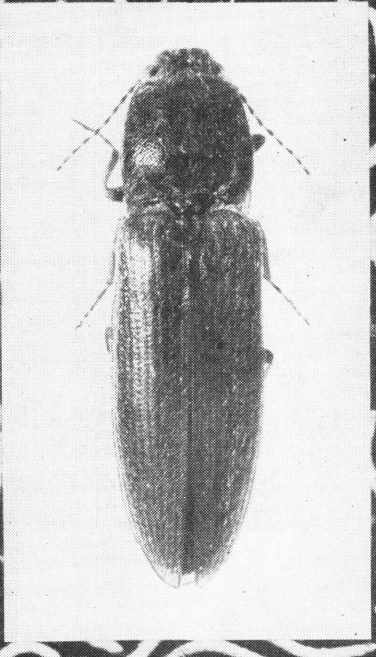
WIREWORMS
and their Control
ON IRRIGATED LANDS



FARMERS' BULLETIN *No.* 1866 U.S. DEPARTMENT OF AGRICULTURE

WIREWORMS have caused heavy losses to farmers on the irrigated lands of the Pacific Northwest. These shiny, tough, yellow- to orange-colored insects are notorious for their habit of feeding only on the underground portions of plants and for their long life cycle of from 2 to 5 years in the soil. They injure crops by destroying seeds in the soil, by cutting off small underground stems, and by boring holes in the larger stems, roots, and tubers. No vegetable or field crop is immune to the damage they do, and such crops as potatoes, onions, corn, lettuce, and melons are particularly susceptible to their attacks.

Intensive studies have developed several methods for their control. Two of these employ chemicals—carbon disulfide and crude naphthalene—which act as fumigants to kill the wireworms in the soil; these are especially suited for use on small acreages or land on which high-priced crops are grown. Other control methods mentioned in this bulletin are based on cultural practices and obviate the expense of chemicals; consequently they are more practical for the average farmer with a large acreage. Certain of these cultural methods are based on the fact that great numbers of wireworms can be killed by producing either an excess or a deficiency of moisture in the soil during the summer season; that is, by flooding or by drying out the soil containing the wireworms. Summer plowing, rotation of crops, and adjustment of planting time are other cultural practices that lessen the number of wireworms or greatly reduce their damage.

Washington, D. C. Issued March 1941

WIREWORMS AND THEIR CONTROL ON IRRIGATED LANDS

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DISTRIBUTION AND IMPORTANCE

WIREWORMS (see cover and fig. 10) have been known for at least 150 years as one of the important native insect pests of agriculture in the United States. They are easily recognized by their shiny, wirelike, yellow- to orange-colored bodies and by their habit of feeding only on the underground portions of plants. Many different kinds attack cultivated crops, under all conditions of climate and soil. Certain species,[2] however, are especially destructive to the crops grown on the irrigated lands of the Pacific Northwest. These wet-land wireworms are native to the region; but, because of the dry-soil conditions of the greater portion of the land during the practically rainless summer months, they were originally restricted to the naturally damp soils near streams and lakes. When irrigation was introduced into the drier areas, however, these wet-land wireworms began migrating to the places made more favorable by the use of water throughout the dry season. At present various species of these wireworms are found in destructive numbers on nearly all the irrigation projects, both private and governmental, in Washington, Oregon, and Idaho, as well as in northern Utah and western Montana (fig. 1). In addition, they are generally distributed in the wet coastal belt west of the Cascade Mountains, where they occasionally cause damage on the more intensively cultivated lands.

It is difficult to estimate the damage done by wireworms in dollars, but the loss to farmers runs into several millions annually. While no crop is known to be entirely immune to the attacks of wireworms, such vegetable crops as potatoes, corn (fig. 2), onions (fig. 3), lettuce, melons, beans, and sugar beets (fig. 4) are particularly susceptible to

[1] The information in this bulletin is based on the results of research work in the Yakima and Walla Walla Valleys of Washington and the Boise Valley of Idaho from 1924 to 1938, in cooperation with the Washington and Idaho Agricultural Experiment Stations.

[2] The Pacific Coast wireworm (*Limonius canus* Lec.), the sugar-beet wireworm (*L. californicus* (Mann.)), the western field wireworm (*L. infuscatus* Mots.), and the Columbia Basin wireworm (*L. subauratus* Lec.), order Coleoptera, family Elateridae, are responsible for practically all the wireworm damage done to garden and field crops in the irrigated and wet lands of the Pacific Northwest.

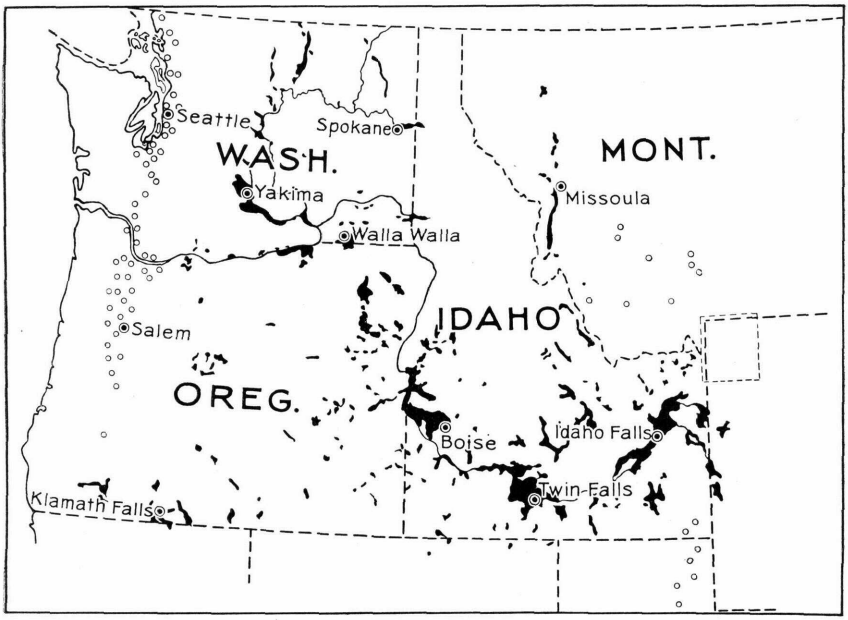

FIGURE 1.—Distribution of wet-land wireworms in the Pacific Northwest. Black areas represent irrigation projects on which one or more species of wireworms cause serious injury to crops annually. Circles represent places where wireworms are known to occur and cause occasional injury.

