THE SEASONAL VERTICAL MOVEMENTS OF WIREWORMS (ELATERIDAE) IN SOIL NEAR MANHATTAN, KANSAS

by

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TABLE OF CONTENTS

INTRODUCTION

Investigators in the field of Economic Entomology have shown a dire need for the study of the relationship which exists between subterranean insects and the soil in which they live, when injury to crops becomes great enough to necessitate the application of control measures. Soil insects offer many problems, because of the inability of workers to trace the development of the life processes of organisms in the soil.

The soil is the habitat of great numbers of insects during some portion or all of their life cycles. Naturally, many complexities arise from a study of soil in relation to insect life, since individual organisms exhibit special adaptations to their environment. The soil in itself is a very complex medium, which must be taken into consideration in a study of any control measures for under ground insects.

If one investigates some of the factors affecting the soil and insects, one must first consider temperature, a measurement of heat which has its source in the solar system in the form of radiant energy, and which has a pronounced effect upon the insect and plant life of the soil. Moisture, another important factor, is closely associated with temperature and works interdependent with it in nature.

As a general rule, insects of the soil have the opportunity to select the moisture and temperature conditions to which they are best adapted.

Wireworms, generally referred to as larvae of click beetles which belong to the family Elateridae, do extensive damage each year to grains, root crops and truck gardens. The extent of the injury is often overlooked by the untrained person, due to the obscure nature of wireworm activities and the fluctuation in amount of injury that occurs from year to year.

King (1928) estimated the loss to crops by wireworms in the province of Saskatchewan in 1926 to be three and one-half million dollars while the loss in 1927 exceeded that of the previous year. This loss, he contends is second only to wheat stem sawfly.

Many control measures have been advocated by workers in the past but many of them have been very unsatisfactory. The wide range of complexities that occur in dealing with insects in the soil are largely responsible for the inefficient control methods and not until a more complete knowledge of the relationship which exists between the soil and life in the soil, will workers be able to solve the great problems of subterranean insect control which face the agriculturalist at the present time.

The experiments and studies of many workers on control measures as records indicate, were conducted in the laboratory under unnatural conditions. Thus it would be probable that many factors which affect insects in nature would be eliminated. It is possible to regulate temperature and moisture to a certain extent, but the biotic potential which insects undergo in nature is greatly reduced, when parasitic and predacious enemies are not present. The wide variation in importance of various pests in different areas, necessitate the need for study in many representative areas before control measures can be successfully introduced.

Consequently, it is the purpose of this experiment to determine the seasonal vertical movement of wireworms in the soil near Manhattan, Kansas and to correlate this movement with the variations in temperature, moisture and vegetative covering.

REVIEW OF LITERATURE

Literature on the subject of wireworms is extensive. Vast amounts of data and observations are presented in regard to portions of life history, habits, economic importance and control measures, but very little literature is available, dealing with seasonal vertical movements.

Early History:

The early history of wireworms is probably best rendered by Curtis (1883) an Englishman, who made extensive studies on farm insects. Curtis found, that in 1813 according to Kollar, a great proportion of the annuals sown in the Botanic Garden at Hall were destroyed by wireworms.

From the Transactions of the Academy of Science in Sweden, 1779, he found reference to experiments by Bierkander, in which he states, "I have made many experiments to discover by what means the wireworms may be destroyed."

Other early day workers and observers on food habits and destruction of wireworms as listed by Curtis, include Hope (1838), Bennet (1840), and Salisbury (1816). Work by farmers and other observers is also mentioned in his review of early history, but are not of consequence here.

An early Entomologist who gives wireworms much consideration is Omerod (1890). He states, "Wireworms may perhaps be said to do the greatest amount of damage of any of our farm pests: They destroy root, grain and fodder crops.

The wireworms are said to live five years in the grub stage, but the length of time probably depends on the food supply. Where they are well fed, it is supposed that they take only about three years before changing to the pupa. But however this may be, with the exception of any temporary pause in winter (when they go deeper and deeper into the ground as the frost increases), they feed voraciously near the surface till the time has come to turn into chrysalis, then they go deep into the soil, and from an earthen-cell in which they change."

Strickland (1927) summarizes the history of wireworm as follows: "From the earliest days of grain production on the Canadian prairies, farmers have suffered some loss owing to the destruction of newly-seeded grain by wireworms. Up until ten years ago, this loss has not been of a very serious nature. More recently, however, especially on fields that have been in crops upwards of fifteen years, depredations have so greatly increased, that, in some sections of the country, wireworms are now looked upon as the most serious menance that the grain producers have to face. Since it is in those fields that have been for the longest time under cultivation, that the increase is most noticeable. It is to be feared that, unless some method for checking this increase can be found, even greater losses are to be anticipated in the future."

Soil Factors:

The soil being the media in which wireworms live, it perhaps would be well to list some of the literature which deals with factors affecting the soil, particularly moisture and temperature. The three ways in which soil water may exist as listed by Cameron (1913) are:

1. Gravitational, which percolates through the soil under action of gravity.

2. Hygroscopic moisture, which condenses from the atmosphere laden with moisture on the surface of the particles of an air dry soil.

3. Capillary water, which is held by surface tension against action of gravity.

Cameron considers the gravitational water to be the most abundant variety and the one which is most destructive to insect life within the confines of the soil. There are many opinions as to the extent in which insect life would be affected by gravitational water. Curtis (1883) believed any endeavor to destroy wireworms is almost impracticable when he found they exhibited signs of life in water for four days, but on the other hand, he believes if a field were laid under water for a longer period of time, it would finally destroy them.

The soil moisture content determined by Anderson (1920) averaged about 10 per cent from April to September under normal weather conditions and from September to April about 16.7 per cent.

Damage:

Britton (1926) found damage done by *Pheletes agonus* Say was severe in early June, but after a few days the wireworms disappeared probably going deeper into the soil to escape extreme heat.

According to Fulton (1928) wireworms become less destructive in summer on account of working deeper into the soil at that time, but in the spring and early summer they are found in upper soil layers or even above the soil in manure in pastures.

He admits his data on the problem are not sufficient to fully explain the influence of temperature on the vertical movements of wireworms, but asserts that soil moisture would be an equal or even greater factor, than temperature in determining seasonal migration.

The results of his experiments show that wireworms cannot live long on the surface of sod ground on hot days, and that the larvae of *Melanotus* are more resistant to heat than the adults, but they did not ordinarily seek higher temperatures.

King (1928) found the severity of damage to the first crop after the fallow year was largely connected with soil moisture, the conditions favoring wireworm activity for a longer period than in other fields in the same year, and was not due to changes in wireworm population. He also determined an increase in population usually followed a year of high precipitation, while an especially dry summer resulted in a decrease.

Hibernation and Habits:

In their work, Conradi and Eagerton (1914) were able to determine the depth of Monocrepidius vespertinius Fab. larvae at Marion, S. C. Their results show larvae three to three and one-half inches below the surface of the ground during winter (1913-1914) and were never found deeper except during dry weather in spring (1914) where they occurred five to six inches below the surface.

Gibson (1916), in Missouri, brings out the fact that wireworms feed upon the roots of their food plants throughout the summer until about the first of October. During this time he finds they are within eighteen inches of the surface, the depth depending upon the moisture content of the top soil.

During a hot dry spell the wireworms were found from 12 to 18 inches below the surface but after a rain they could be found within two inches of the surface, and with the approach of cold weather they began a downward movement. Gibson contends these facts account for the farmers inability to locate the position of wireworms during fall and winter months.

In addition to the foregoing observations, Gibson finds that by the last of February in some localities, or as soon as winter breaks up the larvae gradually make their way to within two to three feet of the surface, and by the middle of April, they are numerous within six inches of the surface.

Howard (1925) found wireworms hibernate in cultivated land in Washington and California during the winter at a depth of about ten inches, and at five to eight inches below the surface of the ground, they appeared to be unaffected by frost. He also concluded that they work to the surface and began feeding in early March, early enough to damage seeds and seedling stocks.

