THE SUGAR CANE ROOT CATERPILLAR [1] AND OTHER NEW ROOT PESTS IN PUERTO RICO [2]

By Francisco Seín, Jr.

Introduction

The sugar cane root caterpillar was discovered by the author on the grounds of the Insular Experiment Station, Río Piedras, Puerto Rico, in the month of November, 1925. The first caterpillar was found above ground late in the afternoon in cloudy, rainy weather. It had the anterior part of its body inserted into a tunnel in the tender part of an aerial cane root from which it was throwing out whitish excrement and upon being disturbed it ran for cover into the soil. Digging in the soil around the cane plant many of the roots were found to have been tunneled, the whitish excrement was observed near the injured roots and several of the caterpillars were collected. They were reared to adult in the laboratory on sugar cane roots.

Systematic History

The adults of this root-boring caterpillar were submitted to the late Dr. H. G. Dyar of the United States National Museum who determined them as *Sufetula grumalis* Schaus (Pyralididæ Pyraustinæ). In the annual report of the Director of the Insular Experiment Station of Puerto Rico for the year 1925–26, a few notes were published on the habits *S. grumalis* abstracted from the Report of the Division of Entomology which latter was not published in full that year. In the Annual Report of the Insular Station for the year 1927–28, in the Report of the Division of Entomology, the author reported that the study of the sugar cane root caterpillar had been carried to a point where it became evident that an error had been committed when it was determined as *Sufetula grumalis* Schaus.

The error is clearly explained by the venation of the fore wing; R_5 is stalked with R_3 and R_4 (Pl. XXVI). The stalk varies somewhat in length as shown in Fig. 20. According to the key given by Hampson, (4) this character makes it impossible to place the sugar cane root caterpillar in the subfamily Pyraustinæ to which the genus *Sufetula* belongs.

The key to the subfamilies of the Pyralididæ given by Forbes (3)

---

[1] *Perforadix sacchari*, new genus and species.
[2] The name of the Island of Porto Rico has officially been changed to its original form.

is intended to cover New York and neighboring States, U. S. A. If we try to run the Puerto Rico moth by this Key we find that there is no place for it. The first *1* reads: "Vein 1st A preserved in fore wing; tongue weak or absent; fringe on Cu weak or absent: Schœnobiinæ." The second *1*, or the alternative is: "Vein 1st A absent in fore wing."

The Puerto Rican moth has vein 1st A preserved in the fore wing but its tongue is present, well developed and functional. Dr. Forbes' key could be enlarged to take in the new Pyralid by inserting another *1* between the first and second to read as follows: *1.* Vein 1st A preserved in fore wing; R_5 stalked with R_3 and R_4; tongue well developed: Endotrichinæ.

In the key for the subfamilies of the Pyralidæ devised by Hampson (4) for the Old World the Puerto Rican moth runs into the Endotrichinæ, but in the key given by the same author for the genera of this subfamily (5) it does not fit into any but comes nearest to *Diplopseustis.* The author has therefore erected the genus *Perforadix* for the Puerto Rican moth, the description of which follows:

The Genus *Perforadix* new genus, smaller moths, about 3/8 as large as *Diplopseustis minima.*

Labial palpi (Pl. XXVII, fig. 21b) obliquely upturned (in dead specimens may be porrect) the second joint longer than the head, thickly scaled and triangular, the third obliquely upturned and set at upper side of end of second (before apex in *Diplopseustis,* see Pl. XXVII, fig. 21a). Maxillary palpi more than half as large as the labial, third and fourth each very much broadened at tip and triangularly scaled. Eye large. Antennæ simple and ciliate (Pl. XXVII, fig 22). Tongue well developed. Fore wing nearly three times as long as wide, broad at base, obliquely truncate at apex and slightly notched opposite cell. Discocellular vein obliterated, at most only very short stubs. Vein 1st A is a developed tubular vein at margin with interspaces of the normal width between it and the veins above and below it. (Vein 1st A is also present in *Diplopseustis minima.*) Vein Cu_1 almost from angle of cell; vein 3rd A entirely lost. Hind wing with wavy outer margin, the notch a little deeper between veins M_1 and M_2; discocellular vein obliterated; vein Cu_1 from before angle of cell; Rs a short vein between base of M_1 and Sc; R extending to about center of cell and then disappearing; 1st, 2nd and 3rd A faintly marked.

The Type of this genus is the following species:

Perforadix sacchari new species. Wing expanse of 1cm. in the female and 9 mm. in the male. The color varies from dirty cream to a pinkish buff with some smoky shading. Costal edge dark with three half ocellated spots defined with dark bars. Ante- and post-medial lines slightly paler, the ante-medial defined with dark beyond and the postmedial before. Spots at the costa antemedial outly oblique to the fold, strongly innerly oblique and irregular to the edge, the dark edge emphasized on cell fold and inner margins. Outer line (post-medial) nearly perpendicular to opposite cell then oblique to inner margin, the border emphasized with dark towards the inner margin. Ante-post-medial lines emphasized by light and dark at the costa. Some black terminal dots, two at the notch opposite the cell and one at the lower notch more or less emphasized. Discal dot dark, vague and transverse; two or three inconspicuous lines in the fringe. Hind wing with black discal dot, a dark followed by a pale post-medial shade slightly excurved and black terminal dots in fringed edge as in fore wing. Head and thorax concolorous; shoulder slightly darker. Abdomen also concolorous with two or three transverse black stripes. Labial palpi, second segment fuscous outer edge pale, third pale with outer bar at middle. Maxillary palpi with basal half fuscous and remainder cream color. Antennæ of ground color dorsally marked with dark band at scape and at each segment. Legs concolorous, front tibiæ and tarsi barred with black, (Pl. XXVIII fig. 23). In darker specimens the front tibiæ and tarsi may be almost black, in light colored individuals the barring may be indistinct.

Geographical Distribution

According to Forbes (3), the Endotrichinæ are almost entirely confined to the Old World. So far, we only know that *Perforadix sacchari* occurs in Santo Domingo and Puerto Rico and that on the latter it is found in sugar cane fields all over the island.

Food Plant

The roots of sugar cane, *Saccharum officinarum* L. is the only known food of the larva of *Perforadix sacchari.* Half grown larvæ collected in the field among sugar cane roots by the writer have however, been fed for some time on roots of *Gynerium sagittatum* (Aubl.) Beauv; bamboo, *Bambusa vulgaris,* and corn.

THE ROOTS OF THE SUGAR CANE PLANT

The work of Venkatraman and Thomas (18) on the roots of the sugar cane plant in India demonstrated the importance of a constant production of new roots for the proper development of the cane plant. These authors have shown how the cane plant under favorable conditions, constantly replaces its root system with a new one and how this constant renovation allows the plant to adapt its root system to changing conditions. When the water table is high, the root system is shallow and when the water table sinks low, the root system becomes deep. From their studies, these authors reached among others, the following conclusion: "To get a good crop the sugar cane should be given facilities for the frequent production of new roots."

Venkatraman and Thomas report a very interesting experiment in which they reproduced artificially conditions similar to those present in sugar cane plantations in Puerto Rico:

> "By a clever arrangement, originally designed by the junior author, it has been possible to grow canes away from the soil, on a definite number of roots and without any possibilities of other new roots developing. Under such conditions the plants gradually lost vigor and died out. When, however, a plant thus starved for fresh roots was given opportunities to develop them, the plant at once grew on in a remarkable manner."

And they repeat the conclusion that "the importance of a continous development of fresh roots in the life of the sugar-cane plant is thus obvious." In the above publication the experiment is illustrated with a color plate. The drying out of the leaves and the stalks when no new roots are produced, and the immediate production of vigorous normal green shoots as soon as new roots are formed is remarkably illustrative of the conditions to be met with in Puerto Rican cane fields. In this Island the hard packed heavy soils do not allow for a constant production of new roots and in addition, the soil animals destroy them as soon as formed.

THE WORK OF THE SUGAR CANE ROOT CATERPILLAR

In most soils the majority of the roots of the sugar cane plant are found in the first twelve inches below the surface. In Puerto Rico the thing that immediately strikes the attention is that the roots are not as long as they should be for their width. If we pick them up and look at them more closely we will see that in the majority of them the tips have been destroyed, that in others the tips have been injured and that there are many neat round holes on their surface. We will discuss later the other types of injury. Let us now take up the roots whose tips have been destroyed. Those in which the injury is old may show nothing but that the tips have gone, but those in which the injury is more recent, especially if the soil is somewhat dry, will look as if the tips had not disappeared but had been mined out. When pressed between the fingers, these hollow tips feel somewhat like an empty glove finger. Obviously the central cylinder and cortex have been removed leaving nothing but the epidermis. If the soil had been moist, or if the injury were old, we could see that these bits of dead epidermis would have rotted away leaving no indication of how the injury was produced. If however, the soil is not very wet and if there are plenty of fresh roots, some may be found in which the injury is very recent and probably near to it, in the soil we will see piles of whitish excrement and may find the root caterpillar.

