STUDIES OF THE CLOVER ROOT-BORER, HYLASTINUS OBSCURUS MARSHAM

BY

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THESIS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Fenner Satterthwaite Stickney

ENTITLED Studies of the Clover Root-borer, Hylastinus obscurus Marsham

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Entomology.

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*Required for doctor's degree but not for master's

Contents.

I. Introduction.

In 1909, Dr. J. W. Folsom stated that most of our literature on the clover root-borer has been based on the excellent accounts that Riley, Webster and G. C. Davis published. Nine years later, the same statement may be made. In looking over the more recent literature scarcely anything new has been noted. Indeed, in recent years the borer has been but little mentioned, especially in our American literature.

During the summer of 1917, the writer began the study of this insect under the direction of Dr. Folsom. The latter suggested that since so much work needed to be done along all lines on the pest, notes and experiments on any phase of the subject would be acceptable. Accordingly, the writer took advantage of any opportunity that presented itself to advance our knowledge of the pest. Some of the work has been trivial (though not necessarily valueless); some of it has been more extensive; much of it has natural conditions as a basis; most of it is a new contribution to our knowledge of the borer.

All the borers the writer collected, came, either from a vacant lot next to the Unitarian Church, Urbana, Illinois, or from a strip of ground bordering Third Street near Armory Avenue, Champaign, Illinois.

It has seemed worth while to describe the experiments in some detail, much in the form of original notes, for it is believed that the reader may thus gain a better impression of what has been accomplished.

To avoid frequent repetition, several factors that have appeared more or less constantly through the experiments, have been

omitted in explaining the latter, and are here stated. Unless otherwise noted, the experiments were performed in moderately moist four-drachm vials, or in jelly jars, and kept in the dark closet of the entomological laboratory, the temperature of which ranged between 70° F. and 76° F. with an average of 73° F. The borers used were all vigorous and fresh from feeding; and the roots used were really pieces of roots, cut so as to slip easily into the containers. The roots were of the same diameter throughout and were either stuck into a bottom layer of soil, or stood against the sides of the containers. Where a root is mentioned as being of so many millimeters, its diameter is referred to.

The writer wishes to offer his sincere thanks to Dr. J. W. Folsom for his interest and advice throughout. To Dr. V. E. Shelford, for his friendly consent to the use of several pieces of apparatus, he also returns many thanks.

II. Occurrence.

The clover root-borer has been known to science for more than a century, having first been named by Marsham in 1802. In 1807 Müller gave it another name, thinking he was the first one to describe it. One of the best accounts of the insect was published by Schmitt in 1844. This is a European insect and, though it is reported as being widely spread in Europe, particularly in Germany, it is said not to be destructive there.

The species was first recorded in this country from western New York by Dr. C. V. Riley in 1878, and had probably been recently introduced, for it was unknown to Dr. Le Conte at the time of the publication of his "Synopsis of the Scolytidae" in 1868, nor is it included in the Crotch "Checklist of Coleoptera", published

in 1874.

In 1881 the species was still unknown in Ontario, but by 1888 it was reported as doing great damage there, and since then has been repeatedly mentioned as a pest in Canada. In 1888 it was also reported from Long Island. It appeared in southern Michigan in 1889, at the west end of Lake Erie, and afterward all over southern Michigan with disastrous results. Davis believed it reached Michigan by being blown across Lake Erie from further east, but Webster believed that it reached Michigan through Ohio, though it was not reported from Ohio until the following year, 1890, in the northern part of the state. By 1892 it had spread into the southern part of the state. Webster believed that the insect was distributed over Ohio and Indiana largely by way of the water courses.

In 1896 the insect was unknown in West Virginia, but in 1905 it was reported as being very destructive in that state. In 1905 it was reported as causing considerable injury in Indiana.

In recent years the insect has been reported as a pest in Illinois, Kentucky, Pennsylvania, Delaware, Virginia, North Carolina, Oregon, and Washington. It is not a pest in New England, nor in the far South, nor in the states between the Mississippi River and the Rocky Mountains. How it reached the Pacific Northwest, the writer is unable to learn.

III. Description.

The beetle is small, short, cylindrical, and about 2.5 mm. in length. On emergence, it is a bright brown in color anteriorly and pale brown posteriorly, and in a day or so the color has deepened considerably, gradually deepening until the insect becomes a dark brown or blackish. The insect is hard-bodied and hairy, with

a short broad beak; and the antennae, which have large hairy clubs, are inserted in deep grooves at the tip of the beak. The head is just visible from above. The pronotum is about one-third the length of the body, almost as wide as the elytra, irregularly punctate, with a trace of a middle line, without tubercles or teeth, and is coarsely pubescent. The elytra have rows of deep punctures, the intervals containing three rows of setae, and decline sharply towards the apex. The tibiae are all dentate on the outer margin.

The egg is minute, though visible to the naked eye, pale, whitish and elliptical, with a small shining surface and about .67 mm. long, and .39 mm. wide. (Fig. 2).

The larva when full grown is somewhat larger than the adult (Figs. 1 and 3), stout, dingy white, with a very shiny orange-colored head and deep brown mouth-parts. It is footless with only the stumps of thoracic legs, which give the thoracic region a swollen appearance.

The pupa is white except for the long brownish-red eye spots. It has two spine-like projections on the top of the head and two somewhat larger projections at the end of the abdomen. The pronotum shows a feeble median ridge and bears a few scattering bristles. The abdomen tapers toward the apex considerably. The legs, mouth-parts, antennae, and wings stand out in bold relief.

It is interesting to observe the gradual change in the color of the pupa as the time of emergence approaches. First, the tips of the wings take on a greyish-black color, followed by a deepening of the color of the eyes and of the mouth-parts, the deepening color gradually appearing in the legs antennae, and thorax. The abdomen is the last body region to take on color, and shortly

afterward the adult emerges.

IV. Life History.

Those who have studied the life history of the clover root-borer state that there is but one annual generation, and that where eggs, for instance, are found as late as September, it is the exception to the rule. A summary of what has been observed by others, is that the borer passes the winter in the roots largely as an adult, along with small numbers of larvae, fewer pupae and no eggs. As soon as warm weather comes in the spring, the borers revive and begin burrowing and feeding. During May the beetles leave the old roots, fly about and pair and seek new roots. According to Davis('94) the borer usually enters the roots at the side, a little below the surface of the ground. The eggs are laid mostly from May 15 to June 20 in the latitude of central Illinois, the female either gouges out a shallow cavity, more often in the crown of the root, into which she deposits singly a half dozen eggs; or else packs the same number of eggs into the dead part of the burrow and covers them with refuse from the burrow. In about a week the eggs hatch. Swaine('11) says that the female cuts niches in the walls of the tunnels and deposits an egg in each niche. The little larvae feed for a time where they hatch but soon burrow downward into the root, and before the first of August have attained their full growth and pupated. By October nearly all have changed to the adult stage.

The larvae are most in evidence in the latter part of May, in June, and in July; and the pupae in July and early August. From the last week in June to the first week in August the adults are said to be almost absent. This would seem to indicate

that the adults which winter over die sooner or later after pairing and depositing their eggs. From August to November adults and larvae predominate, with some pupae and fewer eggs. The writer's investigations, for the period they cover, largely corroborate the life history as given above.

When I began to study the borer on July 5, 1917, I directed my attention mostly toward the life history. A special effort was made to find the egg, but from the begining of the work to May 10, 1918, no egg was found, though a number of eggs were found to have been laid at one time (See section on Length of Larval Stage). Many roots were dug up and examined on April 13, for eggs but none were found, though the borers had been active on every warm day, and there had been a great many warm days before April 13, with the temperature of the air above 45° F. (See experiments on Thermotropism. Many two-year old roots, growing in badly infested areas, were examined for recent infestations but none were found. However, on opening a root on May 10 upon which borers, collected from the field on April 13, had been placed, two eggs were found near each other in a tunnel along with a newly hatched larva. These eggs were covered with frass and were lying singly in the tunnel. No beetles were present. In this same root were eighteen larvae, averaging a millimeter in length, and therefore, not much more than a week old. These little larvae were scattered throughout the root. On May 14, an egg was discovered in a root in its second year of growth. The tunnel in which the egg was found appeared to have been freshly made, being, for one thing, hardly discolored at all, and was 4 mm. long. A beetle was working at the end of the tunnel and the egg, which lay loose in the tunnel but was covered with frass, was

found immediately behind the beetle.

The fact that the borers infest the new plants at only one period in the year, is a very striking phenomenon in their life history. For ten months, the writer had the adult borers continuously under observation, and at no time, until May 2, had one ever attempted to fly, though it seems as if they had had every provocation to fly, being subjected to various degrees of heat and light and moisture, to mechanical stimuli, etc. Some of the borers, after hibernating through most of the winter, had been brought into the warm laboratory and allowed to mate, yet no signs of flight in any had been observed.

Spring migrations seem to be necessary for the dissemination of the beetles, for once they bore into roots they are quite disinclined to leave them. Many times intact roots have been placed in vials containing heavily infested roots, and the writer does not remember any borer to have left an infested root in order to attack a new root. In the field also, the same thing has been noted. Thus in spots where roots three years old and others, probably two years old, were heavily infested, a large number of other two-year old roots were free from infestation. Furthermore, one-year old roots were never found infested, though they were growing next to severely infested old roots (See Experiments on Size of Roots Attacked). As an illustration, on September 24, two badly infested old roots were dug up within six inches of each other, there being a one-year old root within two inches, and a fine healthy two-year old root within three inches of the old roots; yet the one-year old root was free from borers and the two-year old contained a single borer.

V. Notes on Duration of Activity of Adults.

Cold temperature seem to be the deciding factor in sending the clover root-borer into hibernation. The larvae, the pupae, and the adults all remain active in the warm temperature of the laboratory, however, long after cold weather sets in. Indeed, they show no signs of dormancy in the laboratory. For example, two adults were taken from the field on August 15 and placed on a root in a vial. These borers were continually active down to December 12, when they were accidentally killed. There seems to be no reason why they should not have remained active throughout the winter.

On December 1, when the borers had not yet settled down into hibernation, four borers were collected and placed on a root in a vial. These borers remained quite active all the winter up to the middle of February, when they were used in an experiment that killed them.

An interesting problem would be to determine the duration of life of adults that hibernate as compared with that of adults that are not allowed to hibernate. Webster('99) states that there are practically no adults in evidence from the last week in June to the first week in August; which means that those adults that winter over die before the last week in June. The writer has kept adults active through nearly the entire winter with no indication that they would not have lived right on, and the question is, will the continuously active beetles live as long as those that hibernate?

VI. Length of Pupal Stage.

As a contribution to the life history of the clover root-borer, the writer has been able to determine definitely the length

of the pupal stage under summer conditions. Most of the experiments were performed in the late summer, subject to outdoor temperatures. At no time were the pupae allowed to experience temperatures much below 70° F., and most of the time the temperature was higher, being around 74° F.

Table I. Length of Pupal Stage.

Number of pupae.	Pupation.	Emergence.	Duration in days.
1	Aug. 15	Aug. 25	10
1	Aug. 16	Aug. 23	7
1	Aug. 18	Aug. 27	9
6	Aug. 21	Aug. 27	6
2	Aug. 21	Aug. 28	7
1	Aug. 21	Aug. 30	9
2	Aug. 23	Aug. 30	7
4	Aug. 25	Aug. 31	6
1	Aug. 24	Sept. 3	10
1	Aug. 24	Sept. 3	[illegible]
5	Aug. 27	Sept. 4	8
2	Aug. 28	Sept. 4	7
2	Aug. 30	Sept. 5	6
1	Sept. 24	Sept. 29	5
1	Oct. 6	Oct. 16	10
1	Oct. 6	Oct. 18	12
2	Oct. 8	Oct. 18	10
1	Oct. 22	Oct. 30	8

Summarizing:

Length of pupal period in days.	Number of pupae.	Percentage by days.
5	1	3.0
6	8	24.2
7	7	21.2
8	8	24.2
9	2	6.0
10	5	15.1
12	1	3.0
13	1	3.0

Some 69.9 per cent of the pupae had a period of 6 or 7 or 8 days, and more than 90 per cent between 6 and 10 days.

