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TENHET, J.N. HOWE, E.W. 1 OF 1

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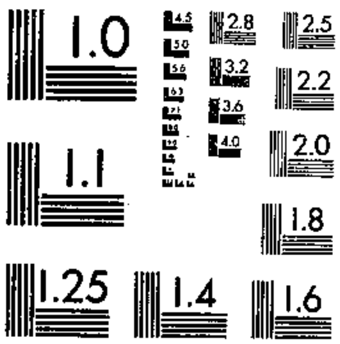

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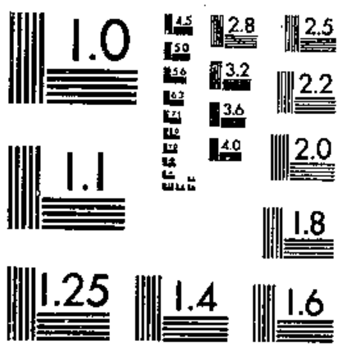

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THE SAND WIREWORM AND ITS CONTROL IN THE SOUTH CAROLINA COASTAL PLAIN[1]

By J. N. TENHET, *assistant entomologist*, and E. W. HOWE, *junior entomologist*,[2] *Division of Truck Crop and Garden Insect Investigations, Bureau of Entomology and Plant Quarantine*[3]

CONTENTS

INTRODUCTION

The sand wireworm (*Horistonotus uhlerii* Horn) has been known for nearly 25 years as a serious pest of corn, cotton, cowpeas, and other crops in the Coastal Plain of South Carolina and in other restricted parts of the country. It is found only in porous, light, sandy soils that are deficient in humus. Most of the crops grown within the economic range of this insect are attacked, and on heavily infested land yields of corn and cotton are often reduced from 50 to 100 percent. In addition to the direct loss caused by the depredations of this pest, there is a serious indirect loss due to the reduction in value of infested land and the necessity of adopting as a cultural control a crop rotation that often does not give satisfactory financial returns. This rotation involves allowing one-half of the infested fields to lie idle (i. e., resting) for 1 or more years.

It is believed that the information contained in this bulletin will be of considerable value to farmers confronted with the problem of growing crops on land infested with the sand wireworm, and that the biological studies reported herein will be of aid to many workers engaged in investigations upon other species of wireworms.

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[2] Resigned July 31, 1933.

[3] The authors wish to acknowledge the assistance of P. K. Harrison, assistant entomologist, and H. C. Eagerton, field assistant, during the course of these investigations.

The investigations upon which this bulletin is based were begun at Fairfax, S. C., in June 1930, following some preliminary control experiments in that vicinity in 1928 and 1929, and were terminated in October 1934.

HISTORICAL REVIEW

The adult form of this insect was first described by Horn (*3, p. 302*),[4] in 1871. The species was not known to be of any economic importance, however, until about 1907, when the larvæ were noted as injuring corn and cotton in Colleton County, S. C. W. A. Thomas (*8*), in 1911, recorded that it had occasioned very heavy losses in a small area. A probable 2-year life cycle was suggested, and trap crops, liming, and heavy applications of fertilizers were recommended as control measures.

In 1914 Conradi and Eagerton (*1*) reported "the corn and cotton wireworm" (*Horistonotus uhlerii*) as scattered throughout the South Carolina Coastal Plain and causing considerable loss, but made no statement concerning the duration of the life cycle. They recommended land resting, rotation, and other farm practices as control measures.

Gibson, in 1916, recorded the "corn and cotton wireworm" as destructive in several States and made the following statement (*2, p. 4*):

> The exact duration of the period of development in the soil has not yet been determined, but the information now at hand indicates that the species lives in the larval stage for two years and possibly three.

Early planting, crop rotation, manuring, and land resting were recommended.

None of these investigators was very successful in obtaining life-history data, and their control recommendations were based on the theory that all wireworms required at least 2 years to complete their development.

SYSTEMATIC HISTORY AND SYNONYMY

The first reference to the sand wireworm, a beetle of the family Elateridae, was Horn's (*3, p. 302*) original description under the name *Horistonotus uhlerii*. This name has been used in all reports with the single exception of those made by W. A. Thomas (*8*), who used the name *Horistonotus curiatus* Say.

ORIGIN AND DISTRIBUTION

In connection with the original description of the adult stage of this insect was the statement that it occurred in Georgia and Florida, but the earliest record of the larva as a pest of cultivated crops was the report of W. A. Thomas (*8*) in 1911, who wrote of its occurrence in the Coastal Plain of South Carolina.

In 1916 Gibson (*2*) noted that it was distributed over the Carolinas, Illinois, Missouri, Arkansas, and Mississippi. Since that time the senior author has found it in Georgia, and it has been reported by the

[4] Italic numbers in parentheses refer to Literature Cited, p. 38.

State entomologist of Florida, J. R. Watson, as occurring in the central portion of that State, and by the State entomologist of Texas, F. L. Thomas, as occurring in the Coastal Plain of Texas. It seems highly probable, therefore, that it now occurs in all the South Atlantic States, most of the Gulf States, and several States in the Mississippi Valley (fig. 1).

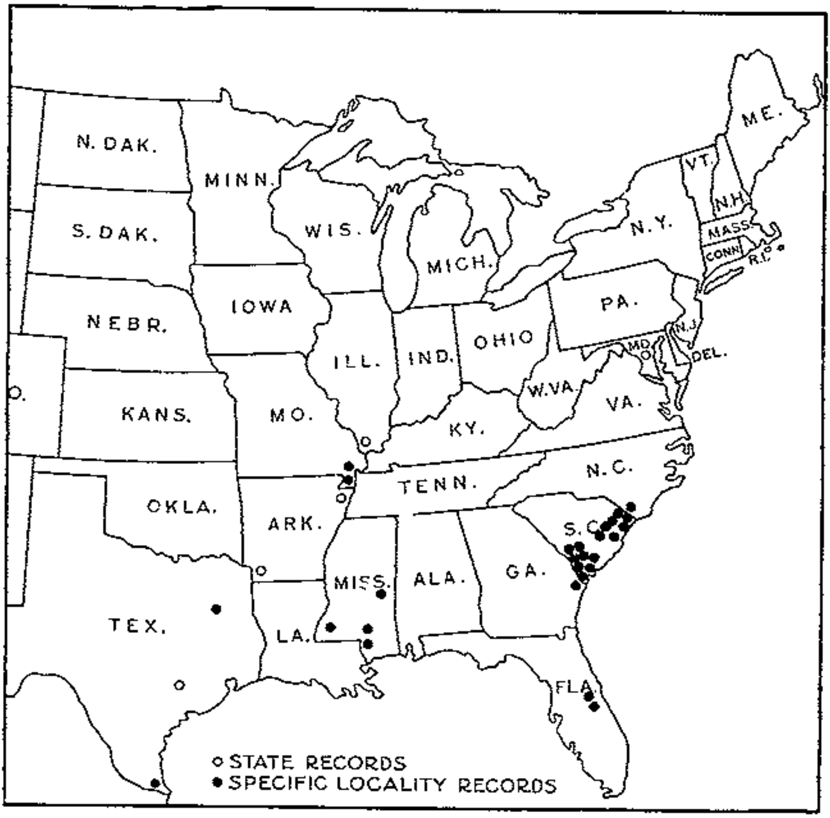

FIGURE 1.—Known distribution of *Horistonotus uhlerii.*

In South Carolina the infested area constitutes a distinct belt extending across the State and roughly paralleling the coast line (fig. 2). Its range seems to be limited entirely to a particular type of very porous, light, sandy soil. This soil in the Carolinas is always characterized as follows: A very light sandy loam topsoil 4 to 6 inches deep, underlain by a stratum of almost pure sand of a medium texture, this layer of sand ranging from 12 to 48 inches in thickness; underlying the stratum of sand, a very hard compact sandy clay subsoil.

As far as is known, *Horistonotus uhlerii* has never been recorded outside the United States, and it seems highly probable that it is a native of this country.

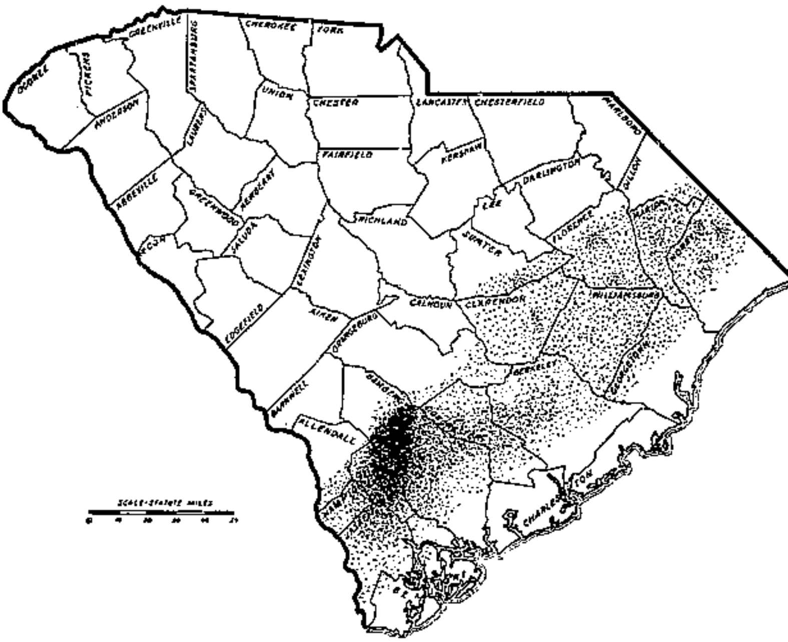

FIGURE 2.—Distribution of the sand wireworm in South Carolina and the relative density of the infestation.

TECHNICAL DESCRIPTIONS

THE ADULT

(Fig. 3, *D*)

The original description by Horn (*3, p. 302*) is as follows:

H. Uhlerii Horn.—Form rather slender, rufo-testaceous, moderately shining, sparsely clothed with short, yellowish hairs. Antennae slender, half the length of the body. Head convex, rather coarsely and closely punctured in front. Thorax longer than wide, apex distinctly narrower than base, sides moderately arcuate, hind angles not divergent, basal plicae small but distinct, disc convex, punctuation fine, not dense and inform in degree. Elytra as wide at base as the thorax, humeri distinct, sides gradually narrowing from the humeri to the apex, moderately deeply striate, striae coarsely punctured, intervals slightly convex at base, near apex costiform, the intervals 2-3-5-7-9 entire and more elevated, the surface sparsely punctulate with a single series on each of somewhat larger punctures. Body beneath shining, not closely punctulate, the punctures intermixed but not conspicuously different. Claws cleft at tip, the tooth being very near the apex. Length .24 inch; 6 mm.

THE EGG

(Fig. 3, *A*)

Pearly white, translucent when first laid, becoming more or less opaque after a few days; ovate, the shell smooth and elastic, the membrane rather easily ruptured. Size (average of numerous measurements): Length 0.62 mm, diameter 0.48 mm.