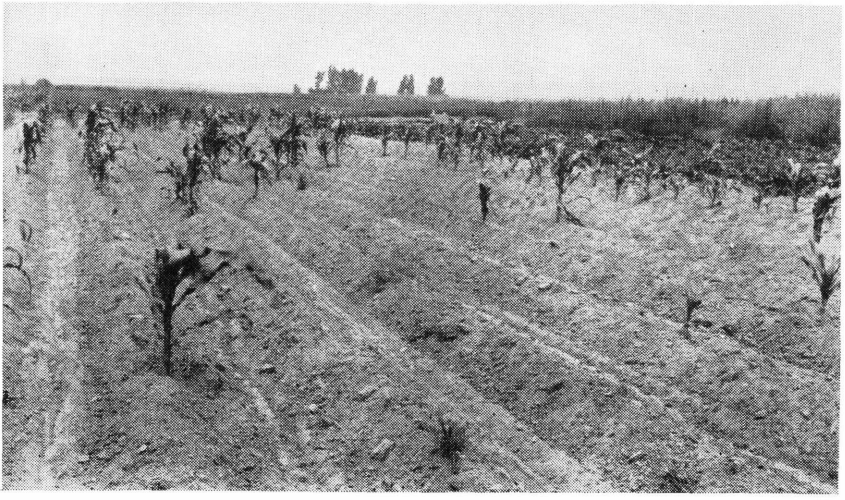

FIGURE 2.—Field of corn severely injured by wireworms.

FIGURE 3.—Field of onions showing injury from wireworms.

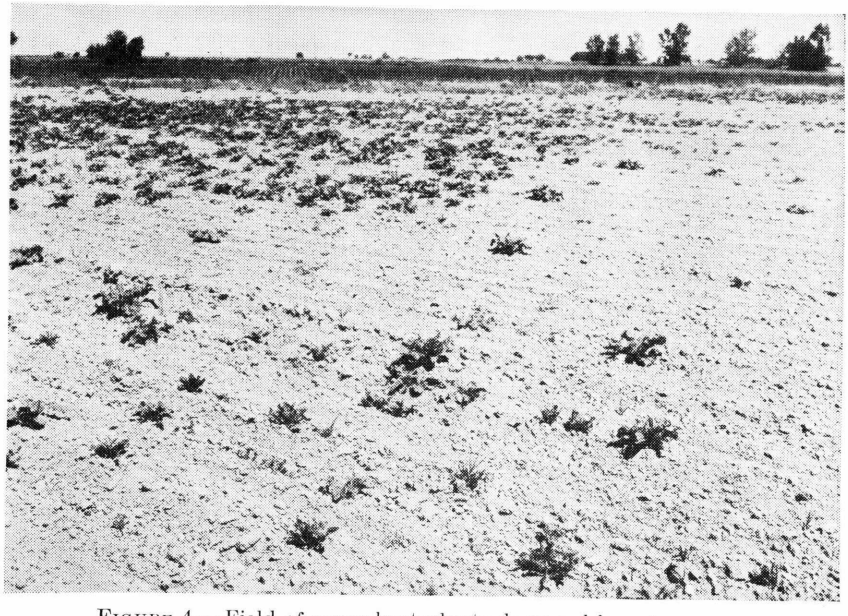

FIGURE 4.—Field of sugar-beet plants damaged by wireworms.

injury. The average annual loss from damage to the marketable potato crop alone amounts to approximately $4,000,000 in the four States of Washington, Oregon, Idaho, and Montana. The probable total loss to truck farmers on the irrigated lands of these States exceeds $6,000,000 annually. Besides these direct financial losses from the destruction of seed and the reduction in grade of marketable crops, several other losses are chargeable to these pests where they are present in large numbers. These take the form of depreciation in land values, reduction in volume of freight to transportation companies, increased financial risks to banks and loan companies, and, finally, in extreme instances the necessity for a complete change of farming methods in a community.

NATURE AND EXTENT OF INJURY

Wireworms have the habit of boring through the outer layers of seeds, stems, or roots, and feeding only on the inner, more succulent portions (fig. 5). In fact, they swallow their food only in liquid form, predigesting it to some extent in the mouth. Solid plant particles or soil have never been found inside a wireworm.

Damage to crops from wireworms is of two distinct types. The first occurs early in the season (April and May), when the newly planted seeds are destroyed and the tender stems of the young plants are cut off just under the soil surface, and replanting is thus often made necessary (figs. 2, 3, 4, and 5). Injury of this type varies with the temperature and the moisture of the surface soil. More damage to seeds and plants may be expected during cool, moist weather. Hot, dry periods cause the wireworms to move farther down into the soil. Damage of the second type occurs later (in June and July), when the maturing tubers, roots, and bulbs are tunneled or scarred by the wireworms, a large part of the crop thus being made unfit for marketing (figs. 6, 7, and 8). This damage causes the greater financial loss to the farmer, because a crop that has survived all the attacks of other insects and of diseases is found at harvest time to be practically unsalable on account of wireworm damage. The high cost of irrigation farming necessitates a crop-rotation system that includes at least one cash crop each year. Potatoes and onions are two of the principal crops grown for this purpose, and they have to be graded under United States or State grading systems before being marketed. Wireworm damage often prevents a large percentage of the tubers or bulbs from passing these grades, and makes them fit only for stock feed (fig. 9).

Under field conditions in the Pacific Northwest, infestations have been found ranging from less than 1 to as many as 40 wireworms per square foot, or from a few thousand to over a million wireworms per acre. The average number ordinarily found in cultivated land ranges from 1 to 10 per square foot. The damage caused by wireworms to vegetable and field crops varies considerably, depending on conditions of the soil, time of planting, amount of irrigation, and other factors. Potatoes are the crop most likely to be injured by small numbers of wireworms, and 1 or more to the square foot will usually injure potato tubers considerably. In wireworm-infested land it will always be necessary to use some method of control if potatoes are to be grown commercially. An average of from 2 to 5 wireworms per square foot

FIGURE 5.—Lettuce plants infested with and damaged by wireworms.

