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SOME PHYSICAL PROPERTIES OF ORGANIC SOILS AS RELATED TO EFFECTIVE DRAINAGE

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Robert W. George

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THESIS

This is to certify that the

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SOME PHYSICAL PROPERTIES OF ORGANIC SOILS AS

RELATED TO EFFECTIVE DRAINAGE

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Robert Worth George

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Major professor

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SOME PHYSICAL PROPERTIES OF ORGANIC SOILS
AS RELATED TO EFFECTIVE DRAINAGE

By

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INTRODUCTION

For many years a difference of opinion has existed as to the most effective methods of drainage on organic soil. This has been due to lack of information on the exact capacity needs of drainage systems, the most desirable water level to maintain, and the effect of such drainage on organic soils over a period of years. There have been only a limited number of investigations directly concerned with the physical properties of organic soils as related to effective drainage.

It was the purpose of this study to investigate the physical properties of organic soils that are related to drainage. It was intended that the correlation of such information would aid in developing drainage recommendations for organic soils based on their physical properties.

The problem is of utmost importance because farmers who have drained organic soils often find a need after three to five years of having their tile lines or open ditches spaced closer together. On the other hand, they sometimes need to establish water level control dams, because of over-drainage.

Any conclusions that would result in more complete and effective drainage recommendations would mean a substantial savings to a muck farmer, not only in the initial drainage operations but in later crop production and soil maintenance.

REVIEW OF LITERATURE

The relation of the physical properties of organic soils to effective farm drainage is extremely complex. The variations exhibited by such physical properties as shrinking and swelling, pore-size distribution, and water permeability are some of the problems encountered.

Organic soils vary greatly throughout the United States and even within the same soil formation due to their origin and type of formation (2, 4, 5, 10, 29). Waksman (29) stated that, "The mechanical structure of peats, their colloidal properties, and other physical and physio-chemical characteristics are determined and controlled by the nature of the plants from which they have been formed, environmental factors, especially nature of water and temperature, and by other conditions which have contributed to their formation and decomposition".

Davis (5) has classified the peats of Florida into four groups according to their variation in origin and physical properties. He classified them as follows: 1/ Fibrous, great porosity; 2/ Sedimentary, macerated, plastic, often colloidal, shrinks and hardens more than group-1 upon drying; 3/ Granular, becomes granular after drainage and cultivation; 4/ Woody, with pieces of wood or stems abundant, woody particles shrink less upon drying than other materials.

The above grouping of peats according to their variation in origin and physical properties has been correlated with volume changes. Davis (5) reported that volume change in peats as related to the above grouping of peats show the following variations: Group 1/ - Fibrous, Everglades saw-grass, shrank 20-25 per cent of original volume upon being air-dried. Group 2/ - Sedimentary, shrank 10 per cent of original volume, and Larabatcher, semi-aquatic, shrank 10-15 per cent when air-dried. Group 3/ - Granular, Woody Gandy, shrank 30-35 per cent, and Fibrous Mangrove shrank 40-50 per cent when air-dried. Group 4/ - Woody, matted, strongly fibrous Florahome Peat shrank 40-60 per cent of original volume upon being air-dried.

Water Content and Absorbing Capacity

Specifications according to water holding capacity were established by Procurement Director of the United States Treasury Department. Davis (5) reported their established specifications as follows:

Peat Moss......................................	1100-2000 per cent
Reed Peat or Sedge Peat........................	350- 800 per cent
Reed Muck or Sedge Muck........................	100- 350 per cent

Davis (5) noted that water holding capacity is difficult if not impossible to measure accurately in the laboratory. However, he added that the field water content of organic soils could be approximated by weighing uniform size samples at or near the deposit and then drying these to nearly constant weight in the laboratory.

Harmer (10) reported that, "Muck water-holding capacity is several times that of a clay loam, and many times that of a sand. It is considerably greater than that of straw". He noted further that, "most muck soils as they exist in Michigan need to be drained, however, when drained they have the capacity, with proper fertilization to produce bountiful crops."

Davis (5) reported, "The average condition in cultivated or nearly constantly drained peat or muck areas in the northern part of the Everglades is 67 per cent water in the upper two feet of soil, and 79 per cent water in the peat or muck below two feet depth. In fact, most of the samples of peat soils below two feet contained over 82 per cent water." The preceding, referred to per cent moisture, was computed on the volume basis.

Clayton and associates (3) showed that rates of seepage vertically downward through Everglades peat varied from a rate of 0.3 feet per day through the top 18 inches to a rate of 27.3 feet per day through the layer from 18 to 36 inches below the surface. They found that the horizontal transmission of water was at a rate of 0.25 feet per day at a depth of 3 feet. These observations concerning water content and absorbing capacity have shown also that the top soil had been greatly changed by cultivation and weathering, causing it to be less permeable than were the lower undisturbed layers.

Drying Characteristics

Davis (5) reported that when peats are dried, their structure, and certain other characteristics are often radically modified. He noted that loss of weight was the most uniform result of drying, and that such loss of weight was due, partially, to the biological activities of organisms in the peat. Oven-drying reduced the weight of peat samples taken from above the water-table by 78 per cent, while drying reduced the weight of samples taken from below the water-table by 86 per cent. The peats in general, after drying, were reported to have a lower specific gravity than when saturated with water.

Shrinking and Swelling Phenomena in Relation to Porosity

Waksman (29), reporting on investigations of peat soils in New Jersey, stated, "Swelling and shrinking of the organic colloids makes the determination of the pore volume rather difficult. The determination of the air-content of peat in a fresh condition is of much greater value than the determination of the pore volume. The degree of decomposition of peat soils is influenced by the air-content." He noted also that additional problems arise when measuring pore volume in peat soils because of the many factors that may appreciably alter its development. The water-level of the bog, the rate of evaporation, condition of drainage, rainfall, as well as dry versus wet seasons, all, were found to be particularly important in regulating the growth and type of peat produced, and its physical and chemical properties.

Lauritzen and Stewart (12) reported that the volume change ratio was equal to the change in volume of the clod that accompanies the loss of a given volume of water, divided by the volume of water lost. They noted that shrinkage which accompanied drying was dependent on the manner in which the moisture was associated with the soil material and the pore space in the soil mass.

Woodruff (30) stated, "Most, if not all of the phenomena of soil water relations may be accounted for by the integration of the effects of surface tension and absorption in pores of different sizes with respect to the vapor pressure of water and to the pressure of the atmosphere."

Russell (22) reported that moisture desorption curves may provide a simples method of measuring the size distribution of soil pores. "They represent the volume of those portions of the void labyrinth through which air-water interfaces are caused to retreat by unit of increase in tension." He found that the similarity of the curves for pores having a radii of less than 30 microns was consistently supported by curves for individual samples, and was significant.

Soil with disturbed structure resulting from a bluegrass sod showed many large pores whereas soils with undisturbed structure showed only a small amount of large pores. Russell (22) concluded that air-water interfaces must exist in a soil void if it is to drain at calculated tensions. He suggested that the size of the channels by which a water-filled void was connected to other voids having air-water interfaces determined the tension at which the void would drain. He said that the characterization of soil porosity from desorption-curves promised to develop into a useful method of attacking problems of soil structure, especially as procedures are refined to improve accuracy of measurement in the important low-tension range.

Lauritzen and Stewart (12) in their investigations of soil prosity concluded that, "Moisture in the soil available to plants may be governed by the relative size of the pore-space which it occupies and the size of the root hairs".

Percolation of Water Through Organic Soils

Woodruff (30) reported that there were three pore size groups that affect water relations of the soil in different ways: 1/ Pores with radii of 1.5 microns or more where water will flow as a liquid from regions of high pressure to regions of low pressure. Water obeys the laws of rise in capillary tubes and adjusts itself rapidly to changes in moisture potential. It moves rapidly and is lost rapidly by percolation or evaporation; 2/ Pores with effective radii of 0.2 to 1.5 microns where water will move through the soil only as a vapor, and can be removed from the soil only as a vapor. Water is unstable and moisture potential adjustments are slow. Water can be used by plants; 3/ Pores with effective radii less than 0.2 microns where water may be extracted from the soil only as a vapor. Water is stable and can not be drawn from the pores by plants.

Woodruff (30) noted that the transition between pores of group 1/ and group 2/ occurred at a moisture potential of pF 3.0. The transition between the pores of group 2/ and group 3/ occurred at a moisture potential of pF 4.1. He stated further that, "Average soil after saturation loses water rapidly until it attains a field capacity at pF 3.0. If soil is vegetated the moisture diffuses to the roots through the vapor state, and the entire mass of soil dries to the wilting point at pF 4.1, leaving water only in the pores of group 3/." The moisture potential at pF 3.0 appeared to be the upper limit on the moisture potential scale for the movement of water as a liquid. He concluded that movement of water through the soil in the liquid phase ceases when the surface of a short column of soil becomes dry. He found that it took four times as long to dry out the second inch of soil, as it did to dry out the first inch in the column.

Russell (23), in his study of water-table variations in peat land, stated, "It is necessary to determine the volume of water-filled pores at all points between the water table and the soil surface. After establishing the vertical distribution of water-bearing pores, it is a simple matter to determine how far the water-table will rise or fall in response to the addition or removal of a known amount of soil water." He suggested that if effect of drainage on water-table elevation is to be predicted, a moisture sorption curve from desorption data should be used. If effect of rainfall or irrigation on water-table position is to be determined, the calculation should be made from absorption data. His method of procedure for soil sampling was to take samples in organic soil having undisturbed structure at 6-inch intervals to a depth of four feet, from each of five different sites. Desorption curves were determined then for each sample.

Haines (8) noted a definite lag in the re-absorption of water into a soil after it was once dried below 40 per cent moisture. He

termed this lag as "Hystersis". Such a lag, hystersis, existing between absorption and desorption curves, validated further the need for both absorption and desorption data if both irrigation and drainage effects are to be determined.

Van Bavel and Kirkham (28) have used a field measurement of soil permeability using auger holes which gave rates of permeability in close correlation with previous laboratory tests. A serious limitation of this method, as the authors state, is that it requires the presence of a water table, either perched or real, which should not be too low. This means that in most locations, for mineral soils, only a few opportunities are available for measurement each year. However, for work with organic soils where the water table is normally less than four feet below the soil surface, it would seem that the method warrants consideration, especially where a large number of sites are to be studied.

The existance of drawdown curves between tile lines in organic soil studied in Indiana was noted by Morris (15). Complete drainage systems with water control were shown to increase crop production and reduce the rate of subsidence of the organic soil.

Slater (25) reported on the attempts made at the correlation of measureable soil physical characteristics and the proper depth and spacing of tile. He computed the depth and spacing of tile from a tile-spacing formula that was based on soil permeability and the application of Darcy's law to the conditions of lateral flow.