By digging in the soil we may not be able to find such a good specimen of the work of the root caterpillar as that shown in (Pl. XX fig. 5, A). Here the root was placed on the surface of the moist soil in a petri dish and to take the photograph after the caterpillar had performed the injury it was not necessary to disturb the root. Otherwise the delicate shell of the very tip and the silk threads which hold it in place would have been destroyed. The entrance hole at B is obstructed with a few pellets of whitish excrement. Here the caterpillar (almost full grown) entered and tunneled into the tip eating out all of its contents. How economical it is of this, the favorite food, seems to be indicated by the silk threads extending from the frail perforated shell to the soil particles as if to facilitate a most thorough consumption. This detail is very interesting when we consider that the supply of root tips is limited and that the destruction of the functional part of the roots will reduce the vigor of the plant and its capacity for further growth and further production of root tips. After tunneling out the tip, the caterpillar tunneled up the root on the other side of the entrance hole. In this upper part the epidermis being stronger required no silk reinforcement. Near to it, the piles of whitish excrement can be seen on the soil lumps. If this root had been injured in the cane fields, and the soil had been somewhat dry, the upper part of the hollow root would be the one we might find later when digging it out.

In the same Fig. is shown another root, C, not as tender and succulent as A. Here a smaller caterpillar worked making the entrance hole as before at a short distance from the tip and laying out some silk threads to hold up the shell of the tip. At D, a more mature root is shown, the tip of which had been destroyed in the field before it was placed in the dish. Here there was no tip to work on but one of the younger caterpillars tunneled in the cortex. Its pile of excrement can be seen on the side of the root near the tip. Fig. 3 in the same plate shows the appearance of such tunnels extending lengthwise like a furrow after the epidermis decays exposing them.

In the same plate, Fig. 7, shows a main root with side or branch roots. The tip of this root had been destroyed in the field before it was dug out, and as a result of the destruction of the tip succulent side roots had developed. (The three round feeding holes on the main root are not the work of the root caterpillar but of the Symphylid *Hanseniella* sp. as will be explained later.) This photograph shows again at A the typical tunneling of the thick tender root. It also shows another type of root-injury. B and C. were succulent but thin roots and a large caterpillar could not tunnel in them. It therefore ate them off and nothing but parts of the base can be seen. This is what might to called "root severing" and is very interesting as will be seen later when discussing some erroneous explanations that have been advanced by other authors for root tunneling and severing in sugar cane in Puerto Rico.

How far the caterpillar will tunnel inside the roots depends on how tender the roots are. The cortex in cane roots is thin and what the caterpillar eats is practically all the central cylinder. This becomes very tough as soon as the root begins to mature and can not be used as food. Whether the caterpillar will tunnel or eat from the outside depends on the relative size between it and the roots.

Figs. 4 and 6 in the same plate show two views of a full grown caterpillar on a root near the entrance of the tunnel at the tip. This root is somewhat mature but soft enough to be tunneled. The photographs give an idea of the comparative size of a full grown caterpillar with that of a good sized cane root.

Bionomics of Perforadix Sacchari

THE MOTH

The moths of this species usually pass unobserved. They do not leave the cane fields and seldom come to lights at night. During the day time they remain concealed in the trash on the ground and among the dead leaves hanging from the stalks of the cane plants. When startled from cover during the day by beating the trash or dead leaves, they fly back to cover again. When alighting, they run briskly and hide deeply into the trash or cracks and cavities of the soil. When caught in a net they tend to work their way out through the mesh. At dusk they leave cover and fly about. In the young cane plantations they probably fly low. In the older plantations, where the stalks are tall, and the moths more abundant, they have been observed in flight under the roof formed by the green leaves in a sort of ondulating up and down slow movement among the stalks and dead leaves hanging on them.

The moths have not been observed feeding in the field or alighting on flowers. In the laboratory when confined in vials and petri dishes they extend the proboscis and take up moisture from the soil, leaves or sides of the container. They also take up sugar and honey solutions from bits of cotton seaked in them. In cane fields, however, the moths probably take nothing else but water.

As many as 164 eggs have been laid by one female collected in the fields and kept in a petri dish with moist soil and a bit of moist cotton. The total number of eggs that each female can lay in nature is probably much greater.

THE EGG

The eggs have not been found in nature, but female moths collected in the field were confined in battery jars with moist soil. Bits of trash and cane roots were placed on the surface of the soil. After sun down the moths were observed inserting the ovipositor under the bits of trash roots and lumps of soil and into the cavities and cracks of the soil. The eggs are laid singly or in groups, usually glued to the soil, bits of trash, roots, or to each other (Pl. XXII). The shape of the eggs depends on the space in which they are deposited and how close together they are laid. When laid singly with ample room they are spherical, flattened at the poles and with light furrows running as lines of longitude and latitude. When laid in groups in small cavities they may be bunched somewhat like grapes or even flattened almost like scales. The color is pearly. The incubation period is about 3 to 8 days in April and probably does not vary much during the rest of the year.

THE LARVA

Eggs placed on moist soil in petri dishes in the laboratory have hatched and the larvæ have been raised to adult by furnishing them with fresh tender cane roots. The very small caterpillars make very small feeding holes into the tender tissues. As they grow they take to tunneling. When tender root tips are not available, they may tunnel in the cortex of the mature roots, between the epidermis and the central cylinder. The very small caterpillars are sometimes found inside their tunnels in the cortex of the more mature roots, but only on one occasion have we found one of the larger instar caterpillars inside its tunnel in a tender root tip. These larger caterpillars remain inside the root only while feeding, living for the rest of the time in the soil cavities.

In nature, the newly hatched caterpillars probably move to the base of the cane plant where tender roots are being produced at the surface of the soil. Thence they reach the tips of the roots following the cracks and cavities of the soil. When all the root tips in one cane plant are destroyed, they seem to move to another plant. The habit of feeding above the surface of the soil on the aerial cane roots in cloudy, rainy weather, that we observed when the insect was discovered, may indicate their ability to migrate from one plant to another above ground. The caterpillars are blind and shun the light, but in cloudy weather, at night, or even during the day time, under the trash that covers the ground in cane fields they may move about freely.

The larval period lasts from 11 to 19 days at the end of which the full grown caterpillar measures 1 centimeter in length and is whitish with brown and light brown plates. (Pl. XXIII, figs. 9 and 10) and (Pl. XXIV, figs. 11–14).

THE PUPA

At the end of its freeding period, the caterpillar moves towards the surface of the soil to pupate in a cell (Pl. XX, fig. 2, A) about half an inch below the surface of the soil. The pupa (Pl. XXV. figs. 15–17) measures from 4 to 6 mm. in length. When reared in the laboratory or collected into vials or petri dishes, if a cell can not be made in the soil, the caterpillars construct a frail cocoon with silk threads and bits of soil, excrement, etc. If enough loose soil is available, the cocoon is constructed with soil particles thus creating a cell. Such cocoons may be formed in nature under the trash in cane fields but we have not found them. The point is of interest because through cultivation to keep the soil loose and preserve moisture, some control might be effected. The pupal stage lasts from 15 to 19 days and during this period the insect is very sensitive to any interference. Breaking up the cell or cocoon or any slight injury to the pupa may be sufficient to kill it.

NATURAL ENEMIES

The only insects found in nature feeding on *Perforadix sacchari* are the larvæ of a subterranean ant. This has been determined by Dr. W. M. Mann as *Cerapachys* sp. While digging in a moist clay loam, a nest of these ants was found in which an immobile and probably dead full-grown caterpillar of *Perforadix sacchari* was lying on its side, partly coiled, while several of the larvæ of the ant were hanging from its sides with their mouth parts attached to its epidermis. Ant larvæ are usually fed by the workers and this habit of directly feeding upon a caterpillar is extraordinary. We have been able to witness it on one occasion only. *Cerapachys* belong to a group of primitive subterranean ants. The condition in which the ant larvæ feed directly upon dead or paralyzed caterpillars is apparently more primitive than the feeding of the larvæ by the adult ants with regurgitated food.

Due to the habit of the adult of *P. sacchari* remaining hidden during the day time, they are safe from lizards and by flying at dusk under the leaves of the cane plant and among the stalks and dead leaves hanging from them they are also safe from bats. Spiders are the only natural enemies that may destroy a few of the adults.

SEASONAL HISTORY

The life cycle of *Perforadix sacchari* is completed in about one month and the generations overlap through the year so that the insect in all its stages may be found in any one place at any time, except in the very young plantations. The roots of the cane plants in such fields, will however be found to be injured abundantly. This is to be explained by the presence of Symphylids, bristle-tails and sow-bugs which work on the roots. When inspecting the roots, it may seem remarkable that the injury is proportionately enormous as compared with the small numbers of soil animals to be found. This will always be the case, and when the plantation is older and plenty of the work of the root caterpillar is to be found, it will also seem out of proportion to the number of insects present.

The explanation of this is that these soil animals move rapidly through the cracks and cavities of the soil and that they are small and soft and easily crushed while digging for them. They never remain close to the injury, but move on to another root-tip for their next meal. When the root-tips become scarce in one plant they move on to another. Thus they may be scarce around the roots of a plant which are practically all injured and more abundant around the fresh roots of some other plant. In judging the seasonal abundance of the root caterpillar these things must be taken into consideration. The abundance of the insect is dependent on the abundance of root tips. During moist weather, when the food supply is abundant, they will increase in numbers and cause more damage but the economic importance of the damage may be slight. With the advent of dry weather, on the other hand, the number of roots decreases and even though the caterpillars may also decrease in numbers, the economic importance of the damage increases because all of the roots may be injured or destroyed. Some observations seem to indicate that the caterpillars are more abundant during the dry months in the fall of the year, and that the eggs are injured by excessive moisture, but the data on this point are insufficient.

Other Soil Animals to be Considered

Besides the root caterpillar we have mentioned other soil animals which work on cane roots. It is impossible to discuss or estimate the work of the root caterpillar without discussing and estimating the work of these other soil animals which are found always associated with it. Something has to be known about them before we can distinguish between the work of one and the other and estimate the relative importance of each. Because they make cavities in the roots we may call these pests the root boring animals.

