THE INFLUENCE OF SOME ECOLOGICAL FACTORS ON THE

DISTRIBUTION OF WHITE GRUBS

by

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INTRODUCTION

Economic entomologists have always been confronted with a cry for immediate relief from insect pests. They have done remarkably well in giving relief, but the measures recommended were often based on general observations without regard for the fundamental reasons underlying them. As the science of entomology has progressed and more men have entered the field it has become possible to go deeper into the factors affecting insect behavior.

Much has been done within recent years with the ecology of insects which spend their life cycles above the ground, but as yet few studies have been made with the subterranean forms. This class of insects has been recognized for a long time as very important pests, and mention of the scarabs especially is frequently made in literature. A knowledge of the basic ecological factors affecting the larval scarabs seems to be essential before satisfactory control measures can be formulated. It was with this idea in mind that this study was undertaken.

The ecological factors affecting the distribution of white grubs are those environmental elements which either independently or collectively affect the larval stage of the plant-feeding scarabs. In a broad sense of the word, host and habitat are the most important ecological factors. Since the latter is the soil, a very complex medium, only a few of the chemical and physical conditions could be studied in the limited time available. Of the chemical factors only the volatile matter and hydrogen-ion concentration were studied. Several physical conditions such as colloidal matter, seasonal moisture variation, soil type, stratification, color, slope, elevation, and shade were included in the observations.

REVIEW OF LITERATURE

The literature on the family Scarabaeidae is voluminous, but that dealing with the biology and ecology of the immature stages, especially the larvae, is very limited. Most of the papers are concerned with a general consideration of the life history and control with only brief reference to the ecological side of the question. It is not to be understood that this paper contains a complete bibliography of the ecological references to the phytophagous scarabs, but it does contain the more important ones up to date.

Shelford (1911) in writing of the distribution and dispersal of animals, states that every animal selects an environmental complex as its general habitat, that the breeding grounds are the most important index to the true habitat, and that each species is usually distributed as far as its environmental complex extends unless barriers are encountered. The indications are that this holds true in the case of the phytophagus scarabs which seem to have certain environmental complexes as will be discussed later.

According to McColloch (1922) the soil is a complex of many factors which separately and conjunctively are of vital importance to soil-inhabiting insects. He states that the more important factors are topography, texture, structure, color, temperature, moisture, evaporation, light, pressure, food, organic matter, materials of abode, nitrogen, carbon dioxide, oxygen, and enemies. Just how important each of these is is left as an open question, but it is suggested that some of them both independently and collectively are of very great importance.

Forbes (1916) attempts to prove that white grubs are more serious pests near woods than they are in the open regions, and uses as his reason the fact that the adults fly to the woods to feed at night together with the fact that the adults have never been seen to move long distances. He had assistants collect behind the plow in various parts of Illinois in order to determine whether the grubs really were worse near the woods or not. The records are based on what he supposed to be Phyllophaga grubs, but the grubs were not reared out to see for specific determination. His results show that there were two and one-half times as many grubs within one-eighth of a mile of the woods as there were between one-eighth and one-fourth of a mile. There were also two and one-half times as many between one-fourth and one-half mile as there were in the area over one-half mile. From this it would appear that there would be few of the genus, Phyllophaga in the prairies. These regions, however, seem to have large numbers of them.

Recently Sweetman (1927) followed up Forbes' work with a statement to the effect that only areas near woods are materially infested by white grubs. As a matter of fact, he states that the presence of trees seems to be a limiting factor in the distribution of the members of the genus Phyllophaga. No mention is made of the species concerned in these investigations. He also overlooked the wide range of host plants fed on by these as adults. These hosts, according to Hayes (1919), vary all of the way from common weeds and grasses to trees, depending on the species involved.

The earliest digging records seem to be those of Forbes in 1905, published in 1907, when he made a brief study of the downward migration of white grubs in Illinois in the months of October and November of that year. His studies were made in a corn field at weekly intervals throughout the month of October and once during the latter part of November. On October 3 all of the grubs occurred between the depths of one and eight inches, and on November 22 they were between the depths of three and twenty inches, showing that the spread became greater as winter approached.

Between the time of Forbes' work and Criddle's work in 1918 there appears to have been nothing done on the depth of hibernation of white grubs. Since Criddle's work was done in Canada where the temperatures are considerably colder than those of Kansas, the depths of hibernation are much lower. The larvae of Phyllophaga rugosa, for instance, go to the depth of seventy-four inches which is almost twice the greatest depth in this region even in the very sandy situations.

Following Forbes' and Criddle's work is that of Hayes and McColloch (1928) who collected by means of plowing, digging, and other ways 18,781 scarabaeid larvae, and who reared 5,884 of them to maturity. Of these 5,884 that were reared 964 were of the genus Phyllophaga or true white grubs represented by seventeen species. These are recorded from known situations and are given in Table I.

Bluegrass sod has the preference so far as numbers are concerned with corn land next, followed quite closely by wheat land. It will be noticed, however, that Phyllophaga crassissima comprises by far the largest part of those found in the bluegrass sod. In the corn and wheat land, on the other hand, the species are more numerous and present in more nearly the same numbers. The majority of P. submucida were under manure in pasture upland. P. longitarsa and P. praetermissa prefer the sand hill region along the Kansas River.

TABLE I. FOOD PREFERENCE OF <u>PHYLLOPHAGA</u> GRUBS

Species of Phyllophaga	Wheat	Bluegrass and Lawns	Oats	Corn	Logs and Stumps	Pasture	Manure	Orchard	Alfalfa	Potatoes	Garden	Miscellaneous	Total
crassissima	23	202	7	45		9	2	2	19	5	45	37	396
rubiginosa	10	16	1	18	2	16	1	1	16	20	14	20	135
rugosa	18	4	6	19		3			6	19	36	14	125
lanceolata	45	1		5		26	1					1	79
submucida	7		2	6	1	3	56				1	3	79
implicita	10	1	3	44	1		1	1		2	4	9	76
hirticula var. comosa	5		9	2		1			6			1	24
praetermissa	2	8				3							13
longitarsa	3				5								8
bipartita	1				1	4							6
futilis		2			1				1			1	5
corrosa	1					4							5
glabricula						4			1				5
fusca	1		1										3
crenulata				1							1		2
tristis						1	1						2
affabilis									1				1
Total	126	234	29	140	11	74	62	4	50	46	101	87	964

Several other references have been made from time to time to the environment and feeding habits of some of the scarabaeid larvae. Some of these were based on conclusions which seem to have been drawn from general observation rather than on careful work. However, Criddle (1918) published some results on some of the members of the genus *Phyllophaga* that were based on facts and not theory. He found that *P. nitida* prefers the drier woodlands, *P. drakii* prefers sandy soils near the open woods, and *P. rugosa* prefers the sandy soil at higher altitudes than *P. drakii*. No special environment is given for *P. anxia,* but is stated that it feeds on organic matter for the first two years and on grass roots the third one.

McColloch, Hayes and Bryson (1928) started digging white grubs in 1919 in order to determine the depths of hibernation of white grubs. The same situations were not gone to consistently, and no records were made throughout the year. Since they were studying only the depth of hibernation, records were unnecessary for parts of the year other than winter. A summary of the situations and the population of each is given in Table I. The depths of hibernation were, in general, the same as those given in this paper.

METHODS

The greatest part of the work in the case of this problem was that done in the field. Nine different locations representing as many different situations from the sand dunes on the Kansas River to the high prairie were chosen arbitrarily. In each of these situations the most representative and uniform places were taken for the digging.

Since a hole of two feet by three feet surface measurements had been used previously for most of the diggings made at this station by McColloch and Hayes, the same size was employed in these studies so that comparisons could be made. The depths to which the various holes were dug ranged from eighteen to fifty-five inches, depending on the vertical insect distribution. Unless some factor such as frozen ground, rock, or very stiff clay was present, twenty-four inches were used as the minimum depth. It was also made a point to dig at least four and usually six inches below the place where any insect was found. This made it impossible to miss any of the insects that might be in the ground.

It was the intention at first to dig one or more holes at each of the locations at least once a month and as nearly the same time each month as possible. At first rains interfered causing the times for the monthly diggings to vary. Then during the first week in January a heavy snow fell followed by severe, cold weather which lasted throughout January and February. The ground became frozen so hard and so deep that digging became an impossibility. The depth to which the ice penetrated varied with the soil, but in nearly all of the situations the frozen ground extended twenty-four inches or deeper. Since there was no possibility of larval movement nothing was lost by the omission of the digging for those months.

There was not a great deal of equipment necessary for the field work. Most of the digging was done with a sixteen-inch tiling spade because it seemed to be the most satisfactory for cutting and removing the dirt in layers, but occasionally a short-handled trench spade, which is admirably adapted for removing the loose dirt from the bottom of the holes, was used. One-ounce salve boxes served as containers for those specimens such as white grubs which were to be reared. All of the other specimens such as cicadas, earthworms, etc., were recorded in the field and discarded because they had no significance other than for faunal records. It was necessary to take along a soil auger and bottles for the obtaining of soil samples for moisture and other determinations.

In the process of digging a hole, a rectangle two feet by three feet was laid out and then outlined by means of marking off with the point of the spade. Then the soil was removed in blocks about six inches in depth. As each block was removed the dirt was sorted carefully by hand in order to determine the depth of the grubs. This method prevents one getting the exact depth at which the grubs occur, but it enables one to be accurate enough for all practical purposes. It has the advantage over the other methods in that only a few specimens are cut by the spade, and it is so much more rapid than any of the others. Two people make a very satisfactory party for this type of work. One digs the holes; the other sorts the dirt and records the insects as they are found.

Soil samples were taken by means of a soil auger at six-inch intervals to the depth of the holes. These samples were taken within eight or ten inches from the holes so that the soil conditions would be the same as those of the holes. In addition to the samples taken at the six-inch intervals for each hole, there was one set of samples taken according to the soil zones for each locality; these samples being used for the colloidal determinations. As each sample was taken it was placed in a tight jar and taken to the insectary.

All of the weighings for the moisture determinations were made, nearly as possible, the same afternoon the samples were taken. During the winter when it got dark so early in the afternoons, it was sometimes necessary to wait until the next morning. Fifty-gram representative samples of the moist soil were taken for these determinations. These were placed in paraffin bags of known weights and left in the insectary to dry. No oven was available when the experiment was started so all of the results were calculated as per cent on an air-dry basis.