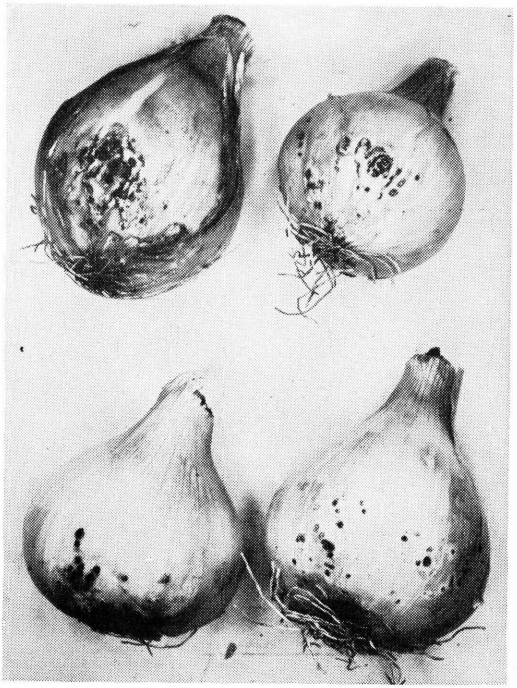

FIGURE 6.—Effects of wireworm feeding on onion bulbs.

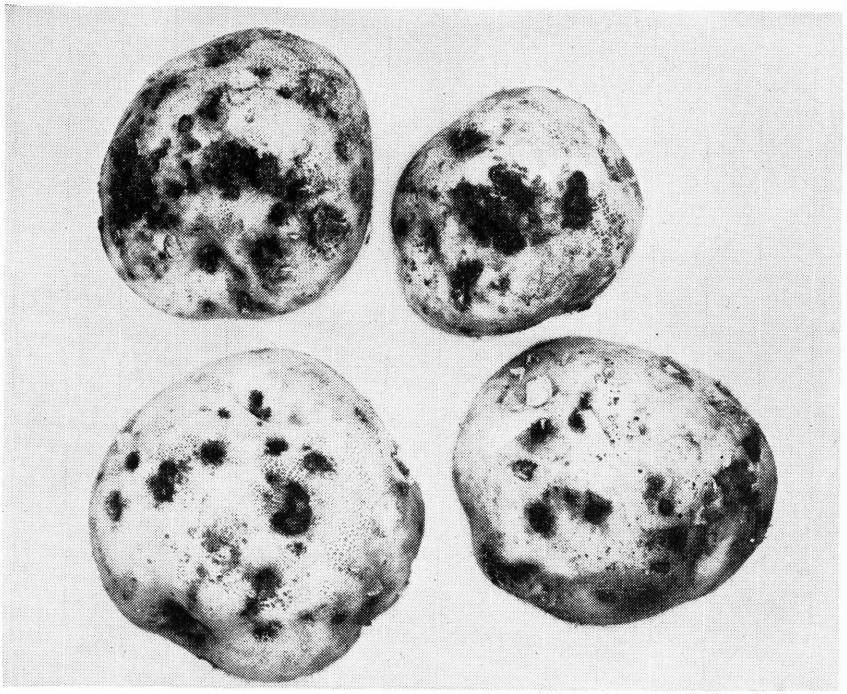

FIGURE 7.—Damage to early Irish Cobbler potatoes by wireworms.

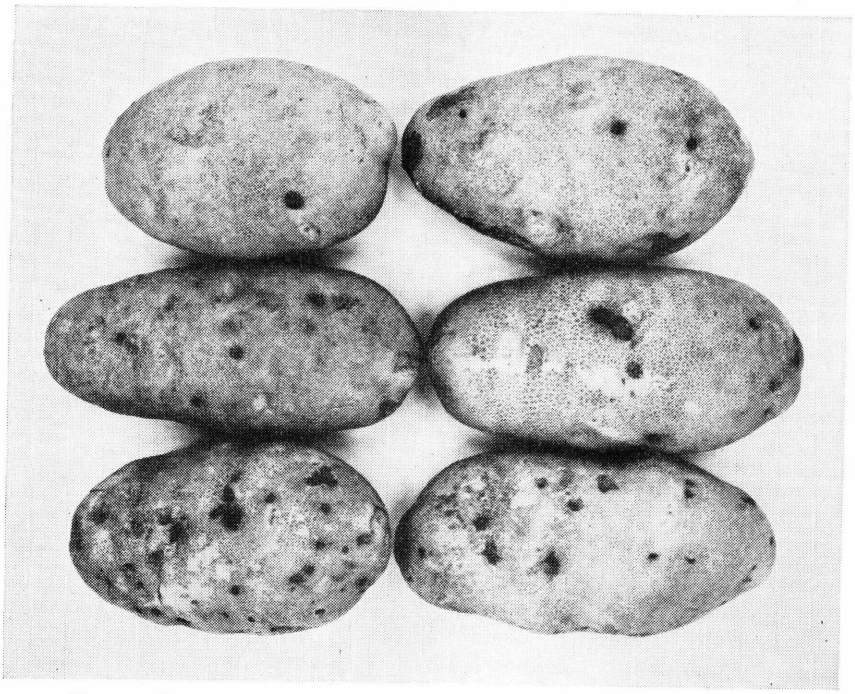

FIGURE 8.—Damage to late Netted Gem potatoes by wireworms.

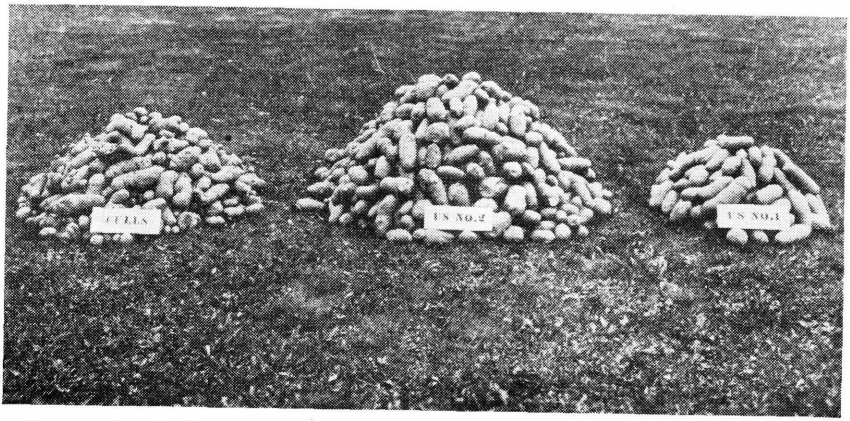

FIGURE 9.—Reductions in grade of potatoes caused entirely by wireworms.

often causes damage to most seed and transplanted crops in the spring, when wireworms are active in the few inches of surface soil. Where wireworms are more numerous than 5 per square foot, it is risky to grow any vegetable or field crop without the application of some method for their control or for avoiding the damage they do. The farmer can save himself much time and expense if he finds out, before planting, approximately how many wireworms are present in the field. The only sure way to determine the number present is to sift a number of cubic-foot soil samples, selected at random over the field. Ordinary window screening tacked to a frame makes a satisfactory sifter for separating the easily seen yellow wireworms from the soil.