THE ROOT BORING ANIMALS

During the course of these investigations on the root caterpillar, the existence of other new root pests of sugar cane has been discovered and the nature, extent and importanc of their damage determined. These new pests have proved to be capable of injuring cane roots when isolated in vials even though supplied with moist decaying organic matter of the types found in cane fields.

The Symphylid, (*Hanseniella* sp., determined by Dr. H. E. Ewing) is the animal that makes the neat round feeding cavities or pits so common in cane roots in Puerto Rico that it is almost impossible to find a single root without them (Pl. XX figs. 3 and 7, Pl. XXI, d). The cavities are also very abundant on the roots of bamboo, *Bambusa vulgaris*. The present tendency is to consider the cortex of cane roots as unimportant and therefore this type of injury as insignificant. We know so little about cane roots that in the future this theory may change, for the cortex, if healthy, protects and nourishes the central cylinder. The pits made by the Symphylid may open the door to decay. A few of the Symphylid pits may at times be found near the root tips in the tender tissues. In these cases they are injurious and undoubtedly open the door to further damage by other soil animals or decay organism. The work of the Symphylid is of special interest to us because previous to its discovery, we naturally attributed its feeding cavities to the younger instars of the root caterpillar. This was rather annoying because the Symphylid is much more abundant than the root caterpillar and we felt quite baffled in trying to explain the enormous abundance of feeding cavities in terms of an insect which did not seen sufficiently abundant to be considered the logical cause or which at times could not be found at all. Incidentally, we have also cleared up another very interesting point, for Matz (9) in 1925 published a paper with photographs taken in Puerto Rico of feeding cavities or pits in sugar cane roots, quite similar, if not identical with those made by the Symphylid, attributing them to nematodes. This is discussed later and more fully in this paper.

The Bristle-Tails, (*Nicoletia* sp., and *Lepisma* sp.) Another cause for puzzling was the continuous finding of another type of feeding cavities or pits which are larger and not so evenly circular as those made by the Symphylid and not located in the cortex of the mature roots but at or near the tips in the tender tissues. These larger pits (Pl. XXI, e) were not the entrance to tunnels and for a time we attempted to explain them as the work of the larger root caterpillars; but this was unusual because they never developed into tunnels. They were merely feeding pits out of which the tender tissues had been scooped. They could also be found in the roots of bamboo, *B. vulgaris* and *G. sagittatum* on which the root caterpillar does not work.

A large white bristle-tail (*Nicoletia* sp.) found in the soil near the cane, bamboo and *G. sagittatum* roots was isolated in vials and found to be the cause of the larger pits. Another bristle-tail, smaller and golden-brown in color *Lepisma* sp., was also found to produce pits but this latter one is not so abundant as the former. When several bristle-tails in a vial are allowed to work on a root they may make several pits close together or even enlarge some of them, but they never make tunnels. Both bristle-tails have been determined by Dr. J. W. Folsom and are probably undescribed species.

The Sow-Bug (*Philoscia culebræ* Moore). When inspecting cane roots in the fields, sow-bugs are frequently fround in the soil among the roots and sometimes inside the root tips that have been tunneled out by the root caterpillar. Sow-bugs (undetermined) had once been reported by Van Dine (17) in 1912 from one locality in Puerto Rico as causing serious damage to cane roots but had never again been considered as possible pests of sugar cane. We have isolated them in vials with soil and decaying organic matter and found them capable of attacking the perfectly sound but tender cane roots. In doing this, they often start at or near the tip eating out irregular shallow cavities. If the sow-bugs are abundant, the cavities may be enlarged and all the surface of the tender root injured. Their injury may also start in otherwise sound roots at some feeding hole made by a Symphylid or bristle-tail in the tender tissues. The sow-bugs get into a pit and enlarge it into an irregular shallow cavity. Inside the tunnels made by the root caterpillar, sow-bugs may continue the injury or merely feed on the decaying epidermis. In the field, sow-bugs are usually found near the surface at the base of the cane stool but it is difficult to determine how much they are feeding on decaying organic matter and injured roots and how much on the tender newly produced roots.

This species has been determined for the writer by Dr. J. O. Maloney of the Division of Marine Vertebrates, U. S. National Museum. It was originally described by H. F. Moore (10) from two specimens collected under drift on the shore on Culebra Island, P. R. Moore's description has been copied by Dr. Harriet Richardson (11) in her Monograph of the Isopods of North America.

THE OLD ROOT PESTS

The White Grubs. There are several species of white grubs (*Phyllophaga*) and the larvæ of the rhinoceros beetle, *Strataegus titanus,* which attack the roots of sugar cane in Puerto Rico. The rhinoceros beetle larvæ are not common, but the *Phyllophaga* species are found all over the Island and at certain times in some localities are quite abundant and injurious. This is especially true of some localities in the South Coast of the Island. Through the rest of the Island they are always to be met with when digging out cane roots, but ordinarily they are not sufficiently abundant to become important, and many plants will always be found that have not been injured at all by white grubs. The white grubs eat off the roots. They may sever them, or, beginning at the tip, keep on eating until the tender parts are consumed. The injury when not fresh may resemble the work of the root caterpillar, but when fresh there can be no mistake. In the first place, if white grubs are the cause of the injury, they will be found near the roots (they take about nine months to develop and moved very slowly through the soil). In the second place white grubs can never produce the emptied out root tips characteristic of a root-borer, nor do they produce the piles of whitish excrement. The root caterpillar is found in more or less the same abundance throughout the Island, while white grubs are abundant sporadically and in restricted localities. Very frequently, the work of the root caterpillar (and the other root boring animals) will seem the only possible explanation for the drying out of the cane when no white grubs or indication of white grub injury is to be found. In such situations the roots may be long and apparently normal, but upon close examination the tips will be found to have been destroyed or injured.

The Nematodes and Other Organisms. It is well known that nematodes work on the roots of sugar cane in Puerto Rico causing the characteristic hypertrophies or "clubbing". They are, however, found only in light sandy soils or in light soils with a very porous subsoil and seldom if ever in the heavy clay loams which constitute a considerable percentage of the soils of the Island. Furthermore, even in the light soils, nematodes are ordinarily of little or no economic importance in Puerto Rico.

Matz (9) who studied "root disease" at the Insular Station of Puerto Rico from 1919 to 1922 and then continued his studies in the South Coast of the Island, attempted to explain the feeding cavities or pits found so commonly in sugar cane roots in terms of nematodes. In doing this, Matz's method was purely speculative for apparently he never reproduced the injury experimentally under controlled conditions. He also admits these two contradictory facts: (1) that the pits are found in cane roots commonly all over the Island in the heavy clays as well as in the light sandy soils, and (2) that nematodes seldom if ever occur in heavy clay soils.

But, if pits in cane roots are found all over the Island in all types of soils, the causative organism can not be of limited distribution. The animal which makes the pits must necessarily occur in all types of soil and be proportionately abundant to the amount of injury. The Symphylid, *Hanseniella* sp., answers these requirements. It can be found easily in any cane soil and will produce neat round pits in the cortex of perfectly sound cane roots in vials in the laboratory.

Similar pits are common in sugar cane roots in Louisiana. Matz mentions in his paper that in Louisiana snails were considered to be the cause of the pits. Recently, in 1927, Spencer and Stracener (14) have demonstrated experimentally that the pits in Louisiana are made by the Symphylid, *Symphylella* sp. A comparison of the photographs of the pits in cane roots caused by the Symphylid *Symphylella* sp., in Louisiana with those attributed to nematodes by Matz in Puerto Rico and with Pl. XX, figs. 3 and 7 and Pl. XXI, d in this paper will show their close similarity.

According to Matz, the gravid females of a nematode living in the cortex of the cane roots caused the cavities or pits which could not become noticeable until the epidermis rotted and the nematode abandoned the cavity. But the pits are frequently to be found near the tender tips in tissues so young that Matz's explanation would be untenable. Thus it seems quite evident that Matz was mistaken in attributing the pits to the work of nematodes. Credit is due to him, however, for having been the first to observe, report and publish photographs of pits in sugar cane roots in Puerto Rico.

The Weevil Root-Borer. The work of the larvæ of *Diaprepes spengleri*—tunneling in the underground parts of the stem or root stalk—is common in certain localities, especially on the South Coast of the Island and the insect is very well known to all. Its common name, however, is inappropriate although very interesting to us because it indicates that those who named it were familiar with a type of root injury—tunneling—which they considered important but the cause of which was unknown. Apparently, in suggesting *Diaprepes* as the cause they were giving it the benefit of the doubt. Thus it has been called the "sugar cane weevil root-borer" or the "root-borer of sugar cane". These terms erroneously convey the idea that there was known at that time some other root-borer of sugar cane not a weevil from which it had to be differentiated, besides leading one to believe that the ability of *Diaprepes* to tunnel or bore in cane roots is a proved fact when actually it is nothing more than a supposition. No one has ever found the larva of *Diaprepes* boring or tunneling in cane roots or determined this ability experimentally. The adults, of course, leave the soil as soon as they transform and practically never eat cane leaves preferring those of bushes and trees on which the eggs are laid glued between two leaves. According to Jones (7):

> "The larvae apparently do not enter the large root-stalks of the cane until some time after issuing from the eggs. During the intervening time they probably feed upon the smaller roots, and it is possible that they do not require living roots altogether, but subsist in part upon decaying vegetable matter. Later they enter the root-stalks making tunnels therein."