Determinations of the volatile matter were made by the loss-on-ignition method. The samples as they were taken from the field were dried in the oven at 105 degrees Centigrade for several hours to drive off the moisture. Then they were pulverized in a mortar. After pulverizing the samples two five-gram representative parts of each were weighed into crucibles of known weight, and the crucibles were then placed in an electric furnace and heated to a red heat for at least thirty minutes. The crucibles were then cooled sufficiently to place in a desiccator where they were left until they were weighed. To calculate the percentage of volatile matter, subtract the weight of the crucible and divide by the weight of the original part taken.

Bouyoucos' hydrometer method which was described by him in 1927 was used for the colloidal determinations. A fifty-gram sample of the air-dry soil was weighed out and placed in the cup of the stirring machine which is described in the same paper. Distilled water was then added to within one inch of the top of the cup to which five cc. of N/1 KOH were added to prevent flocculation. The cup was then placed in the stirring machine, and the sample was stirred for nine minutes. At the expiration of this time the suspension was quickly poured into a 1000 cc. graduated cylinder, made up to 1050 cc., and shaken vigorously. Immediately a Fahrenheit thermometer and a hydrometer were placed in the suspension. After fifteen minutes, readings on both of them were taken. In order to obtain the percentage of colloids the reading of the hydrometer was divided by the weight of the sample and to the result was added or subtracted .35 per cent for each degree above or below 67 degrees Fahrenheit.

The acidity determinations, like the other determinations with the exception of that of moisture, were made only once for each locality. The electrometric method of Clark (1916) was the one employed for this work because it saves time and is in fact the most accurate method.

The apparatus and technique is explained by Clark essentially as follows: The instrument which is used for this work is a very delicate potentiometer that is calibrated to read in millivolts and that obtains its current from a flashlight battery. With it are three test tubes which contain the following solutions: N/20 acid phthalate buffered by quinhydrone in the first, N/5 KCl in the second, and the soil suspension buffered by quinhydrone in the third. In the first and last of the tubes are two platinum-mercury electrodes which are attached to their respective electrodes on the potentiometer. The tubes themselves are connected by means of salt agar bridges. When all of the connections are complete the current is turned on and by means of resistance coils the millivoltmeter is moved backward and forward until the swinging needle of another indicator remains at rest with the current flowing through it. The reading of the millivoltmeter is then taken and referred to a chart for the hydrogen-ion concentration. Duplicates were made on each sample to insure accuracy.

One hundred-twelve holes comprise the series on which the results for this paper are based. They were dug in all kinds of soil from the heaviest of clay having over fifty per cent colloids in them to light sand. The depths of the holes ranged from eighteen inches to fifty-five inches.

From these 112 holes 57.25 cubic yards of dirt were removed and pulverized by hand. On the rough basis of a cubic yard weighing one ton, there were 57.25 tons of dirt sorted by hand.

DISCUSSION

In order to get as many different types of situations as possible in the limited time the types had to be grouped and a representative from each group was taken as typical. Nine places in as many different habitats from the high prairie to the river level comprise the series.

The soil type which is given from each of the following stations was obtained from the soil map of Riley County, Kansas, prepared by the United States Department of Agriculture, Bureau of Soils. Elevations of the stations were obtained from the quadrangle prepared by the United States Geodetic Survey.

Plate I is a map of the region in the vicinity of Manhattan. On it are marked the stations and their locations so they may be recognized more easily than they could be by a description.

Station 1

This station was located at an elevation of 1225 feet on the west slope of Sunset Hill about four miles northwest of the college. The top of the hill would have been selected but there was a layer of limestone gravel very near the surface which made digging an impossibility. The dominant vegetation in the locality was buffalo grass, _Buchloe dactyloides_ and prairie alfalfa, _Psoralea_ sp. with a few _Mimosa_ sp. and _Helianthus_ sp. in addition. The surface eight inches of soil was a black silt which felt greasy to the touch. Underlying this was a very heavy clay layer of unknown depth. According to the soil map the soil type is Marshall silt loam.

Station 2

This station was located at an elevation of 1150 feet on the low rolling hills below the plain level about one mile north of the college. In the region the dominant vegetation was buffalo grass and prairie alfalfa with very few other plants. The surface layer of dark silt varies in depth from a few to twelve inches in depth. Below that the clay becomes increasingly yellow to an unknown depth. Marshall silt loam is the soil type.

Station 3

This station like Station 2 was located on low rolling hills but at an elevation of 1090 feet. In the region the slope tended slightly toward the northwest. The vegetation in the region was predominantly buffalo grass with a little bluegrass, Poa pratense and yarrow, Achillea sp. On the surface at this station was a three- or four-inch layer of dark silt grading off into a light-colored crumbly clay and then into a stiff yellow clay below twenty inches. Marshall silt loam was given as the soil type.

Station 4

This station represented the narrow, dry, U-shaped valleys and was located at an elevation of 1100 feet about a mile north of the college. On the floor of the valley was a carpet of bluegrass mixed with nut grass and buck-brush. The heavy black alluvial silt of the region extended to a depth of about twelve inches. Underlying this was a layer of dark crumbly clay of a varying thickness. Under it all was a layer of lighter clay extending to an unknown depth. The soil type was Wabash silt clay.

Station 5

This station was located about one-fourth of a mile west of Station 4 in a broad flat valley at an elevation of about 1030 feet. It represented the type of situation found in the broad valleys away from the truly river situations. The vegetation was identical with that of Station 2. The soil in the region was dark throughout. On the surface was a six-inch layer of black silty clay, and below it was a crumbly somewhat lighter clay. Soil of this type is called Oswego silt loam.

Station 6

This station was located on a northeast slope in a narrow V-shaped valley on the side of Mount Prospect two and one-fourth miles east of the college at an elevation of 1100 feet. The ground in the region received very little sun because the foliage of the leaves was too heavy to permit it. The white oak, <u>Quercus</u> <u>muehlenbergii</u>, is very abundant in the whole valley. No grass whatever was found in the region. The surface six inches of the soil is largely leaf mold and a very black silt. Below this was a layer of yellow crumbly clay interspersed with limestone gravel. According to the soil map the soil type is Marshall silt loam, but it seems to approach rough stony land.

Station 7

This station was northwest of Station 3 near the bank of Wildcat Creek and at an elevation of 1010 feet. The trees were not too dense to prevent a carpet of bluegrass sod. Here and there were scattered bushes of a wild gooseberry, *Ribes*, sp. The trees were largely *Ulmus* sp. with an occasional white oak of the species mentioned above. A dark sandy silt extended to a depth of about twelve inches where it slowly changed into a yellow fine sand. This soil type is known as Wabash silt loam.

Station 8

This station was located just north of the Kansas River, south of the college about four miles, and at an elevation of about 1000 feet. Several grasses and legumes were common in the region, but *Andropogon furcatus* and a bunch grass were the dominant plants. Cottonwood trees, *Populus balsamnifera*, and sand plums, *Prunus angustifolia*, were the dominant decidious plants in the region. The surface layer of soil was a fine sand extending to a varying depth. At a varying depth of from twenty-five to forty inches was a layer of sandy silt. This type of soil is called Laurel fine sand.

Station 9

West of Station 8 about one-half of a mile this station was located. The woods was somewhat thicker than at Station 8, but otherwise the flora was essentially the same. The surface soil had more organic matter in it than did that at Station 8, and there was no layer of silt underlying the sand. The soil type is Laurel fine sandy loam.

Table II summarizes the habitats and shows the relationship existing between these habitats and the species of scarabaeids for each. All of the species which may occur in each habitat are not given but only those which are definitely known to occur in each one from actual collection of the adults by digging. In all probability the larvae which were collected will add to the species, but it will be another year before the most of them will have emerged.

TABLE II. RELATIONSHIP OF HABITAT AND SPECIES

Station	Dominant Vegetation	Slope	Shade	Color	Soil Stratification	Soil Type	Soil Colloids: Interval inches	Soil Colloids: per cent	Volatile Matter: Interval inches	Volatile Matter: Per cent	pH: Interval inches	pH	Species
1	Buchloe dactyloides Psoralea sp.	Slight South-west	None	Black	Silty clay Clay	Marshall silt loam	12 20	36.0 54.8	6 12 18	8.77 7.06 6.73	6 12 18		P. corrosa P. rubiginosa Diplotaxis sp.
2	Buchloe dactyloides Psoralea sp.	Slight South-west	None	Dark	Silt Red clay	Marshall silt loam	7 15 29	30.1 37.3 41.6	6 12 18 24 30	7.50 6.31 7.14 4.77 5.87	6 12 18 24 30.	6.2 6.2 6.2 5.9 6.1	P. bipartita Bolbocerosoma bruneri
3	Buchloe dactyloides Achillea	Slight North-west	None	Brown	Silt Red clay	Marshall silt loam	11 25	20.8 33.1	6 12 18 24 30	5.35 5.28 4.94 4.20 3.20	6 12 18 24 30	6.8 6.8 6.0 6.5 6.7	P. bipartita P. praetermissa
4	Poa pratensis	Slight South-west	None	Black	Silt Silty clay	Wabash silt clay	12 24	32.5 36.4	6 12 18 24 30	7.45 6.39 5.14 4.64 4.36	6 12 18 24 30	5.8 6.3 6.3 6.3 6.6	P. crassissima P. rugosa P. bipartita Ochrosidia immaculata
5	Buchloe dactyloides Psoralea	Slight South-west	None	Black	Silt Clay	Oswego silt loam	10 24	35.1 50.4	6 12 18	-- 6.98 6.54	6 12 18	-- 7.5 7.1	P. bipartita P. crassissima
6	Quercus Muehlenbergii	North-east	Continuous	Very Black	Silt Gravel Clay	Marshall silt loam	5 13 29	26.0 24.1 22.1	6 12 18 24	-- 5.44 -- --	6 12 18 24	7.6 7.6 8.2 8.2	P. ilicis Geotrupes splendidus Serica sp.
7	Poa pratensis Ribes sp.	Level	Partial	Very Black	Sandy silt Fine sand	Wabash silt loam	12 24 32	26.5 26.5 22.9	6 12 18 24 30	6.44 5.07 3.66 3.34 3.21	6 12 18 24 30	7.4 7.5 7.7 7.5 7.7	P. rubiginosa P. futilis P. rugosa P. vehemens Anomala innubia P. ilicis
8	Populus sp. Andropogon furcatus	Level	Scant	Very Light	Sand Sandy silt Fine	Laurel fine sand	Sand Sandy silt	[illegible] 3.8 16.4	6 12 18 24 30 36 42 48	.74 .57 .63 -- .50 .48 .53 .21	6 12 18 24 30 36 42 48	8.1 7.9 7.7 7.9 7.9 7.9 7.4 7.5	Anomala ludoviciana Polyphylla sp. Cotalpa lanigera
9	Populus sp. Andropogon furcatus	Level	Partial	Light	Sandy silt Sand	Laurel fine sandy loam	6 26 37	4.4 7.4 5.7	12 24 36	.93 3.09 2.00	12 18 36	7.0 7.5 6.4	Anomala ludoviciana Cotalpa lanigera P. implicita Serica sp.

