 1916. The approximate limits of effective dosage had been fairly well established by preliminary experiments. Each dose was applied to 20 trees and these examined in lots of 5 at approximately weekly intervals.

Table I gives the summarized results of several such tests. It is impossible to include all of the experiments made in this connection, but the data given bring out the essential facts in regard to dosage efficiency. The soil on which these experiments were made is classified as Frankstown silt loam.[1]

[1] Determination of soil type furnished by the Soil Survey of the Bureau of Soils, United States Department of Agriculture.

TABLE I.—*Larvicidal action of stated doses of p-dichlorobenzene after specified periods of fumigation. Springfield, W. Va., 1916.*

Dose per tree.	Date of application.	Number of trees.	Date of examination.	Number of days from application to examination.	Number and condition of larvæ of specified maturity.														
					Dead.					Stupefied.					Active.				
					One-fourth grown.	One-half grown.	Three-fourths grown.	Full grown.	Total.	One-fourth grown.	One-half grown.	Three-fourths grown.	Full grown.	Total.	One-fourth grown.	One-half grown.	Three-fourths grown.	Full grown.	Total.
One ounce	July 19	5	July 28	9	6	18	6	2	32	1	4	1		6					
		5	Aug. 2	14	2	16	8	3	29										
		5	Aug. 9	21	2	11	17	10	40										
		4	Aug. 21	33		6	5	3	14										
	Aug. 17	5	Aug. 24	7	21	1	1	1	24		5			5	1				1
		5	Aug. 31	14	21	7	1	1	30	1	2	1		4	5	2			7
		5	Sept. 11	25	13	3			16	1	2			3					
		5	Sept. 25	39			1	1	2										
One-half ounce	July 19	5	July 27	8	1	5	3	1	10	2	3			5					
		5	Aug. 2	14	1	3	5	2	11	1				1					
		5	Aug. 9	21	1	5	9	2	17							1			1
		5	Aug. 21	33	2	6	3	4	15										
	Aug. 17	5	Aug. 24	7	6	1			7										
		5	Aug. 31	14	10	4			14	2	2			4					
		5	Sept. 11	25	1	2	2		5										
		5	Sept. 25	39	1	1			2	2	2	1		5					
One-fourth ounce.	Aug. 17	5	Aug. 24	7	16	3	1		20	3	2			5	1	1			2
		5	Aug. 31	14	7	1			8	2	1			3	2	1			3
		5	Sept. 11	25	5	2			7	2	1			3	2	1	1		4
		5	Sept. 25	39			1		1						26	1	2		29
Total		99																	

It was found necessary in this work to differentiate between what were apparently normally active larvæ and those which, although slightly active, were visibly affected by the gas. The larvæ therefore were classified into dead, stupefied, and active. Whether stupefied larvæ eventually recover or die seemed to be largely a question of the duration and toxicity of the fumigation, and the degree to which the larvæ were affected. Stupefied larvæ when placed in the open air sometimes recovered and sometimes died, but the determination of the exact condition under which either took place was impossible. It was determined, however, that larvæ apparently much affected may be revived. On the other hand, when the dosage was sufficient to provide for a continuation of the fumigation much beyond the time at which the examination was made it may be assumed with safety that the stupefied larvæ eventually would have been killed.

In Table I it will be seen that a 1-ounce dose, applied July 19, showed 9 days after application a small number of larvæ stupefied. By the time of the next examination, however, 14 days after application and in the two succeeding examinations, the larvæ were all dead.

Very little can be added to these data by an extended discussion. The principal facts in regard to dosage are brought out in Table I. In the study of the table, however, it should be emphasized that the relative numbers of dead and living larvæ in the last two examinations for each dose are somewhat misleading, due to the early decomposition of many of the dead, especially the smaller ones. The 1-ounce and one-half-ounce doses were more quickly and fully effective in the July applications than in the August applications. The one-fourth-ounce dose applied August 17 was partially effective but its action was not sustained, and by the time of the last examination, 39 days after application, the dose had been dissipated so completely that young larvæ which were hatching at the time were able to enter the trees. The one-half-ounce and the 1-ounce doses both gave very complete immunity from this current infestation of newly hatched larvæ. The importance of this point will be emphasized later in connection with the time of application and the final control obtained from the use of this gas.

It was observed that the larvæ of the fungus-gnat, *Mycetobia* sp., which feed in the gum, apparently succumb to the action of the gas in about the same proportion as do the larvæ of *exitiosa*.

From the results of the experiments with p-dichlorobenzene given in Table I it will be seen that at the soil temperatures prevailing in late July and August a dose of 1 ounce per tree has a very effective larvicidal action. The vapor apparently acts rather slowly, however, and no definite statement can be made as to the exact time required for the gas to kill all the larvæ. This, of course, depends upon the concentration of the soil vapor and the condition of the insect. These points are discussed more fully in a later paragraph. Occasionally larvæ subjected to the fumigation apparently live for weeks in a comatose condition, their bodies shrinking to one-half or one-third normal size before death. There is no means of knowing whether this is due to an unequal distribution of the gas or to the greater vitality of the individual so affected. As a rule, after the application of an effective dose in late summer and early fall most of the larvæ are killed within a period of about two weeks.