EXPERIMENTAL PROCEDURE

This investigation was made to determine a possible correlation between the rate at which water-table levels are lowered and one or more of the physical characteristics of organic soil. The investigation consisted of two phases. One, an investigation of some of the physical characteristics of an organic soil and two, water table studies of the area.

The investigation proper was carried out at the Michigan State College Muck Experimental Farm. The organic soil at this location, (Site "A"), is classified as Houghton Muck and is well decomposed in the surface with a high percentage of raw-fibrous organic material below approximately nine inches depth. It is a medium acid soil with a pH ranging from 5.7 to 6.4. The land has been cropped intensively for the past twelve years with truck crops. The drainage conditions are good with tile spaced 60 feet apart at a depth of approximately $2\frac{1}{2}$ to 3 feet, with open ditches along the north, east, and west bounddaries to carry both surface and underground water. The outlet is fair with a low-lift drainage pump installed to facillitate drainage under conditions of high water tables.

Three additional sites were sampled to compare the physical characteristics measured at Site "A". These additional sites were as follows:

Site "B" - Robert George Muck Farm, Arcadia, Michigan (Manistee County); drained and cropped since 1948. This is a well decomposed organic soil underlain with marl at four to five feet. Pump drainage is used exclusively.

Site "C" - Alfred Thompson Muck Farm, Evart, Michigan (Osceola County); drained and cropped for the past ten years with considerable drainage problems at the present time.

Site "D" - Leonard Bontekoe Muck Farm, Marion, Michigan (Osceola County); drained and cropped since 1947 with supplemental drainage added in 1951. This organic soil is quite compact with a high content of raw undecomposed organic material. At a depth of 12 to 18 inches below the surface there is a 4 to 6 inch layer of very compact soil which is high in silt. Seepage and springs have constituted a problem in this area.

Physical Characteristics

Equipment used. Soil samples were taken with a core sampler. Soil cores two inches high and three inches in diameter with a volume of 192 cc. were taken.

Preparation of the site. Sampling was done at varying moisture conditions at the surface and at different levels through the soil profile. A minimum of not less than ten replicates were taken for each different level (horizon) and surface moisture condition. The different levels below the surface were sampled where texture, structure, size of visible pores, or stage of decomposition indicated probable differences in drainage characteristics. This significant variation was determined by the author to be at approximately nine inch intervals down through the profile to the water table level.

A pit was dug to expose each respective layer to be sampled below the surface. Each level was sampled separately to insure that no core included any part of two different layers. A minimum horizontal interval of eight inches was maintained between the cores taken from the same pit in order to prevent disturbing the soil of adjacent cores.

Taking and preparing the soil cores for laboratory determination. In taking the soil core sample, the sampler was used as discussed by Neal (17). The soil core was then taken into the laboratory, weighed, and prepared for further determinations.

A filter paper disc was placed on the bottom of each core. The bottom of the core cylinder was then covered with a piece of medium-weight cheese cloth and secured with a rubber band. The soil core was then weighed again to determine the added weight, and placed in a saturation pan. Each core was covered to prevent drying out of the surface, and allowed to saturate for approximately 12 hours.

Making laboratory determinations. As suggested by O'Neal (17), the saturated soil cores were weighed and further prepared for permeability studies by placing an additional core cylinder on top of each soil core and securing it with masking tape. The assembled cylinders were then placed on a heavy screen with one-half inch openings over a draining pan. A filter paper disc was then placed on top of each soil core and 100 ml. of water was added to each assembled core. The time of the initial application was recorded and a head of water slightly more than one-half inch was maintained over the soil core for a period of one hour, recording the amount of water added.

At the end of the one hour period each core was checked after water was added to equal the initial head of water.

The rate at which the organic soils would drain under different tensions was determined by placing the cores on a tension table and permitting them to drain for a period of 12 hours at drainage tensions of 10 cm, 20 cm, 40 cm, 60 cm, and 80 cm. The soil cores were weighed after being subjected to drainage at each of the above tensions to measure the amount of water lost at the different drainage tensions.

Swelling capacity was determined by placing the saturated soil cores in a displacement pan where the volume of the saturated soil plus the core was measured by the cubic centimeters of water displaced. (The volume of the core cylinder was measured after the soil was oven-dried.)

To conclude the moisture determinations the soil cores were placed in the oven and allowed to dry at a temperature of 105° C F~~ahrenheit~~ for a minimum of 48 hours, and weighed. The volume of the oven-dried soil was then determined by adding sieved sand to the core until the core was filled to its capacity of 192 cc.

All data were then summarized for each soil core to determine such physical characteristics as Bulk Density; Per cent Moisture (oven-dry basis); Per cent Moisture (volume basis); Per cent Swelling; Per cent Shrinking; Permeability; Pore Volume distribution as measured in volume of water lost at tensions of 10, 20, 40, 60, and 80 cm. of water, and the Per cent Moisture at these different drainage tensions.

Water Table Studies

Equipment used. Thirty downspout pipes, five feet long and three inches in diameter, were used for test wells in addition to the few wooden wells already installed at Site "A".

Preparation of the site. Holes were dug approximately four and one-half feet deep at each test well location, and the downspout pipes were set vertically in the holes approximately four feet deep with the bottom of the test well below the water table level.

Field determinations. Each well was measured periodically to determine the depth of the water table from the top of the test well. Measurements were made for each appreciable water table variation. Readings were first made with gravitational drainage only, then the gate at the drainage outlet was closed and the drainage pump was used. The period of time which the pump operated was recorded, and well readings were made until the outlet ditch, or sump, was practically dry. The water level in the outlet ditch was measured at each reading of the test wells. The relative elevation of each test well (top), the depth of the tile, and each reference point used for measuring water table levels was determined. Elevations were then calculated for the measured water table level at each reading and summarized.

DISCUSSION AND RESULTS

Physical Characteristics

The physical characteristics of the organic soil such as per cent moisture (oven-dry basis and volume basis) and bulk density were determined for Site "A", first, by taking surface samples, wetting soil, allowing a day or so for equilibrium, and resampling at seemingly different moisture conditions. The mean values for each sampling are shown in Table I. It is noted that the five different samplings, ten replicates each, showed definite variation in moisture content, however, did not appear consistant with the variation in bulk density. This was probably due to the fact that sufficient time had not elapsed for equilibrium with the swelling characteristic of the soil.

TABLE I

MOISTURE CONTENT AND BULK DENSITY
OF SOIL CORES FROM SURFACE SAMPLES OF VARYING
MOISTURE CONDITIONS AT SITE "A" - 1951 1/

Date of core Sampling	Per cent Moisture (oven-dry basis)	Per cent Moisture (volume basis)	Bulk Density (grams per cc)
July 24	230	55.8	.243
July 25	273	69.2	.257
July 26	258	65.4	.256
July 31	231	62.2	.270
August 16	238	64.1	.262

1/ Average of 10 replicates for each date.

Studies of surface samples with varying degrees of moisture gave no appreciable correlation between per cent moisture and bulk density. However, when these moisture characteristics were compared with core samples taken at 0-3 inch, 9-12 inch, and 18-21 inch depths there was a definite correlation between per cent moisture and bulk density. Data on moisture content and bulk density of soil cores from varying depths at Site "A" are shown in Table II. Comparable data for Sites "B", "C", and "D" are shown in Table III. It was noted that there was a constant increase in per cent moisture with depth and a decrease in bulk density on all of the sites except Site "D" which was explained by the existance of a more compact layer at the 18-21 inch depth which caused a higher bulk density and lower moisture content.

When organic soil came to equilibrium there appeared to be throughout the profile a uniform correlation between moisture content and bulk density. As shown in Figure 1, when moisture was decreased there was an accompanying increase in bulk density. Dehydration of organic soil is apparently closely correlated to an increase in bulk density. Likewise, in all samples of the sub-surface layers at a depth of 18-21 inches there was observed a lower bulk density accompanied by a higher per cent moisture. Figure 1 shows a consistant moisture-bulk density curve for three of the four sites.

TABLE II

MOISTURE CONTENT AND BULK DENSITY OF
SOIL CORES FROM VARYING DEPTHS AT SITE "A" 1/

October 12, 1951

Depth of core sample (inches)	Per cent Moisture (oven-dry basis)	Per cent Moisture (volume basis)	Bulk Density (grams per cc)
0-3	351	62.6	.178
9-12	377	66.9	.177
18-21	479	81.3	.169
27-30	498	83.8	.168
	October 30, 1951		
0-3	229	55.9	.243
9-12	319	68.3	.214
18-21	511	80.9	.158
0-3 (compacted)	191	68.4	.357
	March 13, 1953		
0-3	275	70.1	.255
9-12	517	81.6	.157
18-21	553	86.4	.156

1/ Average of 10 replicates for each sampling.

TABLE III

MOISTURE CONTENT AND BULK DENSITY
OF SOIL CORES FROM VARYING DEPTHS AT THE THREE
SITES SAMPLED FOR COMPARISON STUDIES

Depth of core sample (inches)	Per cent Moisture (oven-dry basis)	Per cent Moisture (volume basis)	Bulk Density (grams per cc)
SITE "B" - August 18, 1951			
0-3	158.6*	58.6*	.366*
18-21	437.4	76.8	.178
SITE "C" - August 19, 1951			
0-3	277.6*	78.3*	.283*
18-21	435.8	83.7	.185
SITE "D" - December 1951			
0-3	169	62.4	.369
9-12	196	66.7	.340
18-21	168	61.4	.406

* As is the case in the other tables these data are averages of the results from 10 cores. The others in this table are averages from 5 cores.