VII. Length of Larval Life.

Owing to the fact that eggs were not found sufficiently early for study, it has been impossible to determine the exact length of the larval period. However, on one occasion five very small larvae were found in a common, more or less enlarged tunnel. They were all minute, being about .5 mm. in length. The root containing these little larvae had been placed with sixteen adults in a vial about five weeks before, and at the time the little larvae were discovered, the adults were still in the root, several in the same tunnel with the little larvae. The latter were placed in notches cut into another root which was set in a separate vial. This took place on September 28. On October 6, two pupated. On October 7, another one pupated. The other two larvae had died.

The larvae when just discovered could hardly have been much larger than the egg. Then too, they were bunched up just as

one would expect to find newly hatched larvae, from eggs laid closely together. They must have come from recently hatched eggs. It would seem that it takes the larva some three weeks to reach full growth when feeding constantly under moist conditions at a more or less steady temperature near 74°F.

VIII. Observations on Copulation.

The borers seem willing to pair at any time during the year when the temperature is warm enough to cause them to become active, whether they have just been extracted from outdoor roots or have been in the laboratory for some time, provided enough of them are brought together. If just a few, say, four or five, are placed in a vial, copulation does not seem to take place; should a dozen or more be placed in a vial, however, copulation will invariably take place. When a number of borers are placed in a vial, they constantly crawl over each other, and their coming into contact, so it would seem, furnishes the stimulus to copulate. The act is consummated practically always with the female continuing to crawl, carrying the male behind in an upright position. He clasps her with his two hind legs, his remaining legs hanging free, though sometimes he uses the middle pair to some extent, too. At times the female will fall over, and usually, if she can right herself soon with some help from him, they will remain in connection. Should the male be picked up with a wet brush he will lift the female with him without losing connection. How long they remain in connection the writer is unable to say, an accident such as falling over, or colliding with other borers, usually separating the two. When placed by themselves the female will always crawl out of bounds, which necessitates

disturbing them, with an eventual separation.

The experiments described below were all performed in the indirect sunlight of the laboratory.

November 20.—Twenty-nine adults, taken from outdoor roots, were placed in an empty vial. In about five minutes, a dozen beetles had been placed in the vial, and pairing commenced. Large numbers paired, and after twenty-four hours a number were still in coitu.

November 28.—Eighty-one borers, taken from outdoor roots, were placed in a jelly jar. When about twenty had been placed in the jar, theycommenced to mate, and mated in large numbers. Several pairs were in copulation three hours later.

December 12.—Seventeen borers that had been in the laboratory since December 1, were placed in an empty jelly jar, and pairing began in a few minutes.

December 31.—Eleven borers that had been in the laboratory since December 1, were placed in an empty vial, and within five minutes three pairs were mating.

March 25.—Thirty-six borers, taken from outdoor roots, were placed in a vial. When about fifteen were in the vial, copulation began. At least eight pairs were in copulation over a period of fourty-five minutes. No attempt was made to distinguish any particular pair.

April 2.—Seven borers that had been in the laboratory for some two weeks were placed in a vial, and after thirty-five minutes, no pairing was observed.

In conducting other experiments, four, five, or six borers have on many occasions been placed in vials by themselves, but no

pairing has resulted. Should a pair in copulation be accidentally separated and immediately placed in a vial by themselves, they have not been observed to remate after a considerable time. Consistently through these experiments it will be noticed that the borers do not mate until their numbers become more or less crowded.

The fact that they will mate readily late in the autumn before hibernation, seems interesting when our studies of the borers life history tell us their normal mating season is in the late spring and early summer. Normally, the borers would hardly mate in the autumn. Indeed, the writer has at no time between the begining of his work on the borer, July 3, 1917, to this date, April 22, 1918, found the borers leaving the roots without some evident cause, such as the drying of the root; and inside the root they are rarely found in a common chamber, save under conditions of heavy infestation.

IX. Seasonal Abundance of The Borer.

Webster('99) gives a table showing the various stages of existence of the borer throughout the year, based on observations covering a period of four years, but as he includes no account of the actual numbers present, definite comparisons of the abundance of the various stages from time to time cannot be made. Through a period of nine months, the writer has kept records of the numbers found in his collections, and presents them in the following table.

Table II. Seasonal Occurence of the Borer.

Date	Adult	Pupa	Larva
July 3	2	0	6
July 6	2	0	3
July 16	0	0	2
July 20	0	0	1

Table II.—continued.

Date	Adult	Pupa	Larva
Aug.6	8	8	10
Sept.20	3	5	4
Sept.21	21	9	15
Oct.3	5	4	6
Oct.7	5	4	24
Oct.13	6	4	3
Oct.17	5	5	2
Total number	57	39	75
Percentage	33.3	22.8	43.9
Oct.24	15	0	4
Oct.26	21	0	1
Nov.10	2	0	5
Nov.20	29	0	0
Nov.28	86	0	4
Dec.1	33	0	3
Feb.12	14	0	2
March 2	40	1	6
March 13	20	0	0
March 18	13	0	1
March 19	3	0	1
March 21	62	0	4
April 13	22	0	1
Total since Oct.24	388	1	32
Percentage	92.2	.2	7.6
Grand total	455	40	107
Average percentage over all	75.6	6.6	17.8

One noticeable feature of the table above is the pronounced irregularity in the proportions of the various stages of the borer as collected from time to time. It will be seen that during the summer and during the first weeks of autumn, there were found, in the aggregate, a largernumber of larvae than adults. The adults do not begin to predominate markedly until after the middle of October. On October 17, 43.9 per cent of the collections were larvae and 33.3 per cent were adults; 66.7 per cent, or over two-thirds of the collections up to this date being in the immature stages.

Through the last half of the autumn and through the winter and early spring, it will be seen that the vast majority were adults, though a considerable number of larvae were also in evidence. The almost total absence of pupae and the total absence of eggs during this period, is worth noting.

The preceding data agree almost precisely with Webster's ('99) observations in Ohio, as far as the presence of the various stages is concerned. In Webster's table eggs were found only from May 17 to June 20, a period in the year not covered by the writer's observations, hence the absence of eggs in the latter's table must not be surprising.

X. Food Plants.

In this country the borer is known to attack mammoth clover(Trifolium medium), red clover(Trifolium pratense), alsike (Trifolium hybridum), crimson clover(Trifolium incarnatum), sweet clover(Melilotus alba), alfalfa(Medicago sativa) and garden peas (Pisum sativum). Chapman('69) states that the insect works on

Scotch broom(Cytisus scoparius) and furze(Ulex europaeus) in England. He says that he has never found it on clover. Bedel('88) mentions it as attacking goat root or yellow-flowered rest harrow (Ononis natrix). Swaine('11) states that it works on white Dutch (Trifolium repens) and sainfoin(Onobrychis sativa) in Ontario, but he has never found it breeding on these plants. The borer, thus, seems to be limited to leguminous plants.

Pettit('10) states that mammoth clover suffered most in Michigan in 1910, red clover nearly as much and alsike less. Webster('10) says, that besides red clover, the borer attacks mammoth clover, alsike, peas, and may become destructive to alfalfa. Swaine states that mammoth clover and red clover were seriously injured in Ontario in 1910, and that the insect breeds also in alsike and crimson clover. He says he observed no injury to alfalfa or sweet clover. On the other hand, Gibson('11) states that the borer was working freely in some fields of alfalfa, causing a noticeable loss in the year of 1911 in Ontario.

Some observations have been made by the writer concerning the borer's reactions towards some of its food plants.

October 1.—Two adults were placed in a vial containing a fresh 4-mm. sweet-clover root. The next day both were boring into the root.

September 29.—Two adults were placed on a fresh sweet-clover root in a vial. By the next day both had begun to tunnel in. October 18, the two borers were transfered to a fresh alfalfa root. October 24, one had bored slightly into the root; the other borer was crawling in the vial.

October 31.—Two borers were placed in a vial containing

a fresh 6-mm. alfalfa root. November 9, both had bored into the root.

Sweet clover is very rarely mentioned as being attacked by the borer; yet, if anything, it is preferred to alfalfa, according to the writer's observations.

Out of curiosity, a number of borers were placed on the roots of several common weeds growing abundantly in infested clover fields. The roots used belonged to the following plants: tumble weed (Amarantus albus), horse weed (Erigeron canadensis), butter weed (Senecio lobatus), and another species of Erigeron. They were each about 4 mm. in diameter and were placed in separate vials. The borers could not be induced to attack any of them.

Red clover, alsike and alfalfa roots were used in a number of experiments to determine in what proportions these roots are attacked when the borer is allowed to chose freely between them.

October 18.—Seven adults were placed in a vial containing an alfalfa root and a red clover root of equal size. October 2[illegible], all seven had bored into the red clover root at the base. Five of these were placed in a vial containing an alfalfa root, a decayed red clover root, and a fresh red clover root, all of similar size. November 16, three had bored into the decayed root and the other two into the fresh root.

November 14.—Eighteen adults were placed in a vial containing an alsike root and a red clover root, both of equal size. Thirteen beetles eventually bored into the red clover root and three into the alsike.

November 19.—Seventy adults were placed in a jelly jar

into which were stuck three 6-mm. roots, alsike, red clover, and alfalfa. December 5, eleven had entered the alsike root and nine the red clover root. The experiment was continued, using nineteen borers and an 8-mm. red clover root, an 8-mm. alsike root, and a 9-mm. alfalfa root. December 12, four borers were in the red clover root; four in the alfalfa and eleven in the alsike.

December 5.—One 11-mm. alfalfa root, two alsike roots, one 7 mm. in diameter, the other 4 mm., and one 8-mm. clover root were stuck in well-pressed soil in a jelly jar, to which were added seventeen adult borers. December 12, nine of the borers were in the clover root and eight were in the alsike roots.

December 13.—Three 7-mm. roots, alfalfa, alsike, and clover, were bedded in firmly pressed soil in a jelly jar, to which were added twelve adults borers. December 19, six had bored into the clover root and five into the alsike root, none having entered the alfalfa root.

January 9.—Twelve adults were placed in a jelly jar containing two 8-mm. roots, one of them being a partly decaying clover root, and the other a fresh alfalfa root. January 16, all twelve were in the clover root.

In the experiment of December 5, it will be seen that notwithstanding the large size of the alfalfa root used, no borer entered it. In the other experiments, the roots were all practically of the same size, and for purposes of clear comparison the results are expressed in the form of a table. The cross in the table indicates a kind of root that was not used in that particular experiment.

Table III. Choice of Food-Plants of Adults.

Number of experiment	Red clover	Alsike	Alfalfa
1	7	x	0
2	5	x	0
3	12	x	0
4	13	3	x
5	9	11	0
6	4	11	4
7	6	5	0

Where red clover and alfalfa were used together, without alsike, no borers entered the alfalfa. In the remaining experiments about the same number of beetles entered the alsike as the red clover, and in only one instance did any borers enter the alfalfa root. There seems to be no question, then, that red clover and alsike are preferred to alfalfa; and it is an open question as to whether the borers prefer red clover or alsike.

XI. Nature of Injury to Roots.

Every root badly infested with borers is more or less decayed, and often in quite a rotten condition. When badly infested, the tap root may break sheer off anywhere along its length, though usually near the crown where the borers prefer to work. The fact that the borers are found in or near the crown makes their depredation all the more serious.

Sometimes the borers are found almost up in the base of the stem and undermine it to such an extent that when the plant is disturbed the stem simply falls away from the root.

Very seldom will a borer be found working very far out

on secondary roots or far down the tap root(See Experiments on Size of Roots attacked for data on this subject).