Use as a Control Measure.

TIME OF APPLICATION.

The extent to which an application of p-dichlorobenzene may act as a control measure for the peach-tree borer depends greatly on the season of the year in which it is made. In the central latitudes, where most of the experimental work was done, the hatching period of the insect extends more or less over at least three months—July, August, and September. In exceptional seasons, and perhaps to some extent every season, it may be extended from one to two weeks in either direction from these limits.

It has been found that a single application of an effective dose made in the early fall gives a very fair degree of control. Apparently the ideal time would be from two to three weeks before the end of the hatching period. Applied at that time it kills all the larvæ except a few of the more perfectly protected that have already entered the tree, and provides an immunity from the attacks of those which hatch later and appear during the progress of the fumigation. Also the soil temperatures at this time are sufficient to vaporize most of the material before winter, a point discussed in a later paragraph in connection with injury. The seasonal fluctuations in the period of egg deposition prevent the determination of the time of application to any very great degree of exactness. The period for effective application, however, apparently has no arbitrary time limits. Table II gives the summarized results of about 15 experiments carried on in West Virginia, Virginia, and Maryland in 1916, 1917, and 1918.

TABLE II.—*Relative effectiveness of a single fall application of stated doses of p-dichlorobenzene. 1916–1918.*

Observation.	Application per tree.				Check untreated.
	¼ ounce.	½ ounce.	¾ ounce.	1 ounce.	
Total number of trees	10	88	272	298	224
Number of trees not infested	4	61	226	256	22
Number of trees infested	6	27	46	42	202
Total number of larvæ	25	90	98	85	1,669
Maximum number of larvæ on one tree	11	9	6	6	44
Average number of larvæ per tree for trees infested	4.1	3.3	2.1	2	8.2
Average number of larvæ per tree for total number of trees	2.5	1	.36	.28	7.4
Approximate percentage of control	70	88	95	96	0

The time of application varied from the last of August to the last of September, yet in no case was there a very decided departure from the general average of control given in the table. In some cases when application was made about the 25th of August the fumigation was apparently over a little too soon, indicated by a slight infestation of newly hatched larvæ. On the other hand, applications made the last of September, while entirely effective, had the disadvantage of incomplete evaporation. The ideal time apparently was in early September, approximately the 10th.

In 1917 about 80 trees were treated at Springfield with a 1-ounce dose each. One plat received one application on July 7; one plat two applications, the first on July 7 and the second on August 24; and one plat one application on August 25. The plat receiving one application July 7 gave a control of 45 per cent when examined on October 11. The plat receiving two applications gave a control of 96 per cent, and the plat receiving one application on August 25, 90 per cent. Table III gives the results of this treatment.

TABLE III.—*Relative effectiveness of one and two applications per season of a 1-ounce dose of p-dichlorobenzene per tree, Springfield, W. Va., 1917.*

Applications.		Dates of examination.	Number of trees—		Number of active larvæ.		Percentage of control
Number.	Date.		Treated.	Examined.	Total.	Average per tree.	
1	July 7	Oct. 11	29	20	66	3.3	45
2	...do... Aug. 24	...do...	38	20	5	.25	96
1	Aug. 25	Oct. 16	13	13	8	.6	90
Check	....	....	....	28	169	6	0

The difference in control between the plat treated twice and that treated once on August 25 is too slight to be of special importance, and certainly not sufficient to warrant the double application in practice. Aside from consideration of economy two applications per season have the added disadvantage of subjecting the tree to a double fumigation and a proportionately greater chance of injury, although no injury was observed on the trees so treated.

While very good results have been obtained from applications made all the way from the last of August to the last of September, very late application has been less satisfactory. In 1916 the 1-ounce dose was applied to 48 trees at Springfield on November 1. Examination was made the following spring on May 28, about seven months later. Large numbers of dead and decomposing larvæ were found on the trees. An unusual number, however, had escaped. Compared to adjacent untreated trees the indicated mortality was 87 per cent. A slight amount of the material was still in the soil, and from the appearance of the larvæ it was suspected that a considerable part of the fumigation had taken place in the spring. There was also more or less injury about wounds and exposed tissue. The larvæ are probably much more resistant to fumigation during the dormant period than at any other season of the year.