Preliminary studies on hibernation of wireworms conducted by McColloch, Hayes and Bryson near Manhattan began the winter of (1919-1920). Although they placed emphasis on the study of white grubs, much data on wireworms were collected.

The results of the diggings of (1919-1920) show only one wireworm found in five holes dug and this one being found in a hole dug around the base of a corn plant.

During (1922-1928) 18 wireworms were found in nine holes dug. The greatest depth at which any individual was taken was 16 inches and the minimum depth four inches. The average, as calculated by the workers, for the 18 holes was seven and seven-tenths inches.

The earlier diggings from November 25 to December 21 show the depth of hibernation varying from eight to sixteen inches. One individual was taken at four inches or as generally considered above plow line on December 23, and another at six inches, but from that time throughout the winter no individual was found below 10 inches.

In the year (1925-1926) wireworms were found in 25 of the 38 holes dug. In each of two excavations ten individuals were taken. Between November 20 and February 5, only one larva was found above plow line, while on December 23, one larva was found at six inches.

In summarizing their work these writers came to the conclusions that the fact of greatest interest was that wireworms were frequently found above a depth of six inches even in mid-winter, also that the larvae can endure wide extremes of temperature and the often recommended practice of fall plowing to expose the wireworms to the rigors of winter may have less value than is commonly attributed to the practice. Since their observations were based upon such few numbers, the results were by no means conclusive.

In a preliminary report on the sugar-beet wireworm by Graf (1914), the results of studies under laboratory conditions show wireworms to travel several inches daily in root cages and from his observations he believed it would be possible for one wireworm to destroy several young beet plants in one season.

In a study of the habits of wireworms, Graf observed the young larvae were able to bury themselves in loose soil almost at once, but were temporarily checked by a compact layer about an inch below the surface; however on the following day he noted several had entered the compact layer and one had burrowed to a depth of four inches.

The very young larvae, he found were unable to survive in dry earth even a relatively short time and some which were placed in petri dishes with dry soil were dead at the end of five hours.

The field observations on movement of wireworms in the soil conducted by Miles and Petherbridge (1927) indicate a definite downward migration in autumn and an upward migration in spring. Wireworm activity in surface soil was noted to be at its height in September and October, and March, April and May. There was another downward migration in summer probably in response to temperature and moisture conditions.

From a contribution to the Ecology of Wireworm Foci, Blunch and Merkenochlager (1925) reported from the course of soil analysis of fields infested with wireworms in Germany, the common feature was that larvae assembled in places where the soil had the lowest percentage of alkalis or other bases, and that even a marked degree of acidity in the soil did not repel them.

The studies made by Roberts (1919) showed wireworms still remained in the sod or quite near the surface even in severe weather in winter; provided the soil remained sufficiently damp. They were also found in winter when digging in sod heaps or on grass lands among roots of grasses growing on the surface. Roberts found such larvae were contracted and sluggish at this time but suffered no serious damage and revived quickly when brought under milder conditions. At the same time in which these larvae were found near the surface, others were found at considerable depth. An example of such findings was a hole dug to a depth of 31 inches in sod heaps at the end of December, 1917. Fourteen Agriotes larvae were taken, half of them found among the roots of plants, or within the first nine inches, but the remainder were at depths between 14 and 24 inches.

In a series of tests made in arable land known to be infested, none were found in the subsoil, which in this field was ten to twelve inches from the surface. Roberts believed it was possible that larvae at such depths might move in their burrows nearer to the surface through the influence of rain and mild weather, but very little food would be taken between the time when they went deeply in the soil and when they returned to feed at the surface in the spring.

The population of wireworms as illustrated by Miles (1927) in a certain field where he was working, was 81 wireworms in 82 soil samples, the volume of the samples being nine inches deep and six inches square, indicating approximately 170,000 per acre. The species found were chiefly larvae of Agriotes obscuris Lin., though he found a few specimens of Athous haemorrhoidalis Fab.

METHODS

The experience of previous workers has shown that variations in the activities of insects exist under natural conditions but do not occur in artifical surroundings. Therefore, wireworms were studied in the field and in the laboratory for this experiment in order that the data would be as complete as possible and to overcome some of the difficulties which arise when an attempt is made to control the factors of temperature and moisture.

The equipment necessary for work in the field consisted of one sixteen inch tiling spade with which diggings were made, a soil auger used to obtain soil samples, sand screen, salve boxes, soil thermometer, and hygrothermograph.

Five areas were selected at various points in or near Manhattan and were designated as stations, A, B, C, D, and E. In the selection of the locations two important factors were kept in mind, the kind and amount of vegetation and the type of soil. At each station, four holes were dug one foot square and eighteen inches deep, although in the summer it was necessary to dig deeper.

In the process of digging the hole, an area one foot square was laid out, and the soil removed in layers approximately one inch deep. As each layer was removed, it was carefully screened through the sand screen and the soil examined for wireworms. This process enabled one to determine within one inch the depth of the larvae in the soil.

At times during the winter and summer it was impossible to screen the soil in the field due to the hardness of the ground, when it was then necessary to bring it into the insectary and break it apart before it could be screened.

Soil samples were taken every three inches and put in large salve boxes. They were then taken into the laboratory, weighed out in 25 gram lots and put into envelopes for two to three weeks to allow it to become air dry. Then the soil was removed and reweighed, the loss in weight being taken as the moisture content, and from this the percentage of moisture was calculated.

Temperatures were also recorded every three inches, by means of a soil thermometer.

A valuable check on the depth at which wireworms were found was a series of six inch drain tile in which wireworms had been placed in 1932, for other experiments. Two twelve inch tile were buried one on top of the other in the ground, a number of young larvae were put in the tile filled with soil, wheat was then planted in each. The dirt was removed at various times throughout the year (1932-1933) and examined for wireworms.

As previously stated other problems develop in a study of this kind, making it necessary to use field, insectary, and laboratory methods, to gain the desired results.

The first problem considered in the insectary was to determine whether the wireworms would withstand freezing. The diggings made throughout the winter supplied much data on the problem.

On November 20, ten wireworms were placed separately in one ounce salve boxes with holes punched in the lids. The boxes were filled with moist dirt and a few grains of wheat were placed in each. These were buried in holes every three inches, each box being carefully covered with soil. Then on March 28, they were removed and examined. The dirt in each box was weighed and put in envelopes to dry and at the end of a few weeks was again weighed and the moisture content determined. This method prevented any possible movement of wireworms up and down in the soil to escape the extreme cold.

The second important problem attempted was to determine the degree of heat required to kill the larvae and again field observations were used for information along with the laboratory experiment, but this time five holes were dug and boxes placed every two inches to a depth of eight inches, these were buried on June 10, and examined every two days. An attempt was made to examine the boxes during the hottest part of the day and the temperatures of the soil at that time recorded.

A gas heat controlled oven was used, in order to determine the temperature required to kill the larvae. Five wireworms were placed in the oven, in salve boxes with lids perforated, at 100°F and the moisture content of the soil in the boxes varied from zero per cent to 33 per cent. These were kept in the oven for one hour, and then examined. Successive temperatures of 105°, 110°, 115°, and 120°F. were used with new series of larvae each time but same moisture contents as previously explained. A thermometer was put inside the oven to serve as a check in regulating the temperature.

The moisture of the soil was previously determined by taking dry soil and adding the required amount of water to bring the moisture to the percentage needed.

The data which Horsfall collected on wireworms in (1928-1929), while making a similar study of the distribution of white grubs, were summarized and used as a part of this experiment.

DESCRIPTION OF STATIONS

Station A was an area located back of the field insectary on the west edge of the city of Manhattan. The soil consists of black silt loam of fine texture and very productive. The vegetation consisted of field corn. It was well cultivated so very few weeds were present on the surface of the soil at the time the diggings were made.