From many roots when dug up, large chunks will scale off. This is practically a sure sign of the presence of the pest, whose tunnels running up and down and across, separate sections from the rest of the root. But a root that shows a rotten condition does not always harbour the insect, though, if it shows decay externally it is much more apt to be infested than a root that appears to be sound on the outside, yet is decayed inside. Even apparently sound roots may, however, sometimes contain the insect. For example, the crown of one root, the diameter of which was 7 mm., was considerably hollowed out and contained four adults, four pupae and four larvae. Superficially, this root seemed to be healthy. Furthermore, the borers do not always invade thoroughly the parts of the root wherein they are working. Fourteen adults were once collected from one half of a root which was badly eaten up and rotten; the other half containing no borers. This local concentration of borers, the rest of the root remaining intact, is not very common, however.

The roots most heavily infested are those not quite thoroughly decayed. If all living tissue has disappeared, the root will readily dry out and this the borers do not relish. Since the borer is only found rarely in thoroughly decayed roots, and never has been found in such roots as were fairly dry, it is assumed that the borer deserts the root when it reaches this condition. To illustrate: two adults that had bored deep into a large alfalfa root, finally came out of their burrows when the root was allowed to dry slowly. The same thing was observed in the case

of three other borers on a red clover root. It is interesting to note that the roots became plainly dry before the borers deserted them. Indeed, it would seem that the borers had made their last efforts in leaving the roots, for in both instances, the borers on one day were still inside and on the next day were dead outside the roots. A few instances have been observed in which the borers have died inside the drying roots.

Though the borers often make very short and irregular tunnels, particularly in badly infested roots, yet sometimes a number of borers can be found at the ends of fairly long and straight tunnels. On one occasion, five adults were found at the ends of five parallel tunnels, all the tunnels being at least fifty millimeters in length, following the grain of the root.

In digging the adult borers from their tunnels it has been observed repeatedly that if the borer is picked at, say, with a needle, while in an intact tunnel it will crawl deeper in. Usually, however, the borer is feeding at the end of the tunnel, so is not able to get much deeper in. It takes a good deal of picking to force a borer to back out of its tunnel, even when it is only half way in. Should the tunnel be forced open, however, the borer will invariably leave it straightway.

Picking at the adult makes it crawl about faster; jarring it causes it to simulate death.

For the nature of injury, see figs. 4, 5, 6, and 7.

XII. Effects on the Plant.

Practically all the plants from which the writer collected borers were living. The way he judged a plant to be infested was not through an unhealthy look of the plant but by noting

whether it was an old plant, from the ring of dead stalks around its base. Next, by clearing away the soil a little from its base and noting the appearance of the root. If the root contained holes or broken or rough tissue or seemed to be in a decaying state, it was thought likely to be infested. The writer was never able to judge whether a plant was infested or not by merely looking at the top. Many severly infested plants, that is, plants harbouring a dozen or more borers, possessed good tops even at the end of the season. One root that contained thirty-two adult borers was sprouting a good head of leaves. This root was dug up in the late winter. Thus, the borers had been working in it an entire season.

The consensus of opinion is, however, that the borers sooner or later kill the plant. Davis('94) states that half a dozen beetles will kill a plant quickly; and when a plant is attacked later in the season and by fewer beetles, the first crop of clover can be matured but the plant dies as soon as dry weather comes. He says that, "roots that are not too badly injured will live to produce a fall crop and probably an early one the next year". Webster('99) says that, "if the attack is very severe the field will show the effect of the work of the insect soon after the hay crop is removed, by the plants dying out in spots". He('10) states that the life of the plant "may be lengthened or shortened by meteorological conditions. Thus, if the spring or early summer is very dry, the plants begin to die in patches in June, as soon as the hay crops is removed; but if there is much rain during this period, the weakened plants may continue to live until winter, dying out before spring".

The borer is said to be responsible for an irregular, imperfect blooming of the clover or a failure to bloom at all. If the plants survive, thanks to copious rains, the yield of seed is likely to be almost nothing.

XIII. Areas of Infestation.

A most important piece of information would be definite knowledge as to the kinds and conditions of soil preferred or shunned by the pest. In making his collections, the writer has noted a few items in regard to this subject. Areas in which the clover plants are matted down in grass seem to be less heavily infested than other places. This was observed many times. Many large roots completly free from the borers were dug out of the grass, but off to one side where the grass was less plentiful, larger roots were apt to be infested. Further investigation along this line might prove to be of advantage.

The amount of infestation bears some relation to the nature of the soil. An opportunity was presented to study the infestation in a fine yellow clay subsoil as compared with that of our brown silt loam. The two soils investigated were in narrow strips about twenty feet long by two and a half feet wide adjoining each other, the presence of the clay being due to the fact that it had been thrown over to one side during the construction of a road. Both soils had about the same growth of clover plants. At least one third, if not one half more borers were collected from roots growing in the loam soil than from the clay soil.

XIV. Amount of Infestation.

The number of borers collected has all along seemed few

considering the number of roots dug and examined. An exceptionally heavy infestation was observed, however, on November 19. One root that almost crumbled to pieces on pressure between the fingers harboured thirty-two adults. Within four square feet containing this root five other decayed roots were taken and examined, and they contained fifty-four adults; altogether eighty-six borers being collected from these six roots. Six or seven borers from one root has been the average number, the maximum ever collected being thirty-two, as above.

Many sound one-year old roots and two-year old roots as well, in this same infested area, were perfectly free from borers. (For an explanation of this see Experiments on Size of Roots Attacked).

XV. Size of Roots Attacked.

The most important measure of controlling the clover root borer so far, namely, that of plowing up the clover field after the second year crop is taken off, allowing the soil to lie fallow, is advised because the roots of the plants have by that time reached such a size that they are menaced by the borer.

The writer has made some investigations on this subject. In the field he has observed that in the vast majority of cases the old roots were the only ones attacked, though many one-year old and two-year old roots were scattered profusely about the infected areas. With an understanding of the life history of the insect, one would be surprised to find one-year old roots infested, but the reason that two-year old plants are not infested must be due solely to the fact that the borers in their annual migrations select the

older roots. Whether the borers in their flight pick out the older roots by the size of their tops or not, it is not known.

A number of experiments were performed in vials and in jelly jars, using roots of various sizes, to determine the degree of preference shown by the borers for the larger roots. On each occasion a bottom layer of firmly pressed soil was used, into which were stuck the roots. Except for size the roots were absolutely under the same conditions.

November 2.—Two roots, one 5 mm. and the other 7 mm. in diameter, and six adults were placed in a vial. November 11, all six borers had bored into the larger root.

November 2.—Two roots, one 2.5 mm. and the other 7 mm. in diameter, and six adults were placed in a vial. November 16, one adult was dead in the vial; the remaining five had bored into the larger root.

December 6.—One 16-mm. root, one 4 mm. root, two 5.5-mm. roots and two 3-mm. roots, with twenty-two adults were placed in a jelly jar. December 13, twenty of the borers were in the 16-mm. root, and the two remaining were each in a 3-mm. root.

December 13.—Three roots, one a 10-mm. root, the other two 6-mm. roots, together with twelve adults were placed in a jelly jar. December 19, in the largest root were eight borers; of the smaller 6-mm. roots, one contained three borers and the other one borer.

December 19.—One 14-mm. root and three 4-mm. roots and twelve adults were placed in a jelly jar. December 31, eleven of the borers were in the 14-mm. root, and the remaining borer was in one of the 4-mm. roots.

The above results expressed in the form of a table show clearly how strongly the borers prefer the larger roots. The percentages are all high for the larger roots, though, in the three last experiments more than one small root was used.

It is interesting to note that in experiment 4 where the smaller root is of a fair size the percentage of borers attacking the larger root is diminished.

Table IV. The Proportion of Borers Attacking Roots of Various Sizes.

Number of experiment	Number of roots used	Size of roots in mm.	Number of borers found	Percentage infestation
1	1	3.0	0	0
	1	7.0	6	100
2	1	2.5	0	0
	1	7.0	5	100
3	2	3.0	2	9.09
	2	3.5	0	0
	1	4.0	0	0
	1	16.0	20	90.9
4	2	6.0	4	33.33
	1	10.0	8	66.66
5	3	4.0	1	8.33
	1	14.0	11	91.66

Continuing with the idea of determining the diameter of root prefered by the borer, the following experiment was performed: March 7. Twenty-three adults were placed in a long tin box 50 cm. long, 4 cm. high and 3.5 cm. wide, containing a rough paper bottom. Two roots of similar size and shape, 300 mm. long, with a diameter of

9 mm. at the larger ends and 1 mm. at the smaller ends were laid in the box, the larger ends facing in opposite directions to act as controls against each other. Moist wads of cotton were added to the box to keep the moisture content suitable, and a board was placed over the box to shut out the light. Five days later the roots were examined and seventeen borers were found to have entered the roots. The points of entrance in relation to the diameter of the roots, which alone was considered, are indicated on a diagram, the triangular outline representing the dimensions of the two roots and the small circles the points where the borers entered the roots (See Diagram I).

Two additional experiments were performed with large roots under conditions similar to those just mentioned and the results are shown in Diagrams 2 and 3. In these last two experiments an even more marked concentration of the borers in the larger ends is shown. A point worth noting is that the borers do not absolutely refuse at all times to enter the smaller regions of a root. It will be seen in Diagrams 2 and 3 that a borer entered one root at a point where the diameter was only 1.5 mm. and in another root where the diameter was only 2 mm.

To throw further light on this problem of small diameters two experiments were performed to determine just how readily the borers attack small roots when there are no large ones present.

April 3.—Five adults were placed in a vial containing a firm layer of soil, into which were stuck upright, two 1-mm. roots, one 1.5-mm. root, one 2-mm. root and one 3-mm. root. April 10, two borers had attacked the 1.5-mm. root, one the 2-mm. root and one the 3-mm. root. One had bored into the soil through a crack.

April 3.—Five adults were placed in a jelly jar containing a layer of firmly packed soil. Two 1-mm. roots, two 1.5-mm. roots and two 2-mm. roots were laid flat upon the surface of the soil and a green clover top was also added. April 10, one borer had bored into one of the 2-mm. roots; two others had entered the base of the clover top which had been cut far enough up from the root to leave it green and succulent. The two remaining adults were loose in the jar.

Several interesting facts are brought out by these two experiments. One is, that the borers will not refuse small roots when there are no large ones present; but that they take to them reluctantly is shown by there being individuals in both experiments that failed to attack the roots after a week. In all experiments with larger roots, all the beetles would attack the roots in a day or so. All the roots were examined very carefully for gnawed places, so the writer feels fairly sure that the loose specimens had consistently refused to enter the roots. Another point worth mentioning is that the borers may prefer green, succulent stems to small roots. The fact that in the experiment in which the top was used, only one borer bored into the roots, whereas two had bored into the top, would indicate this.

XVI. Optimum Conditions of Roots.

A number of experiments have been undertaken to find out whether a borer prefers a decaying root or a fresh root. The decaying roots used have in all cases been roots with all of their tissue in a decaying state, but not so far decayed that they were crumbly.

October 3.—Six adults were placed in a vial containing

a bottom of cotton. A fresh and a decaying root of equal size were added. October 8, three beetles had bored into the healthy root and three into the decaying root.

October 8.—Three adults were placed in a vial containing a decaying and a fresh root of similar size. The bottom of the vial was covered with cotton. October 16, all three were found in the decaying root.

October 8.—Five adults were placed in a vial with cotton bottom containing a fresh root and a decaying root of equal size. October 16, four beetles had entered the decaying root and the other the fresh root.

January 1.—Into a jelly jar containing a 7-mm. decaying root and a 9-mm. fresh root stuck into firmly pressed soil, were added eight adults. Notwithstanding the smaller size of the decaying root five entered it, and the remaining three, the fresh root.

January 1.—Seventeen adults were placed in a jelly jar containing five roots as follows: two fresh alsike roots, also one decaying, one slightly decaying, and one fresh red clover root; all the roots being 4 mm. in diameter and stuck in firmly pressed soil. Two bored into the fresh clover root; the remaining fifteen into the decaying root.

January 4.—Nine adults were added to a jelly jar containing one fresh clover root, one fresh alsike root and one decaying clover root, all 4 mm. in diameter, and one 3-mm. fresh alsike root. January 8, one borer had entered the fresh clover root; the eight remaining were found in the decaying clover root.