The root troubles or "root disease" of sugar cane have been the subject of investigation ever since the Insular Experiment Station became established in 1910. Investigators of world wide reputation such as Van Dine, Van Zwalluwenburg, Smyth, Wolcott, Johnston, Stevenson, Matz and Earle studied the problem most intensively. Up to the present, there has never been one record of the larvæ of *Diaprepes* found tunneling in cane roots. There is a possibility that if they were responsible for all the tunneling one finds all over the Island, at least one specimen would have been found directly associated with the injury. Instead, we sense in reading their work that all these investigators were continually meeting with types of root injury, (pitting, pruning, severing and tunneling) which they could not attribute to any known organism. Hence the name "weevil root-borer" for *Diaprepes* when it should have been more properly called "root-stalk borer".

As late as 1919, we still find Smyth (13) explaining root tunneling in terms of *Diaprepes* which he calls the "sugar cane root-weevil" without having found the larvæ doing the damage in the fields or reproducing it experimentally in the laboratory.

The Root Mite. In the same year, Smyth (13, 14) reported the mite, *Uropodus* sp. with the common name of "sugar cane root mite" stating that this animal:

"Eats into, severs, and sometimes tunnels the roots. Damage sometimes serious. This pest was first noted in the Arecibo district . . . and has since been found abundantly at Río Piedras and in other districts. Its damage arises from its attack on the roots which in some cases it tunnels and severs to a considerable degree. Although . . . the roots showing its injury are in many cases diseased and partly decayed, it has been found attacking also healthy roots, so in some cases is believed to be the primary cause of root decay."

Apparently what Symth found was the unknown injury and some mites associated with it, but nothing in Smyth's paper indicates that he ever attempted to reproduce the injury experimentally. In attempting to test whether this or any other mite found associated with cane roots could injure them, the first and main difficulty we have met is the scarcity of the mites. One or two could be found once in a while, but never in sufficient abundance and in constant association with the fresh injury to make them suspicious of it. The very few found associated with decaying roots were not determined, but when isolated with tender sound roots in vials they did not injure them. As an explanation of why they are found occasionally among cane roots Smyth himself in that same paper referring to the *Uropodus* mite, writes: "This animal belongs to a group of mites which possess the habit of attaching themselves to beetles as means of transportation and distribution." Since *Phyllophaga* and *Strataegus* as well as *Dyscinetus* beetles are found in the soil among sugar cane roots where they hide or go to oviposit, this might suffice to explain why the mites are found occasionally in the same situations. It does not necessarily follow however that they are injurious to the roots. As a matter of fact they have sometimes been considered beneficial when apparently attacking larvæ, pupæ and eggs of *Phyllophaga* and *Stratægus*. They might also possibly attack the root caterpillar.

Diseases Whose Symptoms Might be Confused With Those of Root Injury

Gummosis and Dry Top Rot. Gumming disease or gummosis is caused by *Bacterium vascularum* and dry top disease is caused by *Ligniera (Plasmodiophora) vascularum* (Matz) Cook. In both diseases the vascular bundles are obstructed by the causative organisms and the products resulting from their activities. This prevents the water and plant food elements from reaching the leaves and the elaborated foods from moving downwards from the leaves into the stalk and roots. The symptoms above ground are the drying out of the leaves, the dying out of the tops and the final drying and dying of the plant. These symptoms might be confused with those of root injury but the existence of the two diseases can easily be determined in most cases. In the first place, some varieties are immune to both diseases and dry top rot is found only in wet soils. In the second place cross sections of the bases of the stalks will show in the case of gummosis the yellow exudations of gum from the bundles, and in the case of dry top rot the orange color of the bundles characteristic of each of the two diseases.

Root Disease. The symptoms of root disease in the stems and leaves would be the same as the symptoms from root injury produced by soil animals and quite similar also to the symptoms of gummosis and dry top rot since in either case the plant suffers because the circulation of water and soil solutions is affected or checked. Root disease is supposed to be caused in Puerto Rico by species of *Pythium* and *Plasmodiophora*. Matz (8) at the Insular Experiment Station was able to destroy healthy cane roots by inoculations with pure cultures of these fungi, but in the field they are supposed to be facultative, that is, able to attack the cane roots only when injured by soil animals or weakened by adverse soil conditions. Apparently an experiment has never been conducted in Puerto Rico in which all the symptoms which are supposed to be those of root disease have been produced by inoculations with pure cultures of any fungi under conditions in which the soil animals have been eliminated. When one goes through the work of the early plant pathologists of the Insular Experiment Station, such as Johnston and Stevenson, and of the entomologists such as Van Dine and Van Zwaluwenburg it is very interesting to notice now the former considered fungi the main cause of "root disease" while the latter insisted on the importance of soil animals. Now that we know more about the animals that injure sugar cane roots and of the facultative nature of the fungi which can cause root disease, we realize that possibly the entomologists were nearer to the truth than the plant pathologists. The only experiment conducted in 1920 at the Insular Experiment Station by Matz (8) to prove that fungi could produce the condition known as "root disease" proved on the contrary that there was no difference between his inoculated plants in pots and the checks until they were set out in the fields, harvested at maturity and allowed to ratoon. Then, those of the ratoons that showed stunting, drying out of the leaves, etc., happened to be in "a very compact soil." We can see how root pests whose injury may become the limiting factor in compact soils might have complicated Matz's experiment since no precautions were taken to eliminate them. Matz himself admits that: "This unevenness was no doubt due to soil conditions, as the effect of the previous inoculations were entirely lost during the first season of growth after the transplanting to a new location."

THE POSSIBILITIES FOR THE CONTROL OF THE ROOT-CATERPILLAR

SOIL FUMIGANTS

Wolcott (15, 16) has investigated the use of paradichlorobenzene, calcium cyanide and the carbon bisulphide fish oil emulsion recommended by Leach and Thompson for the Japanese beetle, for the control of white grubs in Puerto Rico and found that the first two fumigants kill only a low percentage of grubs and are quite expensive. The bisulphide emulsion kills a high percentage but its cost is also prohibitive and the mode of application by means of a hose or some such arrangement is impractical.

We have made several tests with the carbon bisulphide emulsion. In metal drums it gave an almost complete control of all root pests when applied to the moist soil at the rate of 6cc of the diluted emulsion per square foot of soil. The only possibility of using it would be in cane under irrigation by applying the fumigant with the irrigation water, but it is questionable if this would be practical.

According to Jarvis (6) paradichlorobenzene and carbon bisulphide are used in routine field practice in Queensland for the control of white grubs. We have tested these two fumigants in cane fields on the Station grounds making the applications in the manner and using the largest doses recommended for Queensland attempting to kill all root pests found in Puerto Rican soils, but with complete failure. The soils to which the fumigants were applied may be considered representative of the average on the Island. At different intervals up to two weeks after the applications were made, perfectly healthy white grubs, root caterpillars, Symphylids and bristle-tails were to be found within six inches from the points of application. The fumigants do not diffuse as readily through the soils of Puerto Rico as they do through the soils in Queensland. We have not tested calcium cyanide, but it will also be difficult for this fumigant to diffuse through the hard packed soils.

CULTUREL PRACTICES

Starting from the point that sugar cane will produce satisfactory yields when the soil conditions are favorable even in spite of the injury caused by root pests, it logically follows that when the soil conditions are unfavorable they must be corrected before any other measure of direct control can be contemplated. In all the work of the late Professor Earle on "root disease" (1) and sugar cane culture (2) we find constant reference to the need of keeping the soil in cane fields loose and permeable. When we go through the history of the sugar cane industry in Puerto Rico we find that the loss of organic matter and the resulting bad physical and chemical condition of the soils has been a constant source of trouble, and that the condition we know as "root disease", "root disease complex" or "growth failure complex" is nothing new.

In the beginning, all that was necessary was to make a hole in the virgin soil, plant the seed pieces of the "Criolla" or "Otaheiti" cane and keep down the weeds with the hoe to get crop after crop from the same planting. But gradually, the organic matter content of the soil decreased and in 1872 we hear of an epidemic, a "disease" of the cane plant in which isolated stools or patches throughout the plantations, dried out and died. We have careful reports published at that time of the symptoms and they are exactly those of root injury that we have been discussing or those that Earle gives for "root disease." We have also very careful reports of the observations and the experiments made at that time to determine the possible cause of the trouble. We known that although a few white grubs were observed, they were not abundant enough to be considered the cause. It is also recorded that sections of the stalk taken up into the mountains and planted where no cane had grown produced normal plants and that sections from their stalks when taken back again to the original soil produced "diseased" plants. The conclusion logically reached at that time was that the origin of the trouble was in the soil and not in the cane plant and it was noted that for some reason the root system of the cane varieties grown—the "Criolla" or "Otaheiti" which once produced good yields were no longer suitable for the soil

The cane had not changed, but the soils had. They had lost much of their organic matter. Due to their high organic matter content, the virgin soils were rich, porous and retentive of moisture. In them the "Otaheiti" cane with its shallow and weak root system could find sufficient food and could make up by a constant production of new roots the damage caused by soil animals. As the soil began to loose its good chemical and physical conditions the cane began to suffer. It was not until 1872, however, that the trouble was felt when it became so abundant as to affect the sugar cane industry of the whole Island.