Station B was located near the west field insectary. The soil was of the same type as that of station A with possibly less silt present. The vegetation consisted of alfalfa about one year old with some red clover mixed in with it.

Station C which was located one and one-half miles south of Manhattan on Hunter's Island was characteristic of the laurel fine sandy loam and the laurel silt loam types of soil. The island was formed in 1903 as a result of the Kansas River changing its course. This soil formation is of two origins, laurel silt loam at about thirty inches brought in by flood waters, and the fine sandy soil blown in by the wind. The vegetation on this area consisted of melons and cowpeas.

Station D was located in a backyard garden in the city of Manhattan. The soil was rich black loam with considerable amount of humus matter present, having been fertilized heavily the previous year. The area was planted in garden crops and was well tended, so that when the plants were removed very little vegetation was present.

Station E represented a grassy area, principally blue stem sod with patches of blue grass on the lower levels. The area was located about one mile north of the college campus in the east Animal Husbandry pasture. The diggings were made on the slope of a hill and in the bottom of a small ravine. The soil is a clay loam, very heavy at about 18 inches with small fragments of limestone present.

RESULTS

The results of this experiment are divided into two parts. The first part consists of the writer's observations and studies in the field and at the insectary, while the latter part is a summary of the data collected by Horsfall (1928-1929) while working on "Distribution of White Grub".

The diggings for the writer's problem began in September, 1932, and continued each month until August, 1933. A total of 220 holes were dug during the year and 190 wireworms collected which were mainly *Monocrepidius vespertinius* Fab. and *Melanotus* sp.; also *Monocrepidius lividus* DeG. and *Aeolus dorsalis* Say.

The average temperature for the three months previous to the time the diggings began was 78.8°F and the rainfall 10.9 inches. This showed a rise in temperature of 4.5° over that of 1928 and a loss in rainfall of 6.78 inches. Therefore if the theory that wireworms go deeper in the summer to escape the heat is true, then they should have been deeper in September 1932, than in September, 1928. This conception proved true as the table I will indicate.

During September and October, a considerable amount of rainfall occurred and the temperature was below normal, consequently a slight movement upward began. The temperature in November and December was below normal and as a result the larvae remained above plow line until the middle of January.

On December 28, the ground was frozen to about an eight inch depth, except the upper two inches which had thawed, where three wireworms were observed feeding on the roots of blue stem grass. This activity was quite unusual for December in this locality.

During the latter part of January and continuing through February, severe winter weather was experienced, creating a downward migration of larvae to about seven inches. The soil was frozen to a depth of five inches.

The month of March was warm with approximately 1.5 inches of rainfall and as a result the growing season began early, causing the wireworms to migrate to the surface where they began feeding on tender shoots. They remained near the surface through the months of March and April and until about the middle of May. They could be found in a very active state at bases of corn plants, under manure in pastures, and at the base of grass.

A long period of drought with high temperatures, began the latter part of May, extended through June until the seventh of July. Thirty-five days were recorded without any moisture, and as a result larvae went deeper into the soil, one being found at 24 inches, while the average depth at which they were found was 15 inches. In June, three wireworms were found in the upper three inches, dead, presumably having succumbed to high temperatures and the low moisture content of the soil.

On July 7th, a three and one-half inch rain occurred and was followed three days later by .63 inches. Diggings were made after the last rainfall and the average depth of wireworms was found to be 15 inches, or approximately the same as the preceding dry month. The average used throughout this discussion was a weighted average.

Table I is a complete record of all data collected during the series of diggings.

It shows that a total of 220 holes were dug during the year and from this number 186 larvae were collected, 118 of these were found at or above plow line.

It is interesting to note that during every month except December, some wireworms were found within three inches of the surface.

TABLE 1

Station A

I	October T	October M	October D	November T	November M	November D	December T	December M	December D	January T	January M	January D	February T	February M	February D
1															
2	56	4^8		69	13^6		64	9^2		32			46	4^0	
3															
4			2												
5	57	6^6		68	12^0		64	9^6		31			40	12^0	
6						2			2						1
7															
8	58	$10.^8$		64	12^0		63	12^9		34			39	10^0	
9						1						1			
10															
11	58	8^8		63	14^8		62	12^0		35			40	10^4	
12												1			
13						1									
14	59	6^6		63	14^9		64	10^9		35			41	11^6	1
15															
16															
17	59	5^0		62	8^8		64	8^2		36			41	12^0	
18															

I	March T	March M	March D	April T	April M	April D	May T	May M	May D	June T	June M	June D	July T	July M	July D
1															
2	64	7^0		70	9^2		68	8^0		84	10^1		80	10^0	
3			1			3			1						
4															
5	56	10^0		66	11^0		67	8^6		81	10^0		76	12^9	
6			1						1			2			
7															1
8	54	10^0		66	13^0		67	10^0		80	14^0		77	14^7	
9												1			2
10															
11	54	10^5		64	13^0		64	12^7		78	14^3		79	14^1	
12															
13															
14	52	12^0		64	15^1		63	13^2		78	12^0		79	13^6	1
15															
16															
17	52	11^0		60	14^2		63	14^0		79	13^9		80	12^0	
18															

Station B

I	October T	October M	October D	November T	November M	November D	December T	December M	December D	January T	January M	January D	February T	February M	February D
1															
2	56	14^4	1	64	8^8		62	16^0		33	6^0		46	12^0	
3			3			1									
4															
5	56	15^2	1	61	10^0		63	14^9	1	32	17^6		45	13^2	
6						2			2			1			1
7															
8	55	14^8		61	11^2		62	12^0		33	14^0		41	13^2	
9												1			
10															
11	55	13^2		60	5^2		62	8^8		34	12^0		40	11^2	
12												1			1
13															
14	55	13^0		60	6^0		64	8^8		35	12^0		40	8^9	
15															
16															
17	54			59	8^0		65	7^6		35	9^6		41	8^0	
18															

I	March T	March M	March D	April T	April M	April D	May T	May M	May D	June T	June M	June D	July T	July M	July D
1			1												
2	68	6^0		71	7^0		78	3^0	1	100	2^0	1	97	2^3	
3			3			2			1			1			
4															
5	63	6^0		68	7^4		71	6^1		84	5^7		93	2^6	
6						2									
7															
8	63	6^{08}		69	9^0		70	7^0		78	6^0		88	4^1	
9															
10															
11	59	10^0		67	10^1		70	7^1		77	6^2		85	4^6	
12															1
13												1			
14	58	8^8		65	11^0		69	8^1	1	74	7^0	1	83	4^2	
15															1
16															1
17	56	8^0		63	11^5		69	8^9		74	7^0		82	3^8	
18															

Station C

I	October T	October M	October D	November T	November M	November D	December T	December M	December D	January T	January M	January D	February T	February M	February D
1															
2	72	5^2		48	8^0		69	14^8		34	4^0		56	6^5	
3												2			
4															
5	64	5^2		42	8^0		66	17^0		31	9^2		58	7^0	
6						1						3			1
7															
8	61	4^8		41	12^0		64	13^2		31	8^0		61	7^2	
9						2			1			2			
10															2
11	60	4^8		41	9^2		62	12^8		32	9^6		62	8^0	
12									1						1
13			1												
14	60	2^4	1	40^5	12^0		62	16^2		33	6^4		62	78	
15															
16															
17	59	2^5		40^0	9^6		63	14^8		34	6^6		61	6^0	
18															

I	March T	March M	March D	April T	April M	April D	May T	May M	May D	June T	June M	June D	July T	July M	July D
1						1			4						
2	56	6^0		75	16^0	2	80	9^0	1	96	8^0		82	9^0	
3			6			6			1						
4															
5	53	6^0		68	16^0		78	10^0		84	9^2		80	11^0	
6															
7															
8	52	6^5		64	16^8		76	10^1		78	10^3	1	80	15^9	2
9															
10															
11	50	7^8		57	17^0		74	8^7		78	10^5	1	78	15^0	
12			1												
13															
14	49	7^4		56	17^0		73	82		77	10^0		79	19^7	
15															1
16															1
17	49	8^2		56	16^0		73	8^2		77	10^0		79	13^5	
18															