THE LARVA

(Fig. 3, *B*)

A detailed description of the larva by Hyslop (*4, pp. 181–182*) is as follows:

Elongate, slender and membranous, twenty-seven times as long as wide; color cream white, head ferruginous yellow, prothorax yellow, mandibles brownish yellow to almost black, spines on legs brownish yellow.

Head elongate cylindrical, length exclusive of mandibles, twice diameter, sides subparallel, very highly polished. Front very narrow, sides almost parallel, diameter at middle about one-sixth diameter of head, extending to basal sixth of head, anteriorly dilated to attachment of clypeus; bears a pair of fine hairs near point where it is constricted. Clypeus quadrate, a little longer than broad, anterior angles membranous, anterior margin densely fringed with brush of fine hairs, emarginate and armed at middle with a highly chitinized bidentate prong; the dorsum bears four pair of short erect hairs. Antennae slightly received in fossae on dorsal surface of mandibles, very large, almost one-third length of head exclusive of mandibles; first joint clavate and but little longer than broad; second joint depressed, cylindrical, wider at distal extremity which is obliquely truncate, truncate surface bearing on inner part the very slender and rather short third joint and the accessory appendage, which latter is white and conical; the third joint is about as long as the first joint, cylindrical and three times as long as broad, it is slightly curved and directed at right angles to the long axis of the second joint. Mandibles are two-thirds the length of the head, biramous, and multidentate; the outer surface is slightly concave and each ramus bears two longitudinal carinae; the inner surface of the dorsal ramus bears three stout acute teeth and two smaller teeth, the latter situated on each side of the lowest tooth; the ventral ramus is unarmed, at the base of the mandible on the inner surface is a broad oval molar area and a row of bristles continue the armature of the upper ramus. The submentum is almost obliterated by the highly developed maxillary stipes, it is broadened at the anterior half but almost cut off from the mentum by the maxillary stipes which suddenly converge anteriorly; the submentum bears four hairs on its anterior part and a single pair at its posterior extremity; the mentum is elongate and clavate, and is adorned with a pair of median hairs near its distal end; the labial palpi are about half as long as the mentum, the first joint is twice as long as broad, the second is conical and one-third as long as broad; the maxillary stipes are elongate and armed with nine stout spines on the lateral margins; the maxillary palpi are very stout and two-thirds as long as the stipes; the first joint is one and one-half times as long as broad, slightly clavate cylin-

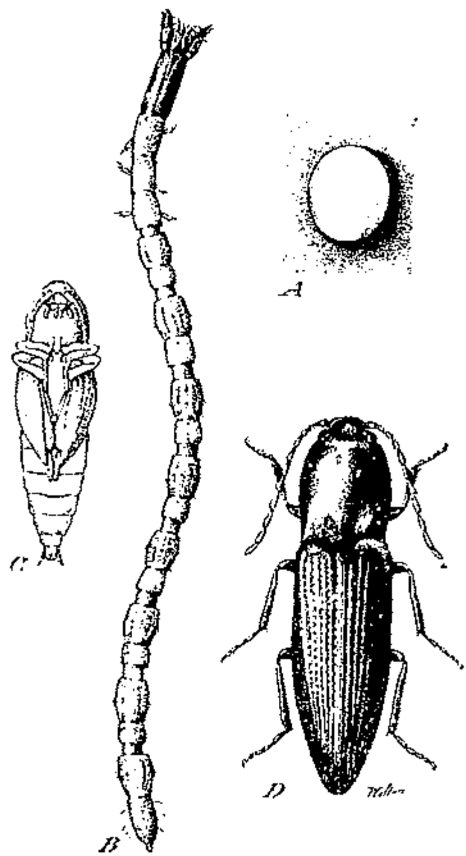

FIGURE 3.—The sand wireworm (*Horistonotus uhlerii*): *A*, Egg, × about 20; *B*, larva × about 4; *C*, pupa, × about 4; *D*, adult, × about 8.

drical, the second joint is one-quarter longer than broad, the third as long as broad, and the fourth twice as long as broad and only half as wide as the third; the galea are two-jointed, the first joint elongate and thickly beset with brushes of complex hairs, the second joint is clavate and bears four stout spines at the distal end; a second brush of hairs arises below the attachment of the galea and a third brush is situated on the under surface of the clypeus.

The first thoracic segment is nearly cylindrical and almost as long as the head exclusive of the mandibles, the second and third are subequal and about three-quarters as long as the first; the legs are very long and quite stout, the coxae are as long as the femora and tibiae united, and serve to receive these two joints when in repose; inner edge of coxae bears a few long hairs; femora clavate and two-thirds as long as coxae, tibia triangular, armed with three blunt stout spines near anterior margin, tarsus beset with one large scoop-shaped spine near the distal end, surrounded by four blunt spines and bearing three additional blunt spines along its inner side.

Abdomen with ten visible segments, segments two to seven are distinctly divided transversely into three distinct areas each, the anterior area of one segment being truncate conical and capable of being invaginated into the posterior area of the preceding segment when contracted, the middle area of each segment is globose, bears the ambulatory papillae and the spiracles. Each segment bears two pair of ambulatory papillae, a lateral pair anterior to the spiracles and a ventral pair near the anterior margin; each papilla is bilobed. and retractile; the spiracles are very obscure but of the typical biforian type; the tergite of each abdominal segment is marked by a median impressed line and a pair of shallow lateral grooves, the ventron of the middle area of each segment is divided into two parts by a median sulcus. The ninth abdominal segment is thimble-shaped and about as long as the middle section of the other abdominal segments; it bears at its extremity a rounded point which is armed with radially arranged stout spines. The tenth segment is concealed from above by the ninth, near the middle of the ventral side of which it arises, it is depressed cylindrical and directed obliquely ventrad; the anus is terminal and the anal lobes are arranged as follows:

The two lateral lobes are quadri-digitate and longer than the tenth segment, the ventral lobe is short and bidigitate, all these lobes are retractile.

THE PUPA

(Fig. 3, *C*)

Dirty white, rather slender, and differing but little from other elaterid pupae in appearance. Size varying greatly, the length ranging from 6.95 to 11.61 mm and the width across the mesothoracic femora from 2.32 to 3.05 mm.

REARING TECHNIQUE

A number of methods of rearing wireworms were tried before a satisfactory procedure was evolved. Pill boxes or salve tins, which have been utilized frequently for this purpose, were found to be unsatisfactory owing to the abnormal reactions of the wireworms to such artificial conditions, and their use was abandoned in 1932. Clay tiles and galvanized-iron cylinders sunk in the soil were tested and gave satisfactory results, but their use was impractical because of the large amount of labor involved in handling any number of such containers. Unglazed earthenware flowerpots with the bottom hole plugged with plaster of paris, filled with soil, and placed in the ground, gave just as satisfactory results as the larger and more awkward clay tiles or metal cylinders and prove much more convenient to handle. They were therefore employed for practically all of the rearing work discussed in this bulletin.

In order to insure against the possible accidental introduction of wireworms, the soil used in the pots was previously sifted and then spread out on heavy paper in a layer less than 1 inch thick and exposed to the sun for several days. Since the sand wireworms cannot live in air-dry soil for even one-half hour, such treatment precluded all possibility of introducing undesired wireworms into the cages with the soil. This soil was then stored in tight containers in a dry building until needed. Before use it was carefully moistened to about normal water content for optimum plant growth.

Each pot was covered with a wire-gauze cover, or cage, made of 20-mesh galvanized-wire screen.[5] These cages (fig. 4) were 18 inches high and slightly tapering, the top being approximately one-half inch smaller in diameter than the bottom and the bottom one-eighth inch larger in diameter than the top of the pot to which it was to be fastened. The top was formed by cutting a disk of wire screening about 1 inch larger in diameter than the upper end of the cage, forcing it down into the top of the cage, and securing it in place. All seams were sewn with heavy linen thread by means of a machine such as is used to sew leather. Seams were all double stitched and then shellacked to protect them from the weather. A metal band fitted with a stove bolt was used to fasten the cone to the flowerpot. By tightening the bolt an absolutely tight joint was secured (fig. 5).

FIGURE 4.—Cage for rearing wireworms, the cover in position on the flowerpot.

The flowerpot, plunged into the soil, maintained approximately the proper conditions of soil temperature and moisture for the wireworms, and two or three grains of sprouted corn (maize) planted at a depth of about 2 inches furnished ideal food. The screen cover provided a cage that was tight enough to prevent the escape of either larva or emerging adult but sufficiently open to afford ample ventilation and to admit enought light to permit normal plant growth. In addition, the contents of the pot could be easily and quickly examined.

[5] TENHET, J. N. AN IMPROVED INSECT CAGE FOR USE OVER FLOWERPOTS. U. S. Dept. Agr. Leaflet ET-14, 2 pp., illus. 1934. [Multigraphed.]

Adult click beetles were readily collected in cornfields late in the afternoon. Pairs taken in copulation were utilized for all breeding work. It is practically certain that the females of such mated pairs were in every case newly emerged individuals, since every such female taken was noticeably lighter in color than the males but darkened to approximately the same shade of color as the males within a day or so. The lighter coloring is characteristic only of newly emerged individuals.

Mated females were confined in small salve tins lined with moist, dark-colored blotting paper and containing a freshly cut section of green cornstalk just long enough to lodge in an upright position

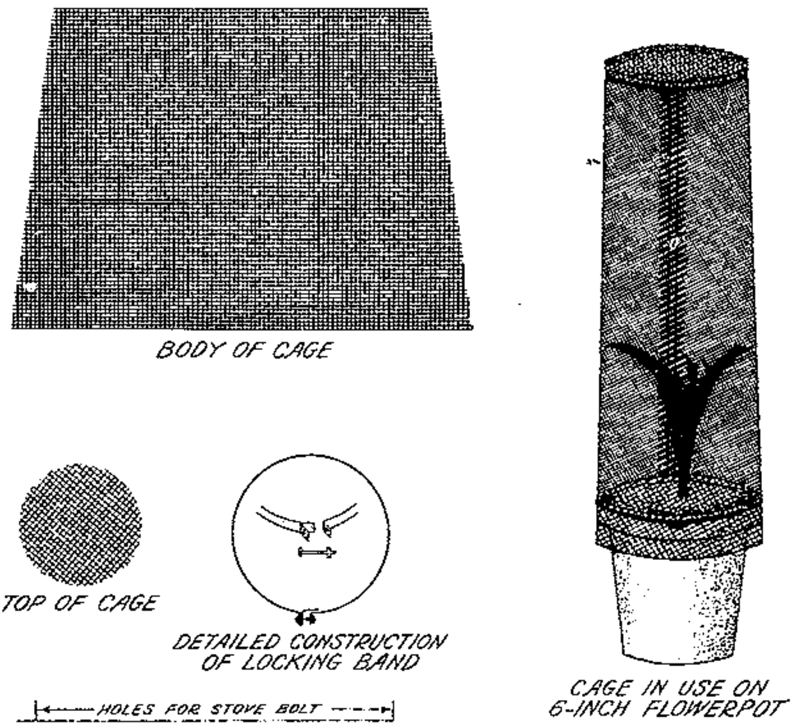

FIGURE 5.—Details of construction of improved cage for rearing wireworms.

between the top and bottom of the container (fig. 6). This section of green cornstalk served as food supply, the beetles rasping the freshly cut ends.