DESCRIPTION OF STAGES

EGG

Wireworm eggs (fig. 10, *A*) are pearly white and nearly round, being only slightly longer than wide. They are very small, measuring only about one-fiftieth of an inch in length, and are very difficult to see in the soil. The eggs dry out easily and cannot withstand exposure to the air for more than a few minutes.

LARVA

The newly hatched wireworms, or larvae, are pure white, with dark jaws, and about one-sixteenth of an inch long. After feeding and molting several times they become hard, jointed, and shiny, and their color gradually changes to dark yellow (fig. 10, *B*). They have three pairs of legs in front; the last segment of the body is pronged or forked behind; and, as ordinarily found in the soil, they range in length from one-fourth to three-fourths of an inch. The size of a wireworm is not always a criterion of its age, however, because size depends largely on the amount of food available and on soil conditions.

PUPA

The pupa (fig. 10, *C*) is white and very delicate, being easily injured by handling. It has somewhat the appearance of the adult beetle and becomes darker just before the adult stage is reached.

ADULT

The adults (fig. 10, *D*) are slender, dull, hard-shelled beetles, ranging in color from tan to very dark brown and in length from one-third to one-half inch. They are popularly known as "click beetles" or "snapping beetles" from their habit of snapping the forepart of their bodies when held between the fingers or placed on their backs. The sexes are similar in shape, but the female is often lighter in color and usually slightly more robust than the male. The antennae are somewhat shorter in the female.

LIFE HISTORY AND HABITS

The adults, or parent beetles, of these irrigated-land wireworms transform from the pupae in the summer but do not emerge from their over-wintering cells in the soil until the next spring when the tempera-

ture at the soil surface reaches from 65° to 75° F. The time of emergence varies from place to place in the Pacific Northwest, depending on exposure and altitude. Species also differ somewhat in their temperature requirements, but the period of emergence begins about the last of March in the earlier districts and extends to early in June in the higher or later portions of the area. After emergence, the beetles

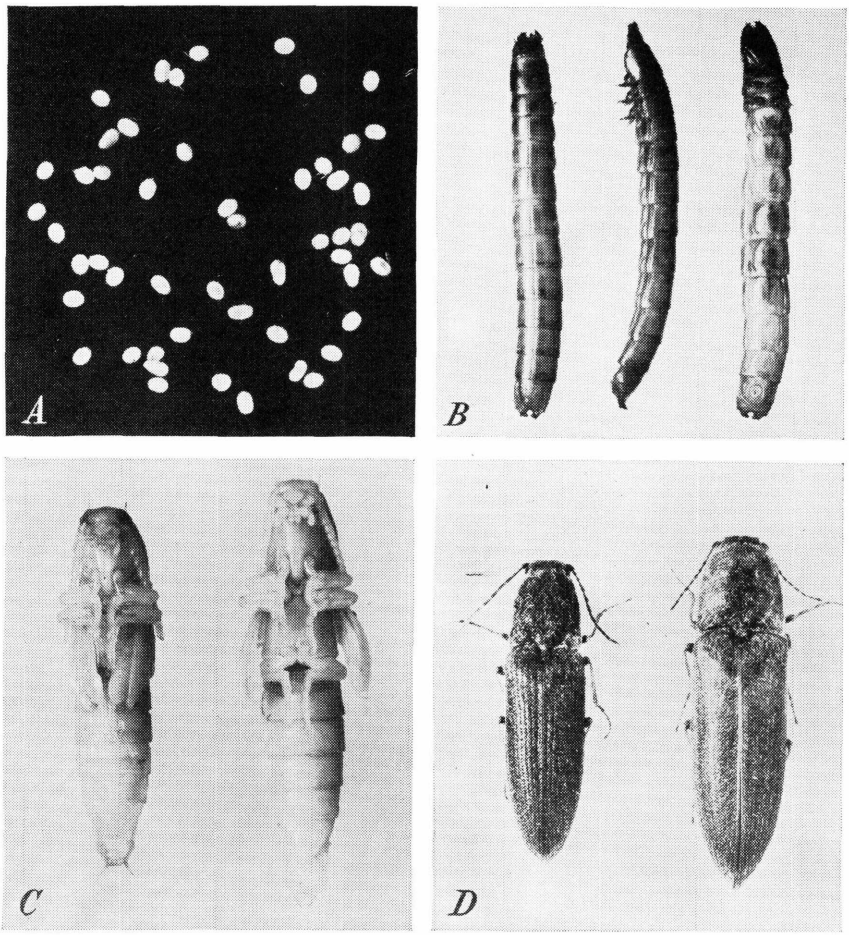

FIGURE 10.—Stages of the Pacific coast wireworm: *A*, Eggs (6 times natural size); *B*, full-grown larvae, dorsal, lateral, and ventral views (3 times natural size); *C*, pupae, male at left, female at right (4 times natural size); *D*, adults, or parent beetles, male at left, female at right (4 times natural size).

crawl about over the soil surface, perch on low vegetation, or make short flights near the ground during the warmer portions of bright sunny days. Food does not seem absolutely essential to the adults, but some species feed on early fruit blossoms, such as those of the cherry, peach, and pear. Migration into new fields takes place only during the adult flight in the spring, but there is considerable evidence to show that the females fly very little until after they have laid most

of their eggs, usually in the same field from which they emerged. Adults remain alive in the spring only long enough to mate and lay their eggs, the whole period of adult life above the soil usually lasting not longer than 3 or 4 weeks.

Immediately after mating, the female beetles burrow back into the soil and within a few days begin to deposit their eggs. These are placed singly, but close together, in damp soil from 1 to 6 inches deep. The eggs are laid at the rate of from 50 to 300 per female. Most of them hatch in 3 or 4 weeks when placed in favorable locations. The young larvae, on hatching, begin working their way through the soil in search of food. It is during this early period of their life, in June, July, and August, that the heaviest natural mortality of wireworms occurs, resulting from the difficulties the tiny larvae experience in finding food and satisfactory soil conditions. The newly hatched wireworms do little damage to field crops during their first season. Those that survive, however, normally attain sufficient size to do considerable damage the second season. Under favorable conditions of food and soil, a few wireworms mature and change to beetles the second year; but in the warmer and lower districts of the Pacific Northwest the majority take 3 or 4 years to complete their life cycle. At higher altitudes it probably takes 4 or 5 years for most of them to mature; and in all districts a few, living under unfavorable conditions, take 5 or 6 years. There is always an overlapping of generations, wireworms of all sizes and ages being present in the soil throughout any growing season.