The table is based on few specimens of each species except *Phyllophaga ilicis* but nevertheless these few indicate under what conditions one would expect to find them. *Anomala* and *Cotalpa* seem to be limited to the sand hill region and very sandy creek bottoms. Most *Phyllophaga*, however, are found in the heavier upland soils and grading off into the sandy creek bottoms. Formerly *P. crassissima* has been considered a species attacking bluegrass, but in a bluegrass situation in the lowland creek bottom where there is sandy soil none of this species was found. The indications are that the soil type might play a part in determining the presence or absence of this species. Another striking example is that of *P. ilicis*. This species has formerly been considered rare around Manhattan, but in the upland wooded valley where the soil is clay with a hydrogen-ion concentration above the neutral point the species was very abundant. In fact more adults by far were found in one hole than in a similar hole in any other region. Counting those collected under leaves 108 specimens were taken in an area less than sixty feet square. *P. bipartita* seems to prefer the medium and low prairie situations to any of the others.

Table III shows the number of grubs per acre and the percentages of the adults for each locality. Three of the situations show quite high grub population with one of them being very high. There was only one really thinly populated area and it was in the very sandy region. If one assume that the percentage of adults collected in the localities be a correct way of determining the grubs for the region it will be seen that species of the genus Phyllophaga dominate all of the regions except those in the sandy localities and the low prairie. In the upland prairie members of the genus Diplotaxis almost equal those of the genus Phyllophaga. It is interesting to note that in the upland wooded situation at Station 6 Phyllophaga ilicis is decidedly the dominant species. Calculations show that this year the population of adults of that species alone was 38,725 individuals per acre. P. crassissima at Station 4 would run P. ilicis a close second but owing to the fact that they left the ground so early in the spring calculations could not be made.

There is an apparent scarcity of Ochrosidia immaculata which, according to notes previously made, is a generally distributed species in the region around Manhattan. This apparent scarcity can be explained by the fact that this species is just beginning to emerge having been delayed

TABLE III. COMPARISON OF THE NUMBER OF GRUBS AND PERCENTAGE OF ADULTS BY STATIONS.

Station	Number of holes	Square feet	Number of Grubs per acre	Adults	Percentage of Adults per Station
1	8	48	97095	P. rugosa	6.7
				P. corrosa	19.9
				Diplotaxis sp.	46.7
				P. rubiginosa	13.3
				P. hirticula	6.7
				P. bipartita	6.7
2	10	60	41382	P. bipartita	80.0
				Bolbocerosoma bruneri	20.0
3	11	66	65993	P. bipartita	33.3
				P. praetermissa	66.7
4	13	78	24002	P. crassissima	80.0
				P. rugosa	10.0
				P. bipartita	5.0
				Ochrosidia immaculata	5.0
5	11	66	20473	P. bipartita	25.0
				P. crassissima	25.0
				Aphodius sp.	50.0
6	14	84	30579	P. ilicis	97.0
				Geotrupes splendidus	1.5
				Odonteus sp.	1.5
7	12	72	27225	P. futilis	45.5
				P. rugosa	9.1
				P. vehemens	9.1
				P. ilicis	9.1
				P. rubiginosa	9.1
				Anomala innubia	18.1
8	12	72	10280	Anomala ludoviciana	75.0
				Cotalpa lanigera	25.0
9	11	66	51444	Cotalpa lanigera	16.7
				P. implicita	33.3
				Serica sp.	33.3
				Polyphylla hammondi	16.7

somewhat more than normal.

The very small grub population in the low prairie at Station 5 can be explained by the fact that the larvae all seemed to be a very small species in the genus Aphodius. One species of this genus was found in the July digging and some have been reared from the larvae collected in the field. An occasional large grub was taken but not many.

Table IV shows the population by stations of all animals exclusive of ants, miscellaneous insects, and microscopic animals. It may be seen that earthworms, cicada nymphs, white grubs, wireworms, and weevil larvae were the most abundant in the order named. Earthworms were by far the most abundant in most localities. At Station 1 millipeds outnumbered any other animal and hardly occurred anywhere else. At Station 7 earthworms were far in excess of other animals.

TABLE IV. COMPARATIVE POPULATION OF STATIONS

Station	1	2	3	4	5	6	7	8	9
Number of Holes	8	10	11	13	11	14	12	12	11
P. rugosa	1			2			1		
P. corrosa	3								
P. rubiginosa	2						1		
P. hirticula	1								
P. bipartita	1	4	1	1	1				
P. praetermissa			2						
P. crassissima				16	1				
P. ilicis						64	1		
P. futilis							5		
P. vehemens							1		
P. implicita									2
Diplotaxis sp.	7								
Ochrosidia immaculata				1					
Aphodius sp.					2				
Bolbocerosoma bruneri		1							
Anomala innubia							2		
Anomala ludoviciana								3	
Cotalpa lanigera								1	1
Polyphylla hammondi									1
Geotrupes splendidus						1			
Serica sp.									2
Odonteus sp.						1			
White Grub	94	57	100	43	31	59	45	17	79
Carabid Larva	1	1	12	30	3	6	17	7	62
Wireworm	7	16	4	42	8	69	7	13	24
Weevil Larva	14	53	5	57	17	191	5	--	2
Tiphia Pupa	2	15	38	5	2	23	21	4	19
Cerambycid Larva	5	15	14	--	12	--	--	2	--
Crambid Larva	8	67	3	24	3	--	4	--	--
Cicada Nymph	116	19	36	13	51	3	42	116	38
Earthworm	70	89	258	533	333	--	583	--	--
Mermis	34	--	--	21	12	--	15	--	--
Milliped	147	--	--	--	2	9	2	--	--
Total	513	337	443	788	478	426	753	163	230
Acre Population	465656	244807	340203	439956	315374	220849	455637	98445	151588

Table V presents an interesting comparison between earthworms and white grubs on a square foot basis for each station. In the higher dryer situations the white grub population is the highest and decreases as the elevation decreases, except for Station 9 where purely sand species are found. On the other hand, the earthworm population goes in exactly the reverse direction. By referring to Table VI it will be seen that the hydrogen-ion concentration increases with the decreasing elevation whereas the colloids and volatile matter are in a descending order with the decreasing elevation. Therefore it appears that the grub population decreases as the hydrogen-ion concentration increases and as the percentage of colloids and volatile matter decreases. The earthworm population goes in the reverse order.

TABLE V. COMPARISON OF WHITE GRUBS AND EARTHWORMS PER SQUARE FOOT

Station	1	2	3	4	5	6	7	8	9
White Grub	1.96	.95	1.52	.55	.47	.70	.68	.26	1.20
Earthworm	1.46	1.48	3.91	6.83	5.04	--	8.1	--	--

TABLE VI. COMPARISON OF WHITE GRUBS AND EARTH-WORMS WITH SOIL ANALYSIS

Station	1	2	3	4	5	7
Mean Hydrogen-ion Concentration						
		6.12	6.55	6.17	7.3	7.52
Mean Percentage of Volatile Matter						
	7.53	6.98	4.94	5.61	6.76	4.63
Mean Percentage of Colloids						
	45.4	36.3	26.9	34.5	44.8	25.3
White Grub	1.96	.95	1.52	.55	.47	.68
Earthworm	1.46	1.48	3.91	6.83	5.04	8.1

Figure 1 shows the average depth at which white grubs were taken for all of the locations except the one in the sand hill region, where the number of grubs was too small for a graph. In order to prevent confusion the curves were divided and half of them were put at the top of the page and the other half at the bottom.

Figures 2 to 9 inclusive show the seasonal moisture variations of each six inch layer of soil to a reasonable depth for every situation. Below those curves is a set of three graphs showing the maximum, mean and minimum depth at