Station D

I	October T	October M	October D	November T	November M	November D	December T	December M	December D	January T	January M	January D	February T	February M	February D
1															
2	51	20^0		57	10^0		64	12^0		34	18^0		46	6^0	
3															2
4															
5	50	20^0	1	58	11^2		63	12^8		32	16^0		45	10^0	
6						1			1			2			1
7															
8	48	19^2		56	9^8	2	63	11^9	2	33	14^4		41	12	
9												1			1
10						1									
11	48	18^9		55	6^9		65	11^0		36	14^2		40	10^4	
12			1						1			1			
13															
14	48	16^9		55	9^4		66	10^0		36	12^9		40	10^0	
15															
16															
17	49	16^2		56	10^9		66	8^9		37	14^8		41	10^6	
18															

I	March T	March M	March D	April T	April M	April D	May T	May M	May D	June T	June M	June D	July T	July M	July D
1															
2	60	8^0		70	7^0		85	4^0		105	3^0		110	2^5	
3			2			1									
4															
5	58	10^1		69	9^3		78	7^2		92	4^0		94	2^9	
6			1			2			1						
7															
8	56	10^3		68	10^2		72	7^0		90	4^4		90	3^4	
9												1			
10															
11	56	9^4		68	8^7		72	6^8		90	50		87	3^9	
12						1						1			
13															
14	54	9^2		66	8^2		70	6^2		88	5^0		82	3^1	
15															1
16															1
17	52	7^0		64	7^6		69	6^0		87	4^3		80	3^0	
18															

Station E

I	October T	October M	October D	November T	November M	November D	December T	December M	December D	January T	January M	January D	February T	February M	February D
1															
2	58	10^0		53	10^8		62			33	6^0		44	14^0	
3			4			5						8			2
4						3									
5	57	14^9		54	10^8	2	57			32			40	14^0	
6			3						1			1			1
7															
8	57	16^0		59	16^0		56			30	10^8		40	14^8	
9									1						
10															
11	56	12^0		55	15^6		54			31	8^8		39	14^8	
12															1
13															
14	54	10^0		58	15^5		53			34	10^9		39	14^0	
15															
16															
17	54	9^6		58	15^0		52			34	10^0		41	18^6	
18															

I	March T	March M	March D	April T	April M	April D	May T	May M	May D	June T	June M	June D	July T	July M	July D
1			10			5			1						
2	50	16^0	2	70	10^0	1	66	7^2	2	78	6^1		104	9^9	
3									2						
4			1												
5	48	13^0		68	11^5		64	8^0		80	8^0		92	11^2	
6															
7															2
8	46	13^2		67	11^5		64	10^0		81	10^0	1	87	11^5	1
9															2
10															
11	45	12^0		66	11^0		65	8^1		81	9^8	1	86	11^0	
12															
13															
14	45	10^0		66	10^0		65	10^2		80	12^0		85	10^7	
15															
16															
17	44	10^0		65	9^5		66	12^0		80	12^0		87	8^0	
18															

I = Depth in Inches
T = Soil Temperature (Fahr.)
M = Percent Soil Moisture
D = Distribution (Inches)

The results given in Table I in full detail, have been assembled in Table II for greater ease in comparison and study.

TABLE II. Depth of wireworms in relation to temperature and moisture content of the soil.

Month	Number of wire-worms	Precipi-tation	Mean soil temperature(°F)	Max. Depth	Min. Depth	Average Depth
Sept.	12	4.03	69.5	12"	2"	5.1"
Oct.	18	.60	55.3	14"	1"	5.22"
Nov.	21	.24	39.8	13"	1"	5.1"
Dec.	9	1.32	28.	12"	6"	7"
Jan.	15	.12	39.80	12"	1"	6.2"
Feb.	16	.08	31.08	15"	3"	6"
March	25	1.82	45.30	12"	1"	2.4"
April	27	2.86	54.94	12"	1"	2.6"
May	15	1.57	65.48	10"	1"	3.1"
June	10	.69	85.74	11"	3"	7.8"
July	18	4.75	82.	11"	7"	8.5"

The results obtained when 25 larvae were placed in an oven at different temperatures, and moisture contents, are represented in Table III. The method employed was very crude, but served very well for a preliminary study of critical temperature.

TABLE III

Moisture: Per cent:	33 1/3	16.5	8.1	3.8	0
Temperature (^{o}F)					
100	x	x	x	x	⊗
105	x	x	x	x	⊗
110	⊗	x	⊗	⊗	⊗
115	⊗	⊗	⊗	⊗	⊗
120	⊗	⊗	⊗	⊗	⊗

x indicates larvae alive.
⊗ indicates larvae dead.

Table III shows that the larvae when placed in a soil with a moisture content ranging from 3.8 per cent to 33 1/3 per cent could withstand temperatures of 100^{o}F. to 110^{o}F. inclusive.

Larvae placed in air dry soil with practically zero per cent moisture could not withstand 100^{o}F. Thus the data submitted in Table III indicate larvae can withstand high temperatures of 100^{o}F. or more, depending upon the moisture content of the soil.

The higher the moisture content, the higher the temperature can be without any injury to the larvae. This probably explains why larvae are killed if confined to the first few inches of the soil, when the temperatures are high and the moisture content is low.

The experiment conducted during the winter to determine whether wireworms would withstand freezing, coincides with experiences of previous workers. It was found all wireworms buried at varying depths were alive on March 28. Also, as previously stated, wireworms were found within one inch of the surface in December in pasture land.

The three months previous to the time Horsfall began his diggings, namely June, July and August, were normal in precipitation and temperature. The average mean temperature for these months was 74.3°F. and the total amount of rainfall 17.68 inches. From previous studies and experiments, with normal amount of rainfall and normal temperature, one would expect wireworms to be above plowline (6 inches) and below the two inch depth. The average depth calculated from the results of diggings for September was four inches.

The temperature during September averaged 2° below normal and rainfall below normal. October temperature was above normal and the rainfall normal. The average depth at which wireworms were found for October was five inches. The months of November and December were mild with excessive amount of moisture. Wireworms had migrated to about 7.5 inches in November and remained there during December. An upward migration began in January (1929) and at the time of digging the larvae were located at about six inches. This upward movement continued through February, but during March remained stationary and the larvae did not continue movement to the surface until the first of April.

April and May were mild with excessive amount of moisture and favorable growing conditions existed. The wireworms remained near the surface and were found within the first two inches of the soil. The first part of June was cool and below normal but toward the latter part, the temperature increased and the wireworms began a downward movement about June 23. July was extremely warm and the moisture below normal, and during this month the average depth of larvae was about five inches. No data were obtained for August of that year.

TABLE IV. Number of wireworms and depth at which they were found monthly during 1928-1929.