The females usually crept between the end of the section of cornstalk and the moist blotting paper to ovipost. Eggs were removed daily and a fresh section of cornstalk supplied. The eggs were transferred to disks of moist blotting paper placed in small salve tins, which served as incubation cages, and kept, until hatched, in a cellar well insulated against heat. Temperatures in this cellar were almost exactly the same as soil temperatures at a depth of 6 inches. During the latter part of June and in July the daily mean soil temperatures ranged from about 78° to 82° F. The incubation cages were examined daily and newly hatched larvae transferred to the flowerpot cages.

The newly hatched wireworms were lifted on a small camel's-hair brush and placed directly on grains of sprouted corn. Five larvae

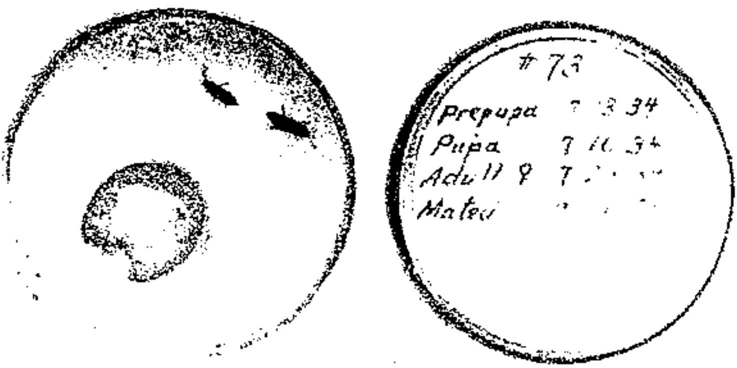

FIGURE 6.—Adults of the sand wireworm in oviposition cage; male on left, female at right. About natural size.

FIGURE 7.—A group of rearing cages in use for breeding and life-history studies of the sand wireworm.

were usually placed in each pot. Moist soil was then gently placed over the corn and the tiny wireworms and mounded about 1½ inches above the top of the pot at the center. This mounding of the soil was essential to insure the run-off of excess water during heavy rains.

The flowerpots were covered by the screen cages during the entire summer, from early in May until October (fig. 7), but from October until the first of May they were left uncovered, since no adults occur during the fall or winter or early in spring. Detailed observations demonstrated that there was no danger of the larvae escaping over the exposed rim of the pots. Throughout the summer corn (maize) was grown in the pots to serve as food for the wireworms, as this plant seems to be a preferred host. During the winter the corn was replaced by Austrian Winter peas.

Cages were not examined during the period from November until late in February, as disturbing the larvae seemed to have an injurious effect upon them. During the period of spring activity examinations were made at approximately 4-week intervals until pupation began. After the last of May, when pupation started, examinations were made every week or 10 days. Such frequent examinations apparently had quite a disturbing effect upon the larvae and sometimes seemed to have a tendency to prolong slightly the larval stage; however, such slight prolongation was unavoidable.

LIFE HISTORY

INCUBATION PERIOD

Under cage conditions the incubation period may range from 6 to 18 days, but the average of several thousand incubation records, made through a period of 4 years, was approximately 12 days, as shown in the following tabulation. The variation in this period in a single batch of eggs is often striking (table 1), in one or two instances having been as much as 5 days. Such variation cannot be attributed to fluctuation in temperature or humidity, since it occurred commonly in groups of eggs that were laid on the same day and were kept in the same container under identical conditions.

Length of incubation period of eggs of Horistonotus uhlerii arranged in a frequency distribution (1931–1934)

Incubation period (days):	Number of eggs laid
6	6
7	9
8	33
9	72
10	476
11	890
12	1,069
13	1,266
14	483
15	216
16	74
17	24
18	22
Total number of eggs	4,640
Average incubation period ....days	12.25

TABLE 1.—*Excerpt from oviposition and incubation records of Horistonotus uhlerii, Fairfax, S. C., 1932*

Date adults mated	Date eggs were deposited	Eggs deposited	Date eggs hatched	Eggs hatched	Length of incubation period	Hatch
		Number		*Number*	*Days*	*Percent*
June 7			June 23	2	12	66.67
			June 24	2	13	
	June 11	17	June 25	3	14	
			June 27	1	16	
			June 28	1	17	
	June 12	2	June 26	1	14	
			June 28	1	16	
	June 13	6	June 26	1	13	
			June 27	5	14	
	June 14	2	do.	1	13	
June 17			June 30	3	9	95
			July 1	2	10	
	June 21	32	July 2	13	11	
			July 3	14	12	
	June 24	8	July 6	6	12	
June 20	June 23	3	----------	0	----------	31.8
	June 24	26	July 6	9	12	
	June 26	3	July 9	1	13	
	June 27	12	do.	4	12	
June 22			July 6	5	12	62.1
			July 7	6	13	
	June 24	27	July 8	4	14	
			July 9	2	15	
	June 25	17	July 7	6	12	
	June 26	8	July 8	5	12	
			July 9	2	13	
	June 27	5	do.	4	12	
	June 28	9	do.	1	11	
			July 10	6	12	
June 29	July 3	32	July 15	2	12	43.2
			do.	9	11	
	July 4	39	July 16	17	12	
			July 17	2	13	
			July 18	1	14	
	July 5	9	July 16	3	11	
	July 6	1	July 18	1	12	
	July 7	6	July 20	3	13	
	July 9	1	----------	----------	----------	

LARVAL DEVELOPMENT

The sand wireworm passes the greater part of its life in the larval stage. Nearly all the eggs hatch in June or July and from then until the following November the young wireworms remain in the topsoil actively feeding. During November the young wireworms gradually go deeper in the soil until, by the last of the month, the majority of them are at a depth of from 18 to 24 inches. Here they remain until March, when they begin to move upward. By the middle of April they are again active in the surface soil. For all the individuals under observation in cages the total duration of the larval stage was slightly less than 1 year, with an average of 352 days (table 2).

TABLE 2.—*Typical life-cycle records of Horistonotus uhlerii Horn, 1932–33 and 1933–34*

Date egg was deposited	Date egg hatched	Length of egg stage	Date larva pupated	Length of larval period	Date adult appeared	Length of pupal period	Total length of developmental period
1932	*1932*	*Days*	*1933*	*Days*	*1933*	*Days*	*Days*
June 21	July 4	13	July 1	362	July 12	11	386
June 25	July 8	13	Aug. 16	404	Aug. 27	11	428
July 16	July 25	9	July 8	348	July 20	12	369
July 17	July 27	10	July 18	356	July 29	11	377
Do	do	10	July 27	365	Aug. 6	10	385
Do	July 28	11	June 15	322	June 27	12	345
July 18	do	10	July 19	356	July 30	11	377
Do	July 29	11	July 8	344	July 19	11	366
July 21	July 31	10	July 9	343	July 20	11	364
Do	do	10	July 12	346	July 24	12	368
1933	*1933*		*1934*		*1934*		
June 20	July 3	13	June 5	337	June 21	16	366
Do	do	13	June 23	355	July 3	10	378
July 5	July 22	17	July 2	345	July 14	12	374
July 8	do	14	June 27	340	July 7	10	364
July 9	July 24	15	July 14	355	July 24	10	380
July 10	do	14	July 1	342	July 15	14	370
Do	do	14	July 16	357	July 24	8	379
Do	July 25	15	July 11	351	July 21	10	376
July 13	July 26	13	July 16	355	July 24	8	376
Do	July 27	14	July 17	355	July 29	12	381

The newly hatched wireworm is approximately 2.5 mm long and 0.25 mm in diameter, so tiny that with the unaided eye it can be seen only with difficulty except against a dark background. By September the length has increased to about 12 mm, but from October to the middle of January growth is slower, the length increasing at the rate of only about 1 mm a month. During January and February there is usually a slight decrease in size, after which rapid growth is resumed. Late in February the average length of field-collected wireworms is approximately 14.25 mm, and by May this has increased to approximately 18 mm. A fully mature larva may be from 22 to 30 mm long.

When the larva has reached maturity, usually in June, it forms an oval-shaped cell at a depth of 4 or 5 inches in the ground. Within this cell, which is approximately 15 or 16 mm long and 4 to 5 mm across, the larva passes through a distinct prepupal stage. There is a very marked shortening in length, accompanied by an increase in diameter, and a very noticeable accentuation of the abdominal segmentation. This state lasts for several days.

PUPAL PERIOD

At the end of the prepupal period the last larval skin is shed and the pupa appears. The average duration of the pupal period is approximately 11½ days (table 2). At the expiration of this period the pupal skin is shed and the imago appears.

PREOVIPOSITION PERIOD

The newly transformed adult remains in the pupal cell for 2 or 3 days until the integument begins to harden and show pigmentation. It then emerges from the soil and mates. After mating, from 1 to 4 days elapse before egg laying begins, but usually the preoviposition period requires approximately 24 hours.

LIFE CYCLE

The life cycle of this species covers approximately 1 year. In the 1932–33 brood the average of over 40 complete life-cycle records was slightly under 370 days. Some typical life-cycle records are presented in table 2.

Data to support this statement of a 1-year life cycle may be listed as follows:

(1) All wireworms collected in the field in the spring either completed their development that summer or died. During the 4 years' study, in not a single instance did a wireworm live over a second season.

(2) All wireworms reared in the laboratory had a 1-year life cycle.

(3) Over a 4-year period (1931–34) practically all larvae in the field appeared to complete their development by the last of June. Large wireworms could be collected in abundance in April, May, and early in June, but they became very scarce the last of June. It was extremely difficult to find any in July. Adults were abundant in June and July, and small to medium-sized wireworms could be collected in September and October but large larvae were never found at this season of the year (table 3).

TABLE 3.—*Length of field-collected wireworms of Horistonotus uhlerii*

Length of larvae (mm)	Field-collected larvae of *H. uhlerii*		Length of larvae (mm)	Field-collected larvae of *H. uhlerii*		Length of larvae (mm)	Field-collected larvae of *H. uhlerii*	
	Collected in September and October 1932	Collected in June 1933		Collected in September and October 1932	Collected in June 1933		Collected in September and October 1932	Collected in June 1933
	Number	*Number*		*Number*	*Number*		*Number*	*Number*
6	4		14	6	13	22		43
7	1		15	6	15	23		21
8	12		16		31	24		35
9	6		17		37	25		17
10	20	1	18	1	54	26		27
11	18		19		29	27		4
12	16	1	20		82	28		3
13	7	5	21		50			

	mm
Average length of fall-collected wireworms	10.8
Average length of June-collected wireworms	20.13

Several scientists working with wireworms have reported that a 2- or 3-year period or even longer was required to complete the life cycle, but most of such records were obtained by the use of the old "pill-box" method of rearing. In rearing *Horistonotus uhlerii* it was discovered that very few if any individuals would complete their development in less than 2 years when confined in salve tins, yet under more natural conditions of moisture, temperature, and food such as obtained in the earthenware pots previously described the life cycle of all the individuals under observation was completed within a period of approximately 1 year. During the seasons of 1932–33 and 1933–34 over 60 complete life-cycle records and 20 additional larval records were obtained. Since the larval period covers approximately nine-tenths of the insect's life period and the winter is passed as a larva, this gives virtually the equivalent of over 80 life-cycle records. In view of these records it seems possible that if more natural rearing conditions were used in studying the life history of other elaterids, many more species might be shown to have a 1-year life cycle.