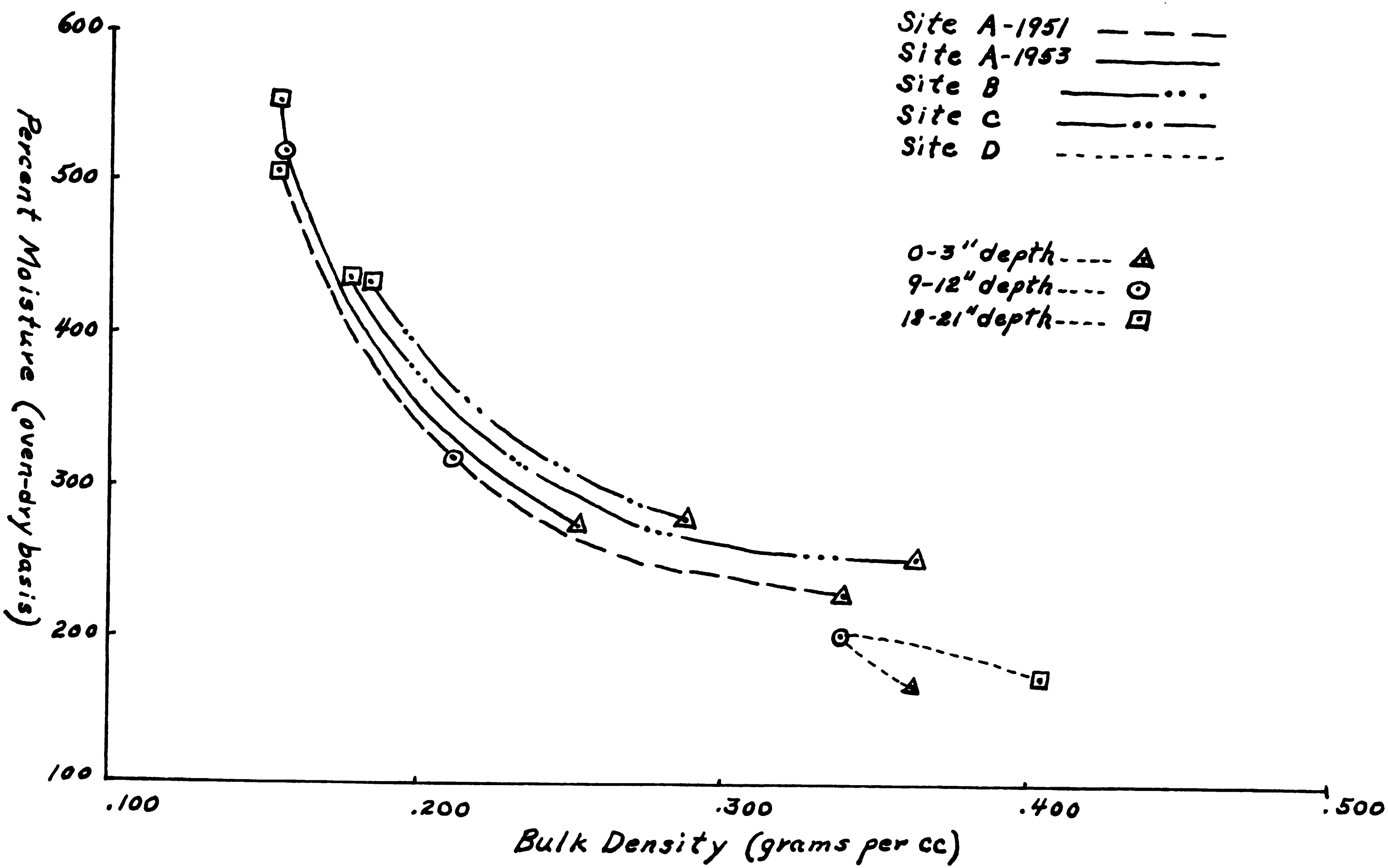

Figure 1. Relationship of percent moisture and bulk density on different sites at varying depths.

Shrinking and swelling characteristics. Samples were taken at Site "A" and measurements made to determine the per cent shrinkage of the soil upon being oven-dried. The surface samples, 0-3 inch depth, showed less shrinkage than did the lower depth samples. This was to be expected because of the higher moisture content of the 9-12 and 18-21 inch samples and the accompanying lower oven-dried weights. Table IV shows the average of 10 replicates and the standard deviation of the mean for each level sampled.

The swelling characteristics of the soil were calculated by measuring the increase in volume of the core sample upon saturation. The surface samples, 0-3 inch depth, showed considerably higher swelling characteristics, especially in the area with the compacted surface. Table IV also gives the mean per cent swelling at different depths. It is evident that the swelling data were less reliable than were the shrinkage data, except for the compacted 0-3 inch cores. This is indicated by the smaller values for per cent swelling and the resulting higher standard deviations from the mean.

Shrinkage and swelling characteristics of organic soil are reported to be an important factor in the effectiveness of drainage systems, because of their affect upon the permeability of the soil. Uhland and O'Neal (24) have observed a significant decrease in permeability attributed to shrinkage and swelling.

TABLE IV

SUMMARY OF SHRINKING AND SWELLING CHARACTERISTICS OF SOIL CORES FROM SITE "A"

Depth of core sample (inches)	Shrinking		Swelling	
	Per cent shrinking 1/	Standard deviation of the mean	Per cent swelling 1/	Standard deviation of the mean
0-3	43.0	$\pm$ 0.52	12.3	$\pm$ 0.95
9-12	80.8	$\pm$ 0.66	11.5	$\pm$ 0.67
18-21	77.5	$\pm$ 0.81	7.4	$\pm$ 0.19
0-3 (compacted)	----	----	16.9	$\pm$ 0.90

1/ Average of 10 replicates for each sampling.

Permeability. Percolation rates were measured through the soil cores in inches per hour. The permeability data, mean values and standard deviations, are summarized in Table V. A noticeable variation was recorded for Site "A" - October 30, 1951 with increasing depth. The percolation rate through the soil cores from the compacted area, 0-3 inch depth, was 0.504 inches per hour. The results of the Site "A" - March 13, 1953 measurements, however, showed less variation throughout the profile. Site "D", where a slow permeability class for the 18-21 inch depth was expected, showed only a slight decrease in percolation rate from the surface samples. The percolation rates from the measurements recorded would appear to place organic soil, largely, in the permeability classof rapid (5.0 to 10.0

inches per hour). These measurements are within the range of the vertical water transmission reported for the Everglades by Clayton (3). He reported that the surface, upon being cultivated and subject to weathering, became less capable of transmitting water downward. This, however, was not the case with the soil cores measured in this investigation except in the case of the heavily compacted area, 0-3 inch depth, which did show a decided decrease in ability to transmit water downward.

Pore volume and desorption characteristics. Soil cores for two samplings at Site "A" were saturated and placed on a tension table for the measurement of the water lost or volume of pores drained at different drainage tensions. Table VI shows the volume of pores drained at the tensions of 10 cm, 20 cm, 40 cm, 60 cm, and 80 cm of water as well as the volume of pores or water lost from saturation to field condition and oven-dry. The volume of pores drained at low tensions, 10 cm and 20 cm, was relatively lower than at the higher tensions. The volume of pores drained at a given drainage tension appeared to increase with the depth of sampling. Figure 2 shows the volume of pores drained at different tensions in relation to depth of the sampled area.

The per cent moisture of the soil cores at saturation, field condition, and at the different drainage tensions are recorded in Table VII. In Figure 3 the per cent of moisture at different tensions are graphically shown in relation to depth of the sampled area. It is believed that the variations between the measurements for Site "A"

TABLE V

SUMMARY OF PERMEABILITY SHOWING MEAN VALUES, STANDARD DEVIATION, AND PERMEABILITY CLASS

SITE "A" - October 30, 1951

Depth of core sample (Inches)	Mean Percolation rate 1/ (Inches/Hour)	Standard Deviation of the mean (Per cent)	Permeability class 2/
0-3	12.08	± 0.46	Very Rapid
9-12	7.22	± 0.43	Rapid
18-21	3.51	± 0.15	Moderately Slow
0-3 (compacted)	0.504	± 0.009	Slow
	SITE "A" - March 13, 1953		
0-3	9.27	± 0.44	Rapid
9-12	6.43	± 0.44	Rapid
18-21	7.89	± 0.57	Rapid
	SITE "D" - December 1951		
0-3	7.5	± 0.81	Rapid
9-12	7.8	± 0.28	Rapid
18-21	7.3	± 0.29	Rapid

1/ Averages of 10 replicates except for Site "D" where 5 replicates were used.

2/ Permeability classes from Uhland and O'Neal (27) for percolation rates in inches per hour through saturated undisturbed cores under $\frac{1}{2}$-inch head of water.

TABLE VI

VOLUME OF PORES DRAINED AT DIFFERENT MOISTURE TENSIONS FOR SOIL CORES SAMPLED AT VARYING DEPTHS

SITE "A" - October 30, 1951

Tension or head of water	Volume of Pores Drained at Varying Depths (Mean Values in Cubic Centimeters) 1/			
	0-3"	9-12"	18-21"	0-3" (Compacted)
10 cm	21.0	22.3	21.7	16.7
20 cm	25.4	25.5	26.7	20.5
40 cm	44.3	34.6	37.1	26.2
60 cm	50.1	39.7	40.9	30.3
80 cm	63.0	58.7	55.5	49.8
Field-Condition	67.2	49.6	28.0	38.9
Oven-Dry	174.7	181.7	183.3	170.2

SITE "A" - March 13, 1953

10 cm	8.8	14.2	12.2
20 cm	14.3	19.6	17.9
40 cm	17.8	23.9	25.5
60 cm	20.2	26.0	28.1
80 cm	25.4	29.7	32.6
Field-Condition	11.4	23.2	14.2
Oven-Dry	146.1	180.0	180.0

1/ Averages of 10 replicates.

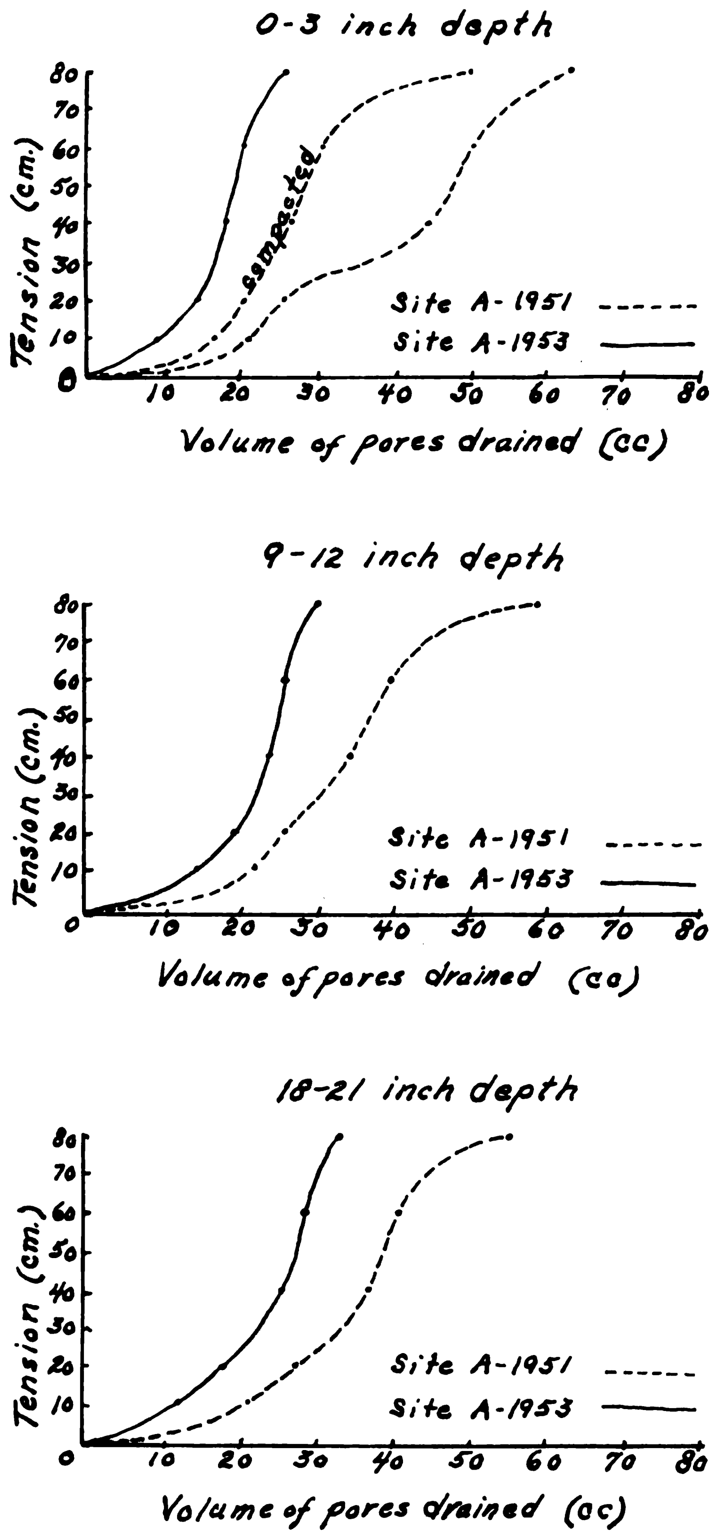

Figure 2. Volume of pores drained at different tensions of water for 0-3 inch depth; 9-12 inch depth; and 18-21 inch depth.