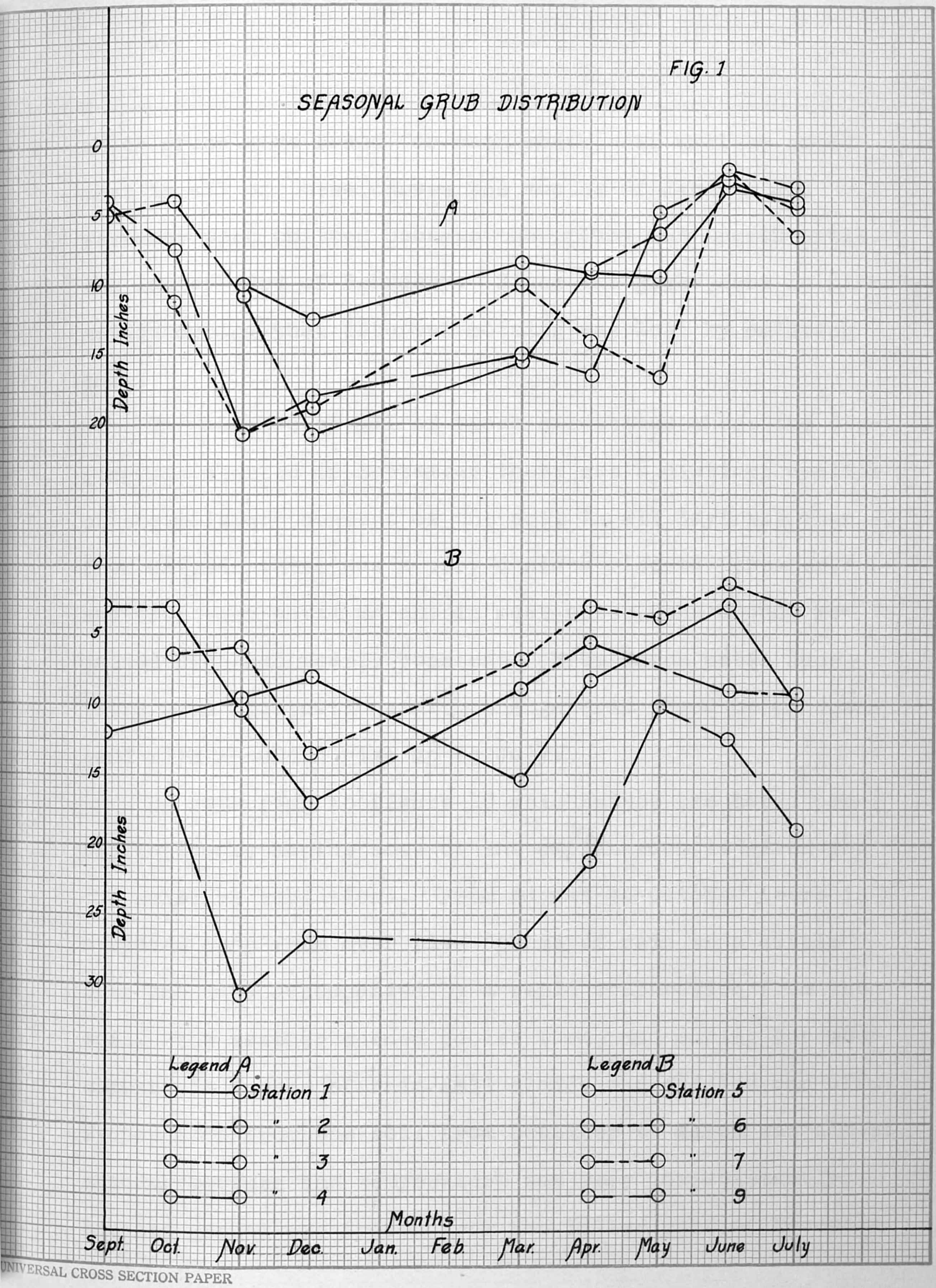


FIG. 1
SEASONAL GRUB DISTRIBUTION
A
B
Depth Inches
Depth Inches
0
5
10
15
20
0
5
10
15
20
25
30
Legend A
Station 1
" 2
" 3
" 4
Legend B
Station 5
" 6
" 7
" 9
Months
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July

which grubs were found for each month. It will be noted that in all of these curves the months of January and February were omitted because the ground was frozen until the latter part of February. Since the grubs were in hibernation during that interval nothing was lost by omitting them.

In the case of all of those situations where the digging was started in September there was a distinct decline of the moisture content of the soil in all layers. Then from October there was a very decided rise to December, and from then until March, in most cases, the amount remained high and nearly constant. From March until June there were fluctuations with the general trend being downward with a sudden rise up to July.

By referring to figure 10 which gives the total precipitation by months some of the explanation is given for the moisture variations. From August to October there is a sudden drop from over five inches of rain to a little over one inch accompanied by a rapid evaporation from the soil. The weather turned cooler then, and during November almost six inches of rain fell slowly and did not run off. Evaporation from the soil from December to March was almost nothing because the temperature was very low constantly, and the ground was frozen from the latter part of December to the first of March and even longer in the wooded areas. Variations occur from March to July in nearly all of the curves, and they can be attributed to several reasons. Evaporation was high, rains falling during the time were mostly showers or hard rains, each locality had different slopes, and the amount of shade was different in each case.

The distribution curves for the depths of the grubs all follow the same general downward trend in the fall, remain low through the winter and come up again in the spring. Each situation shows variations from this, however. In every case where heavy clay subsoil or rock was encountered the depth of hibernation in the winter was at less depth than in the sandy subsoils. The importance of temperature is not known because adequate means for obtaining the data were not available. Since all of the ground froze to a depth of twenty-four inches and more in some cases it would seem that freezing was not a factor. However, it is reasonable to expect that the minimum depth most suitable would be one giving the least diurnal or sudden temperature fluctuations and still not be too difficult to attain because of heavy clay or other barriers. In the sand hill region the average depth was a long way from the surface whereas on the high prairie and the upland woodland the average depth was near the surface having penetrated the heavy clay a short distance in the former case and to the rock layer in the latter.

Climatological data show that the three or four winters previous to the winter of 1928-1929 have been more mild than normal and the notes for the winter of 1925-1926 and 1927-1928 show that the average depths of hibernation were consistently higher than for the winter of 1928-1929. The ground thawed out in February during those winters and the rise of grubs was a month or two earlier than in 1928-1929.

All previous notes agree with those of the author in regard to the comparative depths of hibernation in the clay and sandy soils. In every case hibernation was much deeper in sand than in clay.

Figure 11 is a climagraph for the region of Manhattan based on the weather records from the weather station. A climagraph is a recent adaptation for the plotting of precipitation and temperature together in a seasonal sequence. In the figure the black dotted line is the mean temperature and precipitation by months for a period of over seventy years. The solid black line is the monthly temperature and precipitation for eleven months beginning August, 1928, and extending through June, 1929. The horizontal straight black line represents the departure from normal temperature which is indicated by the dotted black line. The same is true in the case of the precipitation as shown by the vertical lines. It will be noted that the temperature for the period is very nearly normal whereas the rainfall is very much greater.

This figure has as its purpose to show how abnormal this year has been compared to the average for 70 years for the place where the record is kept. Each region would give a different curve, but all would follow within limits the one given.

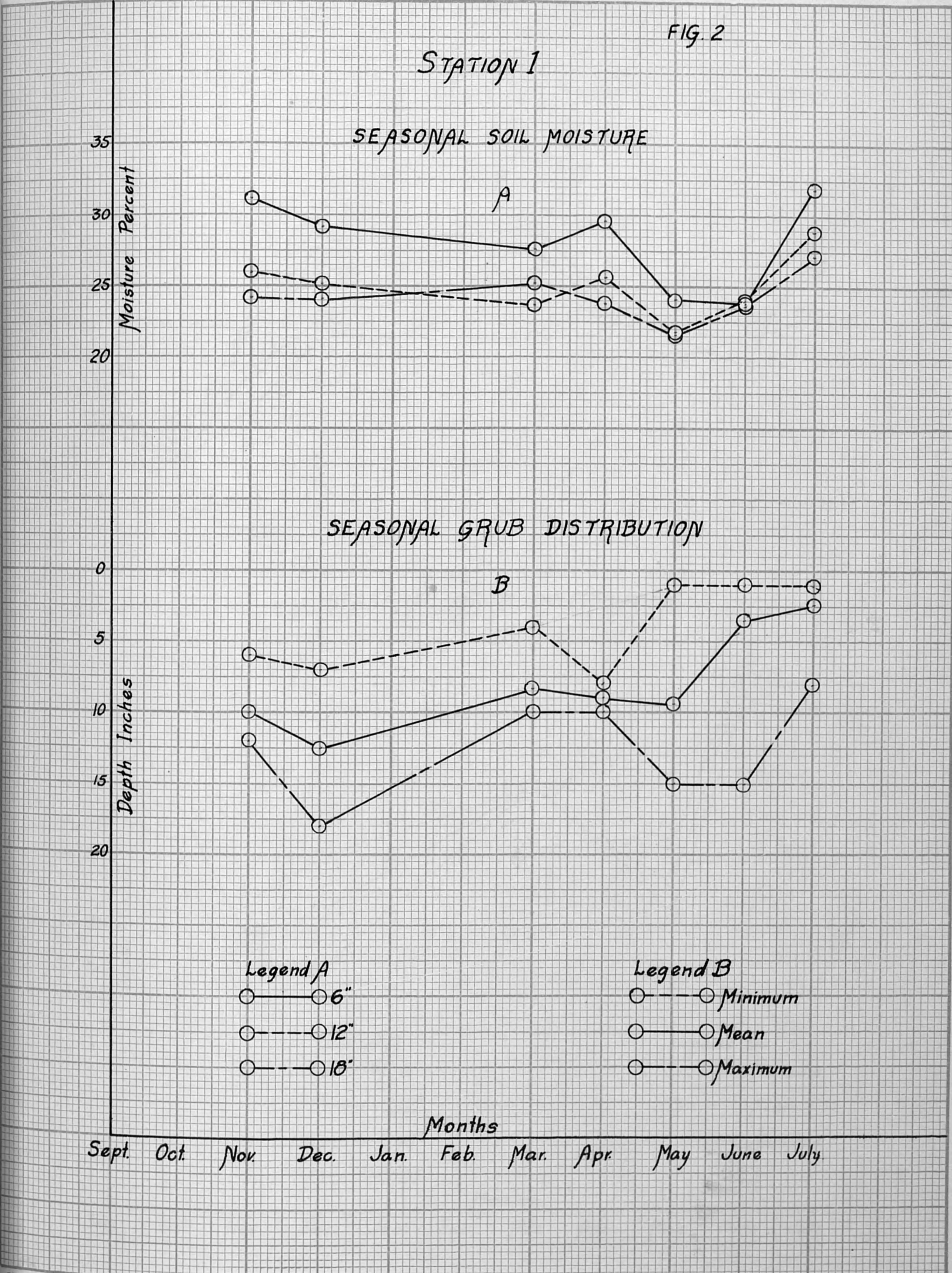
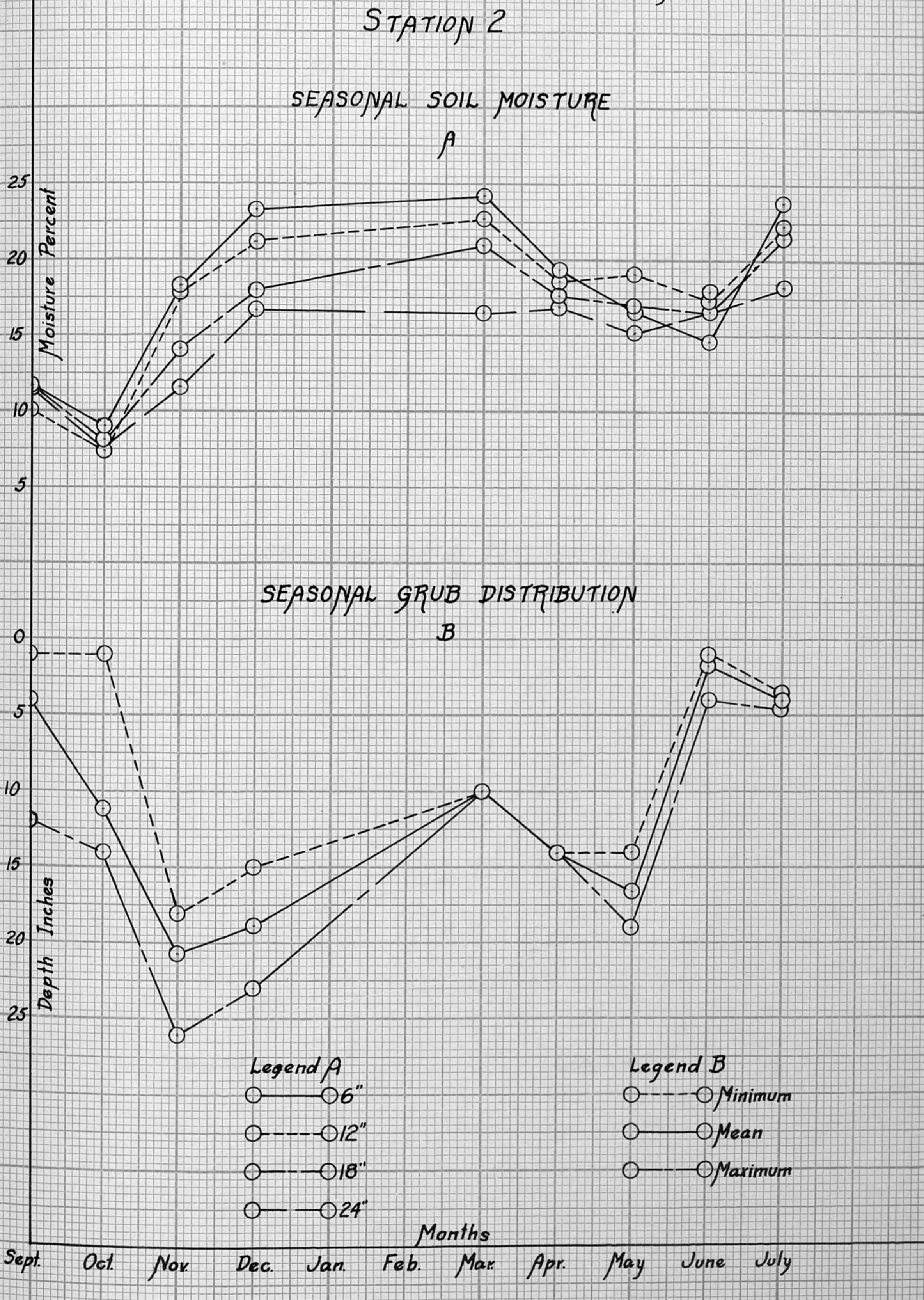