The full-grown wireworm prepares to change into a beetle during the hottest part of the year, namely, July and August. The larva, in preparing for the pupal stage, first makes a small cell from 3 to 8 inches below the surface of the soil. Here it sheds its last larval skin and becomes a naked white pupa. The pupal stage lasts about 3 weeks and results in the formation of the adult beetle. This beetle does not come to the surface immediately, but remains in the soil cell over winter and emerges the following spring.

SEASONAL MOVEMENTS OF WIREWORMS IN THE SOIL

In the spring, when the soil begins to warm up to about 50° F. (usually in the latter part of March), wireworms start moving up toward the surface. The number of wireworms found in the few inches of soil near the surface increases gradually during April and May. In June, when the surface temperatures reach 80° F. and above, a downward movement of wireworms takes place. This movement is most noticeable in fields where a large part of the ground is bare and is probably more rapid in sandy soils than in the heavier loam soils. In midsummer most of the wireworms stay below the 6-inch level in the soil, except in fields that are densely shaded, as by alfalfa or potatoes. A small percentage of wireworms may move toward the surface in September, but the majority remain below the 6-inch depth during the winter. In the Pacific Northwest there are no winter temperatures in the soil cold enough to affect wireworms unfavorably, either in the adult or the larval stage.

NATURAL ENEMIES

The natural enemies of wireworms are comparatively few and cannot be depended on to control them. Insect parasites are practically unknown, there being only a few instances in which other insects have been known to feed on the tough and ever-moving wireworms. Birds sometimes feed on the larvae turned up by cultivation and on the beetles during their period of emergence in the spring. While any means for increasing the abundance of bird life is to be highly commended, it is doubtful whether birds would ever be an important factor in reducing the number of wireworms under irrigated-land conditions. There are a few fungus enemies of wireworms, but it is also doubtful whether these could be increased to become important in wireworm control.

TRAPPING AND BAITING

The baiting of wireworms in the soil has been attempted with many materials and under a variety of conditions. During the spring, when wireworms are very active near the surface, they congregate in great numbers at baits, such as potatoes and ground-wheat balls. Research with baits for several years, however, has shown that not over a third of the wireworms present in the ground can be attracted to baits at any given time. No practical poison has been found that can be used in baits to kill wireworms. Some common chemicals, such as arsenicals and baits containing them, are very repellent to wireworms. Baiting is necessarily a laborious process and does not justify the expense of time, labor, and materials on any large scale.

Considerable effort has been made to trap adult beetles during their emergence period in the spring. Male beetles can be attracted in some numbers, but female beetles apparently are not attracted to anything before they have mated and laid most of their eggs. No successful method has been devised whereby a sufficiently large proportion of the adult wireworm population can be caught and destroyed.

CHEMICAL METHODS OF CONTROL

The control of wireworms on a practical basis by the use of chemicals has been a difficult problem. The fact that wireworms spend nearly all their existence beneath the surface of the soil prevents their being reached by ordinary contact insecticides, and because they feed only on succulent vegetable matter it is practically impossible to reach them with a stomach poison. The only success obtained to date has been through the use of soil fumigants. Since most fumigants will also injure or kill plants, their use is limited to periods when land is free from crops. If it were not for the presence of crops, the best time to apply soil fumigants would be when the largest number of wireworms are active near the surface and the soil temperatures are relatively high. These two conditions do not necessarily coincide. It has been found by several years of study that the irrigated-land wireworms are nearest the surface in the greatest numbers in April and May. In June they begin moving downward in the soil. During the summer months (July to September), after the early crops have been harvested, most of the

wireworms are found more than 6 inches deep. From the point of view of temperature alone, the best time to apply fumigants to the soil is in the summer when the temperatures are highest, but this depends somewhat on the type of chemical used, as will be brought out later. The poorest time of the year to try to kill wireworms by chemical means is during the winter months (October to March) when soil temperatures are low and most of the wireworms are semi-dormant and at a depth of more than 6 inches.

CARBON DISULFIDE

Carbon disulfide is a very effective agent in killing wireworms in the soil, but its use is limited by its expense. When this liquid is introduced into the soil, it forms a vapor that is heavier than air and that penetrates downward into the soil to a depth of 18 inches or more, killing all wireworms and other insects present. The best time to kill wireworms with carbon disulfide is when most of them are fairly deep in the soil or in the period from June to September. During these months the temperature is most favorable for the diffusion of the vapor in the ground, and the chemical can be used on practically all soils except the very heavy clays and those saturated with water. For best results the soil should be fairly moist, but not too wet to be plowed, and the temperature at a depth of 6 inches should be above 60° F. The higher the temperature of the soil, the faster the vapor will diffuse, kill the wireworms, and work its way out of the soil again.

Areas to be treated with carbon disulfide should first be prepared by loosening the ground by plowing and then smoothing it lightly with a float, drag, or planker. One fluid ounce of carbon disulfide should be applied in the soil about 2 inches deep and at points not over 24 inches apart in each direction. A simple procedure is to mark off the area to be treated lengthwise and crosswise, by using a marker with teeth set at 24 inches or less (fig. 11, *A*). At the intersection of the marks, holes 2 or 3 inches deep can be punched with a stick, and the carbon disulfide poured into the holes from a 1-ounce measure or with a device having a valve set to admit 1 ounce at a time. After being filled with carbon disulfide, the hole should be immediately covered with damp soil and pressed down firmly with the foot to prevent evaporation.

Special devices (fig. 11, *B*) are on the market, consisting of a single unit that punches the hole to any depth desired and ejects, under pressure by means of a plunger, the required dose of carbon disulfide into the soil. These devices will probably insure the best distribution of the gas in the soil with the least discomfort to the operator.

In a few days the chemical accomplishes its maximum kill of wireworms. In hot weather the vapor works itself out of the soil, but a second deep plowing after a week helps to aerate the soil and allow the gas to escape faster. It is reasonably safe to plant crops 10 days after treatment, especially if the soil is of light texture and warm and has been given the second plowing. The cost of the carbon disulfide treatment varies somewhat according to the area to be treated. On an acre basis, it takes 900 pounds of carbon disulfide, at a cost of approximately 7 cents a pound, or $63 per acre. The

cost of labor, which will vary, should be added to the cost of the material. A 100-pound (10-gallon) drum of carbon disulfide is sufficient to treat approximately 5,000 square feet at a cost of about $9.50.