TABLE VII

PER CENT MOISTURE AT DIFFERENT MOISTURE TENSIONS FOR SOIL CORES SAMPLED AT VARYING DEPTHS (OVEN-DRY BASIS)

SITE "A" - October 30, 1951

Tension or head of Water	Per cent Moisture at Varying Depths (Oven-Dry Basis) 1/			
	0-3"	9-12"	18-21"	0-3" (Compacted)
10 cm	328	386	531	224
20 cm	318	377	516	218
40 cm	279	356	482	210
60 cm	267	343	468	204
80 cm	238	297	421	176
Field-Condition	229	319	511	191
Saturation	373	439	602	248

SITE "A" - March 13, 1953

Tension or head of Water	0-3"	9-12"	18-21"
10 cm	280	547	559
20 cm	269	529	540
40 cm	262	515	515
60 cm	257	508	506
80 cm	246	496	491
Field-Condition	275	517	553
Saturation	299	594	600

1/ Average of 10 replicates.

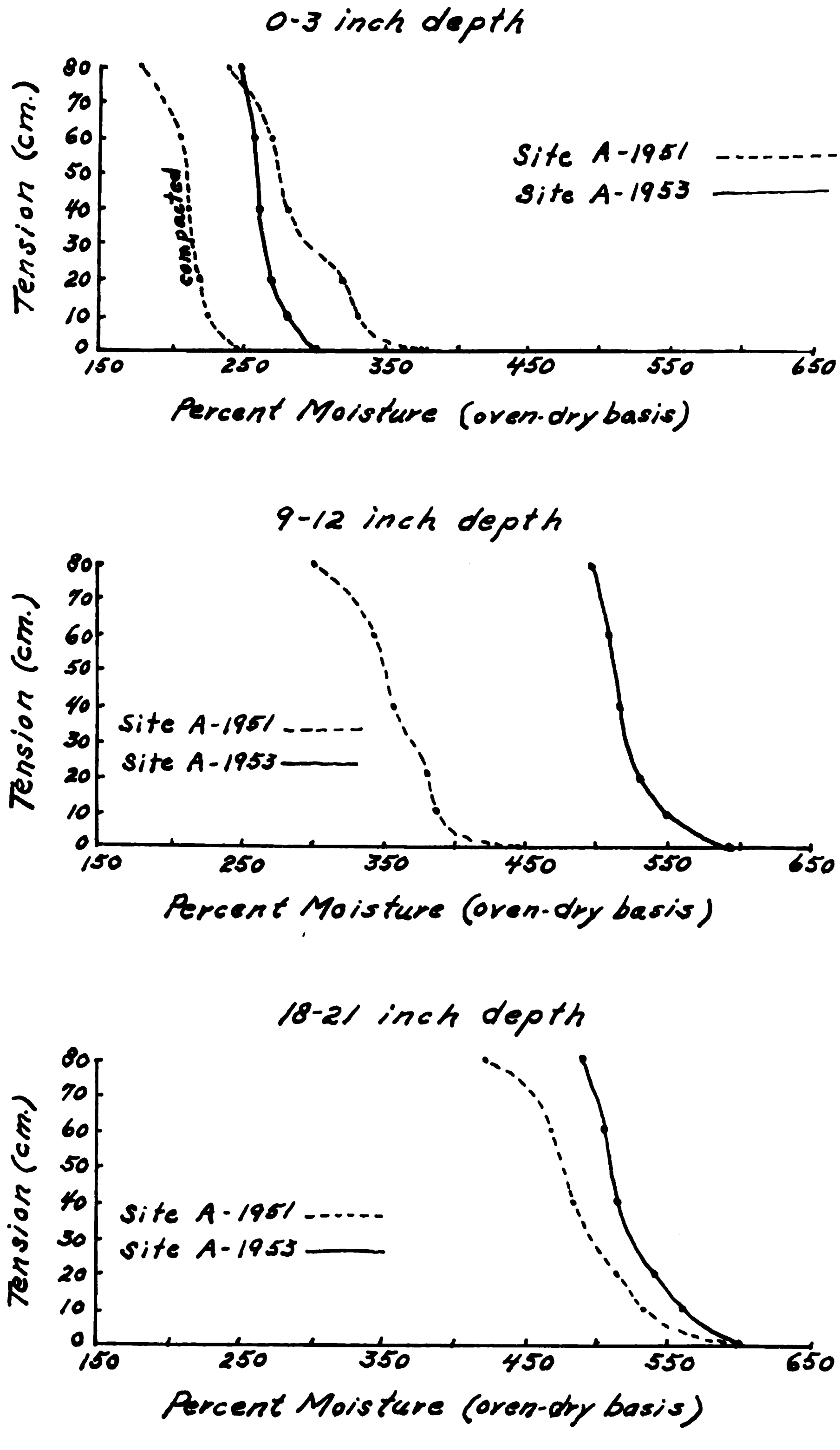

Figure 3. Per cent moisture (o.d. basis) at different tensions of water for 0-3 inch depth; 9-12 inch depth; and 18-21 inch depth.

on October 30, 1951 and March 13, 1953 were largely due to swelling differences caused by different moisture contents. Also, the surface cores from Site "A" - March 13, 1953 may have been low in volume of pores drained, partially because there was still evidence of frozen soil at the time of the sampling at that level.

Water Table Studies

Test wells were measured periodically to determine the draw down of the water table within a given period of time, and to approximate the total amount of water removed. A location plan showing the test well placement and the core sampled areas is shown in Figure 4 for Site "A" - May 1952.

The test wells were placed to obtain water table readings directly over the tile line and at distances of 3 feet, 10 feet, and 30 feet from the tile. The location plan of the various cross-sections for Site "A" - May 1952 is shown in Figure 4. The draw down curves for cross-sections A, B, and C are shown in Figures 5, 6, and 7 respectively. The water table was lowered during the period of May 19th to May 26th by gravity drainage. The water table was lowered further during the period of May 26th to May 27th by supplemental pump drainage.

Figure 6 shows the draw-down characteristics at cross section B, between three tile lines, and quite definitely brings out the fact that no appreciable draw-down curve existed in the drainage of the organic soil except within three feet of the tile line. This is in agreement

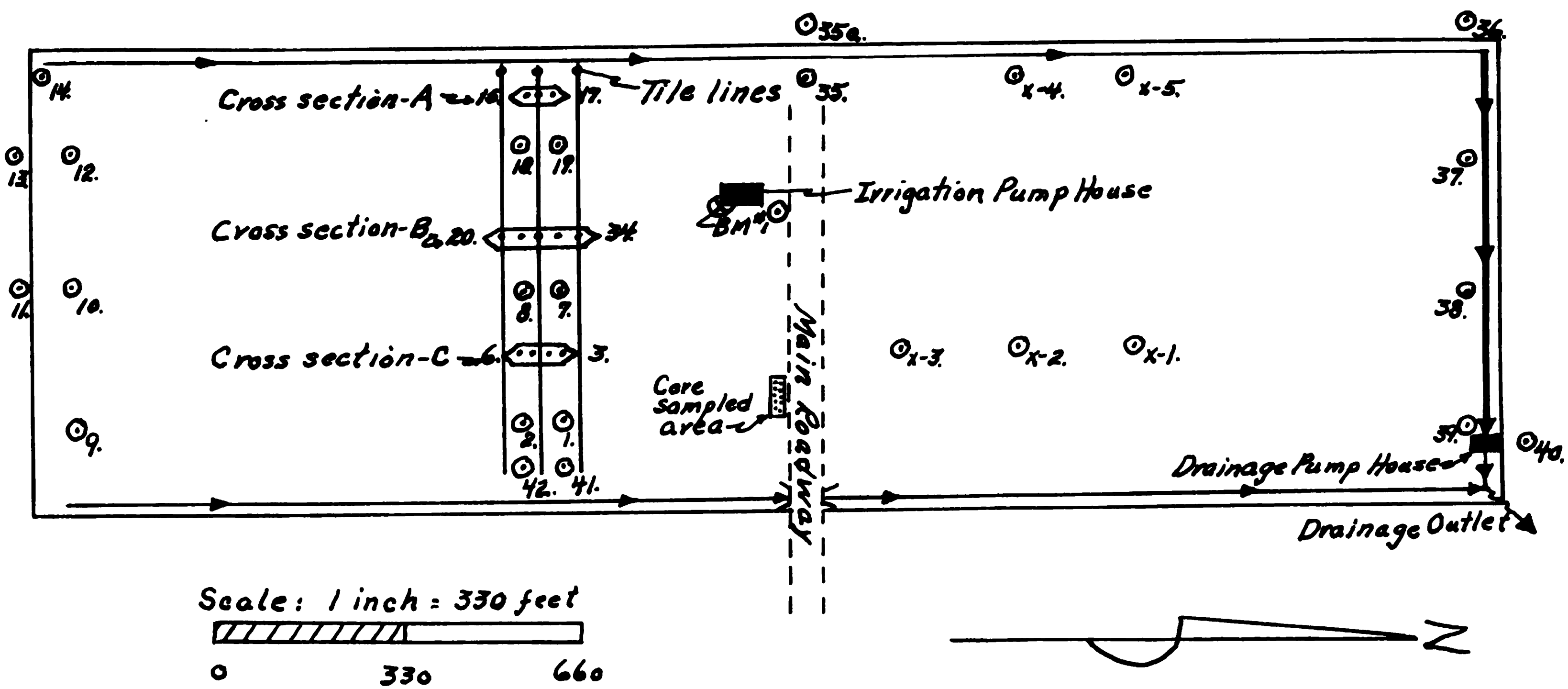

Figure 4. Location plan for water table studies and core sampled area at Site "A" - May 1952.

