MINISTRY OF AGRICULTURE, EGYPT

Technical and Scientific Service.

Bulletin No. 24.

ON THE DISPERSION OF THE PINK BOLL WORM IN EGYPT.

By LEWIS H. GOUGH, Ph.D., F.E.S.,
DIRECTOR OF THE ENTOMOLOGICAL SECTION.

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PREFACE.

It is necessary in considering the results collected together in the following pages to remember that they very probably cannot be applied without modification to results collected elsewhere, unless the conditions in both places are very closely similar. Differences in climate are likely to upset the ratios of growth in the plant, and insect, of emergence of the moths, and of boll-setting and maturing. In places like Madras, where resting stage larvæ do not occur, conditions are obviously so different that no harmony need be expected.

It appears also evident that differences in the variety of cotton grown are likely to upset the agreement between results.

Varieties setting seeds larger or smaller, more or fewer are likely to give results disagreeing from those set out here. It is even possible that climatic variations from year to year combined with the continual change that is going on in any variety of cotton might cause later results to be slightly out of harmony. The whole investigation is still very much in the pioneer stage, and it is impossible to predict at present its final direction. No finality is claimed for the results; they may have to be modified when more material has been examined.

I take the opportunity to thank Dr. Hurst, Controller of the Physical Service, and Mr. Curry of the Physical Service for having helped with suggestions, criticism and corrections, which were most valuable in the presentation of the observations.

The manual work of examination of samples was completed before the theoretic digestion was undertaken, and was done by men who had no knowledge whatever of the object of the research.

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ON THE DISPERSION OF THE PINK BOLL WORM IN EGYPT.

Ever since statistics have been kept relating to the attacks of the pink boll worm it has become increasingly evident that the distribution of the *larvæ* in time and space, *i.e.* through the growing season of the cotton, through the cotton aiea and in the individual bolls making up the cotton crop, must follow definite rules.

In the following an attempt has been made to find out the mode of distribution of the worms in the bolls.

The problem of distribution of worms into bolls is not the same as the classical problem of throwing balls into holes, but is a much more complicated one. Some of the new factors which must be considered are :—

(1) The moth when laying her eggs exercises to a certain extent selection, as can be seen from the fact that flower-buds are not selected unless there is a shortage in the supply of suitable green bolls.

(2) The eggs are frequently laid in batches, not always singly. However, the mortality of the hatching worms appears to be sufficient to eliminate irregularities arising from this source, whereby the exact position on the boll where the egg was placed is of importance.

(3) The time element, carrying with it fluctuations in both the boll population and the worm population. It must be remembered that infestation only takes place during the growing period of the boll, whilst it is still green. This period lasts about seven weeks (fifty days) from the setting to the opening of the boll. During this time two things are happening: the absolute abundance of moths and with it the chances of infestation are increasing, and the supply of bolls is varying. Each boll is advancing towards maturity, and every succeeding night is again exposed to the risk of infestation. It ought thus to be obvious that bolls just set, and consequently exposed for one or few nights only must be much less attacked than older groups. Bolls of the same age have been exposed to the same extent as each other, each night they are old contributing one-fiftieth

of the total possible chance of attack. It will be seen, therefore, that as long as the complete boll population including setting, maturing and ripe bolls is examined, there will be a proportion of sound ones as long as boll production is proceeding. It is also evident that, unless the attack has increased to 100 per cent there must be some sound bolls present of each age, and that finally some sound bolls will mature.

Perhaps it is also well to bear in mind that as long as boll production is proceeding the attack as expressed in percentages is being kept low, by the presence of the young bolls which are not or scarcely attacked. As soon as the production of new bolls ceases, or slackens, the percentage of attack is no longer kept down in this way, and the resulting increasing rise in percentages becomes very evident. To this the steep rise at the end of the season is to a great extent due in a record of percentage attack of green bolls only.

Having shown the considerations which have to be remembered when trying to work out a formula, it is perhaps only necessary to remark that more than one plan of distribution of worms into bolls was studied, whereby the method now to be described was found to fit the observed facts best.

Presuming, that, as is a fact, more than one worm can infest a single boll, and for the moment presuming that the number per boll is not limited in any way (which however is not the case), the distribution of 1, 2 , 3 or further multiples of worms per boll appears to be regulated as follows :—

In each 100 bolls with n per cent attack there will be (100-n) per cent bolls free from worms. Of the n bolls containing worms (100-n) per cent will contain one worm only. Of the remaining bolls (100-n) per cent will contain two worms, of the remainder (100-n) per cent will contain three worms, and so further until the figures representing the number of bolls containing 0, 1, 2, 3, etc., worms when added together gives 100, by which time the last figure obtained (for the largest number of worms per boll) will have become a negligible fraction.

The number of worms in a given sample can be calculated with ease from the figures thus obtained. For example :—

Given 30 per cent attack, the expectations are :—

	70·00	bolls with no worms.				
	21·00	,, ,,	one worm	or	21·00	worms.
	6·30	,, ,,	two worms	,,	12·60	,,
	1·89	,, ,,	three ,,	,,	5·67	,,
	0·57	,, ,,	four ,,	,,	2·28	,,
	0·17	,, ,,	five ,,	,,	0·85	,,
	0.05	,, ,,	six ,,	,,	0·30	,,
	0·02	,, ,,	seven ,,	,,	0·14	,,
TOTAL ...	100·00	,, ,,	in all ,,	,,	42·84	,,

This method of calculation cannot however be applied without modifications being introduced to allow for the obvious fact that each boll can only harbour a limited number of worms, only a certain amount of food and space being available.