March 26.—On the bottom of a jelly jar covered with firm

dirt were laid side by side a decaying root and a healthy root, both 7 mm. in diameter. Twelve borers were added. Twelve borers were likewise placed in a jelly jar, the roots in this jar being 3 mm. in diameter. To a vial containing a loose layer of soil were also added two 4.5-mm. roots and thirteen borers. March 13, in the first jelly jar, eight borers were in the decaying root and four in the fresh root. In the second jelly jar, all twelve borers were in the decaying root. In the vial, nine were in the decaying root and four in the fresh root.

In all the experiments, the number of borers entering the fresh roots was eighteen, and the number entering the decaying roots was fifty-seven, or percentages of 24 and 76, respectively.

There seems to be no doubt that the borer prefers the decaying roots, possibly because they are softer and therefore more easily entered.

The borers do not care for dry roots, but if hungry may be induced to attack them, though, not with much success, as the following two experiments show.

October 3.—Five adults were placed in a vial containing a bottom layer of cotton, the vial being kept only slightly moist. A root which was dry to the extent that it was hard to cut into with a knife was added. October 6, four beetles were in the cotton, one being dead. The remaining beetle was making an effort to bore into the root but had thus far merely dented the root. October 8, the dented spot had been abandoned, and one of the borers had bored into the root elsewhere for one half its length. The root had softened the least bit, and this may have accounted for the progress made by the borer. In the following experiment no moisture was

furnished the insects and it is seen that the latter were quite unable to make any headway.

November 22.—Sixteen borers were placed in a vial containing three 3-mm. roots, each quite dry, and the bottom of the vial was covered with dry soil. November 26, just four days later, the borers were all dead, but significant to relate, all the roots showed gnawed spots, one in particular being severely gnawed about its base.

XVII. Reaction of Borers to Clover Tops.

The preceding experiment would make one curious to learn how the borers react towards the tops alone. The following experiment gives this information. April 3, to a vial containing firmly pressed soil were added two green clover tops, the bases of the stems being light green and tender. Six adult borers were added to the vial. April 10, two of the borers had bored into the base of one of the tops; two others were down in the base between the leaves. The writer tried to determine whether the latter had been feeding there, but could not. One or both of them had, however, entered into the base through a hole which one of them had cut considerably down the leaf. The two remaining borers were crawling on the bottom of the vial.

XVIII. Rate of Tunneling of Adult.

Knowing the rate at which the borers work in the roots, we can form some estimate of the severity of damage any particular number of borers can inflict upon the roots. Davis('94) states that a half dozen or more borers can quickly kill a two-year old root. Practically all investigators of this insect state that it

can do much damage. Such terms as "immense amount of damage", "very destructive", "especially destructive", "seriously injured" and "noticeable loss" are common terms applied to this pest and its work.

Saunders ('81) said that the larvae do most of the damage. The writer has not had sufficient number of larvae to verify this statement, but he has undertaken to find out the rate at which the adults work in the roots. The method used was to place one or more borers on a clean root and after a certain number of days had passed, to measure the length of the tunnels. On such occasions, the environment of the insects was moist and the temperature remained near 74° F.

Table V. Rate of tunneling of adult.

Number of borers	Time	Number of days	Distance in mm.	Rate per day in mm.
2	Oct.26-Nov.2	7	3.0	.42
7	Oct.29-Nov.1	3	2.5	.83
1	Oct.29-Nov.1	3	2.0	.66
1	Nov.1-Nov.16	15	6.0	.40
1	Nov.1-Nov.16	15	5.5	.36
1	Nov.1-Nov.16	15	5.0	.33
1	Nov.2-Nov.16	14	6.0	.44
5	Nov.2-Nov.16	14	4.0	.28
2	Nov.2-Nov.16	14	5.5	.39
1	Nov.10-Nov.16	6	5.0	.83
3	Nov.14-Dec.6	22	7.5	.34
3	Nov.14-Dec.6	22	9.0	.40
2	Nov.22-Dec.6	14	6.0	.42
2	Nov.22-Nov.30	8	7.0	.85

Table V.-continued.

Number of borers	Date	Number of days	Distance in mm.	Rate per day in mm.
3	Nov.22-Dec.6	14	6.0	.42
1	Nov.22-Dec.6	14	4.0	.28
1	Dec.6-Dec.13	7	6.0	.85
1	Dec.6-Dec.13	7	5.0	.42
1	Dec.6-Dec.13	7	7.0	1.00
1	Dec.13-Dec.19	6	5.0	.83

Summarizing:

Number of borers	Distance tunneled per day in mm.	Percentage
6	.28	15.0
1	.33	2.5
3	.34	7.5
1	.36	2.5
2	.39	5.0
4	.40	10.0
8	.42	20.0
1	.44	2.5
1	.66	2.5
9	.83	22.5
3	.85	7.5
1	1.00	2.5

Forty borers tunneled altogether 21.25 mm. per day. Thus the average rate was .53 mm. per day. Sixty-five per cent of the borers fall between .40-.85 mm. per day.

The data above extend from the time the borers were

placed on the roots until the time they were taken out of them. Due to the fact that some hours usually elapse before the borers begin tunneling, the true rates are slightly increased over the rates given in the table. Probable chances of error could appear through the borers possessing different appetites or degrees of vigor, though only vigorous borers were used in the experiments; or through some small personal margin of error in measuring the length of the tunnels. To obtain as accurate results as possible, however, only straight, well-defined tunnels were measured.

Since a good number of these experiments were performed in separate containers and at various times, with all factors as nearly uniform as possible, it is believed that the results obtained are quite indicative of the degree of damage the borers can inflict.

XIX. Direction of the Tunnels.

The majority of the borers under natural conditions confine most of their attentions to the crown. But do they prefer to tunnel downwards, upwards, or across ? Owing to the inaccuracy of charging various tunnels to particular borers in outdoor roots, a number of experiments were performed in the laboratory to clear up this problem. It may be stated at the outset that unless the limits of the tunnels were definite, no account was taken of them. All vials and jelly jars contained loose soil.

October 31.—Two borers bored into a root, resting free upon the surface of the soil, from underneath, boring straight up.

October 29.—Of six borers placed in a vial with a root resting free upon the surface of soil, all six bored in within 4 mm. of the bottom: 3 from underneath straight up; and three near the

bottom diagonally downward.

November 2.—Six adults were placed in a vial containing a root resting upon the surface. One borer bored in from the top straight downward; one from the bottom diagonally upward; the remaining two within 3 mm. of the bottom, one straight across, the other diagonally upward .

November 2.—Six borers were placed in a vial containing one 2.5-mm. root and one 7-mm. resting free upon the surface. November 16, one borer was dead; the other five were in the large root all boring straight up from underneath.

November 19.—Twenty adults were placed in a jelly jar into which was stuck an alfalfa root, a red clover root, and an alsike root, all three roots being of the same dimensions. December 5, all had bored into the roots just beneath the surface; one in red clover bored diagonally upward; five in red clover bored downward; three in red clover bored straight across; and eleven in alsike bored downward.

November 22.—Two borers were placed in a vial containing a root stuck in the soil 3 mm. November 30, both had burrowed upward from underneath.

January 1.—Eight borers were placed in a jelly jar into which was stuck one 7-mm. partly rotten root and one 9-mm. fresh root. January 8, one had bored into the fresh root diagonally down from the surface; two others in the fresh root boring straight across from the surface. Of the remaining five, in the partly rotten root, three had bored in from the top of the root downward and the other two at the surface downward.

The insect will frequently make its tunnels up, down, or

across, but much the larger number prefer to bore downward.

As noted in previous experiments the borers tend to enter the root at or near the surface of the soil. When a root is resting free on the surface a large number of borers enter the root from underneath, boring, of course, upwards. As explained in the introduction, the roots are really pieces of roots, being cut at each end. If the borers do not enter the roots at or near the surface of the soil, they show a marked preference for entering them from the top through the cut surface rather than anywhere along the sides.

Excluding the large number of beetles that bored in from underneath, and therefore were obliged to bore upward; also the smaller number that bored in through the top, and then necessarily downward, it will be seen that of those remaining, twenty-one bored downward, six straight across and two upward; or 72.4 per cent, 20 per cent, and 6.9 per cent, respectively.

XX. Reaction of Adults to Soil.

A large number of experiments have been performed by me to find out the behavior of the adult when it is confronted with various conditions of the soil. How does the insect react towards firm soil; towards loose soil; what is its facility for attacking roots that are, say, buried from sight in the soil; its ability to descend or ascend through the soil? These are all important problems. Measures of control may hinge uopn some or all of these things.

Loose soil:—If the soil is loose the borers will as a rule attack the root just beneath the surface, that is, two or

three millimeters below the surface. The large majority will attack just here. The following experiments bear out this contention.

November 22—A 10-mm. root was stuck in loose soil 25 mm. down, the root sticking out of the soil 30 mm. November 30, one beetle had bored into the root from its top and six had bored in 2-3 mm. beneath the surface. Ten other adults treated similarly, tunneled in the same distance beneath the surface.

November 22—Six adults were placed in a vial in which the base of the clover root had been bedded in for 15 mm. November 28, all six had bored into the root practically at the same place, 3 mm. beneath the surface. The experiment was performed similarly in another vial. All six bored in at the same level, 2 mm. beneath the surface.

January 9—Two 8-mm. roots were stuck in quite loose soil in a jelly jar and twelve borers added. One of the roots was a partly decayed clover root and the other a fresh alfalfa root. January 16, all twelve had entered the clover root, eleven of which were at least 6 mm. from the surface.

In the first four experiments the soil was fairly loose, the borers tunneling in 2-3 mm. beneath the surface; in the second experiment the soil was quite loose and they sank into it some 6 mm. before entering the root.

Firm soil:—The tendency in firm soil is for the borers to attack the root just above the surface of the soil. Considering that they will enter loose soil, this must be due to the fact that they do not care to or cannot bore into hard soil.

December 16—In a jelly jar containing a 16-mm. root

stuck into firmly pressed soil, out of twenty adults that had bored into the root, twelve had bored in just above the surface of the soil.

December 19—In a jelly jar, a 14-mm. root was stuck in firmly pressed soil. Eleven borers were added, nine of which bored in just above the ground.

January 4—In a vial, a clover root was stuck in firmly pressed soil. Out of nine borers entering the root, seven bored in just above the surface of the soil, and two into the top, which was 15 mm. above the surface.

January 8—Under similar conditions of firmly pressed soil all nine bored in just above the surface.

The two experiments below are in all respects similar to the preceding experiments, in which firmness of soil is a factor, save that no roots were used.

December 13—Six borers were added to a vial containing firmly pressed soil. January 1, the soil had not been entered. January 7, one borer had tunneled into the soil 3 mm. This seems interesting, after their refusing to tunnel for more than two weeks.

December 11—To each of two vials containing firmly pressed soil, seven borers were added. December 18, none had entered the soil.

An aspect of the subject not brought out here is that if any holes or crevices are present, the borers will attempt to enter the soil by means of these openings.

The results obtained in these two experiments, corroborate the results obtained in the preceding experiments.

The idea was entertained to try the borer's reaction

towards the whole plant bedded in loose and firm soil.

March 31—Thirty-six borers were used in this experiment. Into two jelly jars were bedded two large clover plants containing vigorous green heads, both plants being bedded above the crown. Around one plant the soil was allowed to remain loose; around the other it was firmly pressed. Eighteen borers were added to each jar. April 4, fifteen borers in the jar containing the loose soil had entered the crown from above, between the leaves. The others had not entered the root. In the jar containing the firmly pressed soil twelve borers had entered the crown from above. The others also, had not entered the soil.

The results in this experiment are not very striking, due to the fact that the tops were left exposed, purposely, in imitation of outdoor plants, yet, even here, it seems that firmly pressed soil does play a role in keeping the borers out of the plant.

XXI. Depth of Roots Attacked.

We have noticed in preceding experiments that the adults will enter loose soil, but seem disinclined to enter firm soil. In the following experiments the extent to which they will enter loose soil is considered.