It has been found that with all gases the trees recover more readily from injury which occurs in early spring just at the beginning of the growing season than at any other time of the year, and other things being equal that would be the logical time to apply fumigation. Records of soil temperatures made at Springfield in 1916, however, indicate that the soil warms up rather slowly in the spring. At a depth of 6 inches the temperatures of the period from September 15 to October 15 were not attained in the spring until about May 15 to June 15. It is hardly probable that effective application could be made in the spring much before May 15. By this time a great number of the larvæ have reached a considerable degree of maturity at the expense of much injury to the tree, and while the gas would probably reach a large proportion, the depth and character of the burrows of the larger larvæ provide more or less chance for their escape.

As already stated, early fall, from two to three weeks before the end of the hatching period, proved the most effective time for application. In the latitude of Washington this is about the 10th of September. At this time larvæ that have already entered the trees are mostly small, feeding in the outer layers of bark in more or less exposed locations, while the soil temperature is sufficient to evaporate the material before winter.

For other localities both north and south of the latitude of Washington, the time of application undoubtedly can be established approximately from what is known of the insects' seasonal history in various parts of the country. In Table VI it will be seen that there was a wide variation in the dates applications were made in the same locality in 1916, 1917, and 1918. As a matter of fact, all of the applications of 1918 were made from two to three weeks later than was originally planned, and, while the results of these experiments were quite satisfactory so far as the larvicidal action was concerned, a considerable amount of the material remained about the trees at the time examinations were made. There is reason to believe that the dates originally adopted are more satisfactory. These dates are as follows:

Michigan, Ohio, Connecticut	September 1
New Jersey, West Virgina, Maryland	September 10
North Carolina and the Ozarks	September 25
Georgia and Texas	October 10

In the study of Table VI it should be remembered that the examinations were made several weeks and in some cases several months after application. Dead larvæ, of course, were largely decomposed after such a lapse of time. Hence no account was taken of anything but living larvæ. Dead skins and partly decomposed bodies were always in evidence but no attempt was made to determine the actual infestation from their numbers. The check plat by which the relative infestation was judged in all cases was made up of consecutive trees in adjoining parallel rows.

DOSAGE.

Table VI sets forth with sufficient clearness the essential features of dosage efficiency. It will be seen that the doses applied as a single fall treatment gave results which agree very closely with their previously determined larvicidal value given in Table I. The trees treated in these experiments varied in age from 6 to 15 years and in size at the butts from one to several inches in diameter. It might be argued that the collar girth of the trees would be a better index to the dosage required than their age. There are certain facts, however, which make this undesirable. First, as will be shown later, injury is more dependent upon the age of the tree and the development of protective tissue than upon its size. Second, there has been a wide latitude in the size of trees treated successfully by a given dose. Under field conditions there is at all times a heavy surface and lateral loss of gas. It seems probable for that reason that there is a certain area of gas diffusion necessary before the vapor in the center of this area attains toxic concentration. There are, of course, limits in both directions in the application of this statement, very large trees undoubtedly requiring larger doses than small ones. In practice, however, the latitude in collar girth of trees which a given dose will treat successfully has been enough to cover the usual variation in trees between the ages of 6 and 15 years.

It will be seen in Table VI that the one-fourth-ounce dose gave only partial control. Although only one experiment included the application of this amount, the results agreed fairly well with its previously determined larvicidal value. The one-half-ounce dose in many instances gave as perfect control as the next two larger doses, and in some cases better. On the whole, however, the results from the application of this dose are not quite so uniform and the general average is slightly less. As will be seen from the table, there is not a great difference in the control obtained from either the one-half-ounce, the three-fourths-ounce, or the 1-ounce doses. Apparently there is considerable latitude in the dosage required, within these limits, but it does not seem likely that much less than one-half-ounce doses would give consistent control. On the other hand, there does not seem to be much point in using doses larger than 1 ounce.

Other experiments were carried on in which very much larger doses than those shown in Table VI were used, but in none of these was there an advantage in the control obtained sufficient to offset the probability of injury from the greatly prolonged fumigation. Table IV gives the results of one such experiment, made at Springfield in 1916.

TABLE IV.—*Effect of stated doses of para-dichlorobenzene on 8-year-old peach trees, Springfield, W. Va., 1916.*

Number of trees.	Dose per tree.	Date of—		Interval in days from application to examination.	Number of active larvæ.		Injury.
		Application.	Examination.		Total.	Per tree.	
5	½ ounce	June 24	Oct. 14	112	29	5.8	None.
5	do	do	Oct. 27	125	12	2.4	None.
5	do	do	Oct. 28	126	3	.6	None.
5	do	Aug. 22	do	67			None.
5	1 ounce	June 24	Oct. 14	112	9	1.8	None.
5	do	do	Oct. 18	116	25	5.0	None.
5	do	do	Oct. 27	125	15	3.0	None.
5	do	do	do	125	6	1.2	None.
5	do	Aug. 22	Oct. 28	67			None.
5	2 ounces	June 24	Oct. 14	112			None (1 tree moderate).
5	do	do	Oct. 18	116	3	.6	None.
5	do	do	Oct. 28	126	4	.8	None.
5	do	do	Oct. 27	125			None.
5	do	Aug. 22	Oct. 28	67			None.
5	3 ounces	June 24	Oct. 14	112			None.
5	do	do	Oct. 27	125			None.
5	do	do	Oct. 28	126			None.
5	do	do	Oct. 27	125			None.
5	do	Aug. 22	Oct. 28	67			None.
5	4 ounces	June 24	Oct. 14	112			None (1 tree severe).
5	do	do	Oct. 27	125			None.
5	do	do	Oct. 28	126			None.
5	do	do	do	126			None.
5	do	Aug. 22	do	67			None.
2	6 ounces	do	do	67			None (1 tree traces).
2	8 ounces	do	do	67			Traces.
2	10 ounces	do	do	67			None (1 tree traces).