The number of seeds set in sound bolls of Sakellarides were found to be on the average in two different samples of 180 and 100 sound bolls 16.37 (Gough, Bull. Ent. Res. 1919, page 296), or 14·99 (page 290) showing that the number of seeds set per lock varies between five and six, or fifteen to sixteen per boll, fifteen being in the two samples examined more frequent.

The number of worms developing completely in a boll depends however as already stated on the amount of food offered. The following figures may facilitate comprehension.

The weight of 100 mature sound seeds in a sample of Sakellarides cotton was found to average 10·300 grammes, 1,000 seeds being used.

Thirty sets of 100 double seeds from the same sample were weighed (without worms), the red and black components being weighed separately. The weight of 100 black components was found to be 6·925 grammes, the weight of 100 red components 5·578 grammes, 3,000 seeds being used in each case. The damage done by 100 worms to 200 nearly ripe seeds was consequently 8·097 grammes, or 79 per cent of a seed per worm by weight. The damage done to younger seeds would necessarily be much greater, corresponding to their less weight and greater moisture content.

One boll of Sakellarides could consequently raise a maximum of twenty worms to maturity, if all seeds were completely destroyed and if the attack was delayed until the seed was nearly ripe.

It may be supposed that ten worms are the average maximum number likely to develop in one boll. This does not mean to say that no boll will contain more than ten, twelve having actually been observed by us; it also does not infer that the limiting factor never begins to act until ten have attacked the boll. But as an average number ten seems to be not far out. If anything, it probably errs on the side of excess.

The question instantly arises, What is the limiting factor which prevents more than a certain number of worms occurring simultaneously in a boll? There are three possibilities which suggest themselves at once, which give different results when calculating the total number of worms required to produce any percentage of infestation, but which do not alter the probable number present in samples of open cotton bolls such as would normally be picked for crop. They are :—

(1) The number of worms may be limited by the attacked boll drying up or falling off the plant, when more than a certain number of worms have attacked it. This would divide bolls produced into three classes:

(*a*) those containing 0 to 4 worms, that ripen and produce pickable cotton; (*b*) those containing five to some higher number of worms, that produce *mabrûma* (*i.e.* unpickable cotton); and (*c*) those that contain more than this higher number and which fall or dry up, and are consequently not included as *mabrûma*.

Note.—The reason for supposing four worms as the limit for pickable cotton will become apparent later.

(2) The number of worms may be limited by the attacked boll becoming unsuitable for food for young larvæ, which try to feed on the boll and die from the effect. It does not appear unreasonable to suppose that the boll gets badly contaminated with toxins arising from the vital processes of the worms or produced by the plant in response to the very serious injury done to it. The problem is one for the physiologist not for the entomologist to investigate. The result would require the production of the same number of worms as supposed under the previous assumption, but (*b*) and (*c*) would be *mabrûma*, whereby the number of worms apparent in the (*c*) bolls would not exceed the top limit for (*b*).

(3) The number of worms per boll may be limited by selection on the part of the young worms, which do not enter bolls containing more than a limited number. This would again have the effect of combining (*b*) and (*c*) as under the preceding paragraph (2), with the difference that the larvæ which had rejected heavily infested bolls would be available to attack other less damaged ones. This would not alter the method of calculation, except for the total production of worms required to produce any given percentage. The total number present whose activities could be demonstrated (supposing those that die early evade observation) would be the same, but the number actually generated from eggs would be less.

The number of worms present in pickable ripe bolls remains the same under all three assumptions, as does the number likely to be observed in the *mabrûma* bolls. Assumption one requires a reduction of the apparent boll population, but not necessarily of the worm population. Assumption two postulates reduction of the apparent worm population, but not necessarily of the boll population. Assumption three demands a higher percentage boll infection for any given number of eggs laid, once certain limits have been surpassed.

Should assumption one be correct, it would require (once the number of worms causing boll-shedding had been reached) that the true percentage attack should no longer be calculated from samples actually gathered from the trees, as such samples would not contain the fallen bolls. In all three cases, samples of "pickable" cotton, not containing *mabrûma*, cannot be used directly to find the true percentage attack, as such samples are incomplete owing to the *mabrûma* and the lost bolls being absent. The apparent percentage attack becomes always lower than the true percentage, but if the assumption that four worms are about the maximum usually included in pickable cotton is valid, the true percentage attack can be calculated. For samples containing about 81 per cent attacked bolls of picked ripe cotton, the true percentage ought to be about 99 per cent.

Table I shows the expected numbers of bolls containing no worms and one to ten worms, respectively, for every third unit from three to ninety-nine per cent true attack.

Before proceeding further with calculations based on this table, the following proof may be offered for the correctness of the figures.

Ballou in his report on the Pink Boll Worm in Egypt in 1916–1917 on pages 42–43 gives the results of the examination of certain samples of bolls which were inspected singly, and the numbers of pink boll worms in which were recorded. The comparisons between Ballou's observations and our calculations are found in Table II, the results being a so extremely close approximation between calculated and observed results as to leave no doubt as to the probability of the correctness of the method of calculating the distribution of the worms in the bolls. (The correllation $r = 0{\cdot}9974 \pm 0{\cdot}0002$ also leaves no doubt that the agreement is not merely a chance one.)

Note.—The objection to utilising Ballou's Table XIV can be made, that the observations on which it was based were made during winter and a long time after the bolls had been infected. Also that many a worm will have had time to leave the bolls and emerge before the bolls were examined. As against this can be placed that the percentages of attacked bolls were based only on the worms actually present at the time of examination, and that the emergence of the moths from the bolls evidently follows the same general rules as the initial infestation. The figures given by Ballou for worms present would be much safer than those found by us in green bolls, as there would be no chance of small ones getting overlooked by the observer when dealing with dead bolls in winter.