STATION 1
SEASONAL SOIL MOISTURE
A
Moisture Percent
35
30
25
20
SEASONAL GRUB DISTRIBUTION
B
Depth Inches
0
5
10
15
20
Legend A
6"
12"
18"
Legend B
Minimum
Mean
Maximum
Months
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July

FIG. 2

FIG. 3


STATION 2
SEASONAL SOIL MOISTURE
A
Moisture Percent
25
20
15
10
5
SEASONAL GRUB DISTRIBUTION
B
Depth Inches
0
5
10
15
20
25
Legend A
6"
12"
18"
24"
Legend B
Minimum
Mean
Maximum
Months
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July

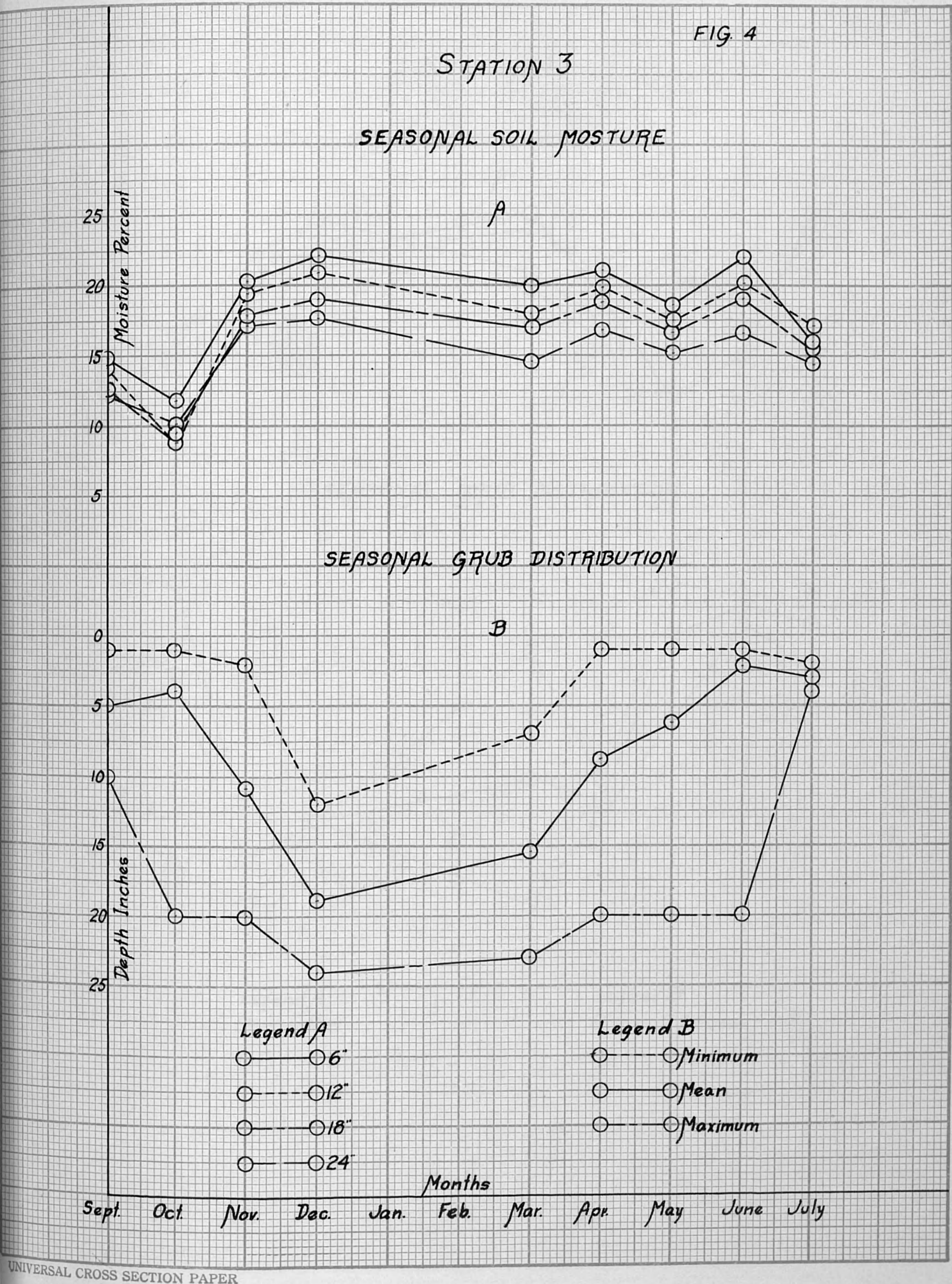
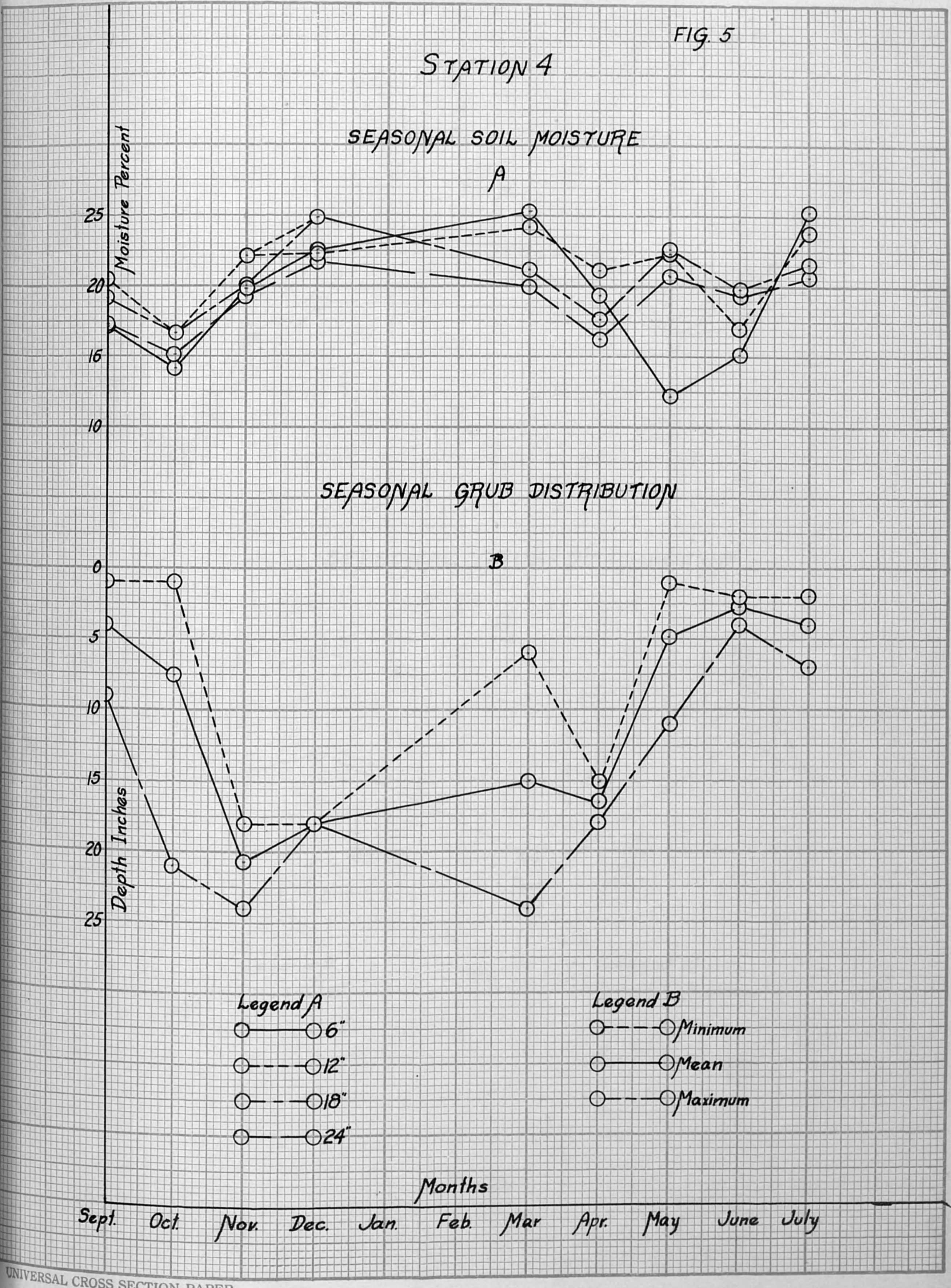