Month	Number of wire-worms	Precipi-tation	Mean Air Temperature(°F)	Max. Depth	Min. Depth	Average Depth
Sept.	15	2.19	66.8	18"	1"	4"
Oct.	36	1.33	59.2	13"	1"	5"
Nov.	12	5.79	43.4	23"	1"	7.5"
Dec.	28	.60	36.6	25"	1"	7.5"
Jan.	12	1.95	21.3	15"	3"	6.5"
Feb.	4	.82	28.9	6"	2"	4"
March	34	.94	47.6	15"	2"	4"
April	7	5.49	57.6	2"	1"	1.5"
May	36	3.35	61.2	12"	1"	1.8"
June	30	7.96	73.	14"	1"	2"
July	8	3.05	79.5	19"	2"	5"
Total	222		Average	14.6"	1.46"	4.44"

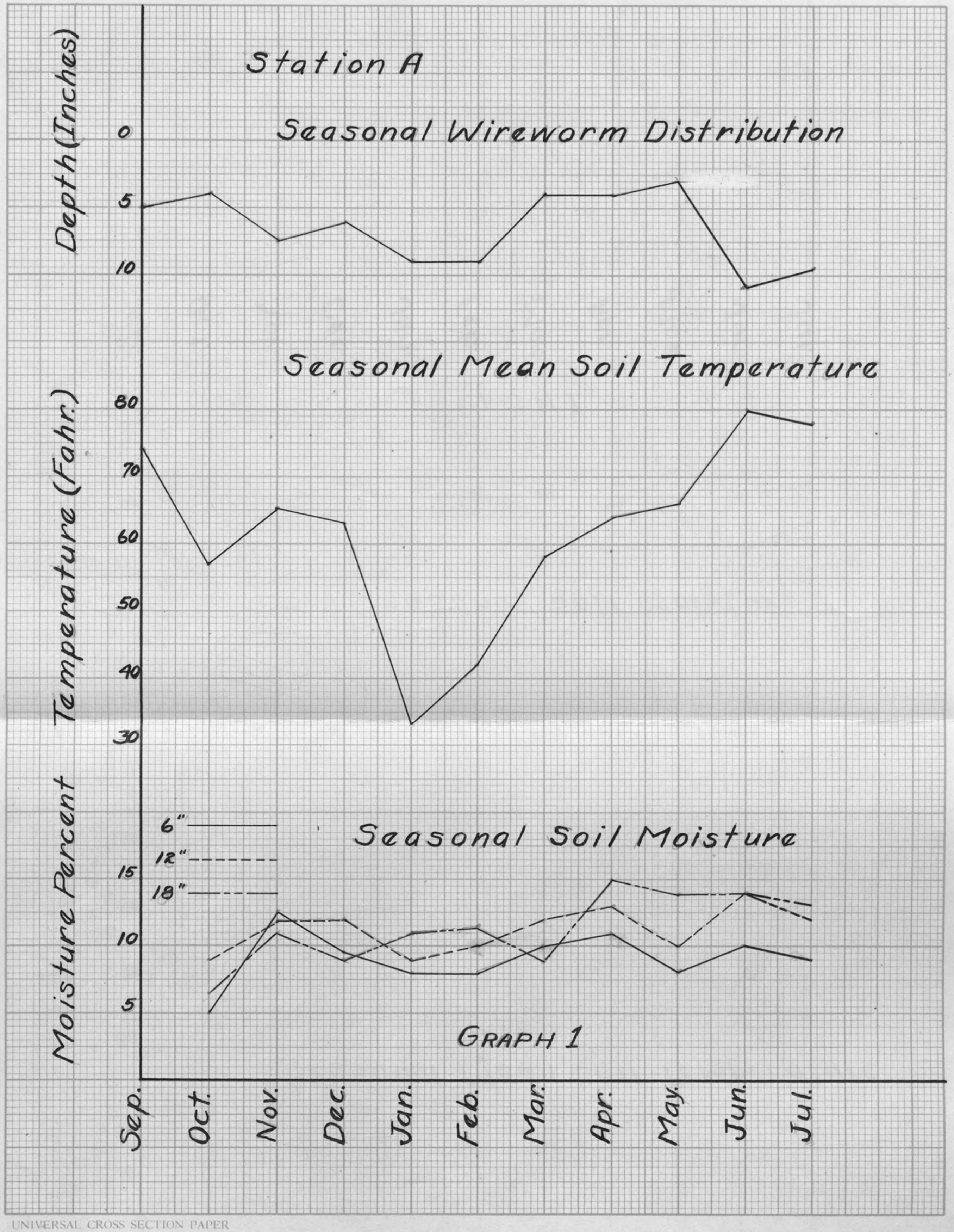
Air temperatures are recorded in Table IV instead of soil temperatures, due to the fact that Horsfall did not record soil temperatures.

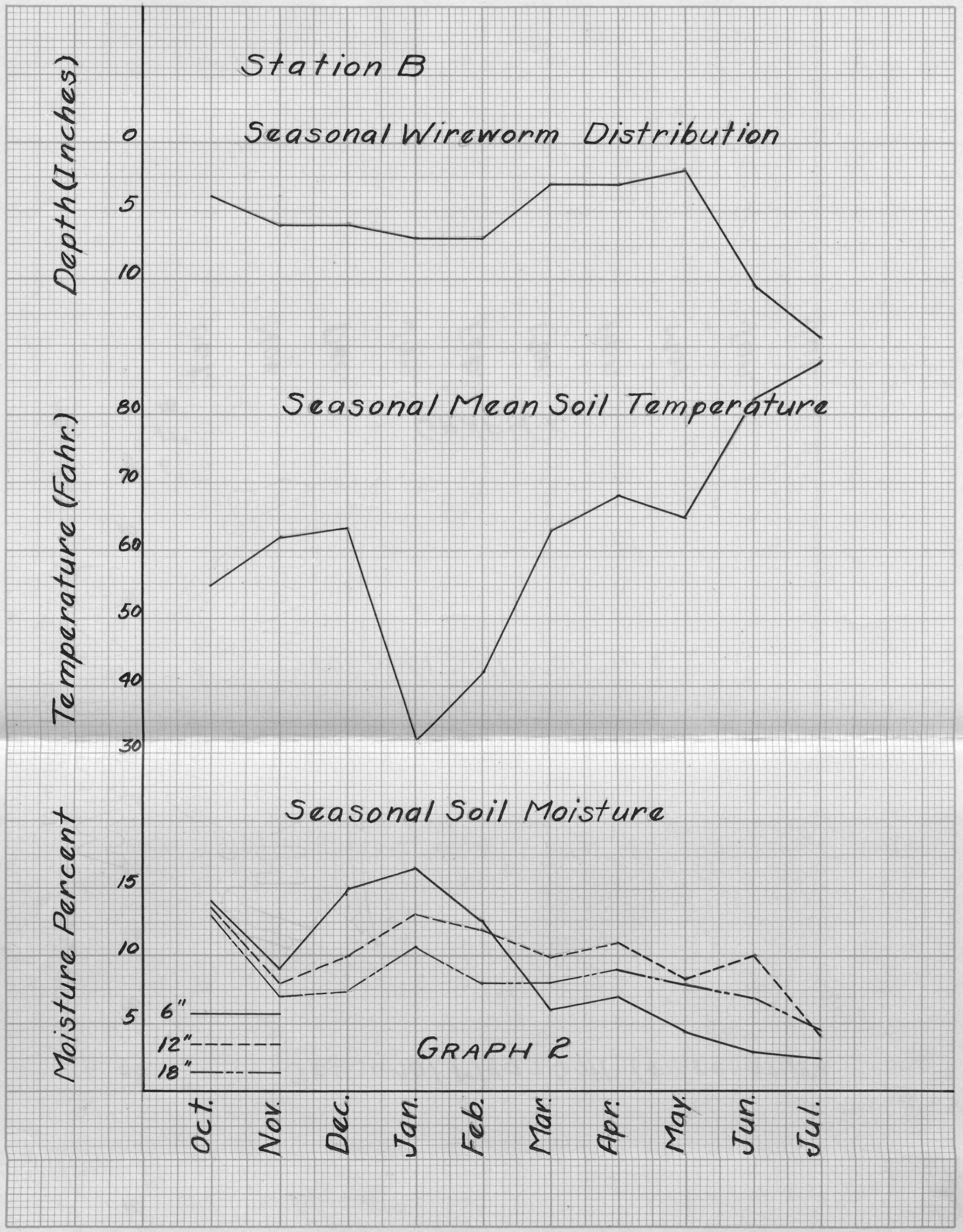
A comparison of Tables II and IV will show that wireworms were found at a higher level during December, January and February in 1928-1929 than in the same months of 1932-1933, although temperatures were much lower. This might be explained from the fact that a greater amount of snow occurred the previous year causing the temperature of the soil to remain warmer.