It will have been observed that the figures compared on Table II all fall within the limit of tolerance of twelve worms. Once the limit of tolerance has been exceeded, the observed boll population consists only of sound bolls and bolls within the limit. This will cause a change to take place in the observed percentage which will no longer coincide with the true percentage, but will show a less apparent attack than the true attack. It is also obvious that when the tolerance is small a difference between true and apparent attack will commence early and become much greater, than when the tolerance is great. Table III has been prepared to show the number of worms required to produce infection for true percentages from 3 per cent to 99 per cent at intervals of 3 per cent, when the tolerance is unlimited, or ten, eight or six worms.

It will be observed that the number of worms likely to be present is greatly influenced by the limit of tolerance of the bolls.

The total number of worms required to produce 99 per cent attack, if there is no top limit of numbers of worms per boll would be about 9,900. This involves certain bolls containing more than 100 worms, and is obviously not possible of occurring.

The number of worms required to give the same percentage damage, when the largest number present in a single boll is limited to ten, eight or six are about nine hundred and fifty, seven hundred and seventy and five hundred and eighty. It will be remarked that the numbers at the commencement of the table are the same for all four columns, and that the rate of rise of the number of worms required is at first slow, becoming more and more rapid as the higher percentages are reached. It is most important to remember that increases in percentages of infestation obviously mean more in numbers of worms present at the upper end of the scale than at the lower. Just how much the difference really is will depend on the average limit of tolerance. For this reason the numbers required for six, eight and ten worms have been calculated and tabulated here. It may, however, be remarked that the probability is that six is too low a figure to take, and that eight or ten are much more probable. Ten and even twelve worms in one boll have actually been observed on more than one occasion.

The actual number probably depends to some extent on the variety of cotton that is being attacked. The material, on which this paper is based, is almost exclusively Sakellarides, which produces on an average about fifteen or sixteen seeds per boll. It is obvious that thetop limit of numbers of worms per boll will vary according to the number and weight of the seed produced. A variety producing more seeds will tolerate more worms, given seeds of equal average weight. Or a variety producing heavier seed might tolerate more worms, even though producing only the same number of seeds. Pink boll worms most frequently (not always) occupy or attack two seeds, though one or three seeds may be required. If each worm used two seeds, eight worms would be the limit in a boll containing sixteen seeds. Eight, nine or ten worms are likely to be the limit, something also depending on the age of the boll when attacked. For the further purposes of this paper the exact number is not material.

It is of much greater moment to know what is the largest average number of worms which shall have attacked a "pickable" ripe boll. The definition of a "pickable" ripe boll is: a pickable boll is a boll of ripe cotton, such as would normally be taken when harvesting the cotton. Unfortunately, it is not possible to be more precise, and different people's idea of pickable will vary to some extent, though probably not much. It will possibly also vary with the price of cotton, and perhaps also become less conservative towards the end of the season, when there is a smaller proportion of good cotton; it may also vary annually. There is, however, considerable uniformity in our samples of ripe cotton, which have been collected during several seasons, and by very many different men. Some samples have, however, been outstanding, much better or worse than the average.

The probable average maximum number of worms in any one pickable boll is about four, as will be shown shortly. This number might involve half of the seeds in a boll of Sakellarides, and would almost certainly require two locks if not all three to have been damaged (*see* Table VI). On Table IV some of the main facts necessary to remember in connection with pickable bolls have been recorded. It will be seen that the first column is entitled "apparent percentage," whilst the second one is headed "true percentage." The apparent percentage is the figure that would be obtained by examining a sample of ripe cotton, picked in the ordinary way, *i.e.*, with the exclusion of badly damaged bolls, fallen bolls, etc. The true percentage would include all bolls produced, whether good, bad or indifferent. Theoretically the apparent percentage can be reckoned from Table I, by utilising only those figures (at any percentage) which refer to bolls with from 0–4 worms. The proportion of attacked bolls to the total number of bolls in the part sample gives the apparent percentage attack. There is no difference between the select population and the total population until 15 per cent attack is reached; from there on the difference is at first minute, but finally becomes enormous. Thus at 99 per cent true attack, equivalent to about 80 per cent apparent attack, there are roughly nineteen bolls in the total population outside the select sample to each one within it. These bolls, which belong to the total population but not to the select population, are pure loss, and represent *mabrûma* (*i.e.*, bolls which have failed to open normally), and fallen bolls. The number of worms within the select population per 100 bolls is given. Compared with the figure on Table III, it will be seen that until 33 per cent attack is reached, the number of worms required per 100 bolls is the same for all possibilities we have considered. The final number required for the special population of 0–4 worms per boll is, however, very low in comparison.

The following example, showing how the set of figures on Table IV for 75 per cent apparent attack were obtained, will facilitate understanding of the table, and the underlying problems.

The first column shows the apparent percentage. This is done, because in practice one will start from a sample of picked cotton, and require to know how much loss of cotton there was in the crop to which it belonged. The corresponding true percentage, supposing four worms to be the average maximum number of worms found in a pickable boll has been calculated in the same way as Table I (eleven sound bolls, 9·79 with one, 8·71 with two, 7·75 with three, 6·90 with four worms, together 44·15 bolls of which eleven sound giving approximately 75 per cent attack.

The third column showing the number of worms per 100 bolls of the apparent sample has been calculated from the same set of figures, as follows :—

11	bolls	with	0	worms	0	worms
9·79	,,	,,	1	,, ...	9·79	,,
8·71	,,	,,	2	,, ...	17·42	,,
7·75	,,	,,	3	,, ...	23·25	,,
6·90	,,	,,	4	,, ...	27·60	,,
					78·06	worms.

but as this represents only 44·15 bolls in all, the number must be increased to bring the bolls up to 100, giving consequently about 176 worms.