Apparently the situation was remedied for some time by the introduction of new Oriental cane varieties with stronger and deeper root systems. In 1910, when the Insular Experiment Station was established, the first plant pathologists and entomologists immediately focused their attention on the "root disease" of sugar cane as of fundamental importance. With the introduction of sugar cane mosaic disease into Puerto Rico, from 1915 to 1919, the center of interest changed to the new disease, but with mosaic under control, by 1919, the investigational interest goes back again to "root disease." Earle (1) wrote in 1920, as follows:

"This trouble is always with us. There is not a cane field in the Island that is not more or less affected by it. It is the cause of the dying out of the cane in so many fields that necessitates such frequent replantings. If it were not for root disease we would be to-day cutting twenty or thirty ratoon crops from each planting of cane as was done in the early days of the cane industry of this Island, and is still being done on virgin lands in eastern Cuba and in Santo Domingo. The expense of these frequent replantings is by no means the only loss caused by root disease. It is safe to say that one form or another of the troubles known under this collective name is causing a loss of tonnage on every acre of cane now growing in Porto Rico. Few cane planters who really understand these facts will question the statements that this is by far the most serious problem that confronts the cane grower not only in Porto Rico but on old lands in all parts of the sugar cane growing world.''

Earle condemns the practice of planting cane in holes as in the early days of the industry and recommends the destruction of weeds through cultivation instead of the hoe, to keep the soil in good tilth and save moisture. He compares the growing of sugar cane, a crop requiring enormous amounts of water during all its life, and without cultivation in the most compact of soils as done in Puerto Rico, with the growing of cotton, a plant which does not require much water and for a short period only, with cultivation in loose soils in the United States. We can not take up all the recommendations made by Earle (2) intended for keeping the soil loose and moist and inducing a vigorous, abundant and deep root system, but we can quote the more important ones:

''Used with good judgment, proper drainage, abundant fertilizer and frequent tillage will prevent nineteen-twentieths; yes, ninety-nine hundredths of the cases of 'root disease' and at the same time will so increase yields that they will prove a decided economy and not an expense.''

We might add that if the dead leaves were removed from the stalks and the trash buried if possible during cultivation, the moths of the root-caterpillar would be deprived of cover. This would tend to restore the organic matter and produce the conditions under which the plants can make up for the damage caused by the insect. Frequent cultivation might also reduce the insect by destroying many of the pupæ and some of the caterpillars. If to this were added the growing of legumes to be plowed under instead of allowing the land to lie fallow and the cane stubble to die out gradually to be replaced by grasses, this would further increase the fertility, and organic matter, and help to control the root-caterpillar, other soil animals and the grasses.

If Earle's recommendations are desirable to control or prevent root desiase, now that we know how the root caterpillar and other new root pests work and affect the sugar cane plant, the same recommendations should be even more desirable. We may, through breeding and selection produce cane varieties with deeper and stronger root systems as Venkatram and Thomas (18) recommend and indeed this is very advisable, but we should first of all correct the soil conditions keeping in mind another of the recommendations made by these authors, namely that: *"To get a good crop the sugar cane should be given facilities for the frequent production of new roots."*

SUMMARY

1. A root-boring caterpillar has been found in Puerto Rico in the soil around sugar cane roots which has been named the sugar cane root caterpillar, *Perforadix sacchari* new genus and species (Pyralididæ, Endotrichinæ). It had been previously reported as *Sufetula grumalis* Schaus (Pyralididæ, Pyraustinæ) and specimens under that name from Puerto Rico and Santo Domingo are to be found in the collection of the U. S. National Museum in Washington.

2. In captivity, the larvæ will also feed on the roots of corn, bamboo and *Gynerium sagitattum,* but in nature no indication of the work of this insect has been found on the roots of these plants.

3. In the early instars the caterpillars feed on the very tender roots or in their absence may tunnel in the cortex of the mature roots of sugar cane. The later instar caterpillars tunnel in the thick succulent tips of the tender roots.

4. The damage is cumulative. As the plantation grows older the number of caterpillars and the amount of injury increases. The injury may not show above ground but probably it causes always some reduction in yield and shortens the duration of the plantation. Upon the advent of dry weather and when the soil conditions are unfavorable for the production of new roots, the destruction of the root-tips may become in some localities the limiting factor in sugar cane growing.

5. The distribution of the caterpillars is not uniform in any plantation, and furthermore they seem to migrate from one plant to another in search of fresh root tips. As the soil also varies within any particular field, the root injury showing in the parts of the plant above ground, is not uniform. Scattered stools or patches of stools will dry out while the rest of the plantation may be uniformly green.

6. As a rule, when the soil conditions are proper for the sugar cane plant, although the injury to the roots may be abundant, it does not show above ground.

7. The root injuries produced by the younger caterpillars may be confused with those produced by other soil animals, but the tunneling in the larger roots made by the older caterpillars and the piles of whitish excrement thrown out of them are characteristic and unmistakable.

8. Soil fumigants have so far proved impractical, but the cultural practices recommended by Earle for "root disease" would make it possible for the plants to keep up a constant production of new roots and to produce satisfactory yields in spite of the injury caused by the root caterpillar.

9. Other new root pests of sugar cane whose injuries are found associated with those of the root caterpillar are the Symphylid, *Hanseniella* sp., the bristle-tails, *Nicoletia* and *Lepisma* spp., and the sow bug, *Philoscia culebrae* Moore.

Acknowledgments

The present study has been undertaken in partial fulfilment for the Degree of Master of Science in the Department of Entomology of Cornell University under the direction of Prof. Glenn W. Herrick. The writer wishes to express his thanks to Prof. Herrick for advice and criticism. Dr. Wm. T. M. Forbes of Cornell University has given invaluable aid in connection with the technical details of the various stages of the root-caterpillar and the determination of its systematic position. Dr. M. D. Leonard, Chief of the Division of Entomology of the Insular Experiment Station has given valued assistance in the preparation of the manuscript and illustrations. Mr. R. Fernández García, Director of the Insular Experiment Station and Dr. Mel. T. Cook, editor of the Journal of the Department of Agriculture of Puerto Rico, have offered many suggestions as to the preparation of the manuscript for publication.

LITERATURE CITED

1. *Earle F. S.* Sugar Cane Root Disease. Jour. Dept. Agr. Porto Rico. **4** (1): **3**–27 (1920).
2. ———. Sugar Cane Cultivation. Jour. Dept. Agr. Porto Rico. **8** (2): 7–13 (1924).
3. *Forbes, Wm. T. M.* The Lepidoptera of New York and Neighboring States. Cornell Univ. Agr. Exp. Sta. Mem. **68**: 523–524 (1923).
4. *Hampson, G. F.* A Revision of the Moths of the Sub-family Pyralidæ. Proc. Zool. Soc. London :590 (1898).
5. ———. On the Classification of Three Subfamilies of Moths of the Family Pyralidæ: Epipaschinæ, Endotrichinæ and the Pyralinæ. Trans. Ent. Soc. London :451 (1896).
6. *Jarvis, E.* The Control of Root-eating Scarabaeid Grubs in Queensland Cane Fields. Trans. Fourth In. Congress Ent. **2**: 25–33 (1929).
7. *Jones, T. H.* The Sugar Cane Weevil Root Borer. Bd. Comm. Agr. Porto Rico, Bul. **14**: 7–19, 3 pls. (1915).

8. *Matz, J.* Investigations of Root Disease of Sugar Cane. Jour. Dept. Agr. Porto Rico **4** (1): 28–40 (1920).
9. ————————. Root Knot on Sugar Cane in Porto Rico. Phytopathology **15**: 559–563 (1925).
10. *Moore, H. F.* Report on Porto Rican Isopoda. Bul. U. S. Comm. Fish and Fisheries, 1900. **20** (2): 176 (1902).
11. *Richardson, H.* Monograph on the Isopoda of North America. Bul. U. S. Nat. Mus. **54**: 604–605 (1915).
12. *Smyth, E. G.* Insects and Mottling Disease. Jour. Dept. Agr. Porto Rico **3** (4): 93 (1919).
13. ————————. List of the Insects and Mite Pests of Sugar Cane in Porto Rico. Jour. Dept. Agr. Porto Rico **3** (4): 135, 142 (1919).
14. *Spencer, H.* and *Stracener, C. L.* Soil Animals Injurious to Sugar Cane Roots. Ann. Ent. Soc. Am. **22** (4): 641–648, 1 pl. (1929).
15. *Wolcott, G. N.* Annual Report of the Division of Entomology. Ann. Rept. Ins. Exp. Sta. Porto Rico for 1922–1923, pp. 51–53 (1924).
16. ————————. Annual Report of the Division of Entomology. Ann. Report. Ins. Exp. Sta. Porto Rico for 1923–1924. pp. 88–91 (1924).
17. *Van Dine, D. L.* Report of the Entomologist. Second Ann. Report. for 1911–1912, Sugar Prod. Ass. Exp. Sta. Porto Rico, p. 22 (1912).
18. *Venkatraman, T. S.* and *Thomas, R.* Studies of Sugar Cane Roots at Different Stages of Growth. Mem. Dept. of Agr. India, Bot. Series **16** (5): 145–157, ten pls. one colored. (1929).

EXPLANATION OF PLATES

PLATE XX

Fig. 1. Adult female of *P. sacchari* enlarged.

Fig. 2. A, empty pupa cell of *P. sacchari;* B, newly emerged adult; C, empty pupal skin.

Fig. 3. Tunnel of small *P. sacchari* caterpillar extending full length in cortex of root after the epidermis has decayed exposing it; A, side roots with pits made by the Symphylid. *Hanseniella* sp.