FIG. 4
STATION 3
SEASONAL SOIL MOSTURE
A
Moisture Percent
25
20
15
10
5
SEASONAL GRUB DISTRIBUTION
B
0
5
10
15
20
25
Depth Inches
Legend A
6"
12"
18"
24"
Legend B
Minimum
Mean
Maximum
Months
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July

FIG. 5



STATION 4
SEASONAL SOIL MOISTURE
A
Moisture Percent
25
20
16
10
SEASONAL GRUB DISTRIBUTION
B
0
5
10
15
20
25
Depth Inches
Legend A
6"
12"
18"
24"
Legend B
Minimum
Mean
Maximum
Months
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar
Apr.
May
June
July

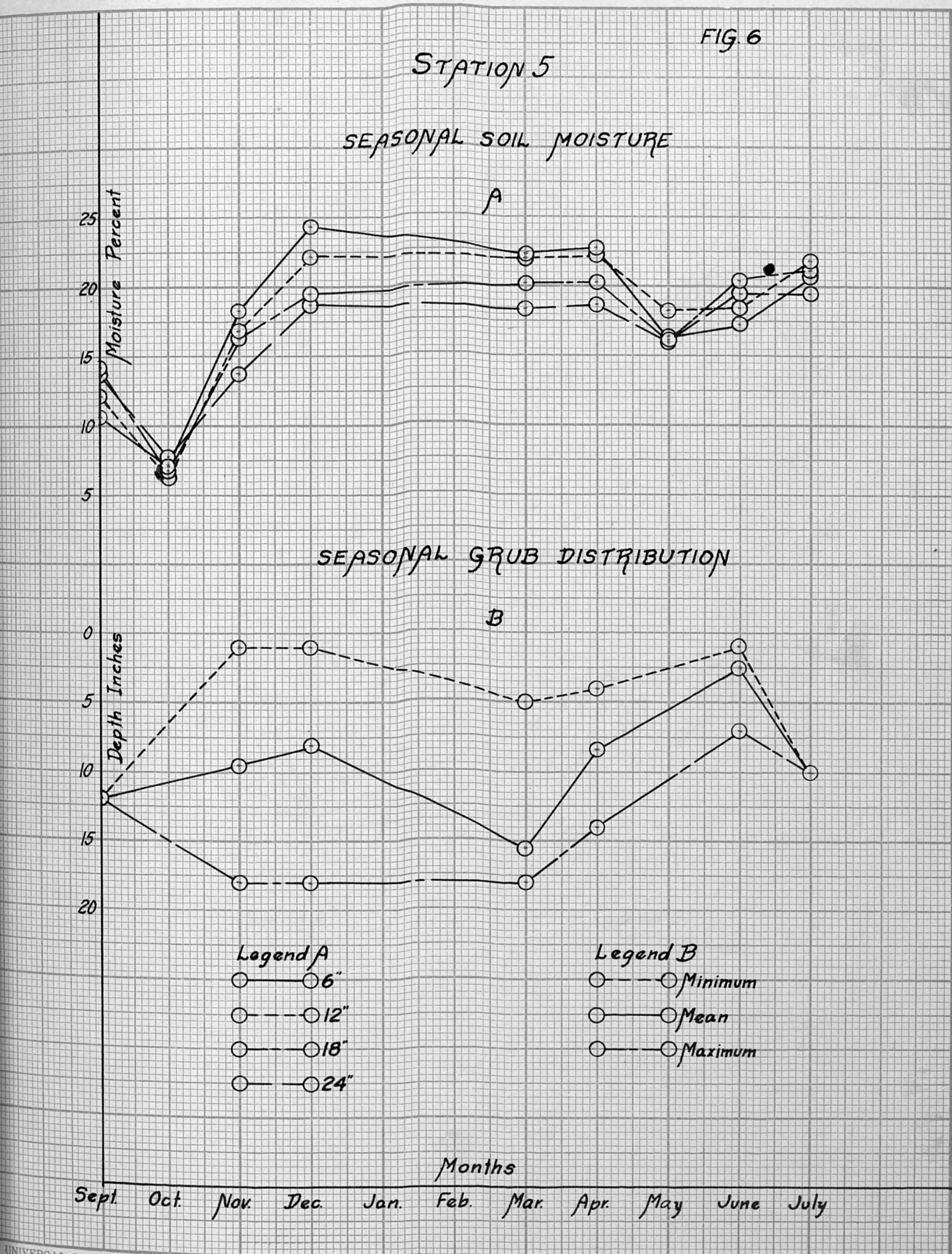
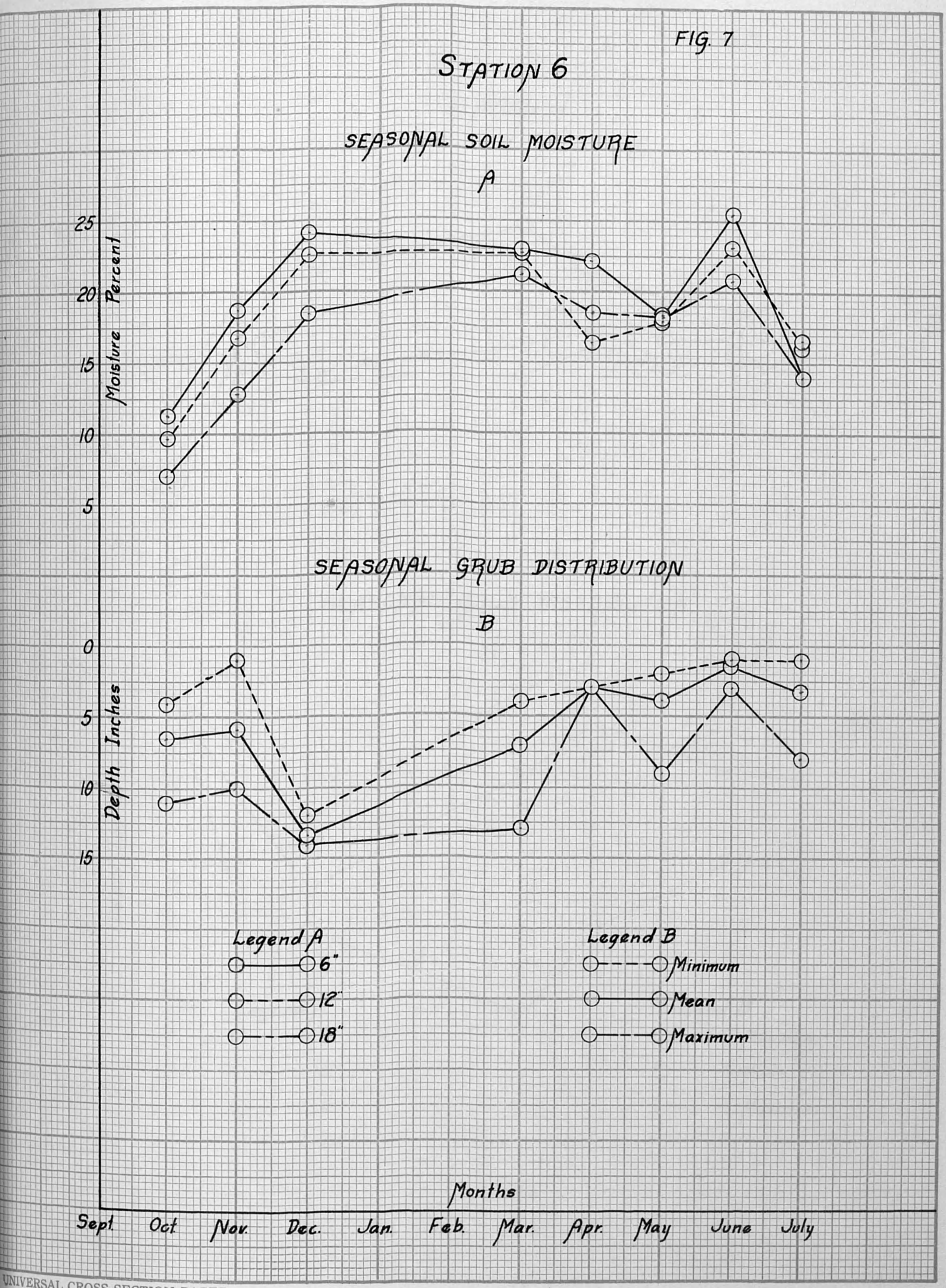


FIG. 6
STATION 5
SEASONAL SOIL MOISTURE
A
Moisture Percent
25
20
15
10
5
SEASONAL GRUB DISTRIBUTION
B
Depth Inches
0
5
10
15
20
Legend A
6"
12"
18"
24"
Legend B
Minimum
Mean
Maximum
Months
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July