October 8—A fresh and a decayed root of equal size were buried upright in soil 25 mm. from the surface. Five adults were placed on top of the soil. November 5, only two of the borers had reached the roots, one boring into the fresh, the other into the decayed root, both at the tops of the roots. The other three had, however, entered the soil, but owing to the length of time that had elapsed, probably, never would have gained the roots.

October 16—Six borers were placed in a vial on top of

soil in which was buried horizontally, 14 mm. from the surface, a 7-mm. fresh root and a 4-mm. decayed root. October 22, four of the borers had tunneled into the decayed root and two into the fresh root.

October 16—A 7-mm. fresh and a 7-mm. decayed root were buried upright in soil 12 mm. from the surface. October 22, all three beetles had bored into the fresh root near its top.

October 17—A 7-mm. fresh root and a 7-mm. decayed root were buried 25 mm. from the surface of the soil. Five borers were added. October 24, all five had burrowed into the decayed root, two of the five at the top of the root, and three within 6 mm. of the top.

It will be seen from the preceding experiments that the borers can descend 25 mm. through loose soil and be working on the roots inside of a week. No very particular preference seems to be shown for the decayed roots, only 10 out of 16 borers entering the same. When the borers have direct access to both fresh and decayed roots, they prefer the decayed roots. (See Experiments on Optimum Conditions of Roots.)

November 1—Three adults were placed on top of soil in which was buried, 12 mm. deep, a 10-mm. root 22 mm. long. November 17, all three borers had bored into the root, but strange to say, at the bottom of the root. They had thus traversed through the soil 34 mm.

November 2—Five adults were placed on top of soil, there being 10 mm. beneath the surface four roots of the same length, three of the roots 2 mm. in diameter and the fourth root 5 mm. in diameter. November 21, three of the borers were in the 5-mm. root;

the other in one of the 2-mm. roots. All four had bored in almost at the top of the roots.

Except for one notable exception, all the borers entered the roots near the top. A discussion of this will be undertaken later.

Two experiments were performed, in each of which from 2-3 mm. of soil were laid over each root. The roots were thus just out of sight. In the first experiment, two 20-mm. roots were used, one red clover, the other alsike, and eighteen adults were added to the vial. Thirteen of the adults entered the red clover root, ten at the top of the root and three scattered along the root. Three others had bored into the alsike at the top of the root. The other two were dead outside the roots. In the second experiment, six adults were added to a vial containing a 5-mm. alsike root buried 2 mm. beneath the surface. All six borers entered the root at the top.

The fact that the borers could not see the roots yet reached them by the nearest path would lead one to conclude that the borers employ some other sense than that of sight in locating the roots. Even more remarkable—we find from the experiments on depth of roots attacked that, with one notable exception, they were able to reach and attack the roots by the shortest way even when roots were buried as much as 25 mm. from the surface. It is believed that the top of the roots was the first part of the roots reached, for the whole tendency of the borers is downward, as shown in the following experiments.

XXII. Tendency of Borers to Ascend through the Soil.

Suppose a field of old infested roots were plowed under, breaking up the roots(which break up more or less easily when they are heavily infested and fast decaying) and scattering and burying the borers, would the borers be able to work their way up out of the soil and find other roots? The writer believes the borers have no great tendency to work their way upwards, as the following experiments will show. In all the experiments the soil was added loose.

October 16—Two adults were placed on the bottom of a vial and covered with 25 mm. of soil. Then, a fresh root and a decayed root were laid flat upon the surface. October 22, neither borer had left the bottom.

November 2—Five adults were placed on the bottom of a vial, upon which were added 15 mm. of soil, and an 8-mm. root was laid on top of the soil. November 8, three of the borers had not left the bottom; one had reached and bored into the root; and the last one had nearly reached the surface of the soil.

October 22—Five adults were placed on the bottom of a vial and 10 mm. of soil added above them, and on the surface of the soil were laid a 2-mm., a 3-mm., and a 6-mm. root. November 21, one had bored into the 3-mm. root and four into the 6-mm. root.

November 22— Six borers were placed on the bottom of a vial, then 10 mm. of slightly pressed soil added, and last, a 6-mm. root. December 12, one borer could not be found; the other five borers had not left the bottom layer. Repeating the experiment, with six other borers, these also refused to leave the bottom layer.

March 4—Twenty-five adults were placed on the bottom of a vial and covered over with 15 mm. of soil. A fresh 6-mm. root

was laid on top of the soil. March 6, after two days, all the borers were still within 5 mm. of the bottom. Nine other borers had been treated similarly and all nine were also found within 5 mm. of the bottom.

March 5--Eight adults were placed on the bottom of a vial and 6 mm. of dirt thrown over them, a root being laid on top of the soil. March 7, all of the borers were either boring into the root or else clinging to it.

The borers behave in an interesting manner. If the root is more than 15 mm. from them, none will leave the bottom layer of soil. If it is 15 mm. or 10 mm. from them, some, if not all, will leave the bottom layer and work up to and bore into the root. However, should the soil be pressed down to some extent, they will not leave the bottom, even when a root is no more than 10 mm. from them. The last two experiments illustrate this sort of behavior quite as clearly as the preceding experiments. In a two-day period the borers will not leave the bottom when a root is 15 mm. above them; should a root be only 6 mm. above them, however, they will all ascend to it. This behavior would seem to indicate that the borers have a sense of smell. This sense that leads the borers to an unseen root has been commented on before. Possibly, during their migrations in the late spring and summer, the borers are guided by a sense of smell to new roots.

XXIII. Ability of Larva to Enter Roots.

The larva of the clover root-borer possesses only the stumps of thoracic legs and no prolegs, so does not crawl. But it can roll over with a fair amount of ease, and, besides, squirms about

with much vigor;but if not placed directly in a crevice it seems to find difficulty in entering a root. Even when placed in a notch it frequently falls out, even repeatedly tumbles out. To insure that a larva enters a root, a small notch into which the larva fits snugly seems to be necessary.

The rate at which the larva "covers ground" is indicated in the following experiment.

April 2—A full-grown, very active larva just taken from an outdoor root was placed on a smooth white piece of paper, on a level surface. Direct light was avoided but the larva was not placed in the dark. The paper was covered with a moist glass cover to retain constant conditions of moisture. In one hour the creature had squirmed from its original position the distance of 7 mm.; in four hours 35 mm. This rate seems exceedingly slow when compared with that of the adult, which is not by any means a fast-moving insect. The data for the adult were taken on a smooth level surface under light conditions similar to those used for the larva. Only records of continuous steady crawling were kept.

Table VI. Rate of Crawling of Adults.

Time in seconds	Borer number 1	2	3
	Distance crawled in mm.		
60	216	236	263
120	211	215	261
180	201	201	

As to the larvae entering the root:

October 3—Five larvae were placed in notches, three eventually making tunnels. The other two would not stay in the notches, eventually dying in the bottom of the vial.

October 30—Two larvae were placed in notches. October 31, one that had fallen out was replaced in the notch. November 8, both had bored 4 mm. into the root.

November 16—Two larvae were placed in notches. November 24, one had refused all along to stay in the notch; the other had entered the root.

XXIV. Phototropism.

Direction of Light.

The clover root-borer is a subterranean insect, passing most of its life history in the dark within the roots of some leguminous plant. Its reaction towards light ought, therefore, to be interesting. To observe its behavior toward the direction of the sun's rays, six adults were placed on a black level table, upon which shone direct sunlight. The experiment was performed at 2 p.m. February 20, and readings were taken every 30 seconds. The heading "indefinite" in the table below means that a borer had stopped crawling . Whenever the borers reached the line of shadow they were placed back into the center of the bright area, and readings were not resumed until after thirty seconds. The place in the readings where the borers reached the line of shadow and before new readings began is indicated by a single line through the table. At times, when a single borer would reach the shadow line a good distance ahead of its fellows, it was placed back in the center of the bright area and counted out for the next reading.

Table VII. Phototropism.

Number of readings	Reaction to sun-light, positive	Reaction to sun-light, negative	Crawling at right angles to sun's ray	Crawling obliquely away from light	Crawling obliquely towards light	In-definite
1				6		
2		1		4	1	
3		2		3	1	
4		3		2	1	
5		3		3		
6		3		2	1	
7		3		2	1	
8		4		1	1	
9		2		2	2	
10		2	1	2	1	
11	1	4		1		
12		2		4		
13		3		3		
14		3	1	1	1	
15		3		3		
16		2		4		
17		2		3	1	
18		2		3	1	
19		3		2	1	
20		4		2		
21		3		3		
22		1	2	1	1	
23		4		1	1	
24		4		1	1	
25		3	2			1
26		5		1		

Table VII.-continued.

Number of readings	Reaction to sunlight, positive	Reaction to sunlight, negative	Crawling at riht angles to sun's rays	Crawling obliquely away from light	Crawling obliquely towards light	Indefinite
27		4		2		
28		4		2		
29		3	1	2		
30		2	2	2		
31				6		
32		1		4		
33		4	1			
34		3	1	1	1	
35		2	1		2	
Total	1	94	12	79	18	
Percentage	.4	46.0	5.8	38.7	8.7	.4

The results are seen to be quite definite. The borer is strongly negative to direct sunlight, eighty-three per cent of the borers heading away from the sun. Indeed, of those headed obliquely away the largest per cent were headed within 45 degrees of directly away from the sun.

A series of experiments have been performed to show the borer's behavior toward direct sunlight. These experiments were performed in the greenhouse, with a constant absence of wind, on a smooth, level piece of brown paper. Temperatures in the sunlight were taken and the rate of movement of the borers was also noted, as indicated in the diagrams by the numbers enclosed in the squares. Representative reactions are illustrated in diagrams, 4, 5, and 6, which are drawn two-thirds of the actual dimensions. The directio

of the sunlight is indicated by the arrows. The black dots indicate the points where the borers were placed on the paper; the squares, the points where they spread their wings; and the spaces between the squares and the cross lines the distances flown. In all the experiments in the sunlight the borers began crawling as soon as they were placed on the paper.

Diagram 4 illustrates a borer's behavior on May 2, with the temperature at 92° F. A clear indifference to the sunlight is shown, for the borer took a general direction at right angles to the rays of the sun. For the first time since the writer began this work he observed the beetle spread its wings and, finally, after four short flights, fly straight up towards the sun until it struck the roof of the greenhouse . The last square indicates the point where it took its final flight. This borer moved slowly and stopped frequently, crawling the distance indicated in twelve minutes. During this same period, two other borers were each allowed to crawl from a point on the paper to its edge six times. These borers were on the whole slightly negative to sunlight, but neither took short flights, nor a final flight, though both spread their wings repeatedly throughout, yet less in proportion than the borer indicated in Diagram 1.

On May 4, further experiments were performed, all factors being similar to those of May 2, except that the temperature was now 106° F; and both fresh borers and some borers from the experiments of May 2 were used. A typical example of marked irregularity in movement with a frequent spreading of the wings is shown in Diagram 5. The borer used was a fresh one, and its trend, on the whole, was negative to sunlight. At first it crawled rapidly and smoothly,

but soon became wobbly, and finally, after much apparent distress, such as trailing of the wings, it came to a halt six minutes after the start, at the point indicated by the asterisk. It was picked up three minutes later and revived in the shade after a few moments. In contrast to this marked irregularity of movement, frequent spreading of the wings and weak resistance to the sunlight, the next case is of interest. Diagram 6 illustrates twelve journeys of a single borer from the starting point to the edge of the paper, when the temperature, instead of being 106°F. was 108°F. The order of the journeys is indicated by the numbers in the circles. Some of the journeys, such as the first two (Nos. 1 and 2) are marked by an evident irregularity; while others, like 7, 8, and 9, show little irregularity. There seems to be no definite correlation between irregularity of movement and frequency of spreading the wings, though as a rule a borer would stop and often turn around one or two times (which cannot be readily indicated in the diagrams) before spreading its wings. The borer showed a persistent negative reaction to sunlight.