Fig. 4. Full-grown *P. sacchari* caterpillar on large sized sugar cane root near entrance of tunnel which is surrounded by piles of excrement.

Fig. 5. The work of the root-caterpillar in sugar cane roots; A, a perfect tunnel with the shell of the root tip held up by silk threads; B, the entrance hole to the tunnel obstructed with pellets of excrement; C, a smaller root whose tip was not as succulent as in A tunneled by a smaller caterpillar; D, a mature root in the cortex of which a small caterpillar has tunneled showing piles of excrement on the side of the root; E, edge of petri dish.

Fig. 6. Same as 4, a different view.
Fig. 7. A good sized sugar cane root whose tip had been destroyed and which had produced side roots. A, entrance hole in tunneled root; B and C, severed roots of which only parts of the base are left attached to the main root; the three round holes in the main root are the work of the Symphylid, *Hanseniella* sp.
Fig. 8. A group of eggs of *P. sacchari* deposited on a cane root that lay on the surface of the ground.

PLATE XXI

Illustrations of work. A, C, D, E, F, G, old injuries; B and H, recent injuries, a, entrance hole of tunnel; b, piles of excrement, c, emptied out region of root tips; d, pits made by the Symphylid *Hanseniella* sp. e, the work of bristle-tails and possibly also sow-bugs.

PLATE XXII

Eggs greatly enlarged. A, C and D, sketches showing grouping as laid; B, E, F and G, eggs as laid singly. E and F lateral views, G, dorsal view.

PLATE XXIII

Fig. 9. Larva, dorsal view.
Fig. 10. Larva, lateral view.

PLATE XXIV

Fig. 11. Seta-map.
Fig. 12. Labrum, greatly enlarged.
Fig. 13. Head and cervical shield, dorsal view.
Fig. 14. Head, cervical shield and pro-thorax, lateral view.

PLATE XXV

Fig. 15. Pupa, dorsal view.
Fig. 16. Pupa, ventral view.
Fig. 17. Pupa, lateral view.

PLATE XXVI

Fig. 18. Fore wing.
Fig. 19. Hind wing.
Fig. 20. Variations in the length of the stalking of R_5 with R_3 and R_4 and origin of veins from cell.

PLATE XXVII

Fig. 21 *a*. *Diplopseustis minima*, head, side view.
Fig. 21 *b*. *Perforadix sacchari*, head, side view.
Fig. 22. *P. sacchari*, head, anterior view, partly denuded with details of antennae and maxillae.

PLATE XXVIII

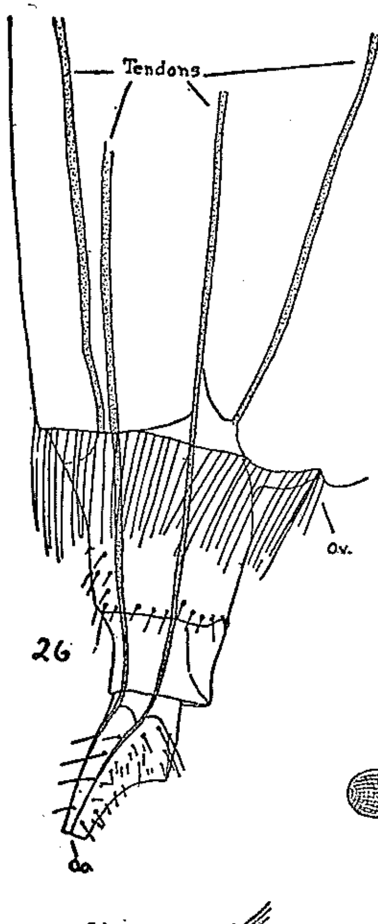
Fig. 23. Fore leg.
Fig. 24. Middle leg.
Fig. 25. Hind leg.
Cl, Claw; Cx, coxa; Ep, epiphysis; F. femur; Pv. pulvillus, Sp, spurs; Tar, tarsus; Tb, tibia; Tr, trochanter.

PLATE XXIX

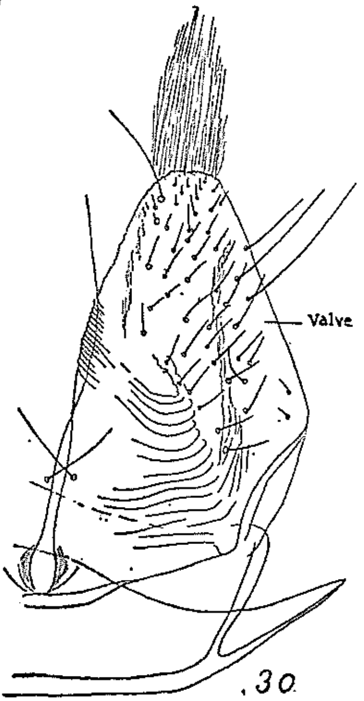
Fig. 26. Female genitalia, latero-ventral view; Oo, ovipositor; Ov, opening of vagina.
Fig. 27. Tip of ovipositor with egg ready to be laid, dorsal view.
Fig. 28. Male genitalia cut through left valve and opened out.
Fig. 29. Male genitalia, ventral view.
Fig. 30. Inner face of valve, more enlarged.

o-O-o

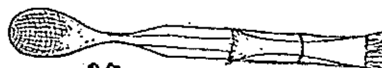
PLATE XXIX



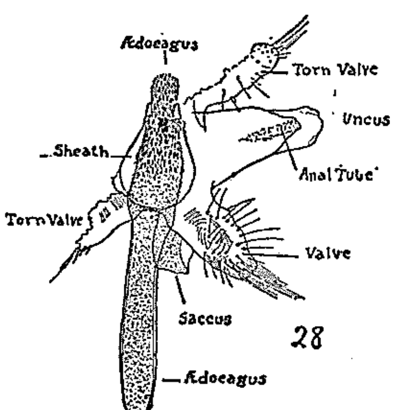
26



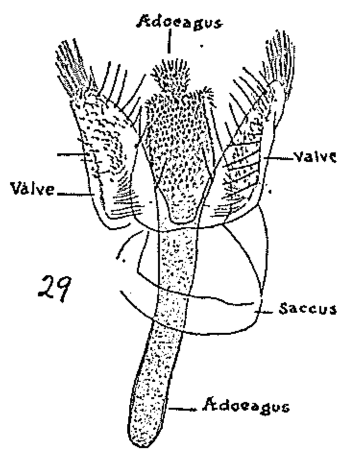
30



27



28



29

PLATE XXVIII

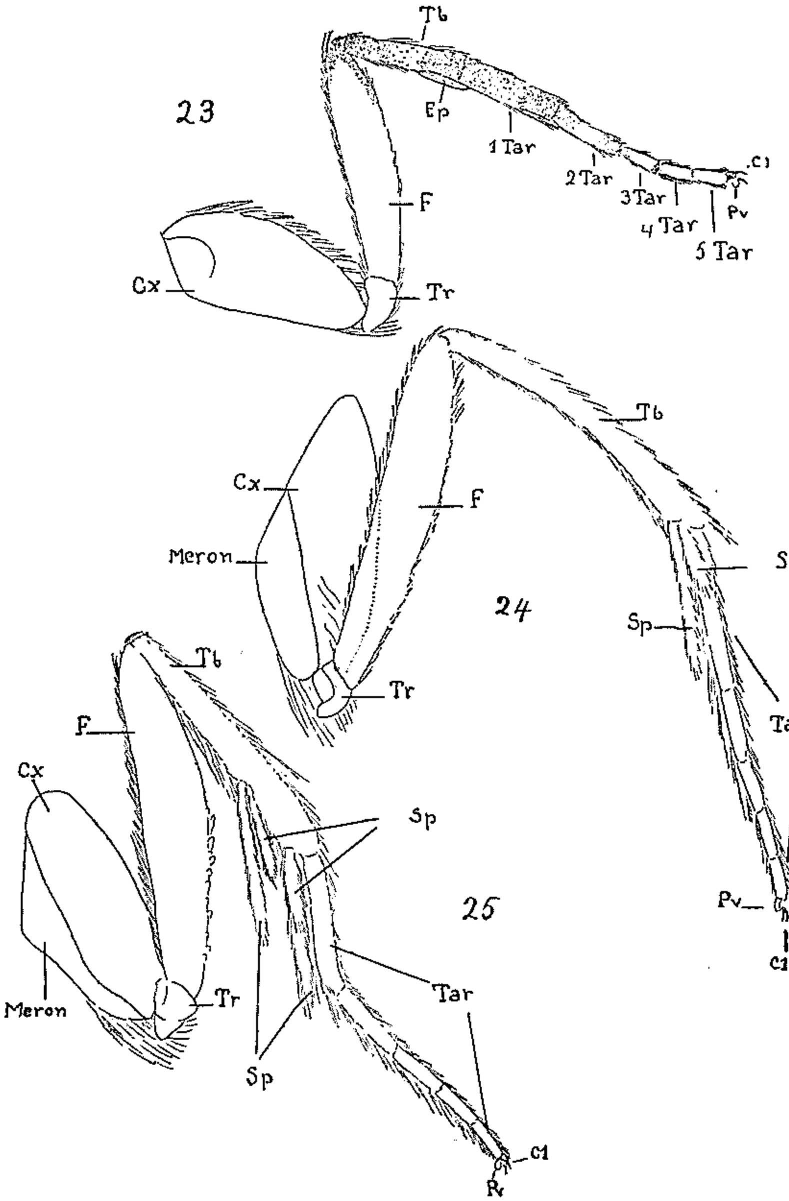
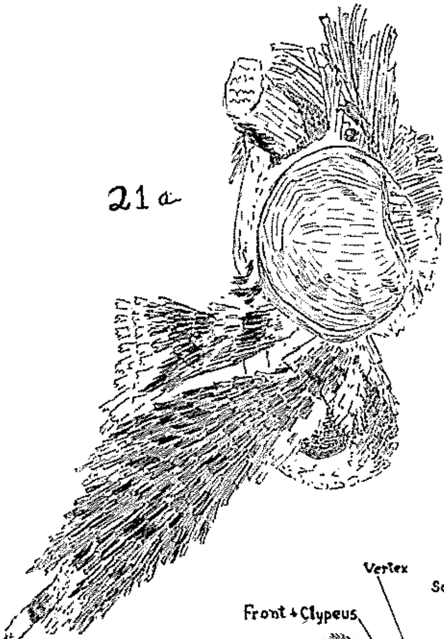
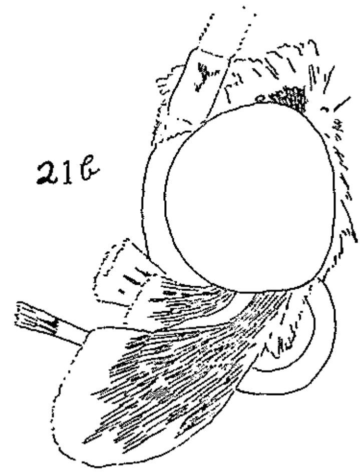