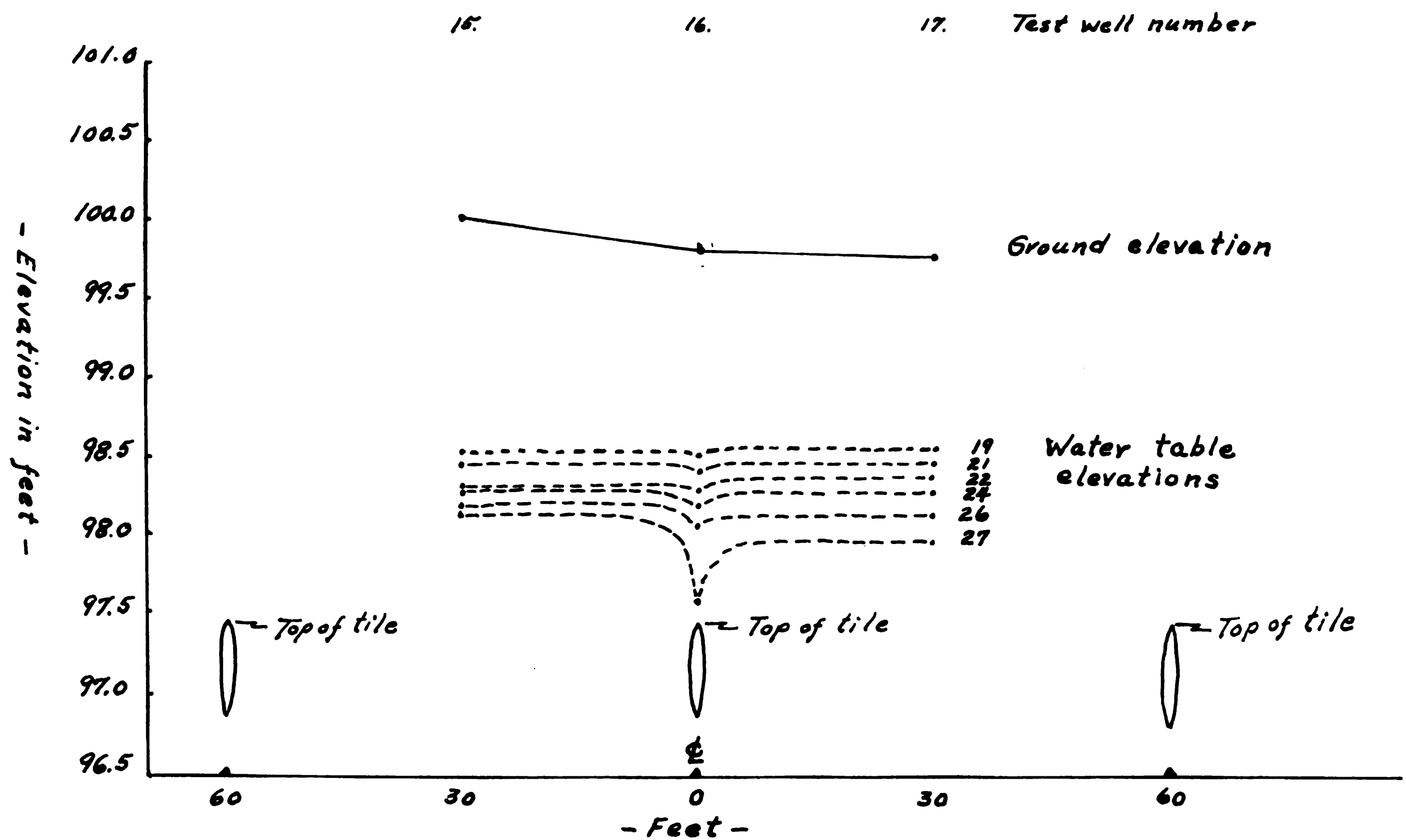

Figure 5. Draw-down curves at cross-section A
May 19-27, 1952.

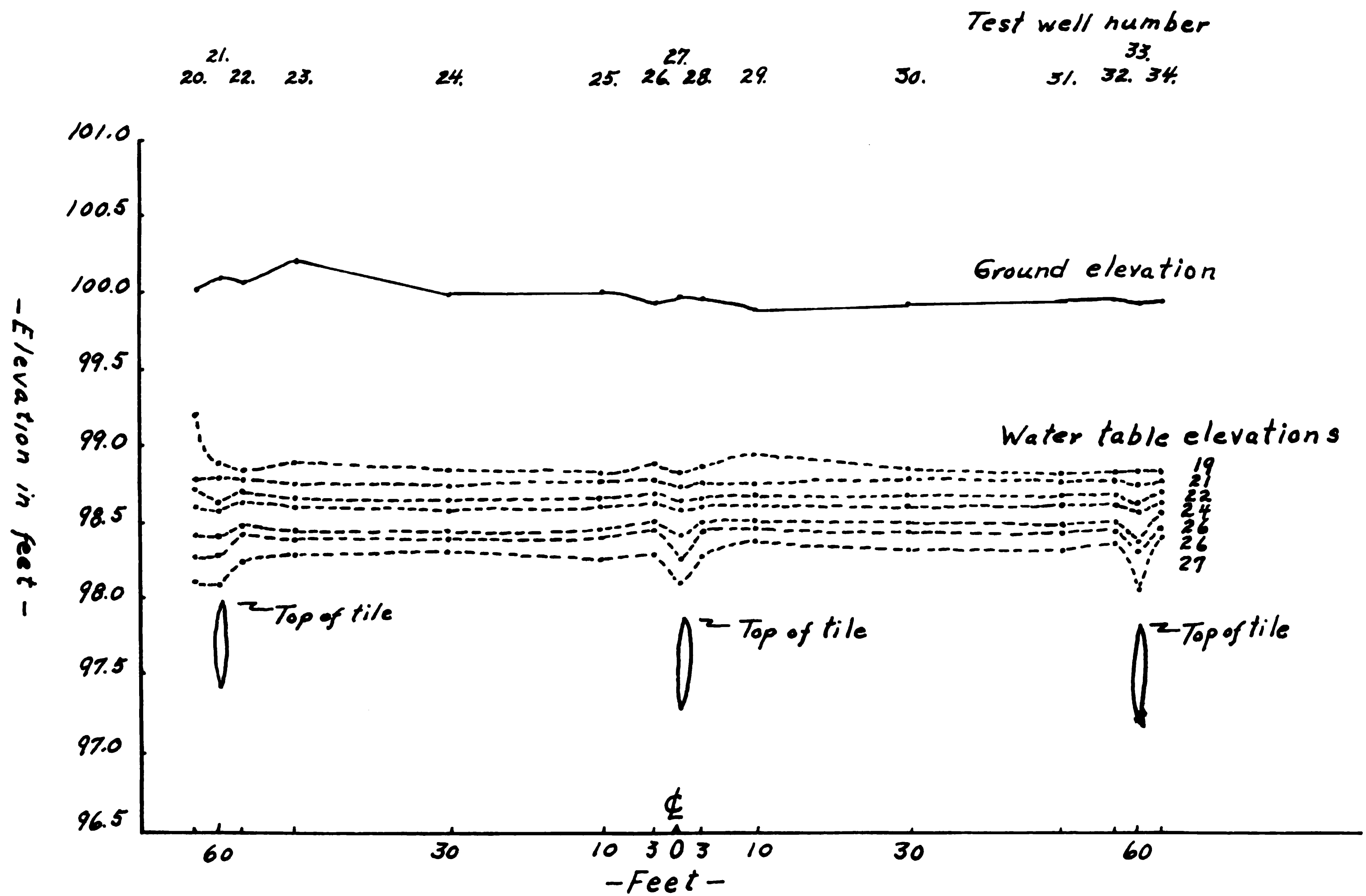

Figure 6. Draw-down curves at cross-section B
May 19-27, 1952.

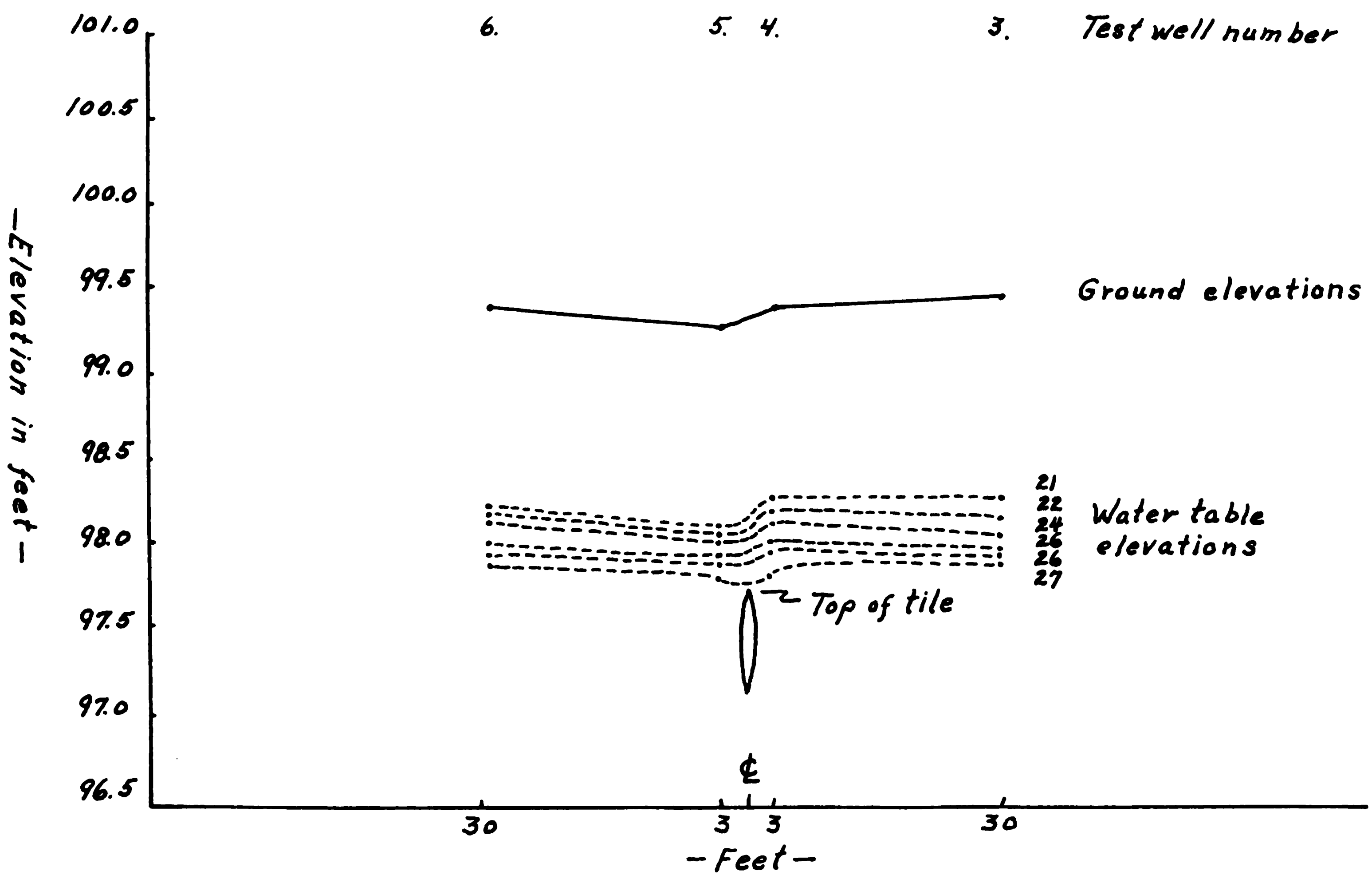

Figure 7. Draw-down curves at cross-section C
May 21-27, 1952.

with the measured permeability of the soil, and a high horizontal water transmission as reported by Clayton (3) for peats in the Everglades. The data indicate that the vertical and horizontal water transmission at Site "A" was equal to, or greater than the capacity of flow of the tile at their present depth of $2\frac{1}{2}$ to 3 feet and spacing of 60 feet.