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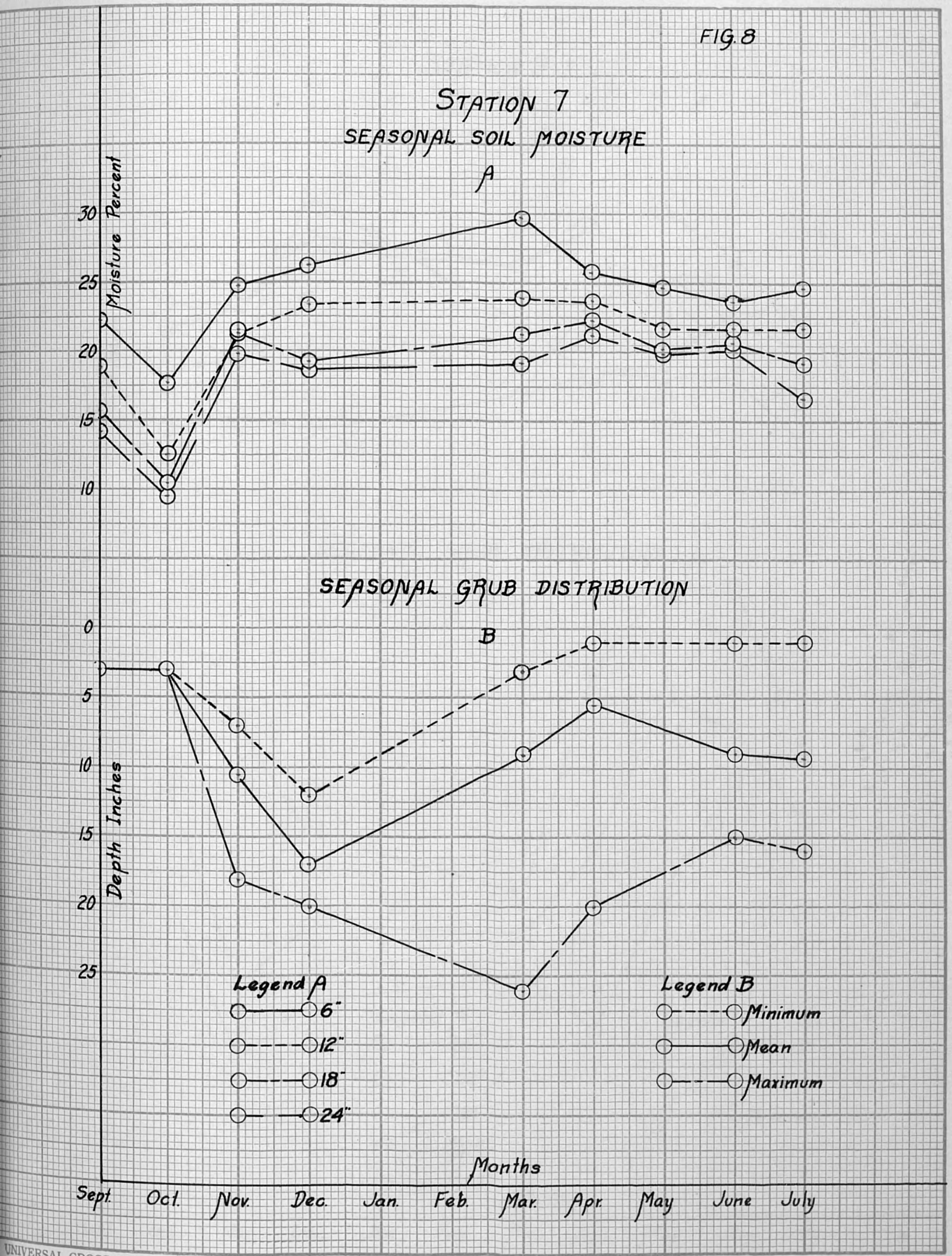
FIG. 8
STATION 7
SEASONAL SOIL MOISTURE
A
Moisture Percent
30
25
20
15
10
SEASONAL GRUB DISTRIBUTION
B
Depth Inches
0
5
10
15
20
25
Legend A
6"
12"
18"
24"
Legend B
Minimum
Mean
Maximum
Months
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July

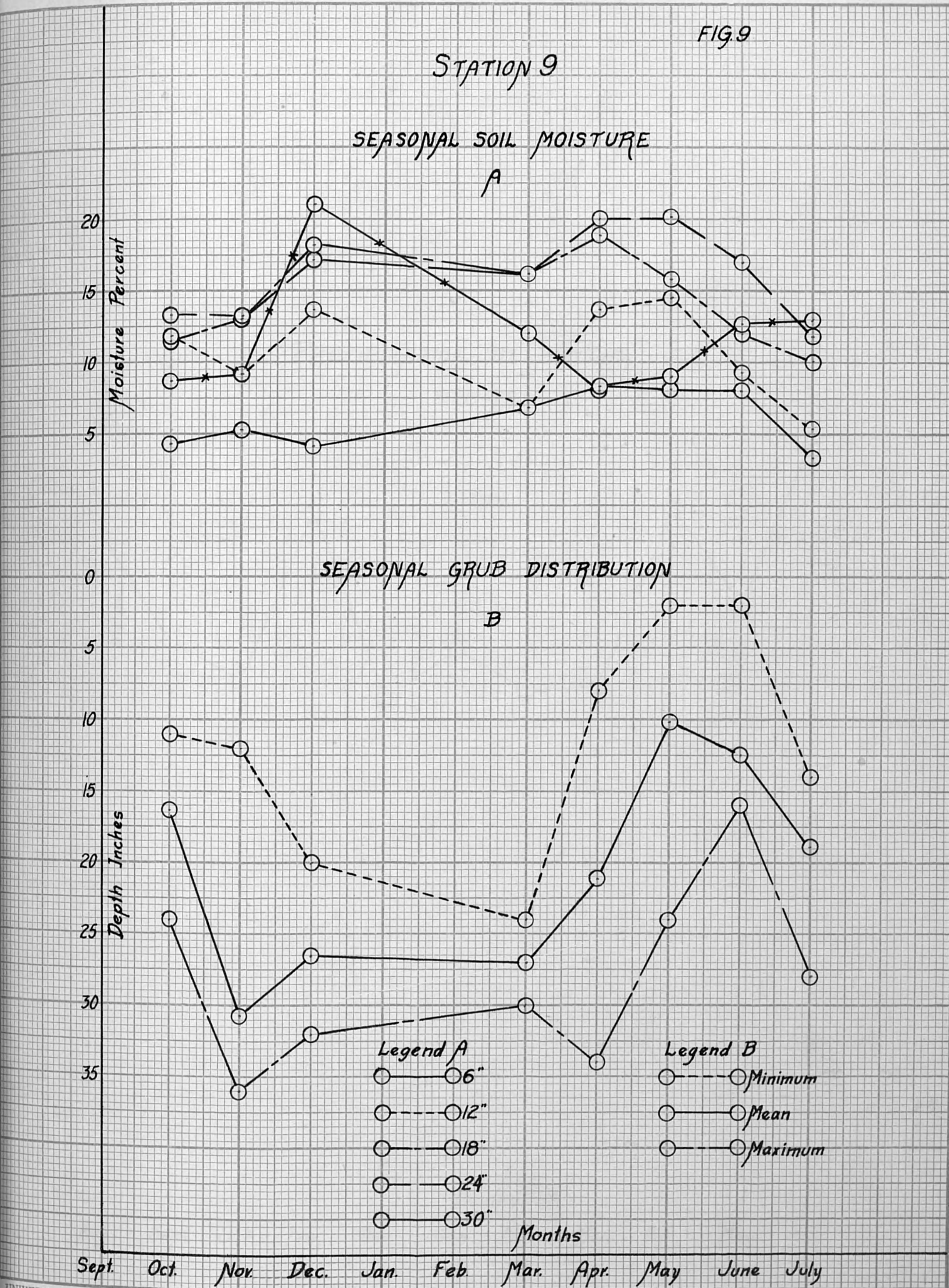
FIG. 9
STATION 9
SEASONAL SOIL MOISTURE
A
Moisture Percent
20
15
10
5
SEASONAL GRUB DISTRIBUTION
B
Depth Inches
0
5
10
15
20
25
30
35
Legend A
6"
12"
18"
24"
30"
Legend B
Minimum
Mean
Maximum
Months
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July