Total number of trees treated, 126.

A total of 126 eight-year-old trees were treated with various doses, ranging from one-half ounce to 10 ounces per tree. Part of the applications were made June 24 and part August 22. The examination was made in October. Of the entire 126 trees, 56 which received

3 ounces each and over were entirely free from larvæ; 20 trees receiving 2 ounces each on June 24 contained 7 larvæ, an average infestation of 0.35 per tree; 5 trees receiving 2 ounces each August 22 contained none; 20 trees receiving 1 ounce each on June 24 contained 55 larvæ, an average infestation of 2.7 per tree; 5 trees receiving 1 ounce each on August 22 contained none; 15 trees receiving one-half ounce each on June 24 contained 54 larvæ, or an average of 3.6 per tree; and 5 trees receiving the same dose on August 22 contained none. It is especially significant that the single application of a moderate dose the last of August gave as good control, in the end, as a June application of a much larger dose.

INFLUENCE OF SOIL TYPE.

So far as the present experiments go the influence of soil type on the effectiveness of the application of p-dichlorobenzene has imposed no limitations on its use. While the fumigation probably may be expected to prove somewhat less effective in some cases where extreme variation in soil types exists, it has been used so far with almost uniform results on a variety of soils. In this respect it possesses a distinct advantage over gases like carbon disulphid and carbon tetrachlorid, which volatilize so rapidly at ordinary temperature that the fumigation is over in a few days. The relative diffusion of gases at various times in a given soil type depends mainly on the variation of moisture content. A highly volatile gas for that reason possesses a distinct disadvantage, since it is governed entirely by the particular condition of the soil, with respect to moisture, which exists within a period of a few days. This condition may be one of extreme dryness or extreme wetness, or, in case of a heavy rain, both conditions may be present. It is apparent, therefore, that a material of low volatility at ordinary soil temperature, which gives a comparatively mild fumigation, and requires a long period for its action, not only takes advantage of the equalization of soil moisture conditions that usually occurs over a period of several weeks, but at the same time is less seriously affected by sudden violent fluctuations that may occur at any time.

Table VI gives the results obtained on several types of soil varying in character from sandy loam to comparatively heavy clay loam. At Pinto, Md., where the soil type is a variation of the Frankstown series, known as stony silt loam, locally called chert land, the greatest difficulty is encountered in its use. When cultivation of this soil is followed for some time, it appears often almost entirely free of fine material on the surface. Below the immediate surface, however, it is usually well filled with fine soil. The chief difficulty in making application to this type of soil was due to the lack of fine material. As will be seen in Table VI the results were quite satisfactory on this type of soil, and the mechanical difficulty involved in its application would probably be no greater than in "worming."

For the types of soil upon which experiments have been made no consistent variation in control has so far been observed. The comparative mildness of the fumigation and the long period over which it acts apparently tend to neutralize the influence of soil type.

Injury to Trees.

The margin of safety in the use of p-dichlorobenzene against the peach-tree borer apparently depends entirely upon the relative extent to which the insect and the tissues of its host are exposed to the action of the gas. In the main this relation varies in proportion to the age of the tree and the development of its protective tissues. It has been found impossible to fumigate young trees with safety. On the other hand trees beyond a certain age have shown so far no ill effects from a fumigation of several times the duration necessary to kill the insect.

In the course of three years' work many hundreds of observations have been made on the collars of trees treated with a great variety of doses on a number of different soils. In some cases blocks of trees have been treated for two successive seasons and in one case for three years. In part, the observations have been made in connection with "worming" data, and in part they are the results of separate dosage experiments.

NURSERY TREES.

In 1916, 57 nursery trees were treated in a nursery at Hagerstown, Md. The trees were Belle of Georgia buds of the previous fall. The soil was a stiff clay loam. The dosage was distributed over the 57 trees as follows: 10 received one-fourth ounce each; 10 one-half ounce; 10 three-fourths of an ounce; 10, 1 ounce; 5, 2 ounces; 5, 3 ounces; 2, 4 ounces; 2, 5 ounces; and 3 individual trees received 6, 8, and 10 ounces, respectively. The application was made on September 6. On October 21 the trees were dug and examined. In this interval of 45 days all of the trees had been injured severely by the gas. No distinction could be made between the various doses in the extent of the injury, which was as severe on trees receiving one-fourth ounce as on those receiving more. The injury was localized on the collar and larger roots lying within 6 to 8 inches of the material. The greatest amount of tissue killed was in the vicinity of wounds, but even on uninjured stems where the epidermis was not ruptured the surface was peppered with tiny lesions extending into the cambium.