The fourth column is intended to show the proportion of the entire boll population not included in the select population. As only forty-four bolls were included in the select population fifty-six must be excluded and represent total loss.

The fifth column shows the loss within the select population. It has been shown on Table V that the amount of loss caused by a single worm approximates to about one tenth of a boll (Sakellarides). One hundred bolls with apparent percentage 75 per cent would thus normally have lost 17·6 per cent of their substance (or from observation 17·1 per cent). But as we are calculating total loss of the entire population in percentages, we can only put into the table 44 per cent of 17·6 per cent, which gives about 8 per cent.

In the sixth column the losses entered in the fourth and fifth columns have been combined to give the probable true loss over the whole boll population.

It is of importance to remember :—

(*a*) That the percentage attack found when examining samples of open pickable bolls is nearly always an apparent one.

(*b*) That when they differ the true percentage attack is always higher than the apparent percentage.

(*c*) That the higher the percentage of attack the greater the difference of the apparent from the true percentage attack.

(*d*) That the difference between the select population and the total population really represents lost crop.

There is great probability that the amount of damage done to a boll by the worms infesting it is proportional to the number of worms themselves. Put otherwise, each worm eats about the same amount, and n worms will eat n times as much as one worm does. Whilst allowing for small individual differences, taken in the bulk, over large samples, the rule can be expected to hold good. It has been utilised to find out, as far as it can be used for this purpose, what the maximum number of worms is that can be present in a pickable boll. But it may conveniently be stated here that there is little likelihood of finding a correct answer to the problem by direct observation. By the time a boll is ripe and picked, some of the worms it had harboured will have migrated. They leave traces, but the traces are hard to class as belonging to one or more worms. The same worm may leave traces behind in two locks, and these traces might be ascribed to two worms.

During the last five years large numbers of samples of ripe "pickable" cotton bolls have been examined in the laboratory of the Entomological Section, for estimation of the amount of damage due to the pink boll worm. The examination requires that the number and weight of all the bolls in the sample be ascertained. The bolls are individually examined, and the sound ones separated. The cotton from the sound bolls is weighed, and the average weight multiplied by the total number of bolls in the sample. The difference between the total weight of the sample and the " ideal " weight it would have had if all the bolls had been sound is the loss. This loss is, for the purposes of comparison best expressed as a percentage of the ideal weight. And here it may be mentioned, that the individual variation of the sound bolls amongst themselves in weight has not been overlooked. It has been found that this variation is likely to introduce serious error, unless the samples are of such a size as to eliminate the effect of individual fluctuations. This makes the determination of loss in samples of high percentage attack perplexing, owing to the increasing difficulty in obtaining sufficient sound bolls to base an average on, and to the number of sound bolls used being too small as compared to the total sample. The safest figures are obviously those where the sound bolls are in the majority, or certainly not less than say one-third of the total.

Two hundred and seventy-seven such samples have been used on Table V to produce the column percentage loss. They have been arranged according to percentage, from three to three per cent. Each figure contains all the results available for itself and the percentage above and the percentage below. Samples containing less than 50 bolls were not used, nor those of more than 75 per cent attack, for the reason given above. (N.B.—75 per cent apparent attack already equals 89 per cent true attack.) It should be unnecessary to remark that the percentages indicated are apparent, not true. These figures have been correllated to the number of worms required to produce the same apparent percentage. Six worms maximum, five and four were tested. The best result was obtained for four, $r=0{\cdot}9906+0{\cdot}0013$, which indicates practical identity of the two series.

Another result is also so suggestive as to be probably based on fact. It will be noticed that the loss expressed as per mille gives practically the same figure as the number of worms required to produce the infection. The totals of the two columns are nearly the same, and the individual pairs of figures correspond closely to each other. This gives a possibility of completing the loss figures given on Table IV, remembering that the percentages now under consideration are of the select population and not of the general total population. The two losses are combined as loss on total population, which is the only fair way of quoting in the last column of Table IV.

In examining any tables on which the percentage attacked bolls, or the reverse, percentage sound bolls are used, whether in connection with time or any other factor, it is useful to remember that all points on such a table do not stand with the same firmness as established facts.

The size of the sample to be used is of very great consequence, if errors are to be avoided and false conclusions are to be evaded. It is obvious, in order to obtain satisfactory evidence when the infestation is one or two per cent only, that samples must contain several multiples of the numbers required to produce one or two per cent infestation. In our work we have early recognised this, and most of our samples of green bolls have been made up of at least one thousand bolls. Even so, it is probable that the low end of the infestation tables are likely to have a somewhat high probable error.

The nearer samples approach to 50 per cent attack, the more accurate the results for the same number of bolls. Thus the middle positions of the tables may be taken to be accurate to a higher degree than the lower ends.

Inaccuracy such as is due to defective sampling observable at the low end of the tables returns at the higher end, but in much more obvious form. Indeed it may be open to doubt whether results obtained from one thousand bolls are usable for infestation records of over 80 per cent. At the low end of the table one worm more or less per hundred bolls produces a change of one per cent. At the high end of the table there must be on an average four, five, or more worms per infected boll. Obviously the chances of distribution of worms non conformably with the rule are now enormously increased, and although over sufficiently large a sample considerable regularity and conformity to the rule are most probable, in small samples consisting of a thousand bolls only this can hardly be altogether expected. This has been especially felt when working up results obtained from open bolls, where samples had to be kept down in size if they were to be examined at all. Examining each seed in 100 bolls one by one is a lengthy process, as 1,600 seeds have to be delinted by hand to do so. Increasing these samples to thousands of bolls meets with obstacles other than financial.