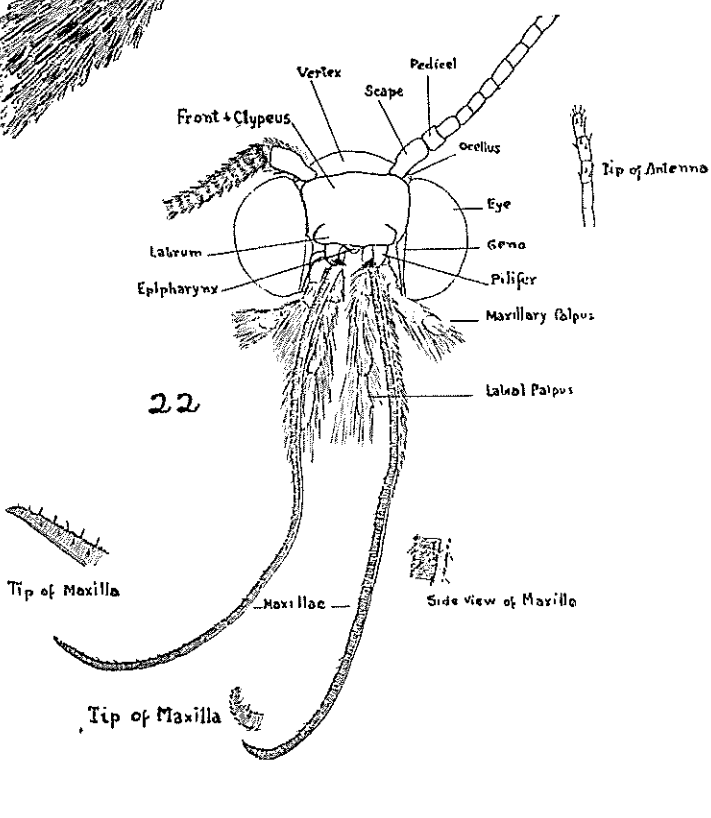
PLATE XXVII



21a

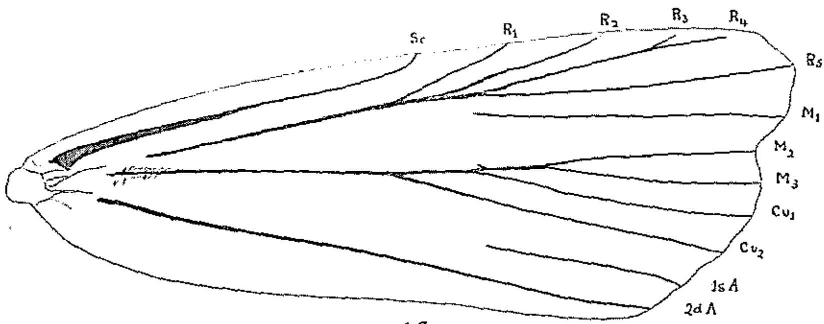


21b

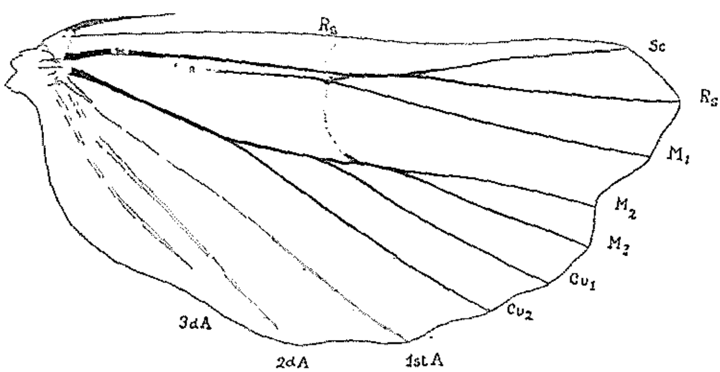


22

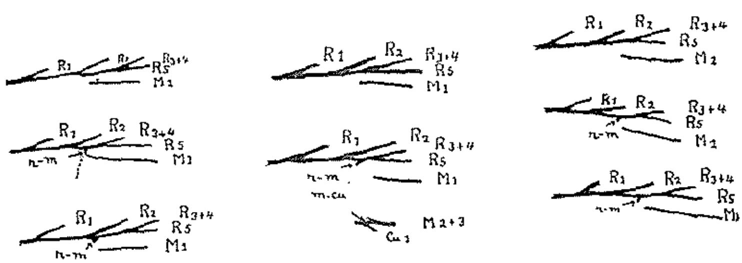
PLATE XXVI



18



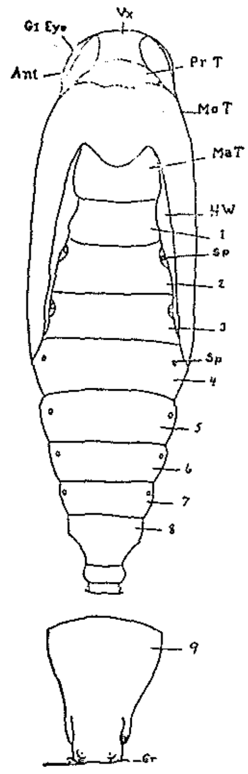
19



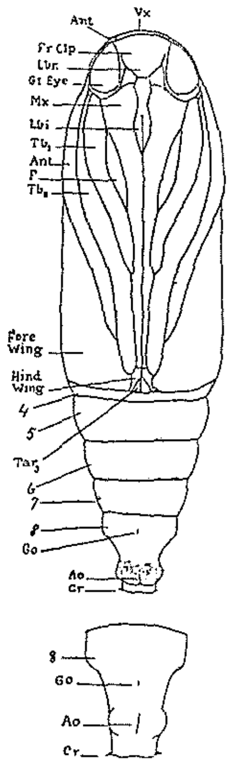
20

PLATE XXV

15



16



17

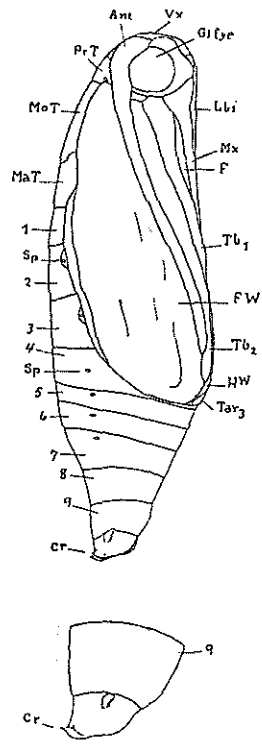
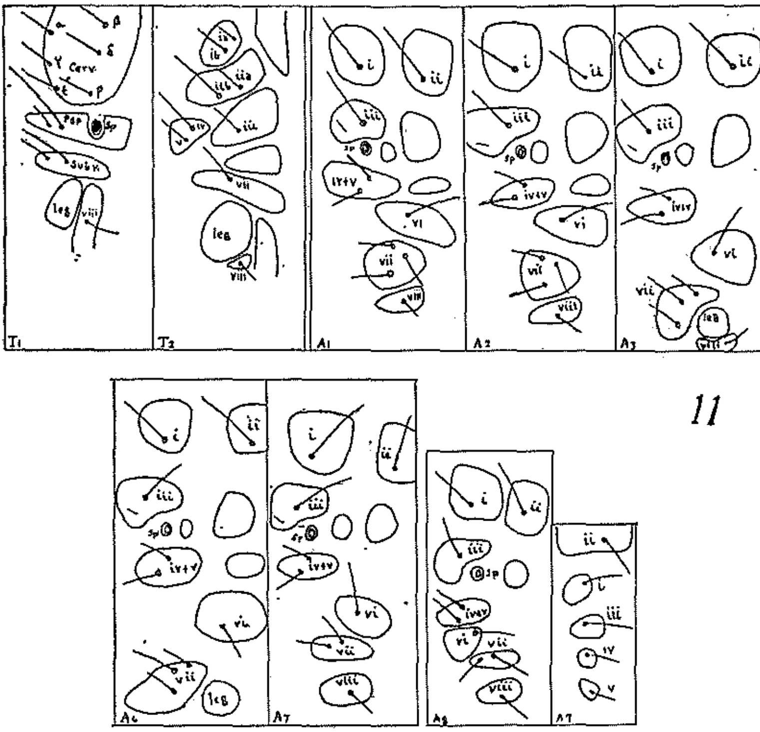
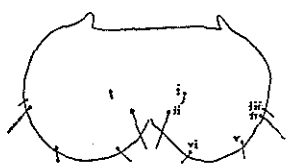