FIGURE 11.—*A*, Three essential operations in the application of carbon disulfide; namely, marking soil to locate points of application, punching holes, and applying the chemical. *B*, latest method of applying carbon disulfide to soil, under pressure, with a special device.

If properly done, this treatment of the soil should result in a kill of more than 90 percent of all stages of wireworms. Considering the long life cycle of wireworms, the land should not need another treatment for several years.

CAUTION: Liquid carbon disulfide evaporates very rapidly on exposure to the air, and the vapor is extremely inflammable and explosive when mixed with air in certain proportions. It should therefore be kept in a cool place and handled with great care. Do not smoke when handling it. It must be remembered that lighted lanterns, cigars, pipes, cigarettes, sparks from electric switches, static or frictional electricity, sparks caused by hammering upon metal, or even hot steam pipes may cause an explosion of carbon disulfide vapor.

CRUDE NAPHTHALENE

Naphthalene has long been recommended for the control of soil insects. The unrefined, or crude, naphthalene in the soft crystalline form containing over 90 percent of pure naphthalene is most satisfactory for use against wireworms. Laboratory and field experiments have shown that naphthalene vapor does not diffuse readily in the soil and that, to be effective, the flaky crystals must be placed near the wireworms. The best time to apply this material is when the largest number of wireworms are nearest the surface and most active, namely, during May and June.

The best method of application known at the present time is to sprinkle the naphthalene by hand or machine along the sides of the fresh furrow from top to bottom as the field is being plowed (fig. 12). It is recommended that the land be plowed as deeply as possible (from 10 to 12 inches) and that the furrow slice be made as narrow as possible (not more than 12 inches). Immediately after the material has been plowed in, the entire field should be disked (fig. 13) as deeply as possible, to mix the crude naphthalene thoroughly with the soil containing the wireworms. The disking is very important, because the deeper and more thoroughly the naphthalene flakes are mixed with the soil, the better will be the kill of wireworms.

When applied in this manner, 500 pounds of crude naphthalene must be used per acre to obtain a good kill of wireworms. To insure an even distribution over the entire field, the crude naphthalene should be weighed out at the rate of 19 ounces to 100 linear feet of 12-inch furrow slice. This material is more effective in killing wireworms in the sandier types of soil. It is less effective in soils rich in organic matter, and it should not be used after heavy applications of barnyard manure or the plowing under of a green crop.

Seed or sets may be planted with little risk of injury within a few days after treatment if the material has been properly applied and mixed with the soil. Crude naphthalene leaves no harmful residues in the soil, and if applied as directed it should kill about 85 percent of the wireworms to the soil depth treated. It is usually sold in sacks of 50 pounds, net. The price ranges from 2 to 5 cents per pound, depending on the distance from the source and the quantity to be purchased, and the cost per acre for the prescribed application is usually from $10 to $25.

CULTURAL METHODS OF CONTROL

Recently developed cultural control methods are based on the behavior of wireworms under various soil conditions and farm practices. These methods obviate the expense of chemicals and are more

FIGURE 12.—Plowing in crude naphthalene as a control for wireworms.

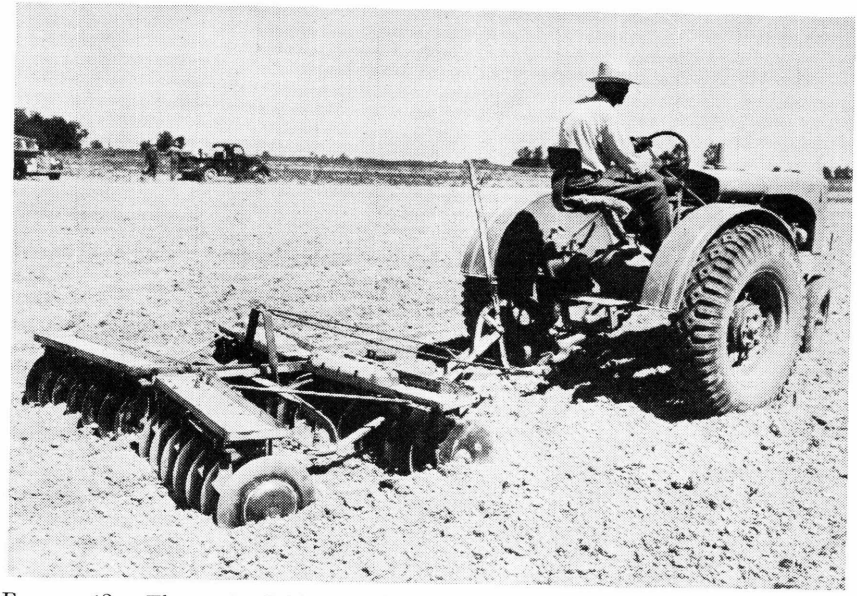

FIGURE 13.—Thorough disking of the soil after applying crude naphthalene in order to mix the naphthalene thoroughly with the wireworm-infested soil.

practical for the average farmer. Neither temperature nor moisture, within the limits normally found in the irrigated soils, is detrimental to wireworms. However, when either an excess or a deficiency of moisture is combined with high temperatures in the summer, wireworms are greatly reduced in number. This reduction can be accomplished by either flooding or drying the infested soil. In the Pacific Northwest temperatures high enough to kill wireworms under extreme moisture conditions occur in most seasons, and when combined with certain crop rotations they help to eliminate a great part of the wireworm problem.

FLOODING SOIL TO KILL WIREWORMS

Wireworms immediately become inactive when submerged in water, and at low temperatures (below 60° F.) they can exist for months

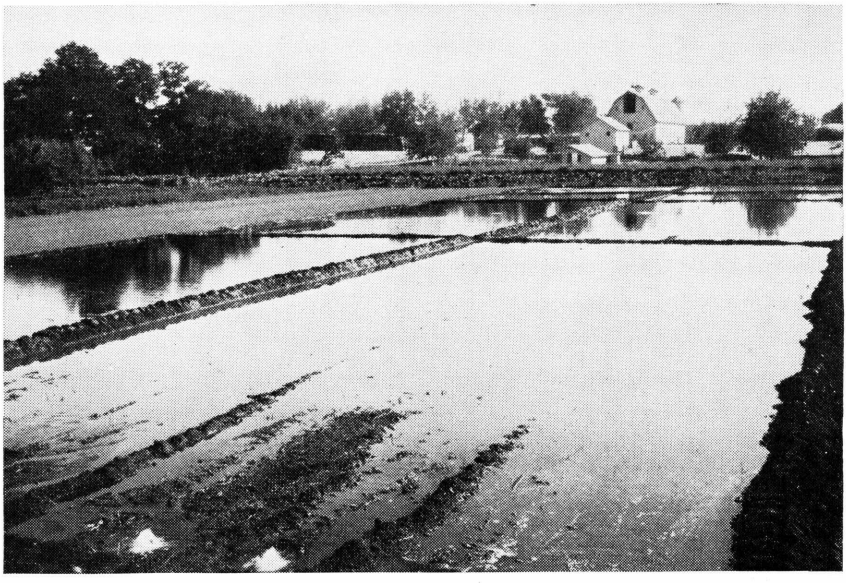

FIGURE 14.—Flooding soil to kill wireworms in the summer.

under water or in flooded soil without permanent injury. When the temperature of flooded soil remains above 68° F. for about 3 days, however, they begin to die; and, if these conditions continue for a period of from 5 to 7 days, a high proportion (from 95 to 100 percent) of the wireworms are killed.