The east-west profile shown in Figure 8, and the north-south profile shown in Figure 9, indicate the relatively constant lowering of the water table throughout the 60 acre site. The east-west measurements show no appreciable drop in ground elevation. There was, however, a calculated area of drop of approximately 0.1 foot per 100 feet from south to north.

The non-existance of any appreciable draw-down curve, contrary to that reported by Morris (15) in organic soil studied in Indiana, was brought out again when the water table studies were repeated with different test well placement as shown in Figure 10 for Site "A" - March 1953. The series of test wells at cross-section D, as shown in Figure 11, were spaced identically, to the test wells in cross-section B, see Figure 6, except that a different area was measured between three different tile lines.

In both water table studies a definite draw down of the water table developed after the pump was started. This indicates the inadequacy of the gravity drainage and possibly the need for flushing out the tile main. However, the draw down of the water table became less

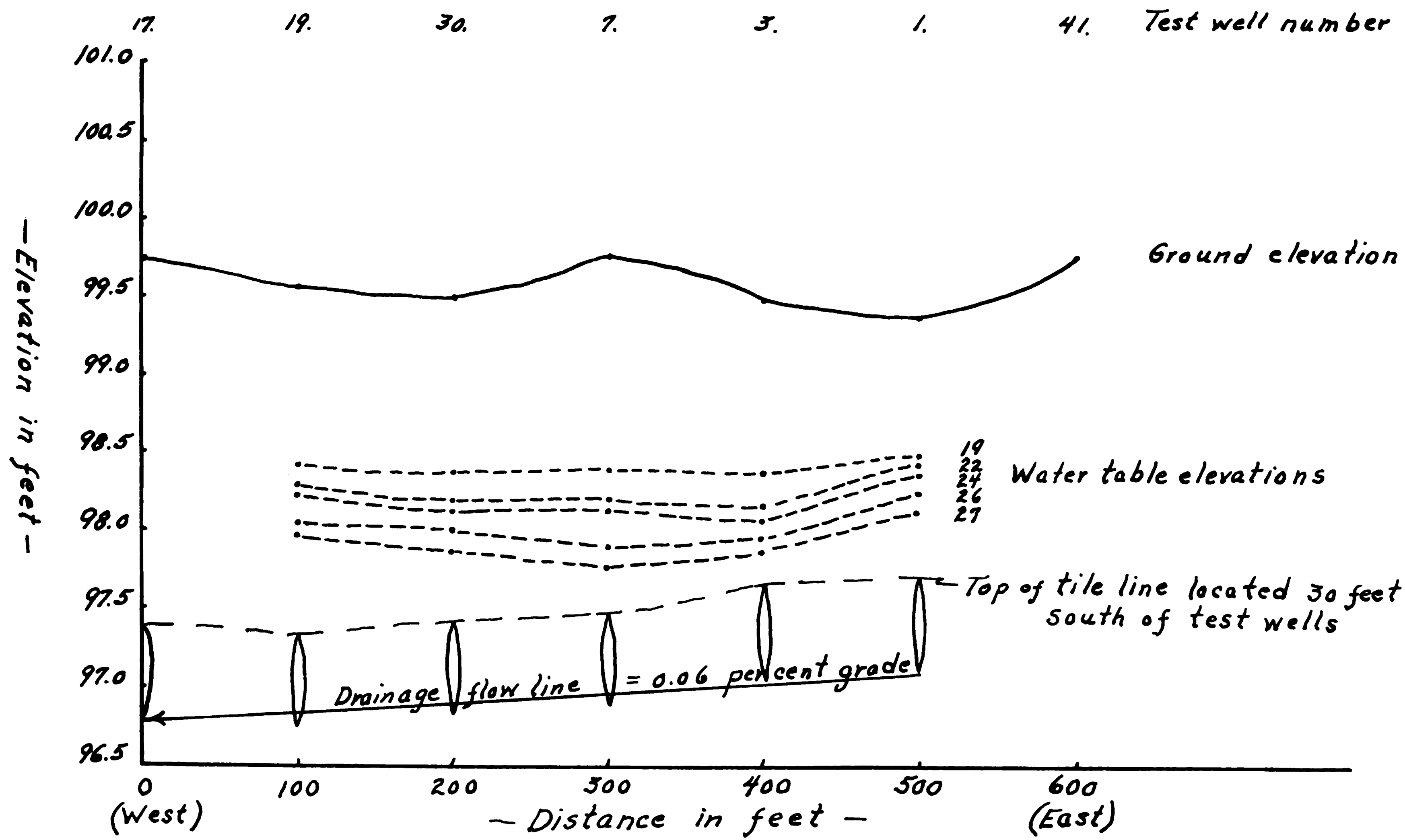

Figure 8. East-west profile showing calculated E-W area of drop and draw-down curves at Site "A" - May 19-27, 1952.

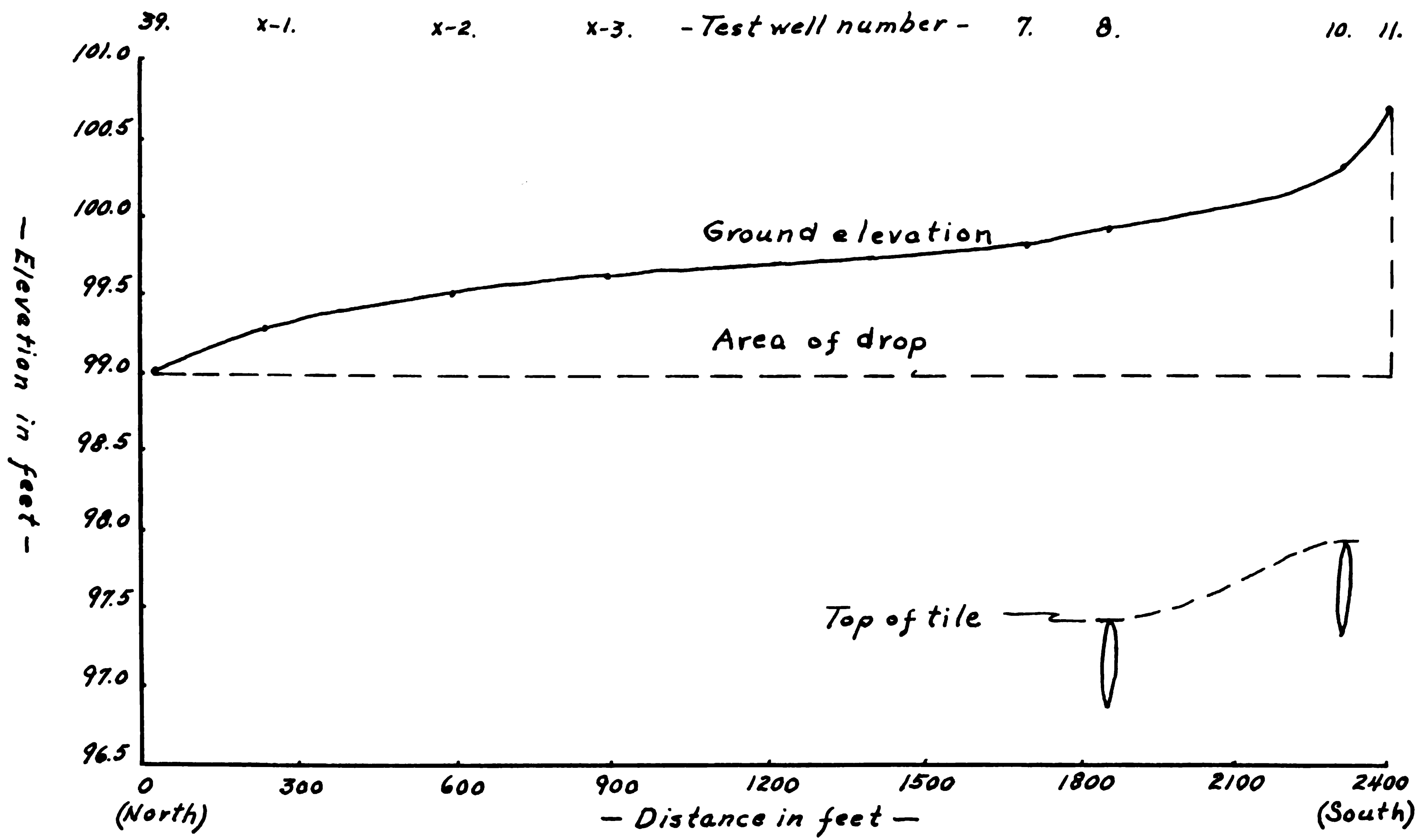

Figure 9. North-South Profile showing Calculated N-S Area of drop, May 1952.