In 1920. with a view of studying the distribution of damage within the bolls composing a sample, sixty-three samples of bolls were examined lock by lock, and records were kept showing the percentage of bolls in each sample, attacked in 0, 1, 2 or 3 locks. Forty-seven of these samples lie within 78 per cent apparent attack (=95 per cent true attack) and are usable. The remainder belong to too high percentages to be used in this connection.

If the theory of distribution of worms within the component bolls of a sample is correct, it should be possible to bring the results of this last examination into consonance with it. The non-entomological reader must be warned, before starting on this examination, that the problem is not quite on a par with throwing balls into holes, where the balls remain to be counted. The worms are animate beings, and the bolls, whose locks represent the holes into which the balls are thrown, are also living things, and the barrier between the component locks of a boll is easily broken down by a worm.

It appears probable to the writer, that given bolls consisting of three locks, and given certain numbers of worms to distribute, that the distribution will follow the scheme outlined below.

Assuming one worm only attacks one lock, and worms show no preference.

With one worm per boll there is only one chance (unless altered by the insect), and that is that one lock will be attacked.

With two worms per boll there are three chances :—

(*a*) Both worms will be in one lock ; one chance.
(*b*) The worms will occupy two locks ; two chances.

With three worms per boll there are nine chances.

(*a*) All three worms occupy one single lock ; one chance.
(*b*) The three worms are distributed over two locks ; six chances.
(*c*) The worms each occupy a different lock ; two chances.

With four worms per boll there are twenty-seven chances.

(*a*) All four in one lock ; one chance.

(*b*) The four are distributed through two locks ; fourteen chances.

(*c*) The worms are distributed in all three locks; twelve chances.

If necessary the chances for larger numbers of worms can easily be calculated by the following rule. Each succeeding increase by one worm requires the number of chances to be trebled 1, 3, 9, 27, 81, 273, etc. In every case there is only one chance of all falling into one lock.

The following table makes the arrangement clear.

TABLE VI.

Number of Worms per Boll of 3 Locks.	Number of Chances.			
	All in one Lock.	All in Two Locks.	All in Three Locks.	Total Number of Chances.
1	1	—	—	1
2	1	2	—	3
3	1	6	2	9
4	1	14	12	27
5	1	30	50	81

To find the figure for any place in the column all in two locks, add one to the figure immediately above and multiply by two.

To find the figure for any place in the column "all in three locks," multiply the figure immediately above by three and add to this the "all in two locks" figure corresponding to the number multiplied.

Using the distribution outlined above, and the numbers of worms to be distributed as found from Table I, the statement has been calculated which is tabulated on Table VII in the middle division. The first division of the table showing the actually observed facts.

Comparison of these two sets of figures shows : (*a*) that the number of bolls damaged in one lock is excessive in the calculation as compared to the observation, and (*b*) that the number calculated to be damaged in three locks is deficient to about the same extent.

The calculation demands more single locks damaged than observed ; it is therefore obvious that in some cases and under certain circumstances one worm is capable of doing damage in two locks. This must be due to the worms wandering from one lock to the other, examination of the material is not likely to give a reason, but it may be when the insect is searching for a way out before pupation, when insects are normally restless, or it may be wandering in search of more palatable food. This is where animate nature differs from balls and holes. Whatever may be the cause, it may be stated that the fact that worms travel from lock to lock has actually been observed in nature, and that a single weighting, if introduced, allows for the movements of the worms. It will be found that if one subtracts one-fourth from the calculated number of bolls attacked in one lock, that the number calculated for the bolls attacked in one lock approaches very closely to the observed facts. Carrying the remainders over and adding them to the figure giving the calculated numbers attacked in two locks, and then subtracting one quarter from the sums obtained, serves to bring the figures calculated for bolls attacked in two locks extremely close to the observed figures. These quarters remaining over added to the calculated numbers of bolls atacked in three locks completes the calculation and brings once more observation and calculation extremely close together. The correlation between the observed numbers and the calculated and weighted numbers is $r=0{\cdot}9557 \pm 0{\cdot}0038$. This examination was made on Sakellarides cotton.

These results cannot possibly be ascribed to chance, seeing that forty-seven observations enter into the calculation, and seeing that fifty-four pairs of figures were compared for correlation.

We are publishing in another paper all the statistics collected hitherto concerning infestation of green bolls by the pink boll worm and by *Earias*. No attempt is being made by us to reduce those figures to statements of percentage damage comparable from one year to another. With the information given here it ought to be apparent that great care must be used before lightly drawing conclusions, and that it is not permissible to use means of percentages indiscriminately, although it might be allowed to use averages after translating percentages of infestation into terms of numbers of worms per hundred bolls. From this, percentages of attack might be calculated again. This would, however, require a knowledge of the average maximum worm population per boll which we do not yet possess. An example will make the preceding more clear. Supposing the average maximum number of worms per boll be limited to ten. Given two samples of 100 bolls each, one attacked to 3 per cent, the other to 99 per cent. If these two are averaged, the attack would appear to be 51 per cent. But the internal composition of the 200 bolls would be very different from that of a normal sample with 51 per cent attack. We would now have (*see* Table III) three worms+946 worms in 200 bolls or 475 worms per 100 bolls, which number of worms would belong more properly to an attack between 84 per cent and 87 per cent, though their distribution would be different. The damage being proportionate to the number of worms, the figure 51 per cent attack would no longer correspond to the normal damage expected at that intensity of attack, any argument based on averages of this kind would be fallacious. In fact, in the extreme case used as illustration, we would really have about 47 per cent damage to record, instead of about 12 per cent which would be expected in a normal sample with 51 per cent attack.