In flooding land infested with wireworms, the soil should first be loosened by plowing, then leveled and diked into small plots, so that the water will not be over 2 or 3 inches deep at any place (figs. 14 and 15). During a period of hot weather, usually in July or August, a shallow layer of water should be turned into the diked areas and maintained for a week. The temperature of the soil under the water should be checked frequently with an immersion thermometer. If an average of 70° F. or higher is found at a depth of 6 inches in the soil, a good kill of wireworms may be expected. Flooding kills all stages of wireworms, including the pupae and adult beetles. The drawbacks

to this method are that it can be used only on fairly level fields where plenty of water is available for at least a week, and in fields not in crop during the period of flooding. It is especially adapted for use in small gardens, and also in the more intensive truck-gardening sections of the Pacific Northwest, where the land is generally fallow in the summer for a short period between the spring and fall crops.

DRYING SOIL TO KILL WIREWORMS

Wireworms subjected to a deficiency of moisture in the air or soil lose their body water within a few days and eventually die. When the upper 18 inches of field soil is allowed to become very dry for several weeks in the summer, most of the wireworms present are killed, especially the smaller or younger larvae. The best method of drying the soil to control wireworms is to allow deep-rooted crops, such as alfalfa or fall grain, to withdraw as much as possible of the natural

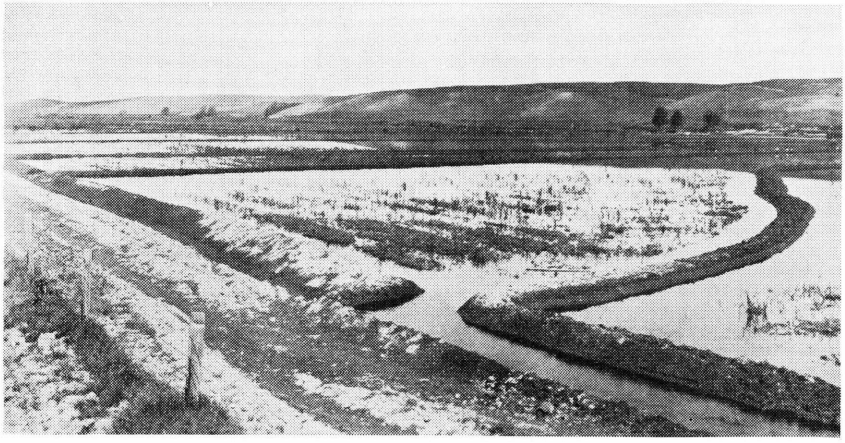

FIGURE 15.—Flooding a 10-acre field to kill wireworms.

moisture from the soil (fig. 16). Merely allowing a field to rest without a crop for a season will not dry out the soil enough to kill wireworms, since fallowing really conserves moisture. All irrigation water should be withheld for a complete season, and the omission of fall irrigations of the previous season helps to reduce the soil moisture even more. Drying the soil to kill wireworms is most effective in well-drained sandy to clay loam soils in which there is no subirrigation near the surface throughout the season. In using this method the farmer must plan on a reduction in his yield of alfalfa or grain, but alfalfa usually produces one and sometimes a second cutting without irrigation. The older wireworms and adults are the hardest to kill by drying, but in most sandy to clay loam soils the wireworms can be reduced about 80 percent by thorough drying of the soil. If soil drying can be fitted into the rotation so that any field that shows heavy damage from wireworms can be dried out while in alfalfa once every fifth or sixth year, the wireworm population can be kept to a minimum and little damage to susceptible crops should occur. One advantage

of this method of control is its practicability for use on a large scale. The main disadvantage is its reduction in farm revenue for the season during which it is applied.

SUMMER PLOWING TO KILL PUPAE

Plowing fields in the hot summer months after early crops have been removed helps to kill the pupae of wireworms (fig. 17). In this stage of development, during which it is changing to the adult form in the soil, this insect is particularly delicate. Plowing to a depth of 9 inches between July 15 and August 15 and allowing the dry, lumpy soil to lie undisturbed for a few weeks reduce materially the number of beetles that would emerge and lay eggs the following

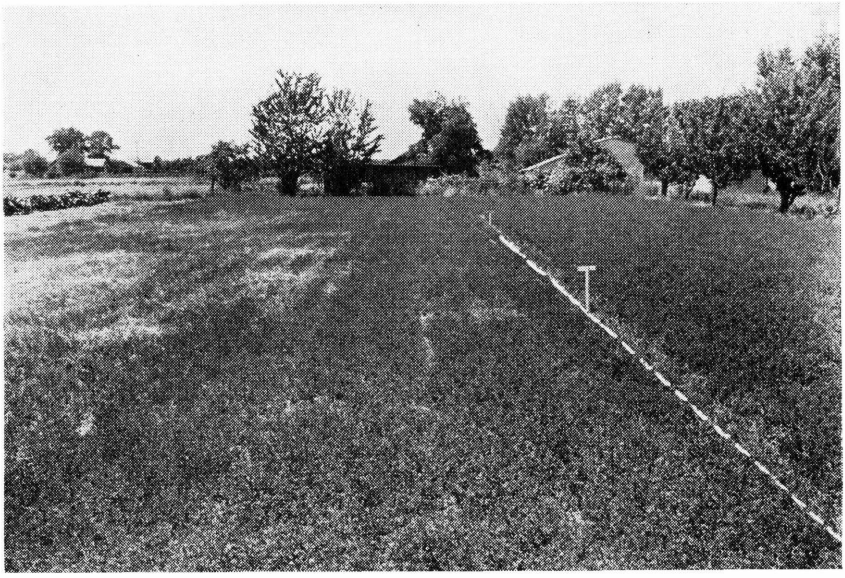

FIGURE 16.—Drying alfalfa fields to reduce wireworm numbers. The alfalfa to the left of the white line was not irrigated; that to the right was irrigated.

spring. This represents a practical aid to wireworm control that can be accomplished with no additional expense except that involved in plowing not more than 3 inches deeper than usual. A small proportion (from 10 to 30 percent) of the immature larvae are also killed by the plowing. Mechanical injury is apparently responsible for the larger part of the pupal mortality, supplemented by exposure to summer heat and low humidities. Fields that have been in small grain and fields devoted to the production of early truck crops, such as peas and early potatoes, can be plowed during the best period for destroying wireworm pupae.