FIG. 10

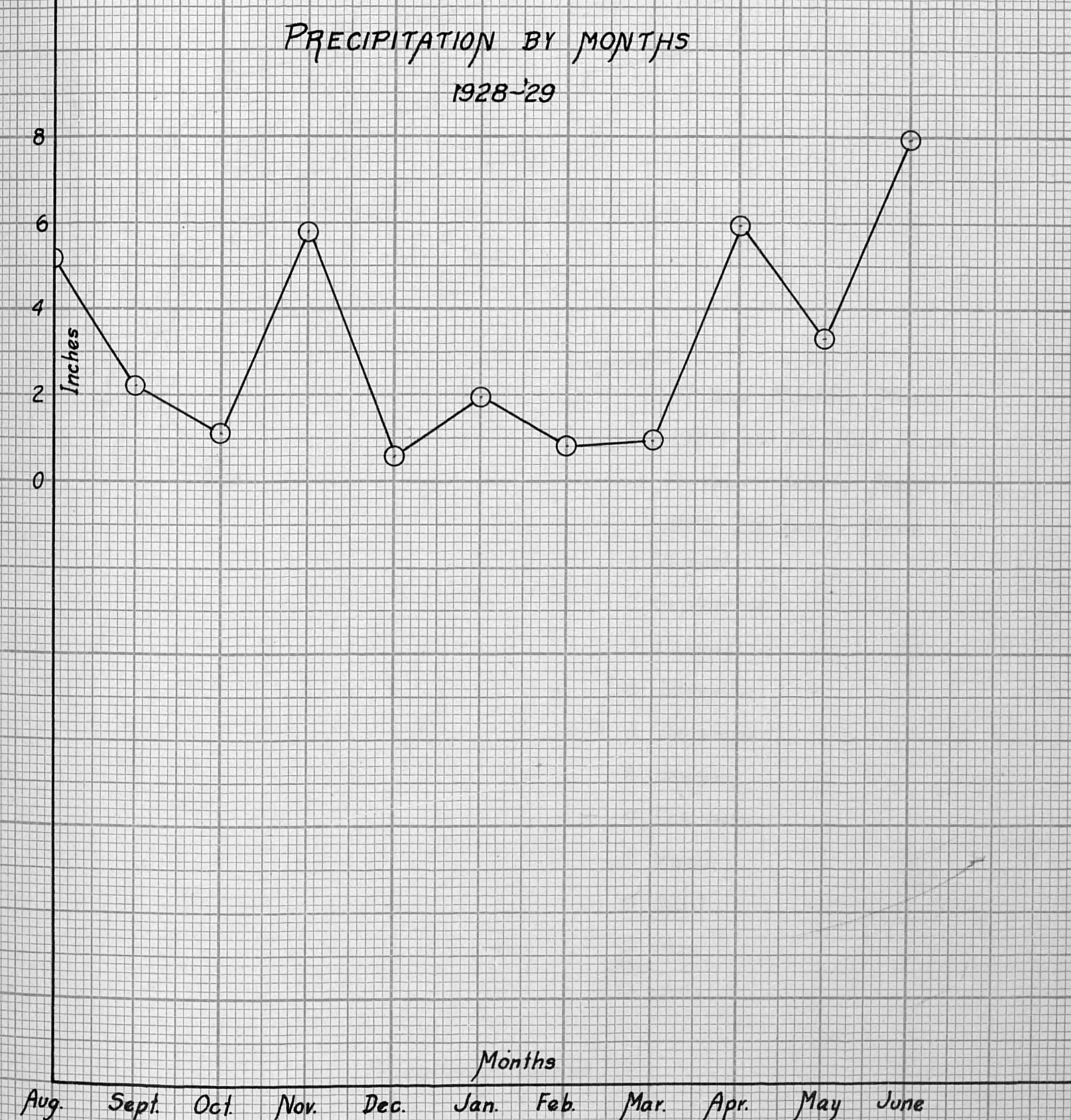

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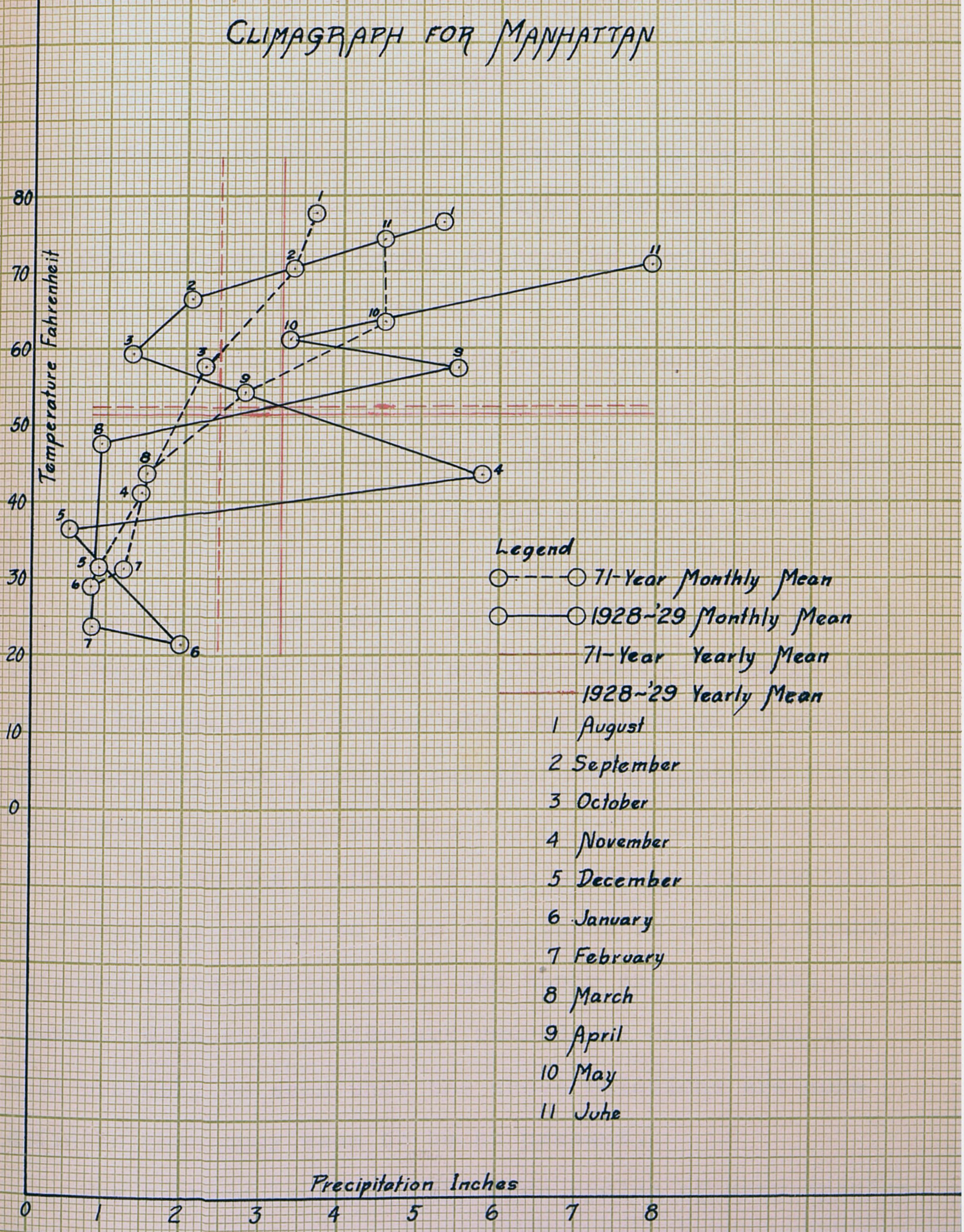
FIG. 11


CLIMAGRAPH FOR MANHATTAN
Temperature Fahrenheit
80
70
60
50
40
30
20
10
0
Precipitation Inches
0
1
2
3
4
5
6
7
8
Legend
71-Year Monthly Mean
1928-'29 Monthly Mean
71-Year Yearly Mean
1928-'29 Yearly Mean
1 August
2 September
3 October
4 November
5 December
6 January
7 February
8 March
9 April
10 May
11 June

SUMMARY

White grubs being subterranean insects must, of necessity, live in intimate contact with their environment. As a result they seem to become adapted to certain complexes of factors existing in the soil.

With an increasing hydrogen-ion concentration and a decreasing percentage of colloids and volatile matter there is a decreasing number of white grubs per unit area. Certain variations from this occur which more data will clear up.

Seasonal variations in the depths at which the grubs are found for each locality are dependent to a large degree on the temperature together with soil texture. Freezing is apparently not a factor but diurnal or frequent fluctuations seem to be detrimental.

It is not the purpose of this paper to give definite habitats, but merely to show that there is a relationship existing between white grubs and their environmental complexes. When the species are reared and determined it will probably be seen that the above relations are more definite than they seem to be at present.

The extreme length of the life cycles of many species of May beetles and the rearing mortality greatly increase

the problems involved in a study of this kind. Since this paper is based only on the results of a year's work it must of necessity be incomplete.

Acknowledgements are hereby given to those who were always ready and willing to assist me in every way possible in accomplishing this work. To my major instructor, Professor J. W. McColloch of the Department of Entomology, I extend my most hearty thanks for his very guidance in the work at all times. Dr. F. L. Duley of the Department of Agronomy offered many helpful suggestions for which I wish to thank him sincerely. To F. S. Kruger, a student assistant is owed a debt of gratitude for his aid in digging the holes and his careful rearing of the collected material. Many thanks are due the Department of Agronomy for apparatus and materials which were used from time to time.

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PLATE I

Station 1

Station 2

PLATE II

Station 3

Station 4

PLATE III

Station 5

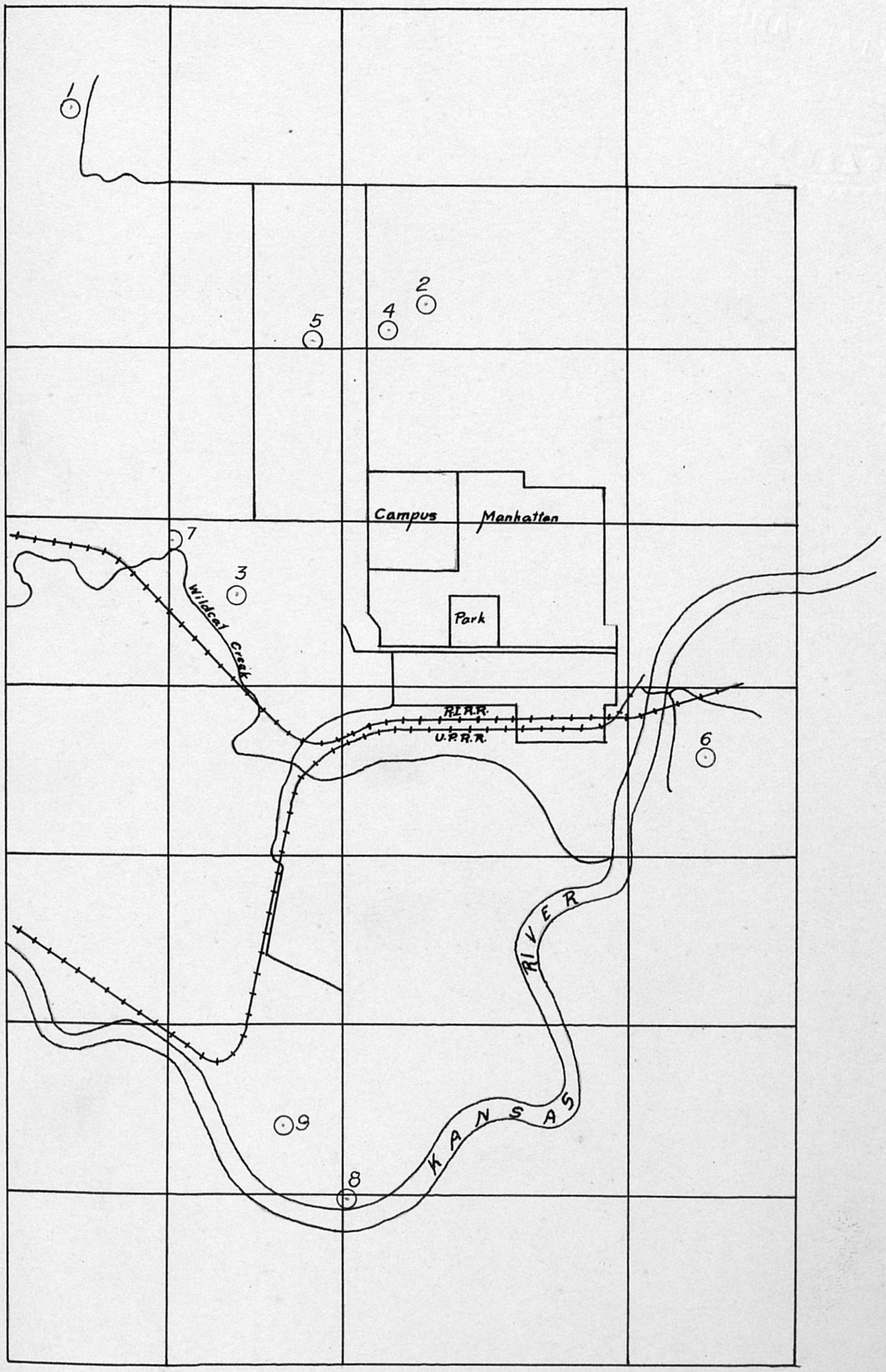
Station 6

PLATE IV

Station 7

Station 8

PLATE V



MAP SHOWING STATIONS

Scale 1" = 1mile