TWO-YEAR ORCHARD TREES.

The effect upon two-year orchard trees proved less serious, although much too great to make their fumigation practicable. On August 18, 1916, 20 Belle of Georgia trees were treated in an orchard at Vienna, Va. These trees were in their second season from planting and were consequently two years older than the nursery trees. The soil was exceptionally stiff clay loam. With one or two exceptions these trees were vigorous and normal. Table V gives the date of application, dosage, and the results of later observations on the effects of the fumigation.

TABLE V.—*Effect of stated doses of para-dichlorobenzene on 2-year-old Belle of Georgia peach trees, Vienna, Va., 1916–17.*

Tree Nos.	Condition of trees before treatment.	Dose.	Date of application.	Condition of trees on specified dates of examination.	
				Mar. 14, 1917.	July 24, 1917.
			1916.		
1	Normal	¼ ounce	Aug. 18	Moderate injury, not serious	Fully recovered, normal growth.
2	...do	...do	...do	Slight injury, not serious	Do.
1	...do	½ ounce	...do	...do	Do.
2	Weak	...do	...do	Dead	
1	...do	¾ ounce	...do	Slight injury, not serious	Do.
2	Normal	...do	...do	Severe injury, girdled	Dead.
1	...do	1 ounce	...do	Severe injury, three-quarters girdled.	Partly recovered, normal growth.
2	Weak	...do	...do	Slight injury, not serious	Fully recovered, normal growth.
1	Normal	2 ounces	...do	...do	Do.
2	...do	...do	...do	Severe injury, girdled	Dead.
1	...do	3 ounces	...do	Slight injury, not serious	Fully recovered, normal growth.
2	...do	...do	...do	Severe injury, three-quarters girdled.	Partly recovered, normal growth.
1	...do	4 ounces	do	Severe injury, girdled	Dead.
2	...do	...do	...do	Traces injury, not serious	Fully recovered, normal growth.
1	...do	5 ounces	...do	Severe injury, serious	Partly recovered, normal growth.
2	...do	...do	...do	Traces injury, not serious	Fully recovered, normal growth.
1	...do	6 ounces	...do	Slight injury, not serious	Subnormal, stunted.
2	...do	...do	...do	Traces injury, not serious	Fully recovered, normal growth.
1	...do	8 ounces	...do	Moderate injury, not serious	Do.
1	...do	10 ounces	...do	Severe injury	Subnormal, stunted.

It will be noted by reference to Table V that for all doses up to and including 5 ounces the injury to one tree is recorded as "slight" or less, while the other was injured more severely. Table V also shows that on July 24, 1917, when they were again examined, all injured slightly had recovered and made a normal growth. For each dose, therefore, up to and including 5 ounces, one tree entirely recovered and made a normal growth the season following fumigation. Apparently for the period over which the experiment was allowed to run, the smaller doses were sufficient to furnish a vapor of maximum toxicity. Had the experiment been allowed to run longer, it is probable that a greater graduation in the toxicity of the various doses would have been observed, as the larger doses had by no means completely volatilized at the time the examination was made. As in the case of the nursery trees, the greatest injury occurred about wounds. There was noticeably less injury where the protective tissue was not ruptured than on the uninjured stems, although in many cases the gas had killed large patches and partly girdled uninjured collars.

FOUR-YEAR ORCHARD TREES.

Four-year orchard trees showed a still greater resistance to the effects of the gas. On September 9, 1916, 28 four-year Champion trees were treated in an orchard at Conway, Md., with doses as follows: Nine received one-half ounce each, 9 three-fourths of an ounce, and 10 one ounce. Five trees of each plat were examined on November 28, 1916, and the remainder on April 2, 1917. Of the entire 28 trees, 17 showed no injury at all. Of the 9 trees which had received the one-half ounce dose 7 showed no injury, while 2 were injured, 1 moderately and 1 severely. On the three-fourths-ounce plat 5 of the 9 trees showed no injury, 4 were injured, 2 severely, 1 moderately, and 1 only a trace. On the 1-ounce plat 5 of the 10 trees were uninjured; of the remaining 5, 3 showed only a trace of injury, 1 a slight injury, and 1 was entirely girdled. Of the entire lot of 28 trees only 1 was killed outright. While one or two others were partly girdled, the one last mentioned was the only tree upon which the effects of the fumigation were ever visible above ground. As usual the injury occurred more or less irrespective of dosage, its severity varying with the condition of the tree with respect to insect wounds, etc. While it was apparent that four-year trees could not be fumigated without more or less injury on lacerated stems, there was a decided diminution in its severity on trees of this age compared to those younger.