SEASONAL HISTORY AND HABITS

THE ADULT

DISPERSAL

The adult form of this insect is capable of sustained flight, and from available records it seems safe to assume that all dispersal of this species occurs in this manner. Adults have been observed to fly for nearly 100 yards, and various observers have collected them 2 or 3 miles from the nearest known point of infestation. It would seem quite possible that under favorable conditions a flight of a mile or more could readily be made.

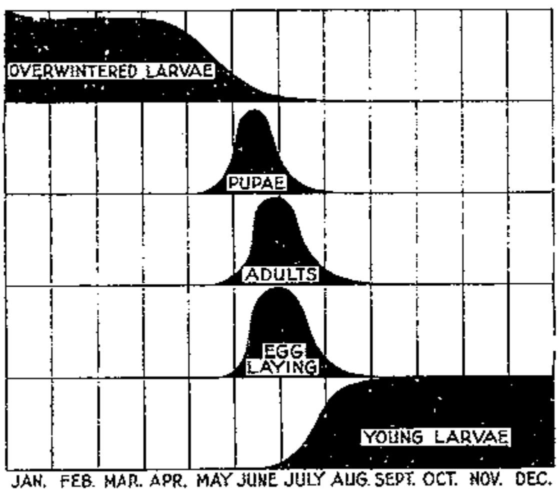

FIGURE 8.—Seasonal history of the sand wireworm at Fairfax, S. C.

SEASONAL OCCURRENCE

Adults first begin to appear the last of May, but are very scarce until about the middle of June. Apparently at least 75 percent of the adult emergence occurs during the last half of June and the first week in July, and usually by the middle of July adults are very difficult to find. A few scattered individuals continue to appear until early in September, but their numbers are insignificant (fig. 8).

MATING

Mating is usually accomplished late in the afternoon, from about 4 o'clock to shortly after sunset. It generally occurs on the ground, but occasionally it has been observed on a blade of grass or even a short distance up a cornstalk. In only one instance has a pair been observed in copulation as much as 2 feet above the ground.

Soon after the female emerges she crawls up on a slight elevation such as a small lump of dirt, a piece of trash, or a blade of grass, and awaits the appearance of a male. There seems to be a very definite attraction of the males to the females from some little distance, but whether this attraction is attributable to scent, to a stridulation, or some other taxis is not known. Males are readily attracted from a distance of 10 feet or more, and in one instance a male under observation was followed and found to travel straight to a female from a distance of fully 40 feet. The male travels by running, jumping, and by short flights. Sometimes a female will conceal herself under a blade of grass, and several males will run all around the immediate vicinity in a highly excited manner, sometimes going within an inch of the female without discovering her. The first male to reach the female quickly mates with her. Copulation continues for several minutes, after which the female usually crawls away a short distance and burrows into the earth. In many instances females have been observed to begin digging into the soil while the male was still attached, and they have been collected with the male still attached when only the tip of the female's abdomen was exposed above the soil. More rarely a female will take wing and fly away.

After mating has once occurred, a female will not immediately accept another male. Males will often attempt such copulation, only to be hurled several inches away by "clicks" of her abdomen.

Several instances have been known, however, of second matings. A female taken in copula laid a few fertile eggs after being caged and then ceased ovipositing. When a male was introduced into the cage mating again took place, and within a day or so another batch of fertile eggs was deposited. Whether or not this often occurs in nature is not known, but it scarcely seems probable. The chief evidence against it is the fact that no instance has ever been observed of a very dark-colored female (dark color indicates age) being taken in copulation in the field.

RATIO OF SEXES

The ratio of females to males appears to be approximately 50 to 50, according to laboratory rearings. Females are relatively scarce in field collections and the apparent proportion of males to females is at least 25 to 1, but this is probably due to the fact that the females spend very little time above ground. In the vast majority of cases the female burrows into the soil within 10 minutes after mating has been completed.

FECUNDITY

Under cage conditions females usually begin to deposit eggs approximately 24 hours after mating and may continue ovipositing for as long as 3 weeks. Most of the eggs, however, are deposited within 5 or 6 days. During four seasons, 1931–34, the average number of eggs deposited per female was approximately 50. This figure probably represents normal fecundity, since the females were known to have been newly matured individuals captured in the act of mating. The maximum number ever deposited by any one female under observation was 116, and the female in the case also was a newly matured insect similarly taken.

OVIPOSITION

Females burrow into the soil to oviposit, and the eggs are deposited at an unknown depth. When first deposited, the eggs are sticky and grains of sand and particles of soil adhere tightly to them. The eggs are also very fragile and are easily ruptured. When merely moving them about in sand, the pressure of sharp-edged particles is often sufficient to rupture the integument. This fragility, and the fact that the eggs are smaller than many of the soil particles, prevent sifting or washing them from soil.

In the laboratory, eggs were deposited singly or in small groups of 2 to 10. A single female has been known to deposit as many as 68 eggs in 24 hours, but over the 4-year period (1931–34) the average number of eggs deposited per day by one female was slightly under 12.

Conradi and Eagerton (*1*) stated that females burrow for oviposition into soft dirt only; that they cannot, or will not, burrow into hard-packed soil that has become crusted over; and that consequently they seek freshly cultivated soil in which to oviposit. Gibson (*2*) repeated this statement, and both authors used this as an explanation of the known fact that stubble land grown up in grass and weeds is not infested.

From the work done at Fairfax it now seems probable that the foregoing conclusion was erroneous. The sand wireworm does not usually infest stubble land, pastures, or land lying idle and grown up in weeds; but on many occasions females have been observed to burrow into soil packed almost as hard as a brick when there was an abundance of soft, freshly-plowed soil less than 2 feet away.

Freshly-plowed soil does not seem to offer any attraction to egg-laying females, but there is a positive attraction to fields in cultivation. The attracting agent, however seems to be the crop growing on the land, such as corn, cotton, or cowpeas, and not the soil. It has been observed that a heavy wireworm infestation often follows these crops. Evidence to this effect is embodied in records and observations on certain fields over a period of years (table 4).

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TABLE 4.—*Relation between the crop of the preceding year and the subsequent wireworm infestation in a number of fields near Fairfax, S. C.*

Field	1928	1929	1930	1931	1932	1933	1934
Dowling field No. 1	Corn completely destroyed.	Corn very severely injured.	Uncultivated	Uncultivated	Good crop of corn; Many hills examined; only 2 or 3 larvae.	Cotton very severely injured.	Uncultivated.
Dowling field No. 2 (adjoining No. 1).	Uncultivated	Good corn crop; no apparent injury.	Corn very severely injured.	do	Uncultivated	Good crop of corn; no wireworms.	Severe wireworm injury to cotton.
Dowling field No. 3 (adjoining No. 1).	Good corn; no apparent injury.	No apparent injury to cotton.	No apparent injury to watermelons.	Slight injury to corn	Cotton very severely injured.	Uncultivated	Un cultivated.
Wm. Lightsey field	Corn destroyed.	Uncultivated	No injury to corn and beans.				
Hogarth field	Uncultivated	Corn not appreciably injured.	Watermelons and cowpeas; melons badly injured.	Corn ruined by 139 larvae to 50 hills of corn.	Uncultivated	Watermelons and cowpeas; only slight injury.	Corn severely injured; 56 wireworms to 50 hills.
Copeland field			Corn injured	Cowpeas apparently uninfested.	Corn severely injured; 87 wireworms to 100 hills of corn.		
Rouse field			Cotton severely injured.	Uncultivated	Corn lightly infested; 30 wireworms to 100 hills of corn.		
L. B. Tuten field			Corn destroyed by wireworms.	do	Good crop of corn; no signs of injury.	Corn badly injured by wireworms.	
Hawkins field				Corn lightly infested.	Corn moderately infested; 45 wireworms to 100 hills.	Uncultivated; screen showed movement to adjoining field.	
Ginn field (adjoining Hawkins).					No infestation of corn	Corn uninfested; sampling showed no wireworms.	Cotton severely injured; 38 wireworms to 50 hills of cotton.
Speaks field			Corn destroyed by wireworms.	Uncultivated	Oats with stubble undisturbed.	Good corn; only 16 wireworms to 100 hills of corn.	
Experimental plot No. 5.			Corn totally destroyed.	Oats followed by late corn; corn destroyed.	Corn and cottonseed; moderate infestation.	Corn seriously injured; 207 wireworms to 100 hills of corn.	
Experimental plot No. 6.			do	Winter oats; stubble undisturbed.	Winter oats; stubble undisturbed.	Corn very lightly infested; 19 wireworms to 100 hills of corn.	Corn very heavily infested; 124 wireworms to 100 hills of corn.
Experimental plot No. 7.			do	do	do	Lightly infested; 28 wireworms to 100 hills of corn.	Corn very heavily infested; 187 wireworms to 100 hills of corn.
Experimental plot No. 8A.			do	Potatoes moderately infested.	Corn, 350 wireworms to 100 hills.		
Experimental plot No. 3.			do	Uncultivated	No wireworm infestation on corn.	140 wireworms to 100 hills of corn.	

Experiments with sticky screens so placed as to capture adult click beetles in flight have proved that there is a definite movement of females from idle fields to adjacent fields of corn and cotton and that this movement is largely against the wind. This would seem to indicate that the movement is a chemotropic response to the scent of growing host plants.

In 1932 and 1933 sticky screens were erected between cultivated and uncultivated fields, and the record of adults taken in flight is extremely interesting (table 5). These data indicate that in both years 76 percent of the females captured were flying out of the idle land toward the cultivated fields of corn or cotton; also, that where the screens were so placed that they were at right angles to the line of the prevailing winds, an average of 77 percent of the females taken on such screens were moving against the wind toward the adjacent fields of corn or cotton.

TABLE 5.—*Numbers of Horistonotus uhlerii taken on sticky screens and in flight between fields, Fairfax, S. C., 1932–33*

Year	Beetles taken on screens							
	Total		On side next to cultivated field		On side next to uncultivated field			
	Males	Females	Males	Females	Males		Females	
	Number	*Number*	*Number*	*Number*	*Number*	*Percent*	*Number*	*Percent*
1932	374	38	205	9	169	45.2	29	76.3
1933	607	25	265	6	342	56.3	19	76.0
Total			470	15	511	52.1	48	76.2

Year	Beetles taken flying toward cultivated fields							
	Total		With the wind		Against the wind			
	Males	Females	Males	Females	Males		Females	
	Number	*Number*	*Number*	*Number*	*Number*	*Percent*	*Number*	*Percent*
1932	135	21	73	7	62	45.9	14	66.7
1933	328	14	154	1	174	53.0	13	92.9
Total			227	8	236	51.0	27	77.1

The number of females taken on these screens seems very small, both numerically and in comparison with the number of males, but this is easily explainable, for the actual sticky surface comprised only 3 linear feet per screen, and the catch was not out of proportion to the surface area of the screen compared with the total area through which the flight occurred.