The rate of movement of the borer, as represented in Diagram 6 was more or less uniform throughout, and was somewhat faster than that of the borer represented in Diagram 5; and more than three times as fast as that of the borer indicated in Diagram 4; but the reader must bear in mind that the latter borer was subjected to a considerably lower temperature than the former two.

Borers were placed frequently in the shade on both May 2 and 4, with the temperature at 80°F. and 82°4 F., respectively. They showed always a clear decrease in rate of movement, sometimes stopping entirely. On May 10, three borers were placed in the shade

at a temperature of 82°F. They remained motionless for thirty-seven minutes, but as soon as the sun came out, immediately began crawling.

The irregularity in movement, the spreading of the wings, the flight of the borer, the tendency of the borer to remain motionless in the shade, were all new aspects of behavior.

Intensity of Light.

One experiment was performed with the Yerkes Light Grader to determine whether the borers react to fairly mild gradations of light. The Grader is so constructed as to throw a light from a lamp above, through an adjustable opening, through a triangular lens, through a heat absorber(tank of distilled water) upon the animals under experimentation, beneath. The intensity of light is regulated by the ajustable opening and the size of the lens; and the box containing the animals is so placed as to receive various intensities of light. The Grader has closed doors, and while the animals are under experimentation, all light is excluded except that which passes through the lens. (See Diagram 7, showing the principles upon which the Grader works).

Six adult borers were used in this experiment and the data obtained are expressed in the following table. Five minutes after the box containing the borers was placed in position, readings began, the observations showing whether the borers were in the brightest light or the dimmest light or medium light or medium dim.

Table VIII. Reaction of the adult borers to intensity of light.

Readings	Bright	Medium bright	Medium dim	Dim
1	3	2	1	0
2	3	1	1	1

Table VIII.-continued.

Readings	Bright	Medium bright	Medium dim	Dim
3	1	4	1	0
4	0	3	2	1
5	1	3	4	1
6	2	1	2	1
7	2	2	1	1
8	1	1	2	2
9	0	2	2	2
10	0	2	2	2
Total	13	18	20	11
Percentage	20.9	29.0	32.2	17.7

The borers had a tendency to climb up the glass walls of the box;and this may have produced some error but not one sufficient to change the nature of the results obtained. It would seem that the light was not sufficiently intense to influence definitely their actions.

XXV. Hydrotropism.

The adults react decidedly to moisture. If the adults be subjected to the relatively dry humidity of the laboratory,they die in a few days;should they be kept in a decidedly moist environment,they will live from three weeks to a month. The adults can endure a great deal of moisture. Should they be buried in soil that has the consistence of thin ooze,they will usually live for a day or so,if not longer. There seems to be no doubt that they can stand any degree of moisture occurring in their natural environment. The following observations support this conclusion.

October 2— Several borers were found on this date in a decayed root quite soaked with water. Indeed water dripped out of the tunnels and the borers were covered with watery films, yet, all were perfectly vigorous.

November 20— Eight adults were placed in a jelly jar containing a bottom layer of soil which was moistened until it was of the consistence of thin ooze with a watery film on the surface. Two days later, the water was drained off, the soil allowed to dry some and six of the eight borers were found still alive.

March 19—Three borers were placed in a thin ooze in a vial. The next day all were alive. The following day two were dead.

April 8— Four adults were placed in a vial containing thin ooze. After twenty-four hours, one borer was alive.

The fact that any of the borers could remain alive for any length of time shows their resistance to such extreme conditions of moisture. On the other hand their resistance to dryness does not seem to be very great. In the following observations the vials were simply stoppered and the air within had essentially the same relative humidity as the laboratory.

September 20—Two adults were placed in an empty vial; four days later both were dead.

October 8—Four adults were placed in a vial containing a bottom of cotton. October 15, three were dead. The next day the remaining one died.

October 8—Six adults were placed in an empty vial. October 15, all were dead.

November 1—Three adults were placed on top of a layer of

fine soil in a vial. November 3, all were dead.

November 22–Six adults were placed on top of a layer of fine soil. The next day one was dead. All were dead on the following day.

March 19–Three adults were placed in a vial containing a cotton bottom, and three others in a vial containing fine dry soil. The next day the three in the cotton vial were alive and two in the fine soil were dead. The following day all were dead.

March 21–Six adults were placed in a vial containing a cotton bottom and six in a vial containing fine dry soil. The next day, two borers were dead from each vial. The following day three others were dead from the fine soil and two others from the vial with cotton. March 24–All were dead from both vials.

It will be seen that the borers under the relatively low humidities that prevail in the laboratory will die within a week, and usually in less than a week. Whether fine soil shortens their lives by clogging their spiracles, or by absorbing an undue amount of moisture, the writer is not able to say.

Now, if the borers are furnished with a moist environment they will easily live three weeks and even as long as four weeks. In the following observations the vials were all given a bottom layer of moist dirt and the humidity was kept practically constant by stoppering the vials with cork stoppers. No roots were furnished the borers.

March 19–Three borers placed in a vial on this date, showed feeble movements on April 4. April 9, they were very feeble. April 11, two were dead. April 13, the last one was barely alive. April 15, the last one died.

March 21—Six adults placed in a vial on this date, showed feeble movements on April 11, when two were dead. April 15, one more was dead, and they were growing feebler all the time. Two others died on April 20. April 22, the last one died.

April 1—Six adults, placed in a vial on this date, showed feeble movements on April 20. One was dead on this date. April 22, three others were dead. April 25, the last two died.

The following table shows the duration of life of these fifteen borers.

Number of borers	Duration of life in days
1	20
2	21
3	22
2	23
3	25
1	27
2	30
1	32

Though all the borers were taken from roots immediately before being placed in the vials, yet some showed more hardiness than others. They all showed uniformity, however, in growing feebler and feebler before death. Evidently they die slowly when starved.

XXVI. Thermotropism.

The temperature factor no doubt plays an important rôle in the life history of the clover root-borer. The question as to what is the optimum temperature for the insect demands attention.

An attempt has been made to find out something about this. To give the borers the opportunity to choose freely between any number of different temperatures with the light and gravity factors eliminated, the writer had in mind a long narrow receptacle, set level and covered over to keep out light, and some heat, that could be regulated, directed towards one end of it. Thus, a gradation of temperature would result between the cold and hot ends. Such a method was employed in the following experiment.

March 6-Twenty-one borers were placed in a long tin box, 50 cm. long, 4 cm. wide, 3.5 cm. deep, which was set level on a rack high enough so that heat from an alcohol lamp beneath could be regulated to the proper degree. The bottom of the box was covered with rough paper, to give the borers a gripping surface to crawl on. Two thermometers were laid down in the box at each end, and a board was laid over the top to keep out the light. The paper had been ruled off in 5-cm. sections, from which the temperatures could be calculated. Three sets of readings were taken to act as controls against each other. After each set the box was allowed to cool and the heat transfered to the other end.

Table IX. Reaction to varying temperatures. Readings every three minutes.

No. of reading	Temperature in C. cold	Temperature in C. hot	Cold end of box 0	5	10	15	20	25	30	35	40	Hot end of box 45--location-cm
			21.5°	23.4°	25.3°	27.2°	29.1°	31.0°	32.9°	34.8°	36.7°	38.7° temperature in C.
1	21	40	3	4	3	2	2	4	3			
2	21	40	6	1	3	1	2	3	3	1	1	
3	21	40	8	2	3	6		2				
4	22	41	7	2	5	3	2		2			
5	22	39	10	3	1	1	3	2	1			

Table IX.-continued.

No. of read'g	Temperature in C. Cold	Hot	Cold end of box 0	5	10	15	20	25	30	35	40	Hot end of box 45
6	22	36	8	7	1	1		3				1
7	21	37	10	2	2	2	1	2	1		1	
8	21	37	8	3		3	3	2		2		
9	22	38	6	5	2	2	1	1		2	1	
10	22	39	6	5	2	2	2	2	2			
Average	21.5	38.7	72	34	22	23	16	21	12	5	3	1
Percentage			34.6	16.3	15.7	11.0	7.7	10.[illegible]	5.7	2.4	1.4	.4

First Control-with readings with heat reversed.

NO. of read'g	Temperature in C. cold	hot	Cold end of box 0 (22.3°)	5 (24.2°)	10 (26.1°)	15 (28.1°)	20 (30.0°)	25 (32.0°)	30 (33.9°)	35 (35.8°)	40 (37.8°)	Hot end of box 45 ([illegible]8)
1	22.0	39.0	2	3	4	3	4	2	2			
2	22.0	38.5	5	2	2	2	5	3	1			
3	22.5	40.0	4	3	2	2	3	3	1	1	1	
4	22.5	40.0	4	1	3	4	5	2	1			
5	23.0	45.0	7	3	2	1	2	4	1			
6	22.0	41.0	6	2	3	4	1	2	2			
7	22.0	40.0	6	3	2	2	3	1	1	2		
8	22.0	39.5	6	5	1	4	1	3				
9	22.0	39.5	5	4	4	3	1	2	1			
10	22.0	39.5	9	1	1	3	2	1	3			
11	22.0	40.0	3	1	3	3	5	5				
12	22.0	40.0	7	2	3	2	3	1	2			

Table continued from the preceding page.

NO.of read'g	Temperature cold	hot in C.	Hot end of box 0	5	10	15	20	25	30	Cold end 35	40	45
13	24.5	40.5	6	3	2	3	2	1	2	1		
14	23.0	39.5	7	2	4	2	3	2				
15	22.5	37.5	6	2	1	2	3	4	1			1
Ave.	22.3	39.8	83	37	37	40	43	36	18	4	1	1
Percentage			27.6	12.3	12.3	13.3	14.3	12.0	6.0	1.3	.3	.[illegible]

Second Control-Readings with heat in original end.

No.of read'g	Temperature cold	hot in C.	Cold end of box 0 21.8	5 23.3	10 25.3	15 27.0	20 28.8	25 30.6	Hot end of box 30 32.3	35 34.1	40 35.8	45 37.7
1	22.5	38.0	3	3	3	1	4	3		2	1	
2	22.5	39.0	5			1	7	3	3	1		
3	22.0	38.5	3	2	1	1	6	2	4	1		
4	22.0	40.5	4	1	2	4	1	5		1		
5	22.0	39.0	5		2	1	4	3	2	1		
6	22.0	38.5	2	1		4	5	5	1			
7	22.0	38.5	5	3	2		2	3	2	1		
8	22.0	36.0	6	3	1	1	2	2	3	1		
9	21.5	35.0	6	2	2	2	1	2	2		1	
10	21.5	36.0	6	2		1	2		2		2	1
11	21.5	37.0	7	2	1	1	2	[illegible]	1	1	1	
12	21.5	37.0	4	4		2	2	2	3		1	
13	21.5	36.0	2	1	2	4	3	3	2			
14	21.5	36.5	3	3	1	3	2	3	2			
15	21.5	38.5	3	4	[illegible]	5	1	[illegible]	1	1		

Table continued from the preceding page:

No. of read'g	Temperature in C. cold	hot	Cold end of box 0	5	10	15	20	25	Hot end of box 30	35	40	45
16	21.5	39.0	6	2	5	1	2	2	1			
17	21.5	38.0	7	3	2		3	1	1	1		
Ave.	21.8	37.7										
Total			79	36	26	32	49	46	30	11	6	1
Percentage			25.1	11.4	8.2	10.1	15.6	14.6	9.5	3.5	1.9	.3

The most marked result from this experiment is the large proportion of borers continually appearing in the cold end. More borers were crawling up the sides of the box at the cold end than anywhere else and this no doubt increased the proportion in the cold end. The writer's opinion is that the borers were seeking colder temperatures and thus piled up in the cold end. Another feature is the fairly equal proportion of borers found in the next five sections and then the sudden dropping off which took place around 32°C. This even proportion is particularly noticeable in the first control. The writer believes that the borers indicate that they do not desire temperatures much above 32°C., but that they are not particular as regards those below 32°C. down to the lowest temperature reached in the experiment; and that the crowded condition in the cold end indicates that the borers might have spread on into even colder temperatures if it had been possible.