The extent to which the epidermal and cork layers of the bark are responsible for the protection of the tree was illustrated by an experiment at Springfield in 1916. A block of eight 10-year-old trees was treated with 1, 2, 3, and 4 ounce doses on July 20, two trees receiving each dose. On August 26 they were examined and no trace of injury found. However, in making the examination the trees of the 2, 3, and 4 ounce plats were considerably scarified, the outer layer of the bark being largely pared and scraped away. These trees were retreated with the same dose August 26, and examined again on October 28. On the 1-ounce plat where the collars were not scarified no injury had developed. On the other plats all the trees were injured severely, and in two cases completely girdled. On the other hand, trees of the same age in adjoining rows withstood during the same period continuous fumigation for 125 days without injury.

TREES SIX YEARS AND OVER.

A single early fall application of a moderate dose of p-dichlorobenzene has caused no injury on trees six years and over. Doses have been applied to trees of this age varying from 1 ounce to several ounces per tree. Where moderate doses of three-fourths of an ounce or 1 ounce per tree have been applied once in early fall no injury of any importance has ever been observed. Hundred of trees have been fumigated in this way, and in some cases blocks of trees have received the same doses for two and three years. While there can be no doubt that trees of any age could be killed if the fumigation was prolonged sufficiently, there is every indication that the time required would be many times that necessary to kill the borer. Occasionally in the vicinity of wounds a slight amount of tissue is killed even in fumigation with ordinary doses, but on the older trees this has been so slight and superficial in character that it may be disregarded.

Table IV gives the results of prolonged fumigation on eight-year-old trees at Springfield in 1916. As will be seen from the data there presented very little injury of importance was found on trees treated with doses giving a continuous fumigation from June 24 to the last of October. Of the entire 126 trees treated with doses ranging from one-half ounce to 4 ounces each, only two developed serious injury and in both cases the trees had been seriously injured by both borers and crown gall. Apparently the gas has considerable effect upon the spongy galls which accompany this disease. Doses of 2 ounces and over gave off a very pronounced odor when the earth was opened, and the fumigation had probably been maintained at a toxic concentration throughout most of the period from June to October. While from the standpoint of control a fumigation of so great duration is not necessary or desirable, it is interesting that all these larger doses gave almost complete immunity from the insect throughout the season.

The greatest amount of injury ever observed on older trees resulted from an application made at Springfield on November 1, 1916. (See Table VI.)

TABLE VI.—*General summary of results obtained by one fall application of para-dichlorobenzene per season, 1916–1918.*