Table IV shows that every month in which diggings were made, wireworms were found within the first three inches and were found within one inch of the surface during seven months of that year. From the total of 222 larvae collected, 135 were at or above plow line.

Graphs 1 to 5 inclusive represent the depth wireworms were found in the soil in 1932-1933, the average temperature and the moisture content of the soil for each month during the year at the five different stations. The average depth of the wireworms is a weighted average. The three lines representing the moisture are the percentage of moisture in each six inch soil sample.

From a study of the graphs one will notice the depth at which wireworms are found varies at different stations during the same month. This variation is probably due to two factors, the type of soil and the amount of vegetative covering. There is also a fluctuation in the moisture and temperature curves, which is due to local weather changes, time of day at which diggings were made, type of soil and vegetative coverage.


Station A
Seasonal Wireworm Distribution
Depth (Inches)
0
5
10
Seasonal Mean Soil Temperature
Temperature (Fahr.)
80
70
60
50
40
30
Seasonal Soil Moisture
Moisture Percent
6"
12"
18"
15
10
5
GRAPH 1
Sep.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May.
Jun.
Jul.



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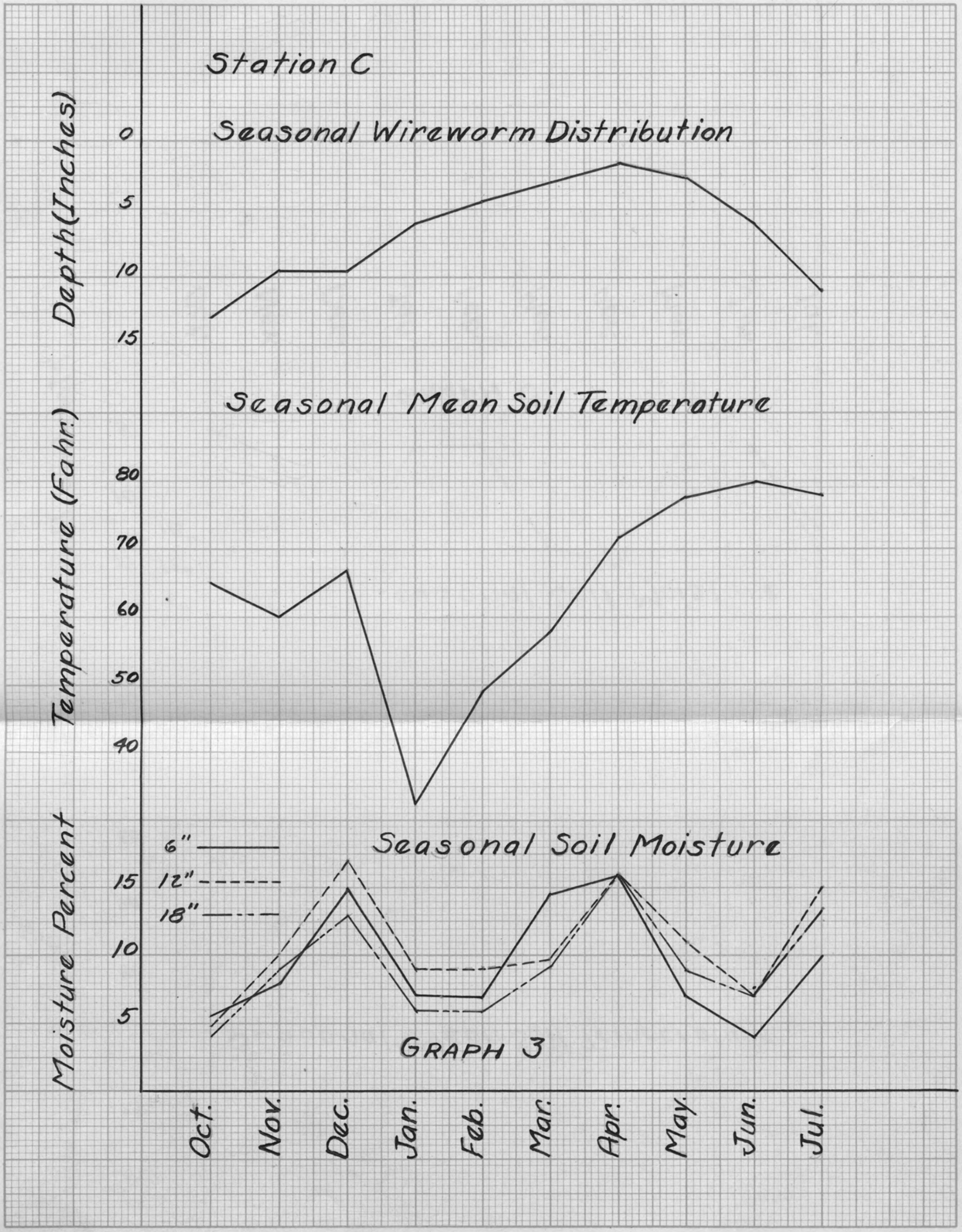
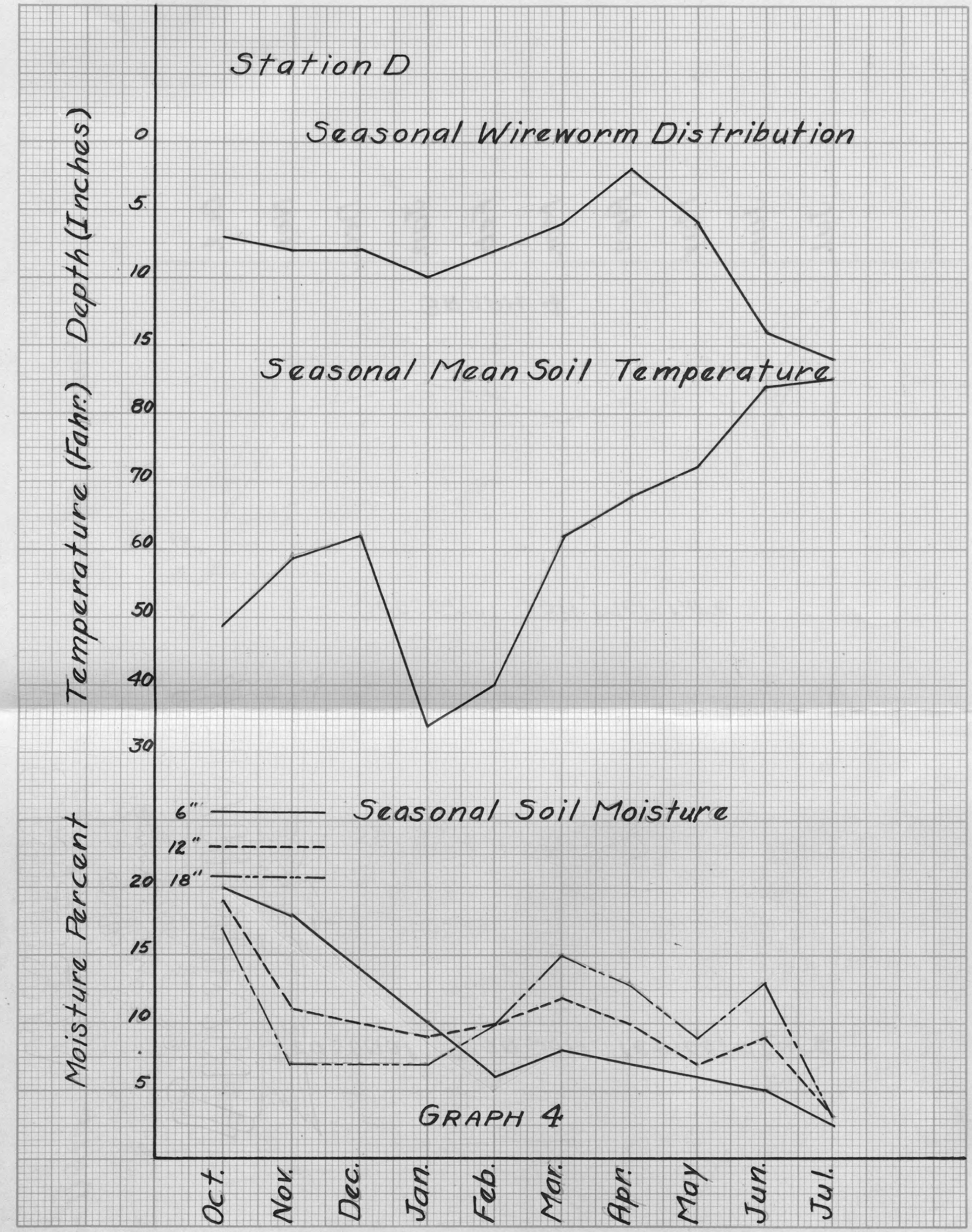
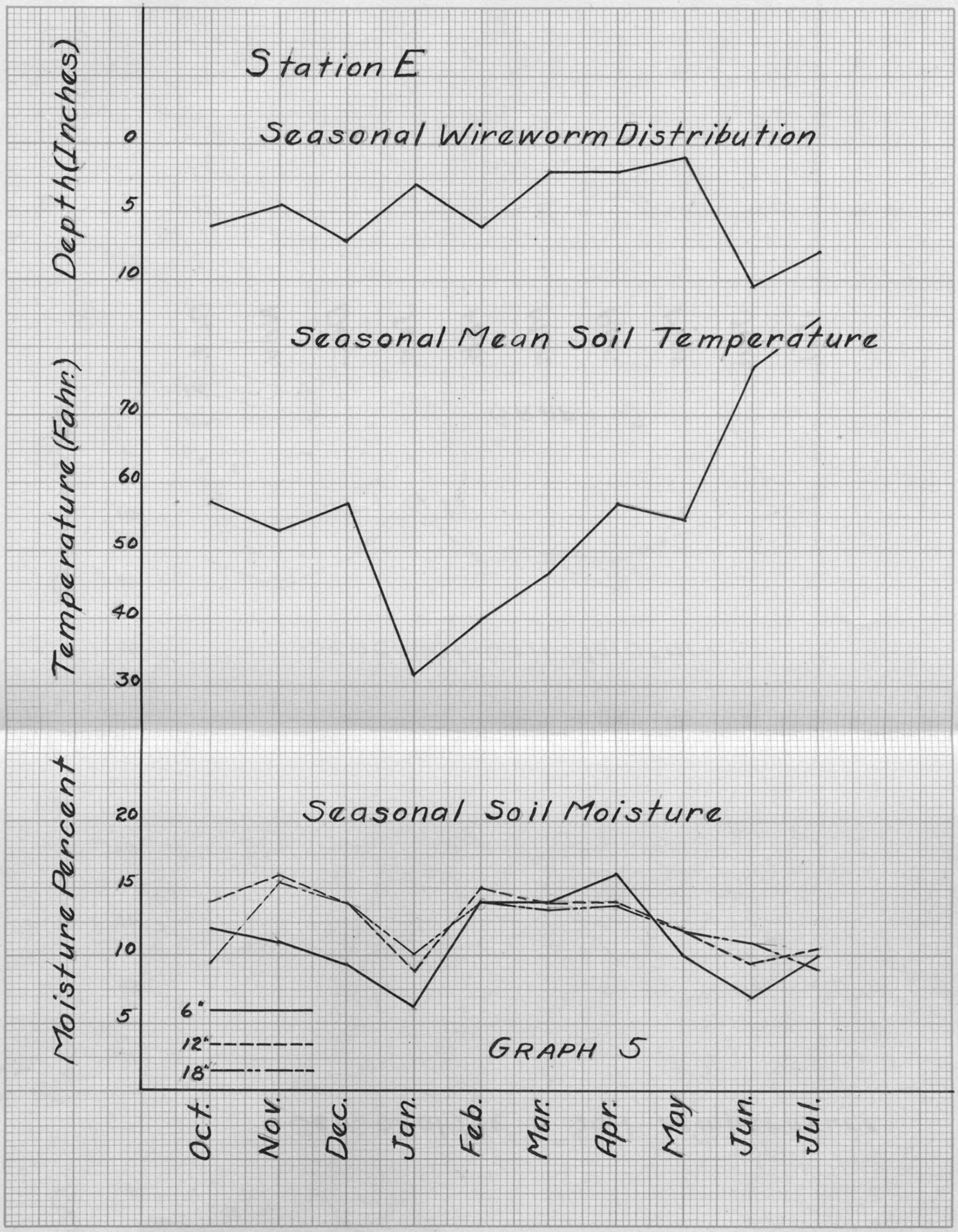