Conclusions.

(1) The distribution of pink boll worm attack in cotton bolls follows definite rules in Sakellarides cotton.

(2) For any given percentage attack it is possible to calculate the numbers of bolls per hundred with 0, 1, 2, 3, 4 and more worms.

(3) The damage is directly proportionate to the number of worms which have attacked the bolls.

(4) The damage done by a single worm is about one tenth of the yield of the boll in Sakellarides cotton.

(5) When the percentage attack is known, it is possible to predict the number of bolls per hundred attacked in 0, 1, 2, or 3 locks, whereby there is evidence that about one worm in four does damage to more than one lock in Sakellarides cotton.

(6) It is obvious from the study of the facts brought forward that it is not permissibile to make averages of percentages attack of bolls, if averages are required they must be made after converting the figures for percentage attack into numbers of worms per hundred bolls or into percentage damage done.

Explanation of Terms used.

(1) Entire population of bolls.
All the bolls set on the plants under examination, whether they mature into pickable cotton or no, including even such bolls as fall off before maturity.

(2) Select population.
That part of the population which has been selected according to any method, or for any purpose.

(3) True percentage.
The true percentage is the percentage over the entire population.

(4) Apparent percentage.
The percentage observed when examining a select population.

(5) Percentage attack.
The number of bolls per hundred which have been attacked by the insect.

(6) Percentage damage.
The loss to the crop due to the ravages of the pink boll worm. Until 100 per cent attack is reached the percentage damage is always smaller than the percentage attack.

TABLE I.—SHOWING NUMBERS OF BOLLS PER 100 CONTAINING 0, 1, 2, ETC., AND UP TO 10 BOLL WORMS AS CALCULATED AS OCCURRING FOR EVERY THIRD PERCENTAGE FROM 3 PER CENT TO 99 PER CENT.

True Percentage Attack.	Numbers of Worms per Boll.											Over
	0	1	2	3	4	5	6	7	8	9	10	10
3	97	2·91	0·09	—	—	—	—	—	—	—	—	—
6	94	5·64	0·34	0·02	—	—	—	—	—	—	—	—
9	91	8·19	0·74	0·07	0·01	—	—	—	—	—	—	—
12	88	10·56	1·27	0·15	0·02	—	—	—	—	—	—	—
15	85	12·85	1·81	0·29	0·04	0·01	—	—	—	—	—	—
18	82	14·76	2·37	0·43	0·07	0·01	—	—	—	—	—	—
21	79	15·69	3·48	0·73	0·13	0·04	0·01	—	—	—	—	—
24	76	18·24	4·38	1·05	0·25	0·06	0·02	—	—	—	—	—
27	73	19·71	5·32	1·44	0·39	0·11	0·03	0·01	—	—	—	—
30	70	21·00	6·30	1·89	0·57	0·17	0·05	0·02	—	—	—	—
33	67	22·11	7·30	2·41	0·80	0·26	0·09	0·03	0·01	—	—	—
36	64	23·04	8·29	2·99	1·07	0·39	0·14	0·05	0·01	0·01	—	—
39	61	23·79	9·28	3·62	1·41	0·55	0·22	0·08	0·03	0·01	—	—
42	58	24·36	10·23	4·30	1·81	0·76	0·32	0·13	0·05	0·03	0·01	—
45	55	24·75	11·14	5·01	2·26	1·01	0·46	0·20	0·09	0·04	0·02	0·01
48	52	24·96	11·98	5·75	2·76	1·33	0·63	0·31	0·15	0·07	0·03	0·02
51	49	24·99	12·74	6·50	3·32	1·69	0·86	0·44	0·23	0·1[illegible]	0·06	0·05
54	46	24·84	13·41	7·24	3·91	2·11	1·14	0·62	0·33	0·18	0·10	0·12
57	43	24·51	13·97	7·96	4·54	2·59	1·48	0·84	0·47	0·28	0·15	0·20
60	40	24·00	14·40	8·64	5·18	3·11	1·87	1·12	0·67	0·40	0·25	0·36
63	37	23·31	14·68	9·26	3·83	3·67	2·31	1·46	0·92	0·58	0·36	0·62
66	34	22·44	14·81	9·78	6·45	4·25	2·82	1·85	1·22	0·01	0·53	1·04
69	31	21·39	14·77	10·18	7·03	4·85	3·35	2·31	1·59	1·10	0·76	1·68
72	28	20·16	14·52	10·45	7·52	5·42	3·90	2·81	2·03	1·45	1·05	2·69
75	25	18·75	14·06	10·56	7·90	5·93	4·45	3·34	2·50	1·88	1·40	4·23
78	22	17·16	13·38	10·44	8·14	6·35	4·95	3·86	3·01	2·35	1·84	6·52
81	19	15·39	12·46	10·10	8·18	6·62	5·37	4·35	3·52	2·85	2·31	9·85
84	16	13·44	11·29	9·48	7·97	6·69	5·62	4·72	3·97	3·33	2·79	14·70
87	13	11·31	9·84	8·56	7·45	6·48	5·63	4·91	4·27	3·71	3·23	21·61
90	10	9·00	8·10	7·29	6·56	5·90	5·31	4·78	4·30	3·87	3·48	31·41
93	7	6·51	6·05	5·63	5·24	4·87	4·53	4·21	3·92	3·64	3·40	45·00
96	4	3·84	3·59	3·54	3·40	3·26	3·13	3·01	2·89	2·77	2·66	63·90
99	1	0·99	0·98	0·97	0·96	0·95	0·94	0·93	0·92	0·91	0·90	91·06

TABLE II, SHOWING THE AGREEMENT BETWEEN THE OBSERVED AND THE CALCULATED DISTRIBUTION OF GELECHIA LARVÆ IN BOLLS AT VARIOUS PERCENTAGES OF THE ATTACK. (THE OBSERVATIONS ARE TAKEN AND COMBINED FROM BALLOU, "THE PINK BOLL WORM," PP. 42 AND 43.)