The apparent discrepancy in the proportion of females to males is easily explained by the fact that the females are known to fly but once in their lives (immediately after mating), and that one flight apparently lasts for a matter of seconds or, at the most, for minutes. On the other hand, the males live and are actively seeking females for several hours each day for several days. Hence the opportunity for capturing males is vastly greater.

In the fall of 1932 two tight cages, each 10 feet square, were erected. One cage was on land which had been uncultivated that year and one was on land which had been planted in corn and had been moderately infested with wireworms. The walls of these cages were sunk in the soil to a depth of 4 feet and were believed to be wireworm-tight. The cages were only 30 feet apart and both were on land that had been uniformly and moderately infested with wireworms in 1931.

Adult emergence in these cages was very light. Only seven adults emerged in the cage on land that had been in corn, and two adults in the cage on the uncultivated land. Although these figures are small, seven adults per 100 square feet represents a good infestation of the sand wireworm—nearly one larva to each hill of corn.

FEEDING

The adults of many elaterids are pollen feeders, but apparently *Horistonotus uhlerii* feeds principally by rasping the stems and blades of corn and grasses and sucking the juices. As far as is known, however, serious damage has never been recorded as resulting from such feeding.

In the laboratory, adults feed freely on the freshly-cut ends of sections of green cornstalk.

LONGEVITY

It is impossible to state how long the adult click beetle normally lives, but in the laboratory the duration of life is only about 10 to 14 days. A few survive for 3 weeks. Females seem to live slightly longer than males.

PHOTOTROPISM

There is a definite attraction of the adult male click beetles of this species to lights, suggesting that some degree of control might possibly be obtained by the use of trap lights. Unfortunately, however, females have never been taken at a light, probably because they remain such a short time above ground.

THE LARVA

NATURE OF INJURY

The great economic loss occasioned by this insect is due to the feeding of the larvae, which attack the roots and subterranean portions of the stem of the host plants. In cases of severe infestation the seed may be attacked as soon as it begins to germinate, and the young plants are often killed before they reach the surface of the soil. This type of injury occurs typically in the dicotyledonous plants such as melons, peas, and cotton. Such damage is, of course, most noticeable in loss of stand, there seldom being any dwarfing or stunting of the plants that escape this early death. The wireworms often bore into or gnaw the surface of the fleshy stem (fig. 9) but there is practically no tunneling as is the case with many other species of wireworms. After such plants have passed the seedling stage and begun to develop a root system damage by the sand wireworm is not so severe.

Injury to corn is of an entirely different character. With this plant and all of the Graminaceae, the stem, which is hard and fibrous,

FIGURE 9.—Injury to seedlings by the sand wireworm: *A*, to beans; *B*, to cotton.

is rarely attacked, the injury being largely confined to the roots. The small feeder roots are cut off as fast as they develop, leaving the plant literally to starve for lack of food and water (fig. 10).

In a heavily infested field of corn the small, stunted stalks may be as easily lifted from the ground as if they were sticks thrust into the soil. In many instances such corn is eventually killed or even if the plants manage to remain alive there is small hope of their producing any yield of grain. This type of injury generally continues over a

FIGURE 10.—Two corn plants of the same age: The one on the left was injured by the sand wireworm; the one on the right is healthy and normal.

longer period than the injury to dicotyledonous plants, persisting usually for from 2 to 2½ months (from the middle of April until pupation of the insect) and is consequently much more noticeable.

A surprising amount of damage is often inflicted by a relatively small number of larvae. A single wireworm will often kill outright a small corn plant or seriously injure a large plant. An infestation, therefore, of even one wireworm per hill of corn means a severely damaged crop. An infestation of two or three wireworms per hill of corn normally means the total destruction of the crop (fig. 11).

FIGURE 11.—Corn badly injured by the sand wireworm: *A*, The corn in the foreground is the same age as that in the middle of the picture, but is on land that was uncultivated the preceding year; *B*, a close-up view of the injured part of the field.

FOOD PLANTS

The larva of the sand wireworm is an omnivorous feeder, and there are very few crops not subject to attack when growing in infested soil. Conradi and Eagerton (*1, p. 8*) stated that "the larvae attack the roots of practically all farm crops, as corn, cotton, cowpeas, oats, rye, peanuts, tobacco, and others. They have also been observed very seriously injuring very young watermelon plants." Gibson (*2*) added sweetpotatoes, crabgrass, Johnson grass, and a wild bamboo to the list; and W. A. Thomas (*8*) further mentioned "hogweed a species of goldenrod, growing in uncultivated fields."

The list of plants recorded in the course of this investigation is even more extensive. and it has been found that these hosts may be divided among three groups, as follows:

Group 1.—Plants that are commonly attacked and severely injured and upon which wireworms can develop satisfactorily: Corn, cotton, cowpea, potato, and native lespedeza.

Group 2.—Plants that are often attacked, but seldom seriously injured for various reasons, particularly the fact that they are grown during the period of wireworm inactivity: Tomato, asparagus, watermelon,[6] cucumber,[6] peanut, oat, rye, Austrian Winter Pea, velvetbean, sweetpotato,[7] cudweed (*Gnaphalium spathulatum* Lam.),[8] wild dewberry (*Rubus* sp.), crabgrass, and *Richardia scabra* L.[8]

Group 3.—Plants that are only lightly attacked and upon which wireworms cannot, or do not, develop satisfactorily: Cabbage, nutgrass (*Cyperus rotundus* L.), bur-clover, bamboo briar (*Smilax walteri* Pursh)[8] (coral greenbrier), and trumpetcreeper (*Bignonia radicans* L.).

Austrian Winter peas and small grains are planted in the fall and make most of their growth during the period when the wireworms are deep in the soil and relatively inactive. When the wireworms are beginning to feed actively in the spring these crops have become hard and tough, with a strongly established root system, so little injury is ever apparent.

Velvetbeans, although belonging to the two-leaved seedling group, seem relatively immune to attack, not because of the time of year when they are planted but because of their immense, fibrous root system and their extremely vigorous growth. It is a matter of common observation throughout the area infested that small grains and velvetbeans are crops that can be planted safely on land subject to wireworm infestation.

METHODS OF FEEDING

Some species of wireworms are predacious, feeding principally upon other insects; and certain species have been suspected of feeding principally upon organic matter in the soil. Langenbuch (*5*) states that in Germany *Agriotes obscurus* (L.) and *A. lineatus* (L.) feed upon organic matter in the soil. However, the majority of the wireworms of economic importance in the United States, including *Horistonotus uhlerii*, are known definitely to feed upon living plant tissue.

The sand wireworm feeds upon the roots, underground stems, seeds, seed pieces, and tubers of plants. It may bore into a stem or seed, gnaw small pits in the surface of a seed, seed piece, or tuber, or cut off the small roots. In some instances the feeding apparently consists of a pressing out of the plant juices, but usually a portion of the stem, root, or seed is completely eaten away.

In the course of various experiments no evidence was obtained to indicate that the sand wireworm utilizes organic matter in the soil

[6] Early-planted watermelons and cucumbers are seldom seriously injured, but late plantings are often badly damaged.
[7] Sweetpotatoes planted after July 10 are seldom injured, but early-set sweetpotatoes are sometimes severely injured.
[8] Determined by S. F. Blake.

as food. Wireworms placed in cages containing soil rich in humus, but without other food, died within 60 days.

MOVEMENT THROUGH SOIL

Horistonotus uhlerii is found only in a very light, sandy soil and, as Hyslop (*4*) has pointed out, the species is admirably adapted for relatively rapid movement through such soil. This movement, however, seems to be confined principally to a vertical rather than a lateral plane. That *H. uhlerii* is capable of considerable lateral travel there can be no doubt, as there have been definite records of a larva traveling as much as 30 feet (not in a straight line) in 24 hours. However, there is much evidence leading to the conclusion that the larvae seldom move 25 or 30 feet away from the place of hatching. In the experimental fields the margins of the various plots have been usually quite sharply defined, and in only one or two instances has there been any indication of an apparent movement of wireworms from one plot into another. In these cases the infiltration did not seem to extend more than a few rows. Both in the field and in the laboratory it has been noted repeatedly that after the soil had been disturbed the wireworms very quickly established a system of burrows, and there seemed to be a distinct preference for moving through these established burrows rather than promiscuously through the soil. This habit of using burrows may explain in part why there is so little tendency for the larvae in heavily infested plots to move over into adjoining lightly infested plots.

SEASONAL MIGRATION

Since this wireworm is very sensitive to differences in soil moisture and temperature, it seems to follow the movement of optimum temperature and moisture up or down in the soil. Late in the spring and in summer soil moisture seems to be the principal factor determining movement but with the coming of colder weather temperature seems to assume a relatively greater importance. This movement is definitely vertical to a surprising degree. During the winter larvae are concentrated directly underneath the host plant upon which they last fed in the autumn.

As evidence of this concentration the following observation may be cited: Fifty-seven samples of soil were taken at a depth of 12 to 24 inches directly under corn or cotton plants during the winter of 1932–33, each sample consisting of approximately one-half cubic foot. From these samples 45 wireworms were taken, whereas 30 similar soil samples from the same depths, but taken at random and not directly under any host plant, yielded only 2 wireworms.

OVERWINTERING

The winter is passed in a stratum of almost pure sand at a depth ranging from 18 to 30 inches. There is very little food at this soil depth, and feeding by the wireworms during the winter period must be very limited. Apparently a modicum of feeding during this period is essential, because larvae confined in cages without food during the winter, but in which winter conditions in the field were otherwise simulated, have never survived for a period exceeding 60 days.

During this winter period all activity seems to be slowed down, but there is never any true quiescent period or hibernation. Wireworms dug up during the winter have been sluggish, but would crawl about slowly or burrow into the soil.

CANNIBALISM

Almost all wireworms are reputed to be cannibalistic, and this tendency seems to be aggravated when a number are confined in a small container. If a number of larvae of *Horistonotus uhlerii* are confined overnight in a pint receptacle full of soil but with no food present, many of the wireworms will be killed. The sand wireworm seems to be very irritable and will attack and bite anything that touches or disturbs it. The integument is neither so tough nor so highly chitinized as is that of most other species, consequently it is easily pierced by the powerful mandibles, and several cases have been observed under cage conditions where one wireworm fed upon another, apparently burying its mandibles in the soft body and sucking the body juices.