ROTATION OF CROPS

The relationship of crop rotations to the abundance of wireworms and to the damage caused by them has been studied over a period of 10 years (fig. 18). General field and experimental plot studies, con-

ducted on different soil types under a variety of conditions, have yielded information that may be used to advantage by the farmer in controlling wireworms.

It has been found that wireworms have a tendency to increase rapidly when red clover or sweetclover is grown more than one season on infested land. In districts where wireworms are known to be present these crops should not be used in rotations with field and vegetable crops that are susceptible to damage. The growing of potatoes in a short rotation with red clover is particularly undesirable. Large numbers of adult wireworms are usually produced in potato fields, and when these deposit their eggs in the red clover the resultant larvae are provided with ideal conditions for maximum survival. Farmers on new irrigation projects, where wireworms have

FIGURE 17.—A field plowed in the summer, when the soil was dry, to destroy the pupae of wireworms.

not become established, should fully understand the danger of developing wireworm infestations by growing red clover for seed. It might be more profitable in the long run to forego the growing of this crop and to grow other cash crops that are not so likely to allow wireworm increase.

In contrast with red clover and sweetclover, alfalfa creates dry, compact conditions in the soil unfavorable to wireworms. A good stand of alfalfa on well-drained land results in a reduction of large infestations, but it must be continued for several years to accomplish the maximum riddance of wireworms. The tough roots and crowns of alfalfa are apparently not favorable as food for wireworms and cause them to mature slowly. Fewer adult beetles are produced in alfalfa fields and, consequently, fewer eggs are deposited the following year.

If alfalfa is grown with a minimum of irrigation water applied in spring, especially until after the first cutting, very unfavorable con-

ditions are created for the survival of the new brood of wireworms for that season. The beneficial effects of the growing of alfalfa as a control for wireworms can be greatly enhanced in most districts by omitting irrigation of the first cutting of alfalfa for 4 successive years, thereby preventing the wireworms from starting a new brood each year. This insures a minimum number of wireworms to damage subsequent vegetable crops, with, under most conditions, little loss in alfalfa tonnage.

Pasture-sod conditions, if maintained for several years, also appear to be detrimental to the wet-land wireworms of the Pacific Northwest. The most important factors causing poor survival in grass pastures are probably the hard-packed, dry condition of the soil during a great

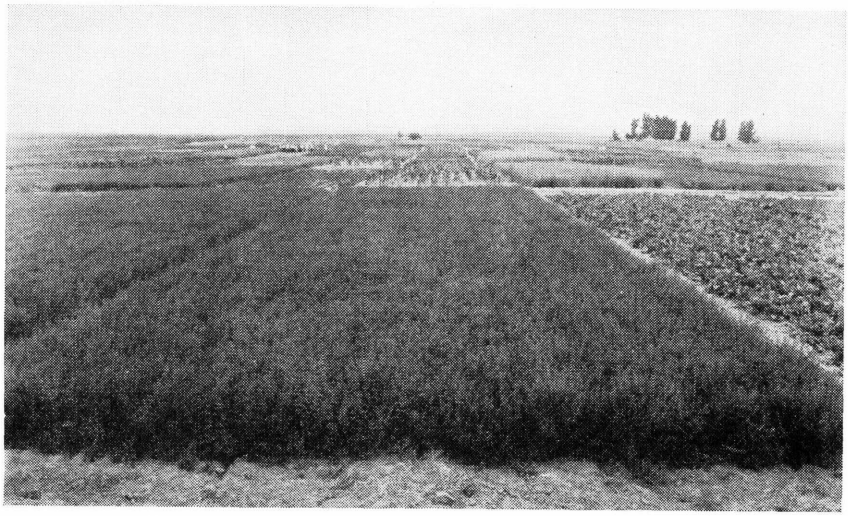

FIGURE 18.—Experimental plots for the study of the relationship of wireworm numbers and damage to various crops and rotations.

part of the season and the practice of irrigating pastures by the flooding method during certain periods of the spring and summer.

The continuous growing of vegetable and field crops on the same land has a tendency gradually to increase wireworm numbers. Asparagus seems to be the only exception; the continuation of this crop for several years has been found to reduce wireworm numbers. Asparagus, with its large, fibrous root system, resembles alfalfa in creating conditions in the soil unfavorable to wireworm survival. Most truck crops grown continuously in the same soil increase wireworm numbers until the periodic application of chemical or cultural control methods finally becomes necessary. Only by constant attention to the problem of wireworms as a major soil pest can farmers hope to grow crops free from damage.

TIME OF PLANTING TO AVOID DAMAGE

The degree of damage to a crop by wireworms is influenced by their vertical movement in the soil, especially when the crop is in the stage of growth most susceptible to their injury. Careful planning to avoid seeding late in April or early in May while the majority of the wireworms are near the soil surface will tend to minimize the loss of seed and the damage to young sprouts from wireworm feeding. The seed of such crops as sugar beets, potatoes, onions, carrots, and peas should be planted early enough to have passed the susceptible stage before the wireworms begin to feed near the surface. The planting of corn, beans, melons, cabbage, and tomatoes should be delayed until wireworms have been driven below the seed depth by the warmer surface temperatures of late spring. As the wireworms move deeper into the soil late in June and in July, they attack the roots and tubers forming from 3 to 6 inches deep in the soil. Early planted potatoes should be harvested as soon as possible to avoid damage by wireworms. The damage to late potatoes can be reduced in districts with longer growing seasons by delaying planting as late as possible in June to bring the tuber development into August, when the majority of the wireworms are below 6 inches in the soil and feeding less actively.

With care and watchfulness of soil conditions, and systematic use of crop rotations and cultural methods, much can be done by the farmers of the Pacific Northwest to avoid damage to their crops by wireworms.

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