Turning from the optimum, what is the minimum temperature that the borer can stand?

January 29—Two borers that had been kept in roots in the laboratory all the winter, were taken from the roots and placed

out of doors where the temperature was 10°F. Both immediately stopped crawling, and in a few seconds dropped motionless to the bottom of the vial. After being out for five hours (temperature now being 23°F.), they were returned to the laboratory. One never recovered and the other, after four and half hours in the laboratory at a temperature of 74°F., showed no signs of activity, but, curious to relate, it did revive in the writer's vest pocket!

February 4—A borer that had been in the laboratory all the winter was set outdoors, in a temperature of 6°F. After three minutes' exposure, the borer was returned to the laboratory. It never recovered.

February 20—One adult that had been in the laboratory all the winter and two adults that had been in the laboratory about a week were placed outdoors a number of times in quick succession. The duration of the exposure, the temperature and the time it took the insects to revive are stated in the table below.

Table X. Reaction of adults to alternate freezing and thawing.

Experiment number	Number of adults used	Duration of exposure in minutes	Temperature, Fahrenheit	Time to recovery in minutes
1	3	6	3°	2
2	3	15	3°	[illegible]
3	3	10	3°	2
4	3	23	3°	[illegible]

These three borers were placed outdoors for the night, and in another vial were placed three other adults that never had been experimented on, and that had been in the laboratory about a week. The minimum temperature for the night was 2°F. at 2 a.m.

Next morning, all the beetles were dead.

It will be noticed that when exposed to a temperature of 3° F., the borers can not only endure it but can revive in two minutes; and can revive just as quickly whether exposed for six minutes or twenty-three minutes. The borer that had been in the laboratory all the winter acted precisely like those that had only been kept in it a week. The borers that had not been experimented on died during the night along with those that had been subjected to a number of freezings and thawings. Whether it was the lowering of the temperature to 2° F. or the prolonged freezing that killed the borers left out overnight, the writer is unable to say.

It would seem that the borer is quite able to weather any sudden drops in the temperature that may take place in this section of the country.

XXVII. Threshold of Activity of Adult.

The borers were active throughout the autumn until my last collection, made on December 1, though there had been many heavy frosts and two snows.

The first collection in the spring was made on February 12. The air had the temperature of 44° F., but the soil was still half frozen. On digging the borers out of the roots on this date, the borers straightway showed signs of life, though rather sluggishly. A larva collected on this date showed signs of activity also, squirming about slowly.

March 2—The temperature of the air was 50° F., that of the soil, 44° F. Forty-eight adults, one pupa and six larvae taken from the roots on this date, all showed signs of life.

February 18—Thirteen adults and one larva dug from the

outdoor roots on this date were active, though not vigorous. The temperature was 41°F. At 39°, they showed fewer signs of activity, crawling about with difficulty.

March 14-Eleven adults just taken from outdoor roots were allowed to remain outdoors where the temperature was 38°F. All moved about appreciably, though with difficulty. Two hours later the temperature had dropped to 33°F., and, though it was near the freezing point, the borers still had their appendages extended and were in motion, though it took close scrutiny to see any movement.

Evidently, the "threshold of activity" is somewhere around the freezing point.

The borer is active whenever the temperature is not sufficiently low to force it into inactivity. Probably during the heavy frosts and snows of the autumn, the borer lay dormant but revived just as soon as the temperature rose above his threshold of activity.

XXVIII. Control.

All investigators agree that the most effective control measure is summer fallowing as soon as the hay crop is removed. The borers are largely in the larval stage at this time and will die from starvation when the roots are turned to the hot sun and winds to dry out. The plowing must not be delayed until the larvae are ready to pupate for the pupae take no food and, so, stand a large chance of surviving. The writer has performed no experiments on the resistance of the pupae to dryness, but it seems from their delicate and soft integument, which is about as soft and

thin as that of the larvae, that drying would be apt to kill them also. The beetle is, however, more resistant and furthermore is able to migrate and thus stands a greater chance of escaping destruction.

Since the borers die during the spring or early summer, the importance of holding off another clover crop until a year has elapsed, has been suggested by Davis('94).

Fertilizers have been tried as repellents by Mr. G. C. Davis in Michigan but with no success. Indeed, he believed that they injured his clover plants.

In looking over the literature, the writer finds plowing up the roots after the hay crop is removed the only measure of control.

XXIX. Natural Enemies.

The only natural enemy of the borer that the writer has been able to find, is a delicate white fungus growth, appearing at times in the vials when the roots have been kept moist for sometime and allowed to decay. The fungus growth on only one occasion has appeared to restrict itself entirely to the insect, however. On this occasion the borer, which was in the larval stage, had retained its natural color but but was dead and rather hard, though not dry. When the fungus appears in the vials, if larvae are present and exposed, they usually die; but no dead adults have been found, no matter how extensive the fungus growth. Should the larvae, however, be enclosed within the root they seem to escape the fungus. This fungus growth, not having fruited, has not been determined and the writer regrets that pressing time precludes his investigating the problem further, for the present.

In the literature on the clover root-borer, Chapman('69) speaks of "a predaceous-looking larva, with a double-hooked tail (very like a miniature Pyrochroa larva)" that is very abundant in old root-burrows in clover. Besides feeding on the larva of the borer, he states, it will devour various kinds of other insects. Dr. C. V. Riley cites a telephorid larva, Telephorus bilineatus Say, as being an enemy of the clover root-borer.

XXX. Summary.

The more important of the original results brought out in my work on the borer are as follows:

1. That the borers, through the greater part of the year, do not show any tendency to leave the roots upon which they are feeding.

2. That the adult borer will remain active all winter in a warm environment.

3. That the borers will copulate at any time during the year, if a sufficiently large number of them are brought together, and the temperature is suitable.

4. That the immature stages are most in evidence in the late summer and early autumn, and that the adult predominates during the late autumn and winter.

5. That the insect seems to be restricted to leguminous plants.

6. That the adult borer prefers the large roots, and in addition decaying roots.

7. That the rate of progress of the beetle in a root is appreciable, and is usually in a downward direction.

8. That the beetle will readily enter loose soil, but not firm soil, and will locate a root by the shortest distance without seeing

it.

9. That it shows little tendency to bore upwards through the soil.

10. That it reacts negatively to sunlight.

11. That it will die in a few days in a fairly dry atmosphere but will live for several weeks in a moist environment.

12. That it selects a temperature colder than 32°C., is very resistant to cold, surviving a sudden drop of seventy-two degrees Fahrenheit, and has a threshold of activity around the freezing point.

XXXI. Synonymy.

Hylesinus obscurus Marsham, 1802.

Hylesinus trifolii Müller, 1807.-Schmitt, '44.-Lintner, '79.-Riley, '79.-Henry, '80.-Lintner, '80.-Riley, '80.-Case, '81.-Devereaux, '83.-Riley and Howard, '89.-Osborn, '90.-Fletcher, '91.-Webster, '92.-Buckhout, '93.-Webster, '93.-Slingerland, '94.-Lockhead, '99.-Lugger, '99.-Fletcher, '05.-Gossard, '11.

Hylastes obscurus Chapman, '69.-Davis, '94.-Cordley, '96.-Hopkins and Rumsey, '96.-Hunter, '99.-Webster, '99.-Webster, '02.-del Guercio, '14.

Hylastes trifolii Chapuis, '73.-Bedel, '76.-Eichhoff, '81.-Lintner, '82.-Saunders, '82.-Cook, '87.-Weed, '88.-White, '88.-Hamilton, '89.-Weed, '90.-Weed, '91.-Smith, '92.-McCarthy, '94.-Webster, '96.-Barbey, '01.-Garman, '06.-del Guercio, '15.

Hylastinus obscurus Bedel, '87.-Bedel, '88.-Fletcher, '01.-Webster, '05.-Folsom, '09.-Webster, '09.-Pettit, '10.-Webster, '10.-Webster and Hillman, '11.-Swaine, '11.-O'Kane, '12.-Sanderson, '12.-Surface, '12.-Gilson, '13.-Swaine, '13.-du Porte, '14.-Marchal, '14.-Wahl and Müller, '14.-Blatchley and Leng, '16.-Crosby and Leonard, '16.-Osborn, '16.

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* indicates those publications that the writer has not seen.

+ indicates those publications that contain good accounts of the borer.

Explanation of Drawings.

Diagrams 1,2,and 3._ Each Diagram represents two or more roots showing the diameter of the root where it was attacked by the adult borer. The circles represent the points at which the borers entered the roots.

Diagrams 4,5,and 6.- Reactions of the borer to sunlight, x 2/3.

Diagram 7.- Yerkes Light Grader. a,lamp;b,adjustable opening; c,lens; d,heat absorber; e,box containing animals.

Figure 1.- Adult, x 58.

Figure 2.- Egg, x 58.

Figure 3.- Larva, x 58.

Figures 4,5,6,and 7.-Roots showing the injury of the borer. a,entrance hole.

Figure 8.-Adult, x 12.

Diagram 1

Diagram 2

Diagram 3

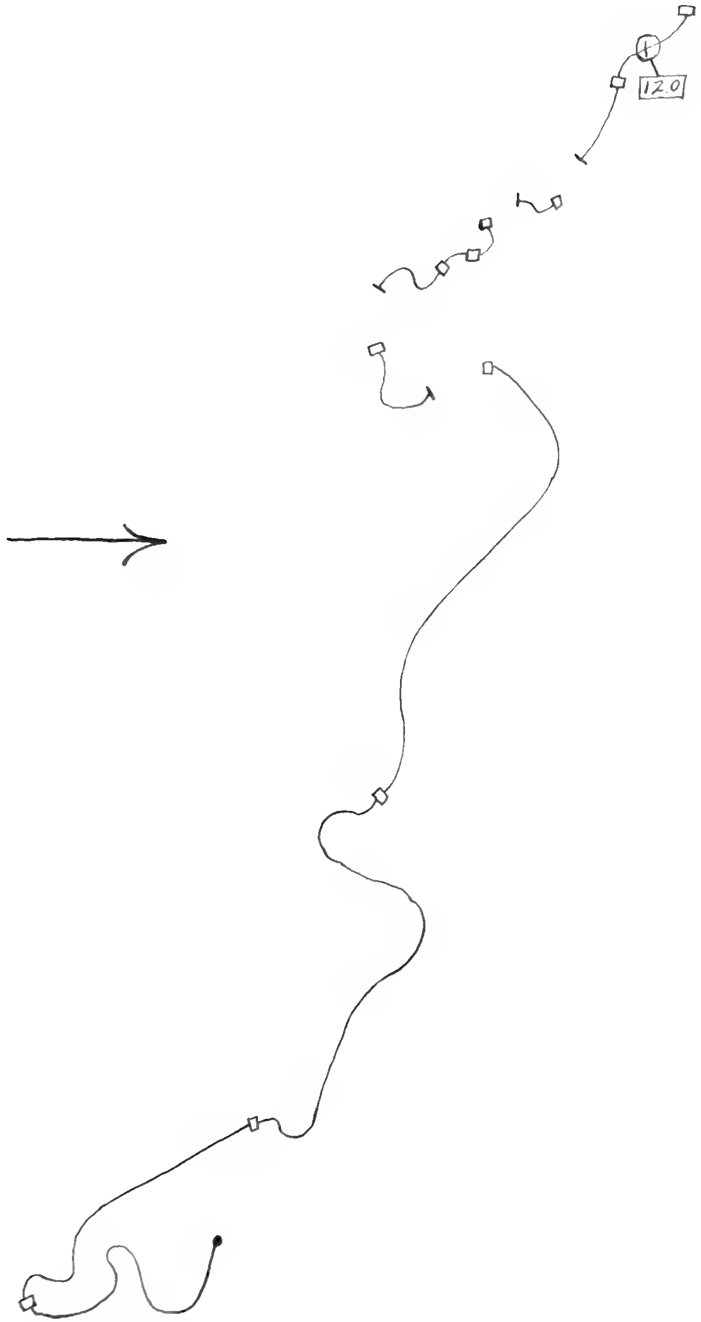

Diagram 4

Diagram 5.