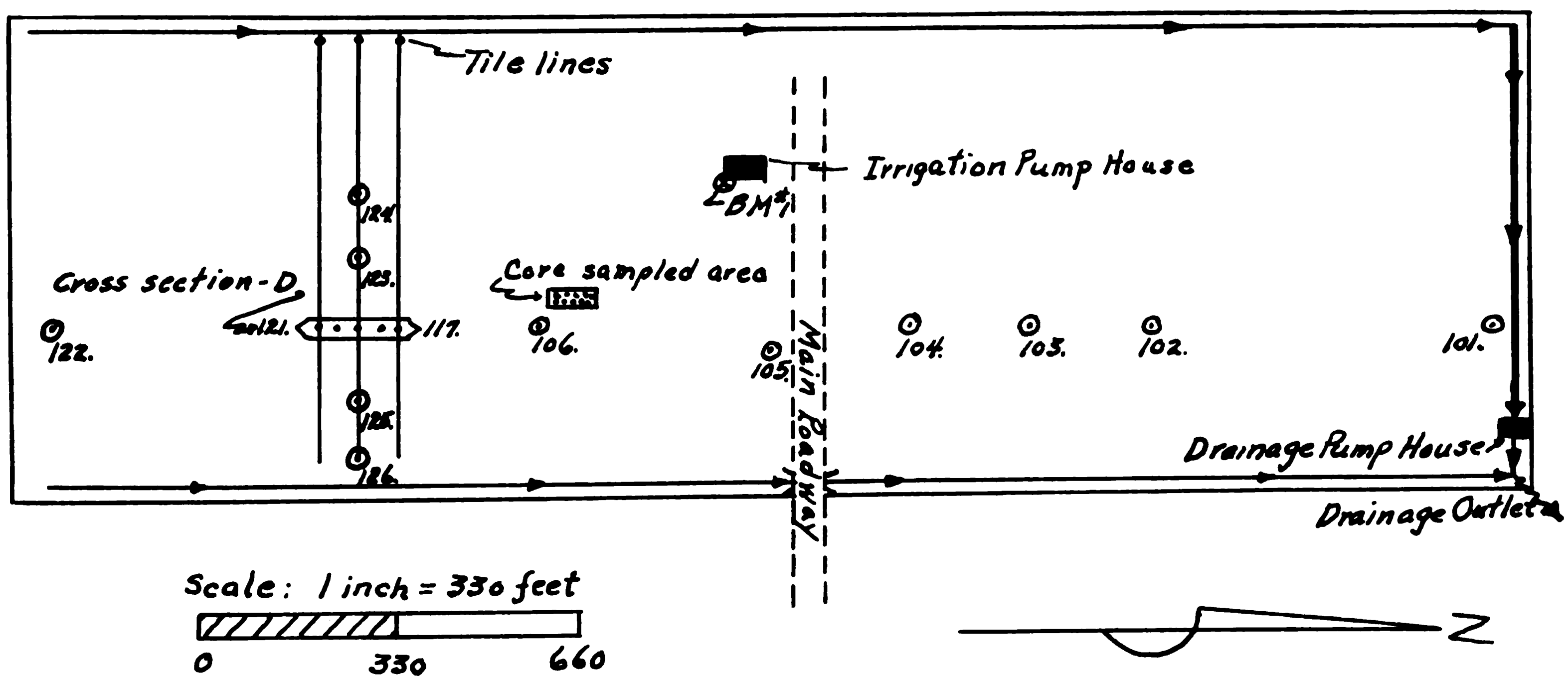

Figure 10. Location plan for water table studies and core sampled area at Site "A" - March 1953.

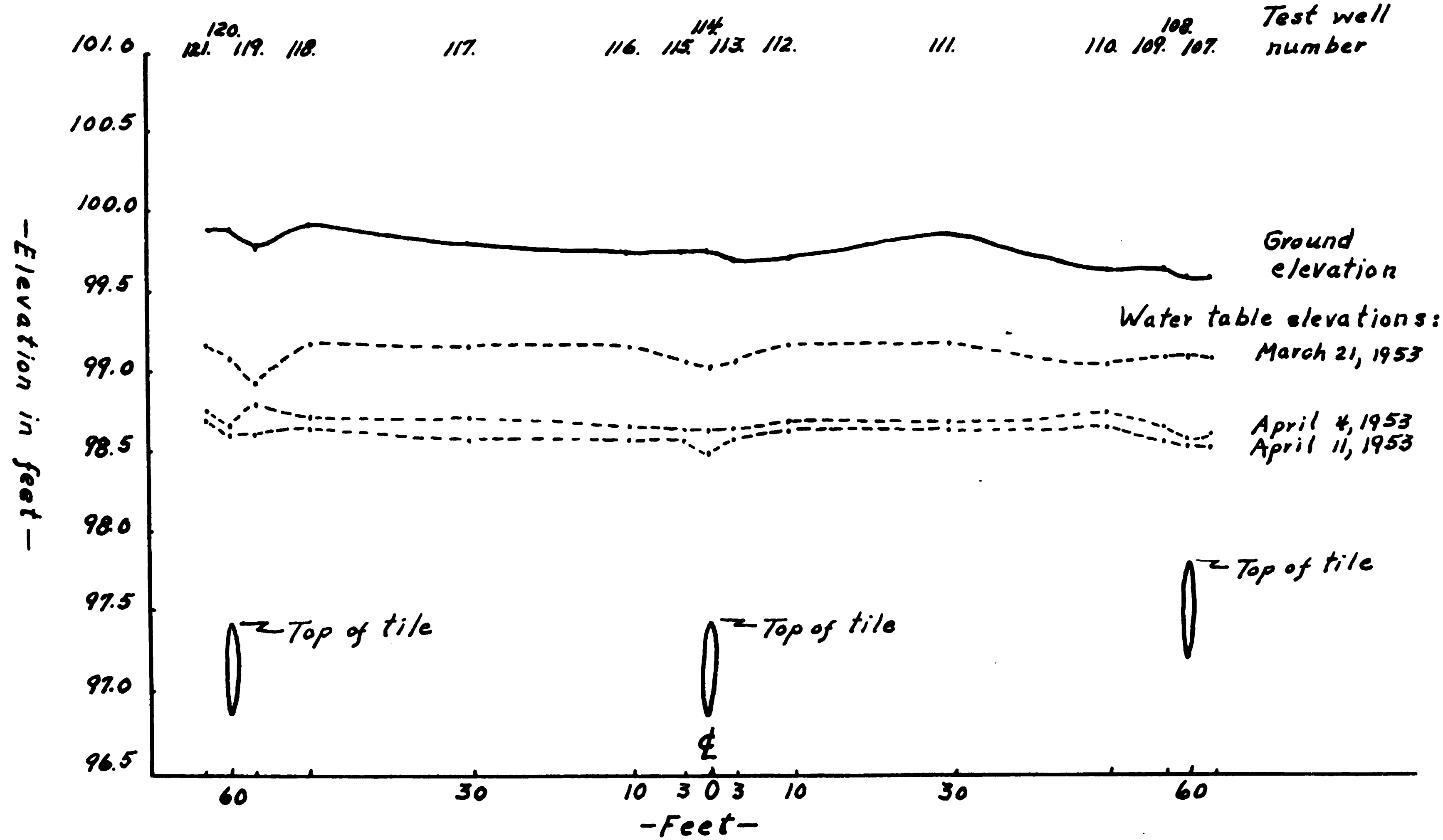

Figure 11. Draw-down curves at cross section D
March 21 to April 11, 1953.

apparent after 6 hours of pump drainage. It was concluded that the pump capacity of flow was not being fully realized due to lack of sufficient reservoir capacity above the pump.

Correlation of water table studies and pore volume data. The loss of water at the various moisture tensions of 10, 20, 40, 60, and 80 centimeters, measured in the laboratory, was compared with an equivalent drainage head for the field water table studies. In Figure 12 the water loss is shown in relation to tension in centimeters of water or the drainage head equivalent in inches from the water table.

In computing the amount of water being removed from the organic soil at Site "A" in a 24 hour period of time the actual tension or drainage head in inches was taken from the recorded water table elevations. Figure 6 shows the varying water table elevations resulting from drainage at test well numbers 23, 24, 25, 29, 30, and 31. The average depth of the water table from the ground elevation for these six test wells was recorded as follows:

May 19th - 1.15 feet or 13 7/8 inches

May 21st - 1.23 feet or 14 3/4 inches

May 22nd - 1.34 feet or 16 1/8 inches

May 24th - 1.38 feet or 16 5/8 inches

May 26th - 1.54 feet or 18 1/3 inches
(12:00 A.M.)
May 26th - 1.56 feet or 18 3/4 inches
(6:00 P. M.)
May 27th - 1.69 feet or 20 1/4 inches.

The effect of lowering the water table on the water loss at the measured drainage head is shown by the data reported in Table VIII. During periods of gravity drainage, May 19 to May 26, water was removed at a rate of 0.11 acre inches per 24 hours. Measurements of the cross sectional area of flow at the outlet were made, however, the approximated velocity of flow was not considered accurate enough to estimate total discharge from the area for comparison with the computed rate of loss of water per acre inch. The water table was lowered 4 3/4 inches during the six day period of gravity drainage.

During the period of pump drainage the computed water loss was at a rate of 0.42 acre inches per 24 hours to lower the water table 1 7/8 inches in 24 hours. The capacity of the drainage pump was rated at 975 gallons per minute with a 3 foot head. This is equivalent to a water removal rate of 0.86 acre inches per 24 hours. There is a discrepancy between the measured rate of 0.42 acre inches per 24 hours and the capacity rating of the pump of 0.86 acre inches per 24 hours. This difference was attributed to the lack of adequate supply of water in the reservoir ditch above the pump to allow for the discharge of water at the full capacity of the pump. Also, a certain amount of seepage from the surrounding area was noted at test well numbers 35a, 36, and 40.

<u>Correlation of organic soil permeability and proper tile spacing and depth for effective drainage.</u> The measured permeability rates previously discussed and shown in Table V, were used in conjunction with Slater's (25) formula for computing tile spacing and depth. A drainage coefficient of one inch of water removed in 24 hours was