Percentage Attack.	Numbers of Bolls containing from 0–12 Boll-worms.													Remarks.
	Numbers of Worms per Boll.													
	0	1	2	3	4	5	6	7	8	9	10	11	12	
4	96·00	3·84	0·15	0·01	—	—	—	—	—	—	—	—	—	Calculated.
	95·60	4·00	0·40	—	—	—	—	—	—	—	—	—	—	Observed by Ballou in 500 bolls.
22	78·00	17·16	3·78	0·83	0·18	0·04	0·01	—	—	—	—	—	—	Calculated.
	78·40	14·40	4·70	1·60	0·70	0·00	0·10	0·10	—	—	—	—	—	Observed by Ballou in 1,000 bolls.
31	69·00	21·39	6·65	2·06	0·64	0·20	0·06	0·02	0·01	—	—	—	—	Calculated.
	69·39	20·82	6·75	2·07	0·54	0·29	0·11	0·00	0·04	—	—	—	—	Observed by Ballou in 1,800 bolls.
48	52·00	24·96	11·98	5·75	2·76	1·33	0·63	0·31	0·15	0·07	0·03	0·01	0.01	Calculated.
	52·30	22·87	13·60	6·77	2·40	1·40	0·43	0·17	0.07	—	—	—	—	Observed by Ballou in 3,000 bolls.
50	50·00	25·00	12·50	6·25	3·13	1·56	0·78	0·39	0·20	0·10	0·05	0·02	0·01	Calculated.
	49·70	24·53	13·63	6·93	3·18	1·25	0·45	0·18	0·13	0·02	—	—	—	Observed by Ballou in 6,000 bolls.
52	48·00	24·96	12·98	6·75	3·51	1·82	0·95	0·50	0·26	0·13	0·06	0·04	0·02	Calculated.
	48·10	17·20	18·42	9·87	3·63	1·46	0·27	0·53	0·13	0·13	0·13	0·00	0·15	Observed by Ballou in 750 bolls.
55	45·00	24·75	13·61	7·49	4·12	2·26	1·25	0·68	0·38	0·21	0·11	0·06	0·04	Calculated.
	45·39	22·18	15·36	8·87	3·75	1·71	1·37	0·51	0·34	0·17	0·17	0·17	—	Observed by Ballou in 586 bolls.

$r = 0.9974 \pm 0.0002$

TABLE III.—PERCENTAGE OF ATTACK AND NUMBER OF WORMS REQUIRED.

True Percentage.	Total Number of Worms required if the Number of Worms per Boll is				Remarks.
	Not limited.	Limited to			
		10 Worms.	8 Worms.	6 Worms.	
3	3	3	3	3	NOTE.—In the last three columns all bolls which should have had more than 10, 8 or 6 worms are counted as having contained 10, 8 or 6 worms only.
6	6	6	6	6	
9	10	10	10	10	
12	14	14	14	14	
15	18	18	18	18	
18	21	21	21	21	
21	27	27	27	27	
24	32	32	32	32	
27	37	37	37	37	
30	43	43	43	43	
33	49	49	49	49	
36	56	56	56	56	
39	64	64	64	64	
42	72	72	72	72	
45	82	82	82	81	
48	92	92	92	91	
51	104	104	104	102	
54	118	117	117	114	
57	132	131	131	126	
60	150	149	147	143	
63	170	169	166	160	
66	194	194	187	178	
69	222	219	211	199	
72	259	246	239	221	
75	300	283	270	247	
78	354	325	306	274	
81	426	375	347	306	
84	526	433	395	361	
87	670	503	450	379	
90	900	586	513	422	
93	1330	686	585	469	
96	2400	805	669	541	
99	9900	946	766	579	

TABLE IV.—DISTRIBUTION, PER 100 BOLLS OF GENERAL BOLL POPULATION, OF A SELECT BOLL POPULATION CONTAINING ONLY BOLLS WITH 0-4 WORMS PER BOLL.

Apparent Percentage of Samples with 0–4 Worms per Boll (Select Population).	Corresponding True Percentage of General Population. (a)	Number of Worms per 100 Bolls of Select Population. (b)	Number of Bolls of General Population (per 100 Bolls) not included in the Select Population. (a)	Percentage Loss in the Select Population, calculated on General Boll Population. (a) (c)	Combined Total Damage. (a)	REMARKS
3	3	3	—	—	—	(a) Stated to the nearest unit. (b) Read off a graph probably not everywhere correct to the last unit, especially after 50 per cent. (c) See also Table V. The cotton used was Sakellarides.
6	6	6	—	1	1	
9	9	10	—	1	1	
12	12	14	—	1	1	
15	15	18	—	2	2	
18	18	21	—	2	2	
21	21	26	—	3	3	
24	24	31	—	3	3	
27	27	36	—	4	4	
30	30	42	—	4	4	
33	33	47	—	5	5	
36	36	53	—	5	5	
39	40	60	1	6	7	
42	43	68	1	7	8	
45	46	74	2	7	9	
48	49	82	3	8	11	
51	53	91	4	9	13	
54	57	100	6	10	16	
57	60	109	8	10	18	
60	64	119	11	10	21	
63	69	129	16	11	27	
66	73	139	21	11	32	
69	78	151	29	11	40	
72	83	163	39	10	49	
75	89	176	56	8	64	
78	95	190	78	4	82	
81	Over 99	—	—	—	—	Not calculated.