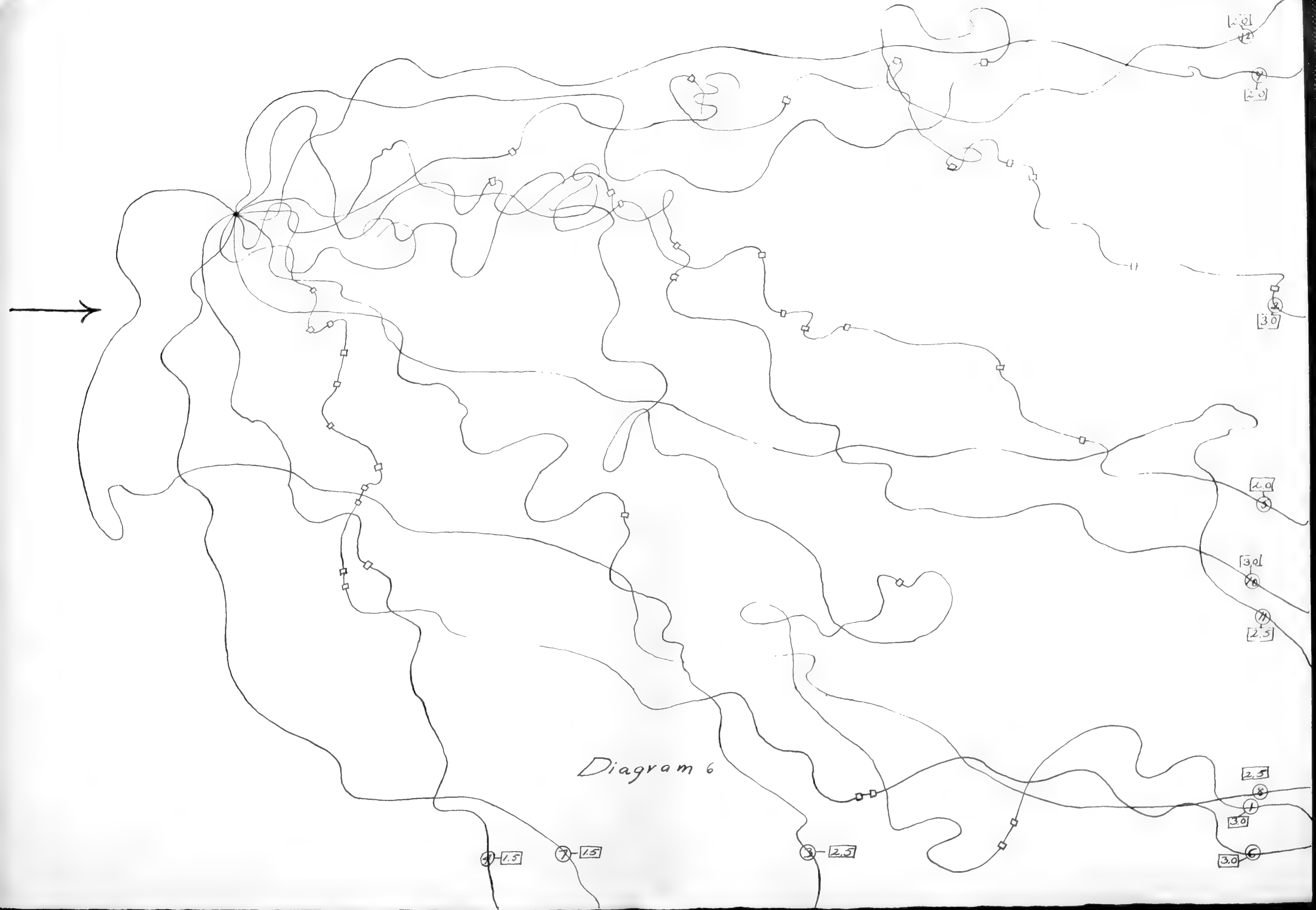

Diagram 6

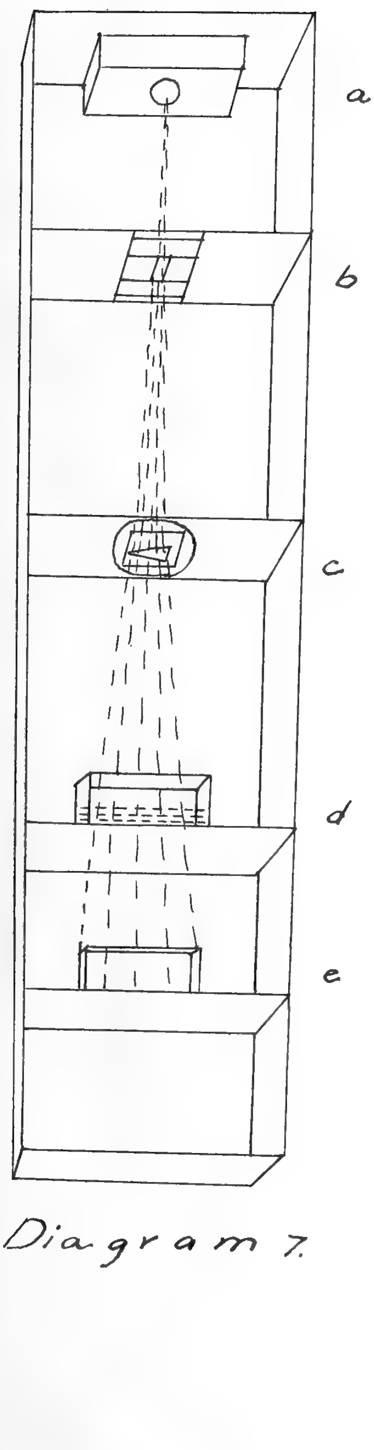

Diagram 7.

Fig 8

Fig. 1

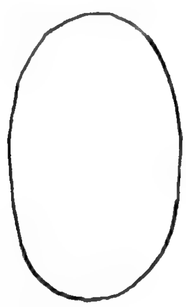

Fig. 2

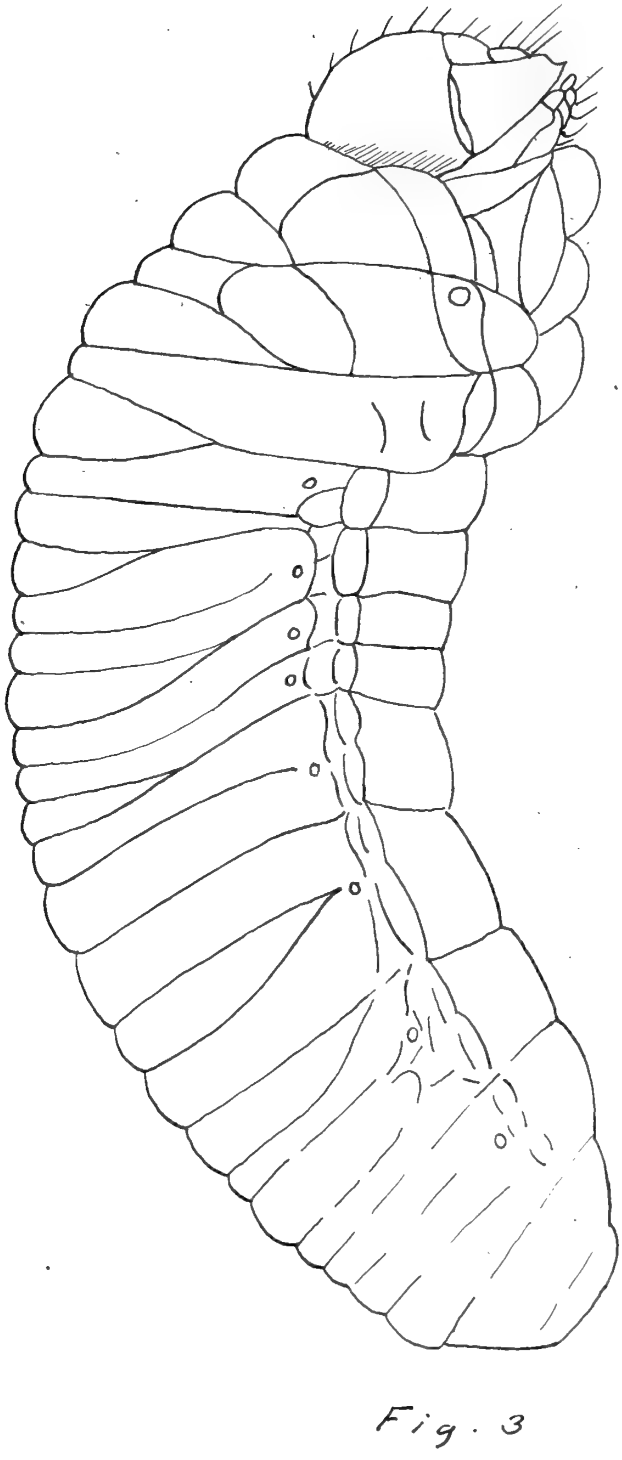

Fig. 3

Fig. 4

Fig. 5

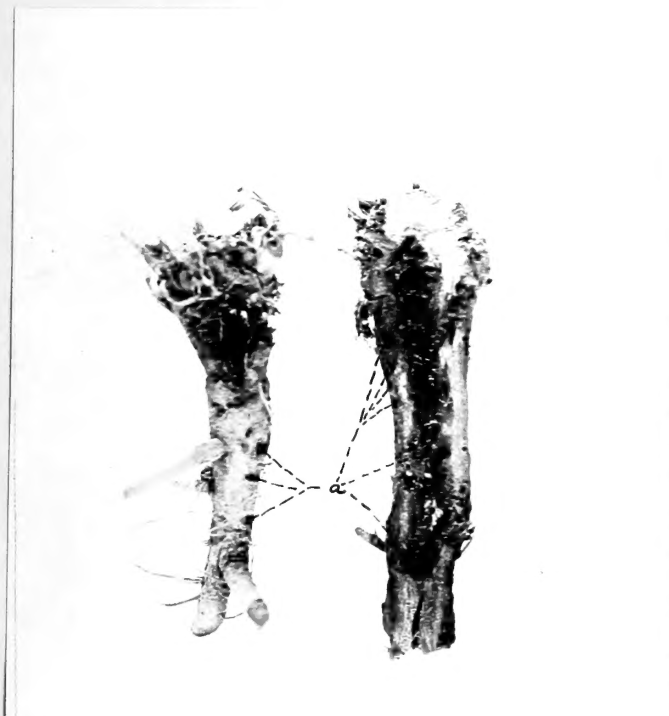

Fig 6

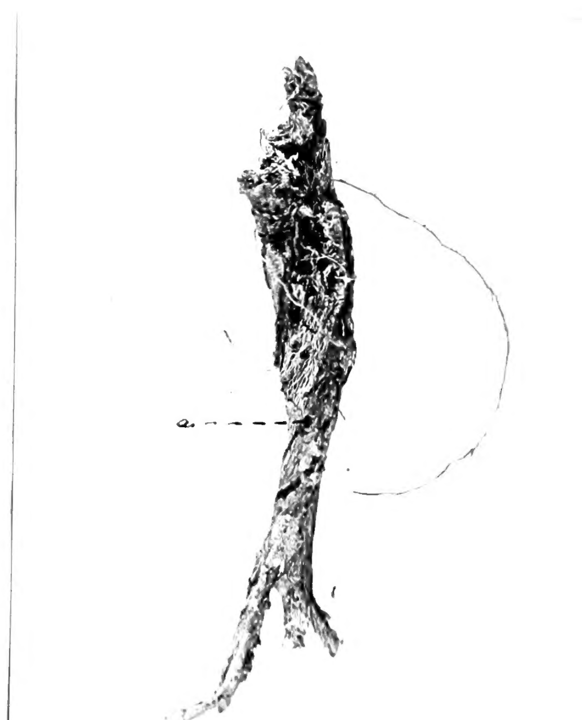

Fig. 7