Station C
Seasonal Wireworm Distribution
Depth (Inches)
0
5
10
15
Seasonal Mean Soil Temperature
Temperature (Fahr.)
80
70
60
50
40
Seasonal Soil Moisture
Moisture Percent
6"
12"
18"
15
10
5
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May.
Jun.
Jul.

GRAPH 3

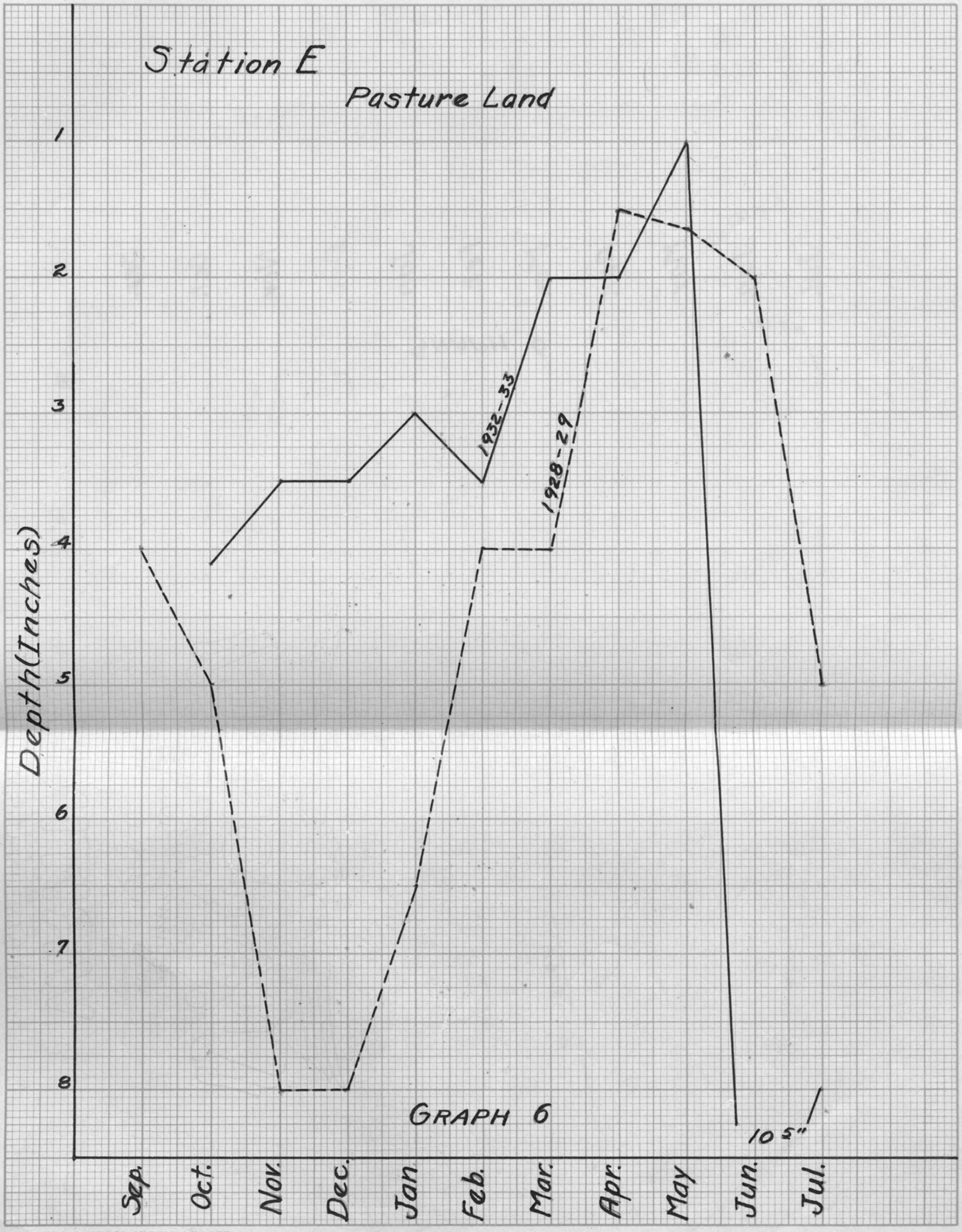

Station D
Seasonal Wireworm Distribution
Depth (Inches)
0
5
10
15
Seasonal Mean Soil Temperature
Temperature (Fahr.)
80
70
60
50
40
30
Seasonal Soil Moisture
6"
12"
18"
Moisture Percent
20
15
10
5
GRAPH 4
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.


Station E
Seasonal Wireworm Distribution
Depth (Inches)
0
5
10
Seasonal Mean Soil Temperature
Temperature (Fahr.)
70
60
50
40
30
Seasonal Soil Moisture
Moisture Percent
20
15
10
5
6"
12"
18"
GRAPH 5
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.

Wireworms began to go lower in December as the temperature decreased, in stations A, B, and D, but at C and E, they remained near the surface. Two factors apparently play an important part in this abnormality. Station C was a loose sandy soil and the temperature and moisture of the soil at various depths were more uniform. Thus it was not necessary for larvae to go deeper in the soil to find suitable moisture and temperature requirements. At station C, the vegetation presumably was responsible for the failure of the larvae to go deeper in winter. The heavy grass covering and large amount of root masses formed ample protection for the larvae from the cold weather and from the abrupt changes in temperature which are so destructive to insect life.

The ascent to the surface in the spring appears to be fairly uniform as illustrated in the graphs and the descending movement which began in April or May is relatively constant at all locations. The rise in the spring for the purpose of feeding on young tender shoots, and the later downward movement is for the purpose of escaping the extreme heat and to pupate.

Graph six is a comparison of Horsfall's and the writer's records of the total number of wireworms collected during the time of diggings, at all stations. It serves



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as a quick method of observing the average distribution, not for a limited area or for a certain soil type but for a larger region, with various types of soil and vegetation.

SUMMARY

The study of the vertical movements of wireworms is quite difficult as the larvae spend their entire life within the confines of the soil, where visionary methods are nearly impossible. It is necessary to deal with relatively small numbers of specimens, as the methods involved are laborious and require a great amount of time, but by careful selection of areas and a thorough study of the data obtained, the results are satisfactory.

Seasonal variations in the depth at which wireworms occur are dependent to a great extent on the temperature of the soil together with the moisture content and vegetative covering. Wireworms do not seek the greatest moisture concentration in the soil but that which is sufficient to support life providing the temperature range of that area is suitable. The movement does not fluctuate to any marked degree with variations in local weather conditions, but is a gradual seasonal movement which follows a uniform curve from year to year.

During extremely cold winters most of the larvae migrate below plow line, while in mild winters they remain at or above plowline. Hot, dry summers bring about a migration to lower levels to escape extreme heat, and to

seek soil with higher moisture content. In summers of cool temperatures and large amount of precipitation, wireworms do not migrate so deeply in the soil.

The present year has experienced extremes in both directions, in fact it has been very abnormal, but the general line of distribution holds fairly close to that obtained by workers in previous years.

The ability of wireworms to withstand freezing temperatures has been clearly shown by data collected by McColloch, Hayes, and Bryson, (1927), also from the writer's observations and experiments.

The minimum lethal temperature was not determined, but it offers an interesting phase for future work.

Heat has a much more serious effect on wireworms than cold. In perfectly dry soil larvae die at 100°F. and at 110°F. with normal moisture content.

Effect of Vegetation

Observations indicate that vegetative covering is an important factor in wireworm movement. A heavy amount of vegetation offers protection for larvae from the rigors of winter and from extreme heat.

The kind of vegetation is also important in determining the location of larvae. It has been observed by the writer and other workers, that wireworms are more plentiful where a certain type of vegetation is grown as compared to other types. This is particularly true on grassy areas.

The type of soil determines the kind and amount of vegetation. It was found wireworms were at lower levels in sandy, and loose soils than in more compact soils, such as clay or loam, during periods of least activity.

The periods of greatest activity in soils near Manhattan, for 1932-1933 are September, October, March, April and May. It is quite probable that these periods may vary somewhat, depending upon the kind and growth of vegetation.

LITERATURE CITED

Anderson, G. M.

The slender wireworm and its relation to soils.
S. C. Exp. Sta. Bul. 204, 2 p. 1920.

Blunck, H. and F. Merkenschlager.
A contribution to ecology of wireworm foci. (In German)
Nachrichtenbl. deutschen Pflanzenschutzdienst, 12, p. 95-98. (1925) (Abstracted from Rev. App. Ent. 14: 313)

Britton, W. E.
Tobacco plants severely injured by wireworms.
In twenty-fifth report of the State Entomologist of Connecticut. Agr. Exp. Sta. Bul. 275: 312-314. 1926.

Cameron, A. E.
General survey of the insect fauna of the soil within a limited area near Manchester. Jour. Econ. Biol. 3: 159-204. 1913.

Conradi, A. F. and H. C. Eagerton.
Corn and cotton wireworm. (Horistonotus uhlerii Horn).
S. C. Agr. Exp. Sta. Bul. 180, 16 p. 1914.

Curtis, John
Wireworms...In Farm insects...London. John Van Voorst. p. 152-210, 452-454. 1883.

Fulton, B. B.
Some temperature relations of Melanotus (Coleoptera, Elateridae). Jour. Econ. Ent. 21 (6): 889-897. 1928.

Gibson, E. H.
The corn and cotton wireworm in its relation to cereal and forage crops, with control measures.
U. S. Dept. Agr. Farmers' Bul. 733, 7 p. 1916.

Graf, J. E.
A preliminary report on the sugar-beet wireworm.
U. S. Dept. Agr. Bul. 123, 68 p. 1914.

Howard, L. O.
Wireworm investigation.
In report of the Entomologist for 1924-1925.
U. S. Dept. Agr. p 23. 1925.

King, K. M.
Economic importance of wireworms and false wireworms in Saskatchewan.
Scientific Agr. 8 (11): 693-706. 1928.

McColloch, J. W., W. P. Hayes and H. R. Bryson.
Preliminary notes on the depth of hibernation of wire-worms.
Jour. Econ. Ent. 20 (4): 561-564. 1927.

Miles, H. W.
The control of wireworms.
Agr. Progress. (Agr. Ed. Assoc., London) 4: 5 p. 1927.

Miles, H. W. and F. R. Petherbridge.
The control of wireworms in glasshouses.
Jour. Min. Agr. (Gt. Brit.). 33 (10): 931-939. 1927.

Ormerod, E. A.
Wireworms.
In Manual of injurious insects. 2nd. Ed. London.
Sipkin, Marshall and Co. 88-96. 1890.

Roberts, A. W. R.
On the life history of "wireworms" of the genus Agri-otes...Part 1. Ann. Appl. Biol. 6: 116-135. 1919.

Strickland, E. H.
Wireworms of Alberta (a preliminary report).
Univ. of Alberta, College of Agr. Res. Bul. 2, 18 p. 1927.