It is quite probable that the cannibalistic tendency is influenced by food supply. Indications are that cannibalism seldom occurs under natural field conditions. It is not at all uncommon to find as many as 15 or 20 wireworms under a single small hill of corn, and the writer has collected as many as 41 active wireworms from a 6-inch cube of earth about the roots of one small corn plant; yet in no instance has a wireworm ever been collected in the field showing injury from the bite of another. Furthermore, no mortality occurred from the confinement of four or five larvae in a 6-inch flowerpot where there was plenty of food, although the period of confinement on several occasions lasted 4 or 5 months.

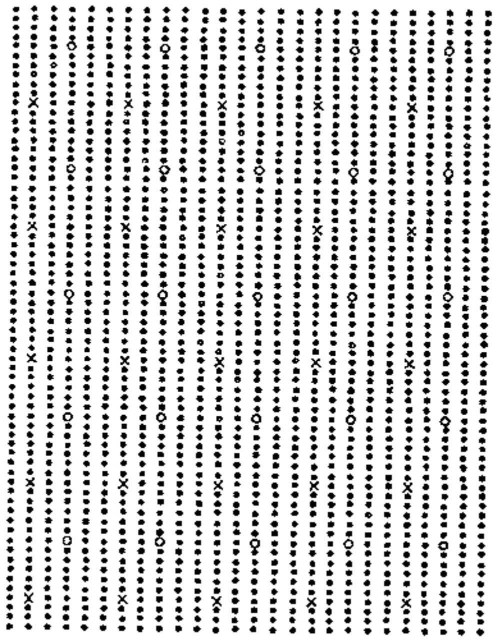

FIGURE 12.—Diagram showing method of taking samples for estimating the wireworm population in a cornfield. Each dot represents one hill of corn in a half-acre plot. The rows were 5 feet apart and the hills 30 inches apart in the row. Two examinations were made, each by a different person and at a different time, the circles representing the locations of the first samples taken and the cross marks those of the second examination. Approximately a 6-inch cube of soil was examined from around the roots in each sample hill.

POPULATION PER ACRE

Workers with other species of wireworms have reported very heavy infestations, in many cases several hundred thousand per acre. Miles and Petherbridge (*6*), in 1927, reported an estimated population of *Agriotes*, in England, of from 215,000 to 510,000 per acre. M. C. Lane, in recent correspondence, has stated that in the Pacific Northwest, infestations of the Pacific coast wireworm (*Limonius canus* Lec.) often exceed 1,000,000 per acre.

Such records are in marked contrast to infestations of the sand wireworm noted in South Carolina. The heaviest infestation ever found by the writers was estimated at only 9,185 per acre, based upon a count of wireworms per 100 hills of corn with a theoretically complete stand, whereas the actual stand was far from complete, so the infestation probably fell much below that figure. In North Carolina and South Carolina during April and May most of the wireworms in a given field are concentrated in close proximity to the young corn plants. In no instances have larvae ever been taken in the middle of the rows, and at this season it is doubtful whether even 5 percent of the wireworm population at one time would be found at any distance from a hill of corn. In the spring of 1931, as soon as the young plants were above the ground, infestation records were taken on strips 1 foot wide and 50 feet long (50 square feet) directly on rows of drilled corn, cotton, and potatoes, and also on check strips of the same size between the drilled rows which were 8 feet apart. In the upper 6 inches of the 50 square feet of corn row there were 79 wireworms; in the cotton row, 19; and in the potato row, 23; whereas in the three check strips between the rows there was not found a single wireworm. Even assuming, however, that 50 percent of the wireworms were scattered through the large surface area not directly under the hills of corn there would still be a hypothetical infestation of less than 20,000 per acre.

In making examinations to determine wireworm population during the course of this work, a systematically random method of sampling (fig. 12) was used which furnishes an indication of the infestation in each part of every plot.

FORMATION OF PUPAL CELL

The pupal cell is found in the soil at a depth ranging from 4 to 5 inches. It is merely a small, unlined, oval-shaped space formed by the twisting movements of the mature larva.

NATURAL ENEMIES AND CHECKS

PARASITES

Wireworms are remarkably free from parasites. In his review of literature referring to parasitism among elaterids, C. A. Thomas (*7*) mentioned only one instance of a wireworm parasite attaining economic importance. In this instance, a serphid, *Paracodrus apterogynus* (Hal.), was recorded as parasitizing an average of 25 percent of the larvae of *Agriotes obscurus* (L.) collected in Esthonia in 1925.

Gibson (*2*) stated that he never succeeded in rearing any internal parasites from larvae of *Horistonotus uhlerii* Horn, and Conradi and Eagerton (*1*) merely recorded the death of a few larvae "presumably from an annelid parasite observed in their bodies."

In 1931 a number of sand wireworms were collected in the field near Brunson, S. C., and many of them were found to be dying, apparently from the attack of a nematode, identified by G. Steiner of the Bureau of Plant Industry, United States Department of Agriculture, as a species of *Diplogaster*, a form not known to be parasitic. However, during the course of the season of 1931, 8½ percent of all field-collected larvae, several thousand in number, died, apparently from the attack of this nematode.

In 1934, nematodes in dead, laboratory-reared wireworms were identified by Dr. Steiner as *Cephalobus persegnis* Bastian, a known parasitic form.

On various occasions sand wireworms have been collected which were apparently killed by a parasitic fungus. In the spring of 1934 a group of such larvae collected at Fairfax, S. C., were found by Vera K. Charles of the Bureau of Plant Industry, to be attacked by a species of *Fusarium* and by *Aspergillus flavus* Link, but Dr. Charles stated that these fungi were apparently secondary rather than actually parasitic. At a later date Dr. Charles observed in another collection of dead wireworms what appeared to be resting spores of an *Entomophthora* very closely resembling *Entomophthora carpentieri* Girard, a definitely parasitic form.

PREDATORS

Conradi and Eagerton (*1*) recorded that a dipterous larva, *Psilocephala* sp., probably *pictipennis* (Wied.), and another elaterid larva, *Conoderus vespertinus* (F.), are predacious upon the sand wireworm; and that a robber fly, *Proctacanthus brevipennis* Wied., a tiger beetle, *Cicindela rufiventris* Dej., and a spider, *Peucetia viridans* (Hentz), are predacious on the adult beetles.

Gibson (*2*) did not mention predators except to state that birds feed upon "all kinds of wireworms."

At Fairfax the larvae of a therevid fly, *Psilocephala rufiventris* Loew,[9] has been known to prey upon the sand wireworm to a minor extent. When confined in experimental cages, however, these therevid larvae did not prove to be effective predators, since only an occasional wireworm was attacked by them.

Three hemipterons, *Oncocephalus geniculatus* (Stål), *Apiomerus crassipes* (F.), and *Zelus cervicalis* Stål,[10] have been observed feeding upon adults of *Horistonotus uhlerii*, as has also the spider *Peucetia viridans*. It seems probable that the robber flies, the cicindelids, and numerous birds must feed upon these click beetles to some extent, but no definite observations have been recorded upon this point.

All the predators combined, however, are very inefficient, since their activity is necessarily confined almost entirely to the male beetles. The females are exposed to attack for such a short period of time that the predators' opportunity to attack them is necessarily very limited.

EFFECTS ON THE WIREWORM OF EXTREMES IN SOIL MOISTURE

The sand wireworm is known to be exceptionally sensitive to extremes in soil moisture. It is not so highly chitinized as the majority of wireworms, and consequently is not so well protected from adverse

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[9] Determined by C. T. Greene.
[10] Determined by H. G. Barber.

conditions. Very dry soil, or even exposure to air-dry soil for a few minutes, is invariably fatal. Conversely, excessive moisture is equally fatal. The sand wireworm was never found in completely dry soil or in low, heavy, wet soils (fig. 13). From 34 to 65 wireworms per 50 hills of corn were found in soils that had a moisture content of from 4.07 to 6.18 percent down to 14 inches below the surface after a heavy rain, but none were found in soils that at such a time could hold from 14 to 20 percent of water. In periods of drought the larvae move deeper into the soil, apparently in search of moisture. In rearing cages the larvae quickly succumbed to either excessive dryness or flooding.

In 1932 the rearing cages were located on relatively low ground, and a very heavy rain completely flooded them. The water was

FIGURE 13.—A cornfield showing the effect of wireworm infestation in the foreground on light soil, while there is a good stand of corn beyond on a lower, heavier type of soil.

drained off within an hour, nevertheless approximately three-fourths of all the wireworms in the flooded cages were killed. This was probably due to the flowerpots being tight enough to prevent rapid drainage, and as a consequence the contained soil was maintained in a supersaturated condition for several hours. It has been suggested that the reason the sand wireworm is found in only one particular type of soil is that this type cannot be flooded for any length of time. In such soil the underlying strata of sand function as subterranean channels to carry off quickly any excess water, even under conditions of very heavy precipitation.

In view of the indicated sensitiveness to excessive soil moisture, reports of drowning of sand wireworms as the result of heavy rains would seem entirely credible, at least under some soil conditions. On several occasions reputable farmers have been heard to state that they had seen entire fields depopulated of wireworms by heavy rains and that the wireworms were evidently drowned, since they came to the surface of the soil, where they could be readily seen, and died in large numbers.

Field observations, however, have not substantiated the belief that excessive soil moisture induced by heavy rains causes high wireworm mortality under all conditions. On May 28, 1934, over 5 inches of rain fell at Fairfax within a period of 24 hours, and the soil of the experimental plots was apparently saturated with water for at least 24 hours. Again on June 4, only 6 days later, nearly 3 inches of rain fell, and the soil was again saturated for a period exceeding 24 hours. Air temperatures recorded on these dates were, for May 28, maximum, 53°, minimum, 51° F.; and on June 4, maximum, 81°, minimum, 66°. The mean soil temperatures at the 2-, 4-, 6-, and 21-inch depths were 53.5°, 54°, 55°, and 56°, respectively, on May 28, and 66.5°, 66°, 67°, and 62°, respectively, on June 4.

Since infestation counts had been made in the plots just prior to the first rainfall, the wireworm infestation was definitely known. One week after the second rain the soil in the plots was again examined and it was found that there had been no appreciable decrease in the infestation in any of the plots. It seems extremely doubtful, therefore, whether heavy rains would be effective in drowning this wireworm, under the soil conditions in these plots.

ARTIFICIAL CONTROL

DIRECT CONTROL

Since the wireworm spends practically all its life in the soil, where a poison spray or dust cannot easily reach it, almost the only possible direct control measure is soil fumigation. This, however, would be very expensive, and its benefits are so temporary that its use can be justified in only a few exceptional cases, as the cost of soil fumigation is usually more than the value of the crop involved. The average farmer or gardener living in the area infested by the sand wireworm cannot afford to consider such a method; for even if the treatment were effective in completely ridding the land of wireworms, the protection would last only a few months.

No tests of soil fumigants against the sand wireworm have been made by the writers. Both carbon disulphide emulsion and calcium cyanide have been used successfully against other species of wireworms, but the expense of using these materials is so great that only florists or gardeners might at times make use of such a method of control. Perhaps some very cheap soil fumigant may be discovered in the future, but the writers know of no such material.