TABLE V.—PERCENTAGE LOSS WITHIN SAMPLES OF PICKED RIPE COTTON, AND THE CALCULATED NUMBER OF WORMS REQUIRED TO PRODUCE INFESTATION TO THE EQUIVALENT APPARENT PERCENTAGES, IN A SELECT POPULATION CONTAINING BOLLS WITH 0–4 WORMS ONLY.

Apparent Percentage Attack.	Number of Samples used.	Percentage Damage observed.	Number of Worms required per 100 Bolls.	REMARKS.
3	5	0·2	3	277 samples have been used, none containing less than 50 sound bolls. This number is admittedly too few for the higher percentages.
6	10	1·0	6	
9	10	1·4	10	
12	11	1·2	14	
15	6	1·7	18	
18	14	2·4	21	
21	12	2·9	26	
24	6	3·0	31	
27	11	3·0	36	Correllation between damage observed and worms required :—
30	6	3·5	42	
33	10	4.8	47	$r = 0{\cdot}9911 \pm 0{\cdot}0011$
36	10	5·8	53	
39	13	6·9	60	
42	10	7·3	68	
45	16	8·4	74	
48	12	6·9	82	
51	14	8·5	91	The cotton used was Sakellarides.
54	13	8·6	100	
57	12	12·7	109	
60	18	13·0	119	
63	7	13·8	129	
66	14	16·2	139	
69	9	15·6	151	
72	18	16·6	163	
75	10	17·1	176	

TABLE VII.— DISTRIBUTION OF DAMAGE WITHIN "PICKABLE" ATTACKED BOLLS, PER 100 BOLLS: COMPARISON OF OBSERVATIONS AND CALCULATIONS.

	Numbers of Bolls with 1, 2 or 3 Locks attacked.									
	Observed.			Calculated.			Calculated and Weighted.			Remarks.
Apparent Percentage.	attacked in 1 lock.	attacked in 2 locks.	attacked in 3 locks.	attacked in 1 lock.	attacked in 2 locks.	attacked in 3 locks.	attacked in 1 lock.	attacked in 2 locks.	attacked in 3 locks.	
21	14	6	1	18	3	0	13	6	2	The observations were made on Sakelarides cotton.
24	15	7	3	19	4	0	14	7	2	Weighting might have to be varied for other varieties of cotton.
27	18	7	2	22	5	0	16	8	3	
30	17	10	4	23	6	1	17	9	3	The observations are quoted to the nearest multiple of 3 per cent attack.
33	20	10	5	25	7	1	19	10	4	
36	18	13	6	26	8	1	19	13	5	There were no samples with 57 per cent or 75 per cent attack.
39	22	11	6	28	10	2	21	13	6	
42	19	16	7	29	11	2	22	13	7	Co-relation between the observed and the calculated and weighted figures :—
45	23	15	7	30	12	2	22	15	7	
48	23	17	8	31	14	3	23	17	8	$r = 0{\cdot}9577 \pm 0{\cdot}0038$.
51	26	17	8	32	16	3	24	18	9	Forty-seven samples were used.
54	27	18	10	32	18	4	24	19	11	
60	27	20	13	33	22	5	24	23	12	
63	29	16	18	33	24	6	24	24	14	
66	25	24	18	33	26	7	24	25	16	
69	28	24	17	32	28	8	24	27	17	
72	24	25	23	32	30	9	24	29	18	
78	22	30	27	31	35	12	23	32	23	

Addendum dated July 14, 1922.

Since writing the foregoing, the author has received a copy of *U.S. Bulletin No. 918*, "Report on Investigation of the Pink Boll Worm of Cotton in Mexico," by Messrs. Loftin, McKinney and Hanson.

Some figures given by them allow comparison to be made between Mexican and Egyptian crop-loss.

On page 31 they put the fallen and unpickable bolls as 20 per cent of the possible crop.

The pickable crop is divided into three picks, the first giving 40 per cent, the second 40 per cent, and the third 20 per cent of the crop (page 29).

It appears to the present writer that it ought to be quoted, first pick 32 per cent, second pick 32 per cent, third pick 16 per cent, unpickable 20 per cent.

The loss found was 3·1 per cent of the first picking, 4·6 per cent of the second, and 19·1, per cent of the third. This would give 1 per cent of the total crop lost in the first, 2 per cent in the second, and 3 per cent in the third picking, plus 20 per cent unpickable, totalling 26 per cent; not 6·9 per cent as calculated by the authors.

It is noticeable that the third picking contains 52 per cent damaged seed; and that it is smaller than the lost part of the crop.

Unfortunately the authors do not give any information as to the numbers of bolls used, neither do they state the variety of cotton the observations refer to. But it is probable that the size of the loss observed by them was of the same magnitude as occurs in Egypt. There can have been very little unpickable cotton in their first and second pickings, the lost bolls consequently nearly all belonged to the third, The apparent percentage of attack at the time of the third picking must have been very high to produce over 50 per cent seeds damaged, and the lost bolls outnumber the third picking bolls. For the select population comprising the third picking plus lost bolls the damage must have been about 58 per cent. It is also obvious that the standard of pickable cotton used in Mexico was lower than the Egyptian. Here samples of pickable cotton would hardly contain such a percentage damaged seed. With a higher standard for pickable cotton, the total loss figures would also be greater.