Date of application.	Locality.	Number of seasons applied successively.	Soil type.	¼ ounce.				½ ounce.				¾ ounce.				1 ounce.				1½ ounces.				Check untreated.			Remarks.
				Number. Trees.	Active larvæ. Total.	Active larvæ. Per tree.	Per cent control.	Number. Trees.	Active larvæ. Total.	Active larvæ. Per tree.	Per cent control.	Number. Trees.	Active larvæ. Total.	Active larvæ. Per tree.	Per cent control.	Number. Trees.	Active larvæ. Total.	Active larvæ. Per tree.	Per cent control.	Number. Trees.	Active larvæ. Total.	Active larvæ. Per tree.	Per cent control.	Number. Trees.	Active larvæ. Total.	Active larvæ. Per tree.	
1916.																											
Aug. 26	Springfield, W. Va.	1	Silt loam	10	25	2.5	69.9	10	16	1.6	80.8	10	3	0.3	96.4	11	2	0.18	97.8					10	83	8.3	9 to 10 year old trees.[1]
Sept. 9	Conway, Md	1	Sandy loam					9	1	.11	98	9	0	0	100	10	0	0	100					10	55	5.5	4-year-old trees.[2]
Nov. 1	Springfield, W. Va.	1	Silt loam													15	16	1.06	87.2					10	83	8.3	9 to 10 year old trees.[3]
1917.																											
Aug. 24	do	2	do									14	10	.72	86.9	25	20	.8	85.5					18	99	5.5	10 to 11 year old trees.[1]
Aug. 28	do	1	do					15	28	1.9	85.8	14	19	1.35	89.9	15	9	.6	95.6					10	134	13.4	6-year-old trees.[1]
Sept. 19	do	1	do					12	0	0	100	12	1	.08	99.4	12	1	.08	99.4					10	134	13.4	6-year-old trees.[1]
Sept. 9	Pinto, Md	1	Stony silt loam									25	13	.52	94.2	25	15	.6	93.4					10	91	9.1	10 to 12 year old trees.[1]
Sept. 7	Three Churches, W. Va.	1	Fine sandy loam									20	0	0	100	20	4	.2	97.4					10	77	7.7	6-year-old trees.[1]
Sept. 11	Hancock, Md	1	do									25	8	.32	96.4	25	6	.24	97.3					20	176	8.8	6 to 8 year old trees.[1]
1918.																											
Sept. 14	Winchester, Va	1	Clay loam					21	43	2.0	78.9	23	24	1.0	89.5	23	7	.3	96.8					21	199	9.5	6-year-old trees.[1]
Sept. 24	Springfield, W. Va.	3	Silt loam									25	3	.12	94.6	20	1	.05	97.7					20	44	2.2	11 to 12 year old trees.[1]
Sept. 27	do	2	do					21	2	.09	98.2	21	1	.05	99	23	0	0	100					20	98	4.9	7-year-old trees.[1]
Sept. 25	Pinto, Md	2	Stony silt loam									25	11	.44	96	25	3	.12	98.9					15	167	11.1	11 to 12 year old trees.[1]
Sept. 26	Three Churches, W. Va.	2	Fine sandy loam									25	2	.08	98.6	25	2	.08	98.6					20	112	5.6	7-year-old trees.[1]
Sept. 30	Hancock, Md	2	do									24	3	.12	97.9	24	0	0	100					20	117	5.8	7-year-old trees.[1]
Sept. 11	Vermilion, Ohio	1	Light clay loam					20	7	.35	96.1	23	25	1.08	88	25	17	.68	92.5					25	225	9	8-year-old trees.[1]
Sept. 15	Sandusky, Ohio	1	Clay loam					25	3	.12	97.5	25	4	.16	96.7	25	6	.24	95					25	121	4.8	7-year-old trees.[1]
Sept. 30	Wakefield, Ohio	1	Light clay loam					25	11	.44	93.7	25	23	.92	86.9	25	36	1.4	80					25	175	7	9-year-old trees.[1]
Oct. 12	Springdale, Ark	1	Gravelly loam													25	6	.24	94.3					25	105	4.2	15-year-old trees.[1]
Oct. 22	Fort Valley, Ga	1	Fine sandy loam					18	2	.11	97.5	19	6	.31	92.8	21	4	.19	95.6	20	1	0.05	98.8	16	69	4.3	15-year-old trees.[1]
Do	do	1	do					18	2	.11	96.2	17	2	.12	95.9	20	5	.25	91.4					18	52	2.9	6-year-old trees.[1]
	Total			10	25	2.5	69.9	194	115	.59	91.7	381	158	.41	94.1	439	160	.36	94.7	20	1	.05	98.8	358	2,416	6.77	

[1] No injury. [2] Moderate injury. [3] Slight injury.

The trees treated were about 10 years of age and had suffered heavily from borer attacks. They received 1 ounce each. On May 28, 1917, 15 were examined. Nine showed no injury at all, 5 showed traces, and 2 what was classified as slight injury. So far as the final effect on the trees was concerned none of this injury was of importance. It was more than hitherto had been observed for this dose, however, and while the reason is not entirely apparent it is felt that it is best to make the application sufficiently early in the fall to allow for complete evaporation before winter. This fact, coupled with its less effective action, should be sufficient reason for avoiding late application. When the application is made in the central latitude as late as September 15, it probably would be wise to uncover the trees after five or six weeks, and either allow them to stand open for a time or refill with fresh earth. In fact, at the present stage of our knowledge of the problem the writer is inclined to feel that this might be a wise precaution to follow in every case.

The varieties treated have included many of the leading commercial sorts as well as a large number of unknown seedlings. So far there has been nothing to indicate that one variety of peach is more susceptible to the effects of the gas than another.

A summary of the results obtained by one fall application of paradichlorobenzene is given in Table VI.

RELATION OF INJURY TO SOIL TYPE.

No special relation between injury and type of soil has been discovered in the use of p-dichlorobenzene. Very porous soils probably give a somewhat less concentrated vapor than very retentive soils, but in practice the effect of soil type has not seemed important, although the soils on which experiments were carried on have varied from light sandy loams to heavy clay loams.

INJURY TO APPLE.

In August, 1916, an application of p-dichlorobenzene was made to twelve 3-year-old apple trees at Springfield, W. Va. These trees were treated with doses varying from 1 ounce to one-fourth of an ounce each. All were quite well infested with *S. candida*. The application was made on August 23 and the examination on September 1–2. Practically all the smaller larvæ of the borer had been killed. The more mature specimens working in deeper burrows were still living, although several were affected noticeably by the gas. The trees were severely injured, however. Apparently, the action of the gas on the insect and the tree was almost simultaneous. Several of these trees were so severely injured that they died the following season. On another occasion an 8-year-old apple tree not infested with borers or injured in any way was treated with an ounce of p-dichlorobenzene.

When examined, about one month later, it was found to be two-thirds girdled by the fumigation. While these observations are very limited they indicate a wide difference in susceptibility of apple and peach. This difference apparently is due mostly to the difference in the thickness of the bark and its layers of protective tissue, which exists between the two.