INDIRECT CONTROL

Since a direct control is impractical, it is necessary to adopt an indirect method. Such a control has been developed; and although slower and less spectacular than a direct control would be, it is efficient, economical, and so easy and simple to apply that any farmer can make use of it.

There is no known method by which this pest can be completely eradicated from the land, nor is any *single* satisfactory method known by which the sand wireworm can be controlled. Nevertheless, by the adoption of the farm practice discussed in this bulletin and by the modification of certain other practices wireworm losses may be greatly curtailed.

LAND RESTING

Land resting is one of the oldest and most effective methods of controlling the sand wireworm. If a farmer has sufficient land to permit half of his fields to lie idle each year, the wireworm problem is easily solved. The adult beetles emerge in the uncultivated fields, and the majority of the females fly to adjacent fields of corn, cotton, or cowpeas, to deposit their eggs. Consequently, the following year the infestation is usually very light in the fields which were rested. Pasturing is just as effective in ridding land of wireworms as is letting it grow up in weeds.

When prices were low, the wireworm problem was of minor importance in South Carolina, since the majority of the farmers had much more land than they could cultivate profitably. Under such circumstances the procedure of land resting offered a very simple and effective remedy for this pest. Under normal conditions, however, most farmers feel that it is necessary to utilize every acre as fully as possible all the time in order to make a profit; and under such conditions land resting cannot be practiced, except at a very heavy economic loss.

PLANTING RESISTANT CROPS

There is a marked difference in the ability of various crops to tolerate wireworm attack. Corn, cotton, and potatoes seem to be the most susceptible of the major crops to injury by the sand wireworm, with cowpeas a close fourth. Peanuts, asparagus, beans, and cucumbers are also sometimes injured.

The more resistant crops are probably the small grains, particularly oats and rye, velvetbeans, tomatoes, early watermelons, and late sweetpotatoes. Cabbage seems practically immune to attack by this insect.

The comparative immunity to injury of some of the foregoing crops is largely dependent upon the season of the year the crop is planted. Thus small grains escape wireworm injury on infested land, not because the sand wireworm does not attack them, but because of the fact that these grains are usually planted in the fall and make most of their growth during the period of the year when the wireworms are deep in the soil and relatively inactive.

PLANTING AT SAFE DATES

In South Carolina the sand wireworm usually does not begin to attack crops in the spring until about the middle of April, and for all practical purposes the injury may be said to cease about the middle of June. Crops are never seriously injured late in the summer, in fall or winter, or early in the spring. The danger period is from April 15 to June 15. It is obvious, therefore, that the planting of susceptible crops should be avoided during this period.

AVOIDANCE OF INFESTATION

The eggs laid by the females of *Horistonotus uhlerii* one summer produce a wireworm infestation which is injurious the following spring. Evidence has been obtained that the female beetles are definitely attracted for egg laying to land on which certain crops are growing. Corn, cotton, cowpeas, and potatoes seem to be especially attractive. Approximately 75 percent of the eggs are usually laid during the last 2 weeks of June and the first week of July. It is evident, therefore, that if land is kept free, during that period, of any crop that will attract the egg-laying females, an infestation can be avoided on that land the following year.

CROP ROTATION

Since the female beetles of the sand wireworm are attracted to growing crops of corn and cotton, this attraction may be used to advantage in arranging crop rotation as an important method of combating this pest. Land planted to a susceptible crop for 2 or more years in succession will build up a large wireworm population so quickly that almost any crop planted therein will be destroyed. On the other hand, by using a rotation in which a susceptible crop is followed by a resistant crop, a wireworm infestation may often be reduced to a point where serious crop injury will not occur.

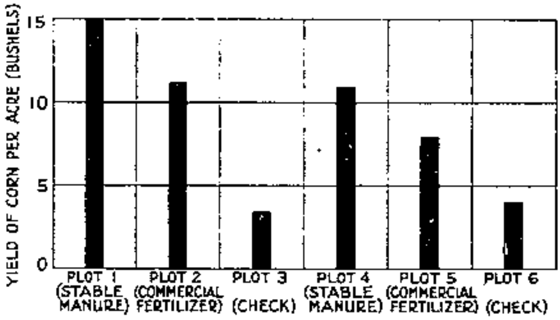

FIGURE 14.—Effect of applications of stable manure and commercial fertilizer on land infested with the sand wireworm, Fairfax, S. C., 1932. The manure was applied broadcast in the fall of 1931 at the rate of 10 tons per acre. The commercial fertilizer, 8–3–3, was applied just prior to the planting of the corn, at the rate of 400 pounds per acre. Infestation was fairly uniform and was approximately 40 to 45 larvae per 100 hills of corn.

MAINTAINING SOIL FERTILITY

Fields infested by the sand wireworm are almost invariably characterized by a soil deficient in humus. Field experimentation has demonstrated that much benefit can be obtained, and the wireworm injury reduced, by the incorporation of organic matter in such soils, especially through the plowing under of leguminous or other cover crops and by heavy applications of stable manure or compost.

The improvement of the soil with heavy applications of organic matter will not rid land of wireworms, but it will aid greatly in enabling the growing crop to overcome or tolerate wireworm attack (fig. 14). Humus increases the water-holding capacity of the soil and stimulates a heavy, vigorous growth condition which is especially needed in combating the sand wireworm.

In the presence of heavy wireworm infestation, the plowing under of winter cover crops over a 3-year period, without other treatment, increased the yield of corn from practically nothing to 19 bushels per acre (fig. 15). In studying this figure, an increase of wireworm population will be noted in 1933. To some extent this increase is common to both plots, and in part may have been due to unknown factors such as often cause a natural seasonal fluctuation in the size of wireworm broods. However, the unusually sharp rise in population in the no-cover-crop plot might perhaps have been due to the fact that in 1932 three-fourths of this plot received a treatment of raw cottonseed. Some of this seed germinated and the cotton stalks grew among the cornstalks during the entire season and remained alive all winter. It is quite possible that the presence of this cotton increased the winter survival of the wireworms.

The relation between the humus content of the soil and sand wireworm injury is often illustrated in fields of corn or cotton which, although practically ruined by the sand wireworm, contain one or more spots where the plants are large, vigorous, and normal in every way (fig. 16). Such spots are almost invariably either on low ground representing a heavy type of soil in which wireworms will not live, or in a portion of the field where a pile of oat straw or hay was allowed to stand the previous winter, with the result that much of the straw in contact with the damp ground rotted and was later plowed under. These examples provide evidence of the benefit to be derived from incorporating humus in the soil as an aid to wireworm control.

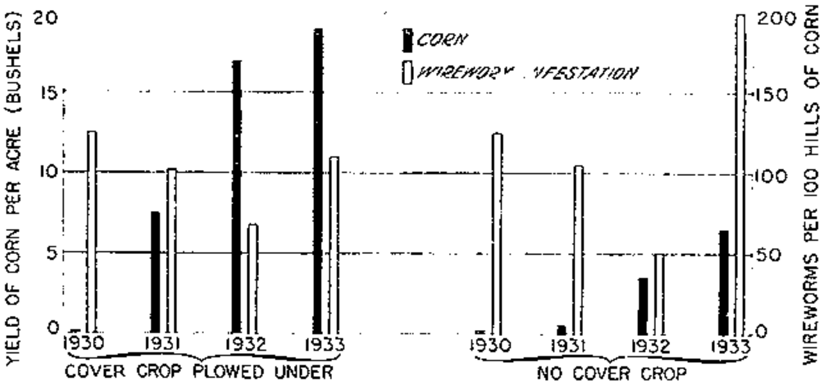

FIGURE 15.—Effect of a winter cover crop, plowed under, on land infested with the sand wireworm, Fairfax, S. C., 1930-33. The yield of corn and the wireworm infestation on two adjoining plots are shown. In both plots the cornstalks were plowed under each year, but in the plot on the left a winter cover crop was grown and plowed under each year.

IMPRACTICAL REMEDIES

Numerous methods of direct control have been tested against the sand wireworm but all have proved valueless, impracticable, or, at the best, of only slight benefit. Some of these methods are worthy of brief discussion.

SEED TREATMENT

There is no known seed treatment that will prevent the sand wireworm from attacking young plants, because this species does not feed upon the surface of planted seed. They sometimes bore into a germinating seed and feed upon the tiny sprout, but the principal injury is to the young stem and roots. Even if the seed could be entirely protected, this practice would still not prevent wireworm damage.

INSECTICIDES

With the exception of soil fumigants, which are impractical on a field scale in the South Atlantic States at this time because of the expense, there is no known method of reaching this pest with a poison. Wireworms feed upon the roots and underground portions of the stems of growing plants, and consequently they cannot be killed by mixing a stomach poison in the soil in quantities considered practical. Treatment of the soil with lead arsenate at dosages up to 400 pounds per acre has proved worthless.

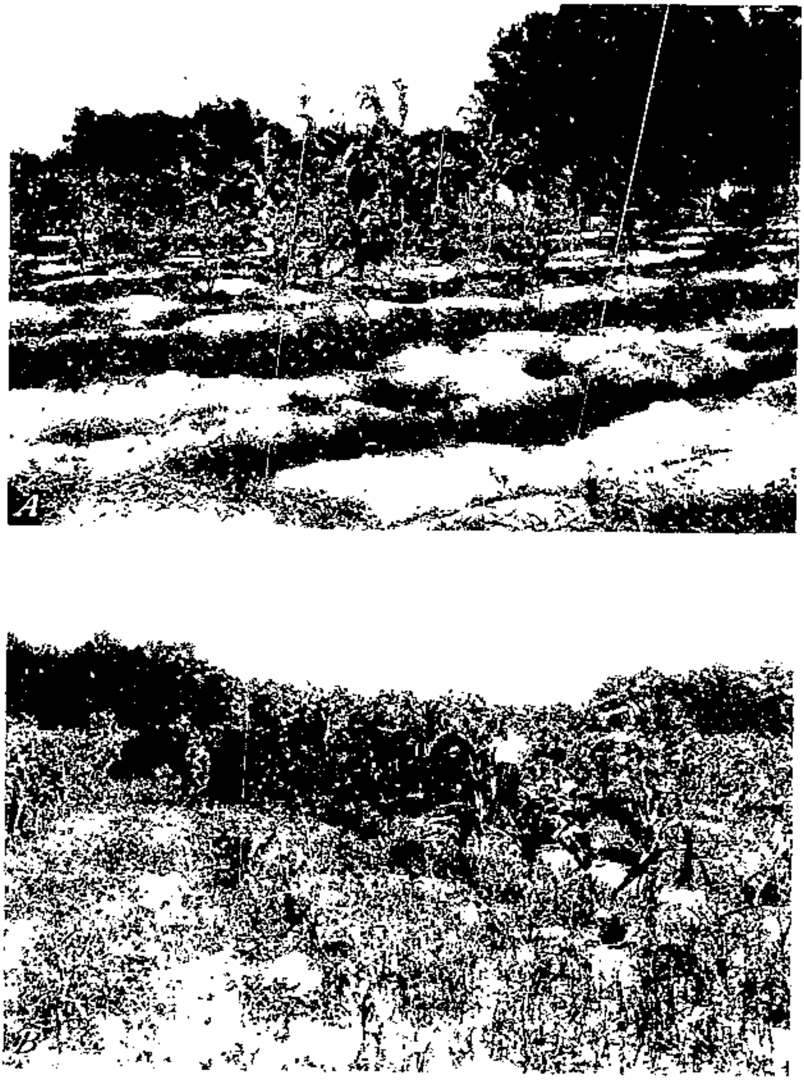

FIGURE 16.—Effect of humus on land infested with the sand wireworm: A, The spot in the center of the picture with normal growth of corn is where a haystack stood during the previous fall and winter. Much of the hay which was in contact with the wet ground rotted and was plowed under. B, The spot with normal growth of corn is where oats were threshed the previous year and a large quantity of the remaining litter was plowed under. The corn surrounding this spot is severely stunted by wireworms.