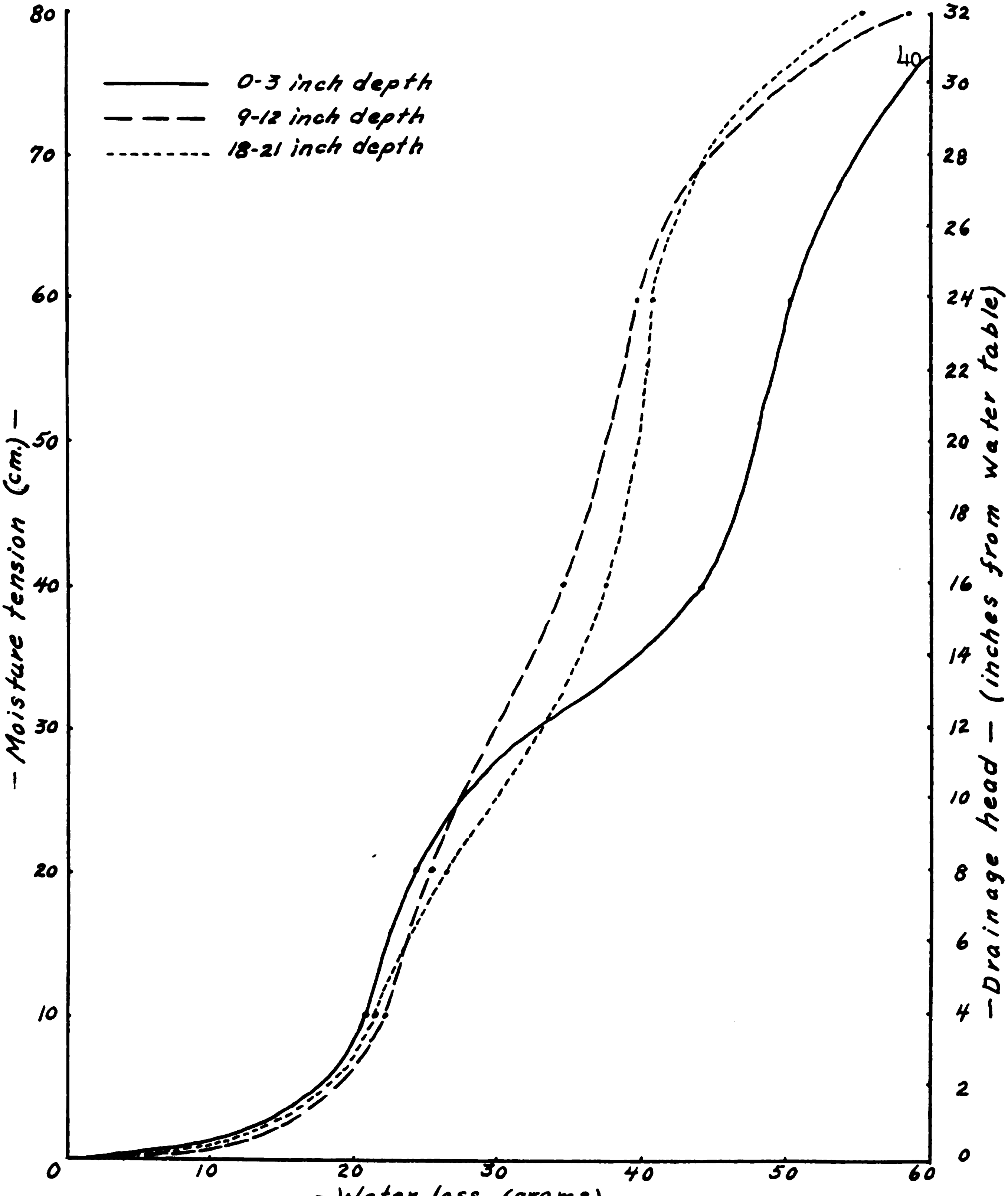

Figure 12. Water loss in relation to tension or drainage head.

TABLE VIII

THE MEASURED WATER LOSS FROM PORE VOLUME CORRELATED WITH WATER TABLE STUDIES 1/

May 19 to May 26 (144 hours)

Depth of core sample (inches)	Drainage head 2/ Before (inches)		Drainage head 2/ After (inches)	Water loss as result of lowering water table (grams per core)
0	13 7/8	-	18 1/2	5.5
9	4 7/8	-	9 1/2	5.0
18	0	-	1/2	11.0

Total water loss - 21.5 grams per core

- 0.67 acre inches in 144 hours

and rate of water loss - 0.11 acre inches per 24 hours.

May 26 to May 27 (24 hours)

0	18 1/2	-	20 1/4	1.0
9	9 1/2	-	11 1/4	2.5
18	1/2	-	2 1/4	10.0

Total water loss - 13.5 grams per core

- 0.42 acre inches in 24 hours

and rate of water loss - 0.42 acre inches per 24 hours.

1/ Water loss is converted to acre inches by multiplying the water loss, grams per core, by the factor of 0.031.

2/ Drainage head is determined by converting moisture tension, centimeters, to inches from depth of core sample to measured water table.

used to afford adequate drainage for truck crops on organic soil. Table IX shows the recommended drainage coefficient for varying crops and soil conditions. The calculations for determining tile spacing and depth in relation to organic soil permeability are shown in Table X. The use of the tile spacing formula for the removal of one inch of water in 24 hours gave fairly close results to the measured removal of water at Site "A", in that a 65 to 88 foot spacing of the tile at a 3 foot depth was required for effective drainage. The tile spacings calculated from measured permeability rates using Slater's (25) formula were closely related to the general recommendations now being used.

In an effort to correlate permeability and drainage for organic soil, Table XI was developed. This table gives the approximate tile spacing and depth in organic soils where crops are to be grown. The drainage coefficient of 3/4 inch per 24 hours is designed for field crops on organic soil, and the drainage coefficient of 1 to 1 1/2 inches per 24 hours for truck crops. Refer to Table IX.

It is possible that the use of the tile depth and spacing formula (25) in conjunction with extensive field measurements of organic soil permeability (28) could be used to group organic soils in Michigan as to their permeability class and drainage needs. If this could be accomplished, a close correlation of current drainage recommendations and the physical characteristic, permeability, would be established for organic soils.

TABLE IX

DRAINAGE COEFFICIENT FOR VARYING CROP AND SOIL CONDITIONS 4/ (WITH AND WITHOUT SURFACE INLETS)

Soil Permeability	Without 2/ Surface inlets		With 3/ Surface inlets	
	Field Crops	Truck Crops	Field Crops	Truck Crops
Mineral soils 1/	3/8"	3/4"	3/4"	$1\frac{1}{2}$"
Peats & Mucks	3/4"	1 to $1\frac{1}{2}$"	3/4 to $1\frac{1}{2}$"	$1\frac{1}{2}$" to 4"

1/ For mineral soils with sandy or otherwise permeable subsoils the drainage coefficient may be reduced approximately 1/4".

2/ Figure only the area to be tiled as the drainage area. It is understood that surface water is removed by field ditches or water-courses.

3/ Use entire contributing watershed as the drainage area.

4/ From USDA Soil Conservation Service, Engineering Handbook, Upper Mississippi; (Region III), Milwaukee, Wisconsin (1952).

TABLE X (continued)

CALCULATIONS FOR DETERMINING TILE SPACING AND DEPTH IN RELATION TO ORGANIC SOIL PERMEABILITY.....DRAINAGE COEFFICIENT OF 1 INCH PER 24 HOURS OR 0.04 I.P.H.

Site "D" - December 1951

0-3" depth ... 7.5 i.p.h. permeability
9-12" depth ... 7.8 i.p.h. permeability
18-21" depth ... 7.3 i.p.h. permeability

Tile to be at a depth of 3 feet, so the assumed barrier will be at 5 feet or 2 feet below the tile in Slater's (25) Formula.

a = 2 feet
b = 4 feet
P = 0.30 i.p.h.
v = 0.04 i.p.h.

$$S^2 = \frac{4 \times P\,(b^2 - a^2)}{v} = \frac{4 \times 7.30\,(16 - 4)}{0.04}$$

(Tile spacing)
S = 94 feet

Site "A" - October 30, 1951 ... with compacted surface

0-3" depth ... 0.504 i.p.h. permeability
9-12" depth ... 7.22 i.p.h. permeability
18-21" depth ... 3.51 i.p.h. permeability

Tile are at a depth of 3 feet, so the assumed barrier will be at 5 feet or 2 feet below the tile in Slater's (25) formula.

a = 2 feet
b = 4 feet
P = 0.504 i.p.h.
v = 0.04 i.p.h.

$$S^2 = \frac{4 \times P\,(b^2 - a^2)}{v} = \frac{4 \times 0.504\,(16 - 4)}{0.04}$$

(Tile Spacing) S = 24.2 feet

TABLE XI

RECOMMENDED TILE SPACING FOR ORGANIC SOIL IN RELATION TO PERMEABILITY AND THE DEPTH OF TILE

Permeability (inches per hour)	Tile Spacing, in feet, when tile is at varying depths		
	Depth of 3 feet	Depth of 4 feet	Depth of 5 feet
Drainage Coefficient of 3/4 inches per 24 hours, (0.031 inches per hour)			
0.05	9	12	15
0.2	18	24	30
0.8	36	50	60
2.5	65	85	105
5.0	90	120	150
10.0	125	170	210
Drainage coefficient of 1 inch per 24 hours, (0.04 inches per hour)			
0.05	7	10	13
0.2	15	21	26
0.8	31	41	51
2.5	55	72	90
5.0	77	102	126
10.0	110	145	178
Drainage coefficient of $1\frac{1}{2}$ inch per 24 hours, (0.062 inches per hour)			
0.05	6	8	10
0.2	13	17	20
0.8	25	32	41
2.5	45	59	73
5.0	63	84	103
10.0	90	120	146

SUMMARY

The purpose of this investigation was to study the drainage ability of organic soils as characterized by their physical properties.

The investigation proper was carried out on Houghton Muck at the Michigan State College Muck Experimental Farm, with three additional sites investigated for comparison of physical properties.

Core samples were taken at varying moisture conditions and also at nine-inch intervals down to the water table. The samples were analyzed for moisture content, bulk density, shrinking and swelling, permeability, and volume of pores drained at varying moisture tensions.

A second phase of the investigation, water table studies, was carried out to determine the nature and amount of draw down of the water table. Test wells were used to measure the variation in the water level.

Water table studies were correlated with the volume of pores drained at varying moisture tensions to determine the amount of water removed per acre inch associated with a measured lowering of the water table.

Permeability data were correlated with drainage recommendations for depth and spacing of tile, using a formula based on Darcy's Law for lateral flow.

The following observations were made:

Studies of surface samples at varying moisture conditions resulted in a variation in moisture content from 230 to 250 per cent

(oven-dry basis), and an accompanying variation in bulk density from .243 to .270 grams per cubic centimeter. There was, however, no correlation between per cent moisture and bulk density.

Where samples were taken at 0-3 inch, 9-12 inch, and 18-21 inch depths there was a definite correlation between per cent moisture and bulk density.

Dehydration of organic soil was closely correlated with an increase in bulk density. Consistant moisture-density curves were observed where per cent moisture and bulk density were correlated at varying depths in the soil profile.

Shrinking varied from 43.0 per cent in the surface samples to 80.8 per cent in those from the 9-12 inch depth. Swelling varied from 7.4 per cent at the 18-21 inch depth to a high of 16.9 per cent in the field compacted surface samples.

Permeability was measureable within an allowable standard deviation with all samples in the rapid class (5.0 to 10.0 inches per hour) except for the compacted surface samples and those from the 18-21 inch depth.

The volume of pores drained increased with depth at a given moisture tension. Pore volume data, using moisture tensions of 10, 20, 40, 60, and 80 centimeters, correlated directly with drainage.

The water table studies confirmed the relatively rapid movement of water through organic soil, and the results were in agreement with permeability data and the measured volumes of pores drained.

The non-existance of draw down curves except within three feet of the tile line was attributed to the following factors: the inadequacy of the outlet for efficient gravity or pump drainage, seepage from the surrounding area, and rapid permeability.

The computed water removal by pump drainage, using pore volume data, was at a rate of 0.42 acre inches per 24 hours to lower the water table 1 7/8 inches. The pump capacity rating was 0.86 acre inches per 24 hours. The inadequate capacity of the reservoir ditch above the drainage pump and seepage from the surrounding area are reflected in the variation between actual water removal and calculated pump capacity.

The use of Slater's (25) formula to correlate organic soil permeability and drainage recommendations for proper depth and spacing of tile showed conclusively that drainage recommendations can be based on the physical properties of the soil.

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