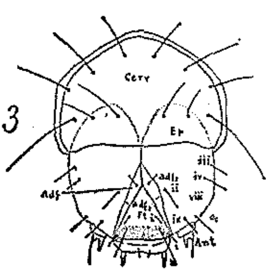
PLATE XXIV



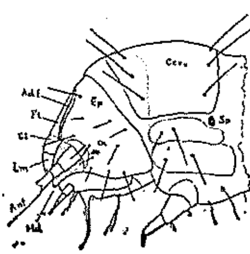
11



12

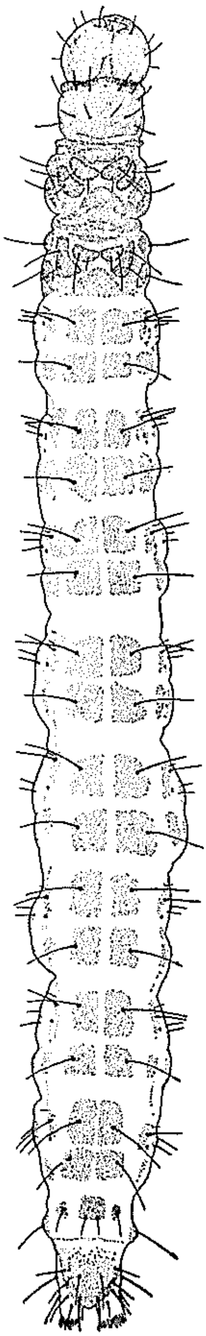


13

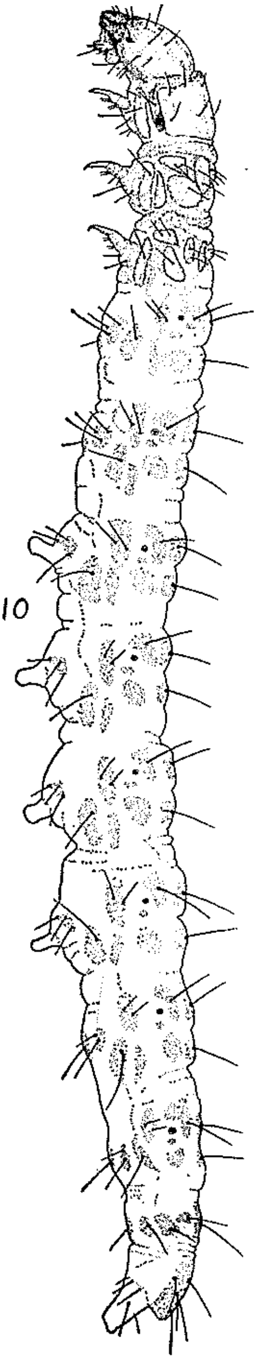


14

PLATE XXIII



9



10

PLATE XXII

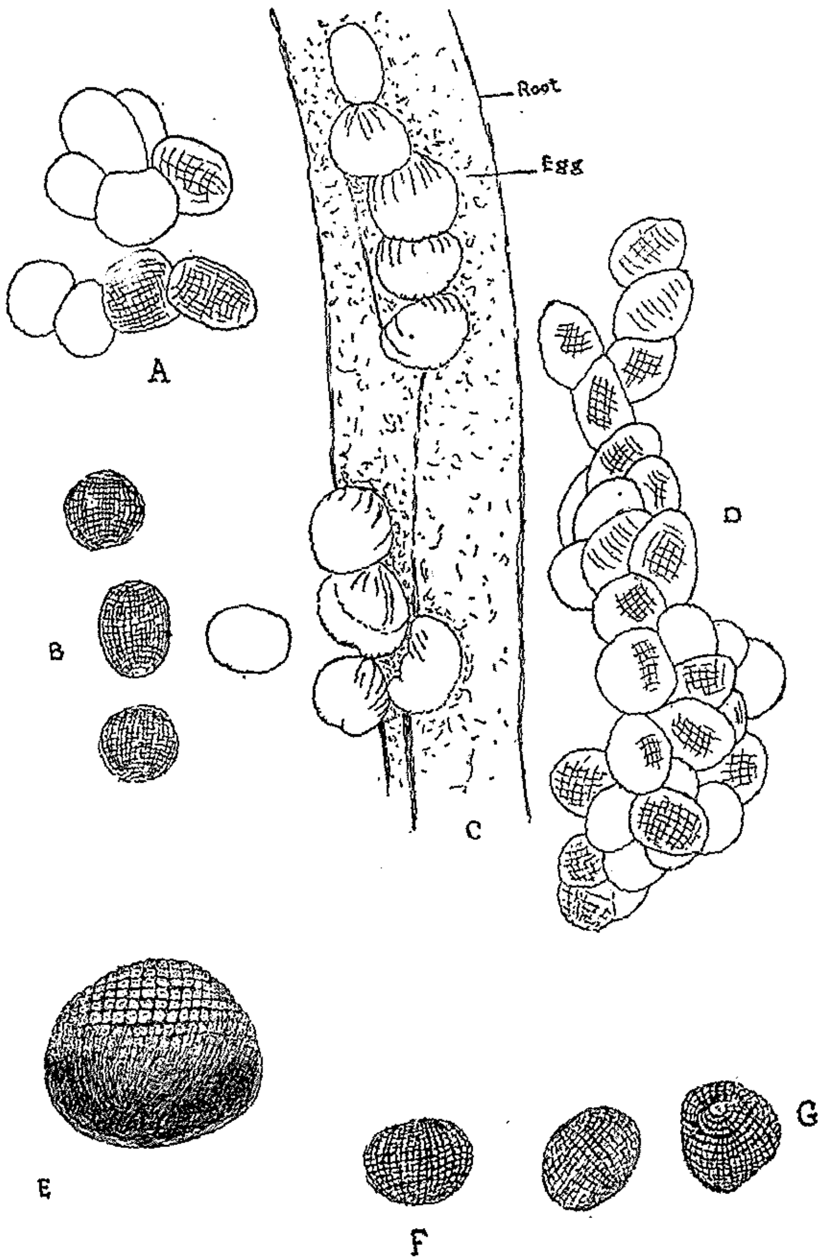


PLATE XXI

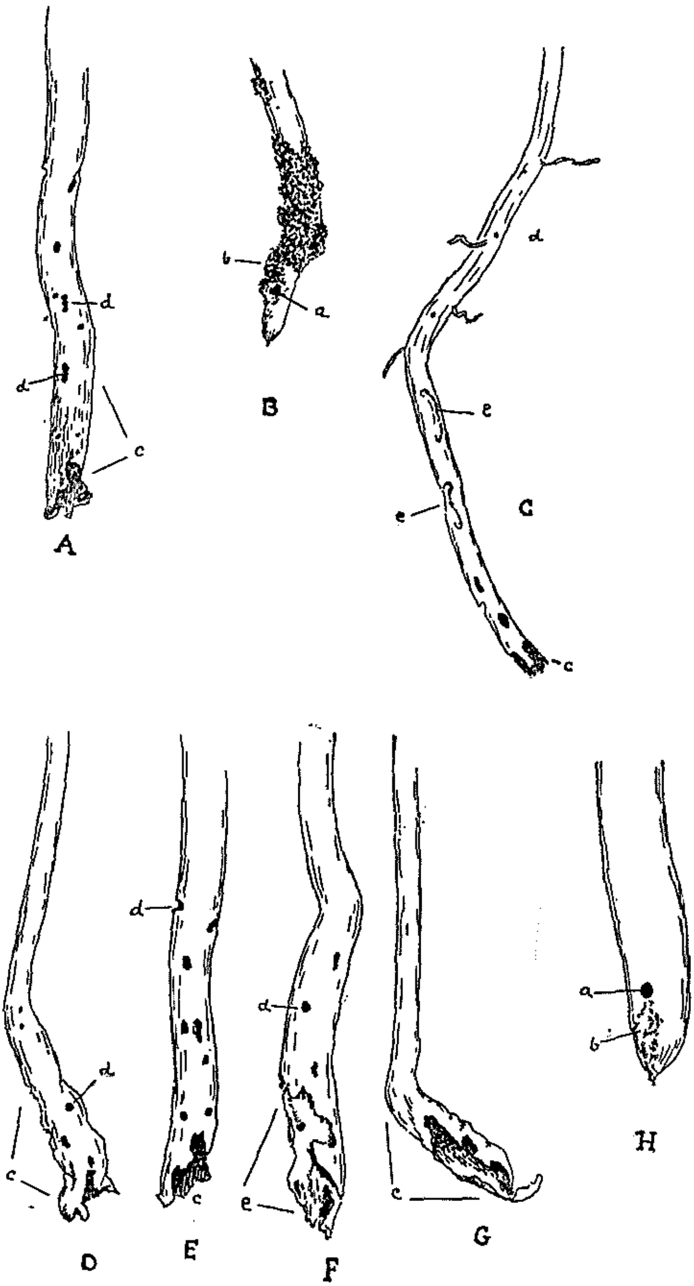


PLATE XX