Soil treatment with crude naphthalene has been ineffective except at dosages of 1,200 pounds or more per acre, and dosages as low as 400 pounds per acre caused severe injury to growing corn.

Soil treatment with paradichlorobenzene was ineffective, even at dosages of 2,000 pounds per acre.

Treatment of land with lime, kainit, nitrate of soda, and cyanamid, although beneficial to crops from a fertilization standpoint, showed no value as a direct control method against this wireworm. None of these materials evidenced any repellent action at any of the dosages tested.

BAITING

Larvae of the sand wireworm do not seem to be attracted to any bait except germinating seed. The germinating seeds of corn, cotton, and oats exert some attraction but not to a degree that will allow this reaction to be used as an aid to control.

There seems to be a theory, rather prevalent among the farmers of the Fairfax section of South Carolina, that drilling cottonseed adjacent to a row of an infested crop or burying a handful of cottonseed adjacent to an infested hill of corn will afford protection from the sand wireworm. Experimental tests have not substantiated this theory. A few wireworms are attracted to the germinating cottonseed but not in sufficient numbers to afford any degree of protection to the crop. On the other hand, the use of cottonseed has the decided disadvantage that unless care is exercised to prevent the growth of the cotton it may serve to increase the wireworm population the following year. This reaction is probably due to the fact that in South Carolina, and farther south, cotton grows as a perennial and the roots serve as a food supply for the wireworms during the fall and winter and early in the spring. Even when the cotton is plowed under in the fall, many roots remain alive all winter, and the sand wireworm feeds to a limited extent during this period.

PLOWING

Winter plowing will not control this pest. The winter is passed at a depth of 18 to 30 inches in the soil, far below the plow line.

Summer plowing is also ineffective. A few individuals might be killed by actual contact with the plow, but the sand wireworm is very active, and merely turning them up to the soil surface has no appreciable effect in reducing their abundance. They burrow back into the soil too quickly for any significant number of them to be caught by birds or other natural enemies. Furthermore, only a small percentage of the total wireworm population is turned up by the plow, since the larvae are concentrated under the rows of growing plants.

FALLOWING

Laboratory tests indicated that the sand wireworm might be successfully starved by maintaining an absolutely clean fallow during the fall and winter and early in the spring. Sixty days of such treatment in the laboratory was sufficient to kill 100 percent of the wireworms. Consequently a series of field experiments was conducted in 1933–34 to test the possibility of utilizing fallowing as an aid to sand wireworm control. Eight plots of 1 acre each were prepared, and one-half of each plot was cultivated thoroughly at regular intervals for a varying length of time. In three plots the fallowed half of the area was maintained in a state of clean cultivation for a period of 150 days, from November to April. In two plots the fallowed half was cultivated for 100 days, from January to April. In three plots the fallowed half was kept clean for a period of 60 days, from February to April.

A study of figure 17 will readily show that fallowing was of little or no value as a control measure for the sand wireworm in any of the three series of plots. This experiment leaves several unanswered questions. In particular, was there an actual die-off in the undisturbed fields? It is doubtful, even though there seems to be an apparent indication of this in some plots. There was certainly an abundance of food in the undisturbed plots, and at that season of the year it scarcely seems as if there would be very much difference in the temperature or moisture between the fallowed and the undisturbed fields.

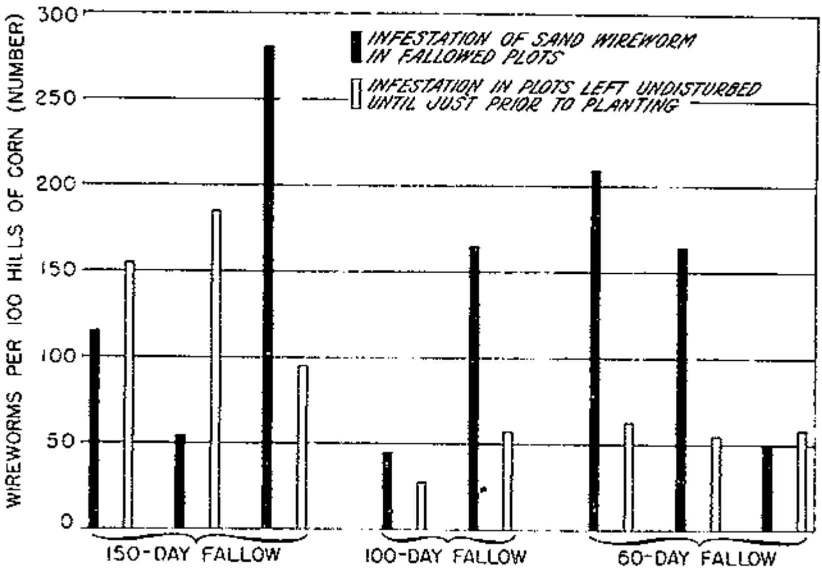

FIGURE 17.—Experiments in allowing land to lie fallow for various periods for the control of the sand wireworm, Fairfax, S. C., 1933–34.

Rainfall was lighter than normal during a part of the period, but the soil of all plots was moist during the entire period.

One reason for the success of fallowing in the laboratory and its failure in the field was the inability entirely to eliminate a food supply in the field. The fallow plots were kept absolutely free of all growing vegetation—there was never any weed or grass growth on top of the soil—but soil samples showed that germinating weed and grass seeds were present in the soil below the surface throughout the entire winter. In plowing these plots many seeds were buried to a depth of 8 or 9 inches, and some of them germinated and made a growth of several inches without approaching the surface of the soil. It is even conceivable that these buried seeds furnished a better and more readily available food supply than did the roots of the plant growth on the undisturbed plots.

TRAP LIGHTS

Trapping of adults of this wireworm with lights is ineffective. Many adults may be caught in this manner, but all those caught have proved to be males.

CONTROL RECOMMENDATIONS

When a surplus of land is available, fields infested by the sand wireworm should not be planted oftener than every other year. Resting land for 1 year will greatly reduce the number of wireworms the following year.

Crops such as corn and cotton, which are susceptible to severe wireworm injury, should either be planted as early as possible and stimulated into rapid growth with commercial fertilizers and cultivation, or the planting of such crops should be delayed until after July 10.

Potatoes and watermelons should always be planted as early as possible in the spring. Early planting is particularly important in the case of watermelons because most of the injury to this crop occurs when the plants are in the seedling stage. It has been demonstrated repeatedly that on land infested with the sand wireworm, early planted melons will come up and produce a satisfactory crop when it is almost impossible to obtain even a partial stand with those planted late.

On infested land forage crops, cover crops, and sweetpotatoes should not be planted before July 10. By practicing such a delay, injury by the large, nearly mature wireworms is avoided and the danger of attracting the female beetles is also largely eliminated. For instance: Cowpeas planted in April or May are not only liable to serious injury but will probably attract egg-laying female beetles, and thus be responsible for a heavy wireworm infestation the next year. However, cowpeas planted after July 10 are not subject to serious wireworm damage that year, and there is no chance of their causing an infestation the following year.

This should not be construed to mean that cowpeas should not be planted in corn before July 10. The female beetles are attracted to cornfields in any event, and it can add very little to the danger to plant cowpeas in the corn. Planting cowpeas or beans between the rows of corn during the last cultivation is a very valuable means of increasing the soil humus, and such an opportunity should not be neglected.

Seedbeds should be carefully and thoroughly prepared, commercial fertilizers used when possible, and a good state of cultivation maintained at all times. Such practices are important in any system of farming, but in combating the sand wireworm it is particularly necessary to have all early crops up and growing vigorously in the spring, when the attack of the pest begins.

The soil should be improved at every opportunity by additions of organic matter such as stable manure and compost, and by the use of leguminous or winter cover crops, supplemented by the planting of beans or peas in corn.

In addition to the foregoing, an agronomically acceptable plan of crop rotation is extremely important. Such a rotation should take advantage of the advisability of early and late planting, the susceptibility of different crops to wireworm injury, and the necessity of building up the soil fertility. The following rotations are recommended:

In instances of severe wireworm infestation a 2-year rotation, as described below, is advised.

First year.—Small grain (oats or rye). After cutting the grain, the land must not be planted before July 10, if infestation the following year is to be avoided. After July 10 plant a cover crop, a hay crop, or late sweetpotatoes. Late in the fall, after hay or sweetpotatoes have been harvested or cover crops turned under, plant a winter crop such as Austrian Winter peas or vetch.

Second year.—Turn under winter cover crop and, as quickly as the land can be prepared, plant corn, cotton, or other susceptible crop.

When the wireworm infestation is known to be light, a 3-year rotation may often be used to advantage. Thus:

First year.—Same as first rotation plan.

Second year.—Turn under winter cover crop early in spring, and as soon as possible plant corn, cotton, or other susceptible crop. After the crop is harvested in the fall, plant a winter cover crop such as Austrian Winter peas, or vetch.

Third year.—Turn under the winter cover crop early in the spring and, as quickly as the land can be prepared, plant one of the less susceptible crops, such as velvetbeans, tomatoes, or early watermelons.

Susceptible crops such as corn, cotton, or cowpeas should not be planted on the same land 2 years in succession. The practice of following corn with cotton, cotton with corn, corn with corn, or cotton with cotton leads usually to severe wireworm infestation in localities where the pest is abundant.

SUMMARY

The sand wireworm range is confined to a particular type of light, sandy soil, and the insect occurs in certain areas of the South Atlantic States, the Gulf States, and several States in the Mississippi Valley. It is a pest of nearly all cultivated crops, particularly corn, cotton, and cowpeas.

In the South Carolina Coastal Plain this wireworm has a 1-year life cycle, with approximately 12 days passed in the egg stage, 352 days in the larval stage, 11 days as a pupa, and, in the laboratory, 10 to 14 days as an adult.

No important natural enemies were found during this investigation, nor have any been reported.

Direct control of this insect is not practical, but a large measure of relief from the pest can be obtained by the following practices: Land resting, attention to favorable planting dates, avoidance of attracting the egg-laying female beetles, and building up soil fertility with humus. An acceptable crop rotation has been very successful.

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