Discussion.

The experience so far obtained indicates that there are pronounced possibilities in the application of poison gases to the control of the peach-tree borer. At present p-dichlorobenzene remains the only material of decided value. Despite the fact that for three seasons it has given uniformly good results, however, it is not the purpose of this paper to encourage its use except in an experimental way. The control obtained has been by no means 100 per cent efficient, and it is doubtful if such a degree of control could be secured safely by any artificial means. Certainly it is not obtained in practice by the ordinary "worming." Unfortunately the use of this gas is restricted to trees of somewhat advanced age, but this limitation might apply as well to the application of other fumigants for the control of this insect.

The question of the volatility of p-dichlorobenzene was submitted to the Bureau of Chemistry.[1] It was found that the vapor pressure, while very low at ordinary temperature, is, roughly, about ten times as great at 100° F. as at 50° F. In the soil, however, the relation of vapor pressure and temperature to the rate of volatilization is greatly modified by such factors as barometric pressure, humidity, circulation of air, surface exposure, etc. Although there is undoubtedly a considerable variation in the rate of volatilization within the seasonal range of soil temperatures, it has not seriously interfered with the effectiveness of the gas in the field tests so far made. Soil temperature records taken throughout the season of 1916 at Springfield, W. Va., showed a variation at a depth of 6 inches from about 50° to 55° F. in April and October to 75° and 80° F. in July and August.

The vapor of p-dichlorobenzene has a very decided repellent effect upon the ovipositing moths. On several occasions females were followed through treated blocks of trees and observed to visit tree after tree, hovering about the base for a short time or alighting for an instant without depositing a single egg.

The effective range of the gas is rather local, being confined to the area reached in practice by "worming." On the bole of the tree at a depth of from 8 to 12 inches and on lateral roots at less than that depth, but more than 6 to 8 inches from the trunk, larvæ usually are not affected.

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[1] Correspondence and notes of the Bureau of Entomology.

The writer is indebted to a number of observers for cooperation in experiments made in various parts of the country during the season of 1918. In Ohio the treatments and examinations at Sandusky and Vermilion were made by Mr. G. A. Runner, in charge of the laboratory of the Bureau of Entomology at Sandusky, in cooperation with Mr. H. J. Speaker, of the bureau of horticulture, Ohio Department of Agriculture. The work in southern Ohio at Wakefield was conducted by Mr. Speaker. At Springdale, Ark., the observations were made by Mr. A. J. Ackerman, of the Bureau of Entomology, and Mr. F. L. Pierce, of the Bureau of Plant Industry. At Fort Valley, Ga., the work was carried out by Mr. J. J. Culver, of the Bureau of Entomology, and the writer. The writer is also especially indebted to Mr. B. R. Leach, in charge of the bureau laboratory at Winchester, Va., for many valuable suggestions and for cooperation and assistance in the experiments in Virginia, West Virginia, and Maryland.

SUMMARY.

(1) It has been found impossible to standardize the use of carbon disulphid and carbon tetrachlorid as treatments for the peach borer. The great volatility of these substances at ordinary temperatures renders them too sensitive to varying conditions of soil porosity.

(2) Sodium cyanid on account of its solubility was too susceptible to the effects of variation in soil moisture and soil type, and proved to be injurious to trees.

(3) Naphthalene on account of its low volatility within the seasonal range of soil temperatures was only a partially effective larvicide for a very short period in midsummer.

(4) P-dichlorobenzene has proved quite effective over a wide range of varying conditions imposed by field practice, with a considerable margin of safety for trees six years and over.

In making the application the surface crust about the collar of the tree is broken. Excessive amounts of gummy exudations at the surface are removed. The lower levels of soil are disturbed as little as possible, and the required dose is distributed evenly about the trunk in a band 1 to 2 inches in width. (See Plate I, A.) Two or three shovels of earth are then placed over the material, and compacted with the back of the shovel, being mounded slightly to cover surface galleries (Plate I, B).

In the latitude of Washington and northern Virginia about September 10 has been found to be the most satisfactory time of application. Based on the insect's seasonal history, the theoretical time of application in the North generally would be about September 1; in the Ozarks, September 25; and in Georgia and the cotton belt, October 10.

For 6 to 15 year old trees of average size, doses of 1 ounce and of three-fourths of an ounce per tree have been found effective in destroying the borers without injury to the trees. For very large trees of advanced age, a somewhat increased dose may be desirable.

As an added precaution against injury the base of the trees should be uncovered 4 to 6 weeks after application, allowed to remain open for a few days, and recovered. This precaution is especially necessary if the application has been made very late.

The use of p-dichlorobenzene in this way has been found to reduce the infestation on the average from 6.77 to 0.41–0.36 larvæ per tree, approximately a 94 per cent control.

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