

DRAINAGE STUDIES ON DAYTON, AMITY, AND WILLAMETTE
SOILS IN THE WILLAMETTE VALLEY, OREGON

by

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DRAINAGE STUDIES ON DAYTON, AMITY, AND WILLAMETTE SOILS IN THE WILLAMETTE VALLEY, OREGON

INTRODUCTION

There is a problem of draining the excess winter precipitation from the fields of Dayton, Amity, and Willamette soils in the Willamette Valley of Oregon. This problem of drainage is caused by the low permeability and flat relief of the soils. These soils are found on the old valley fill which is found at higher elevations than the recent alluvial soils on the present flood plains of the river.

These three soils occur on level to slightly rolling topography. Willamette and Amity soils are found on more rolling land than the Dayton soils. The Dayton soils have well defined claypans¹ and consequently offer the most problems to artificial drainage. Amity is a moderately well drained soil being mottled at 12-16 inches from the surface, while Willamette soil is the well drained member of the catena². Due to the uneven annual rainfall pattern, an average of 30 inches between November and April, and 10 inches for the rest of the year, high water tables are prevalent on these soils during most of the winter months.

¹ A claypan is defined as a compact horizon or layer rich in clay and separated more or less abruptly from the overlying horizon.

² A catena is defined as a group of soils within one zonal region developed from similar parent material but differing in characteristics of the solum (profile) owing to differences in relief or drainage.

The Dayton soil is often referred to as "white land" because it has a bleached color which is associated with water action over extended periods of time. Amity and Willamette are not so bleached.

There are other soils in the Willamette Valley that have drainage problems and not included in this study. Some of these soils are: Salem, Concord, Whiteson, Wapato, and Cove. It is believed that these soils have clays with an expanding lattice which helps restrict the water passage through the soil. Willamette and Salem soils are commonly well drained with occasional fields moderately well drained. Whiteson, Amity, and Concord soils are commonly moderately well drained, while Wapato, Dayton, and Cove are commonly poorly drained soils.

The horizons of the Dayton, Amity, and Willamette soils increase the complexity of a mathematical analysis of the drainage problem. This prevents the application of existing mathematical equations derived for more nearly homogenous soils to these soils, which in turn gives rise to the diversity of opinions regarding proper tile installation.

Current recommendations made to farmers tend to be of a general nature, disregarding soil type and any possible development of surface drainage. These recommendations are often found by the farmers to be inadequate. Stop-gap

measures are sometimes taken which include laying new tile between existing tile laterals. In some cases this process is repeated, resulting in the use of three or four times the amount of tile originally recommended.

Some fields being tiled recently had been tiled several years earlier, unknown to the present owner. These old tile lines had not done the desired job, and shed some doubt as to the effectiveness of tile in these locations. This study was designed to evaluate the adequacy of installed tile systems in Dayton, Amity, and Willamette soils and to relate the rate of drainage to the water conductivity of each soil. It is hoped that through this study and similar studies information will be gathered and methods developed that will allow more accurate drainage recommendations to be given.

REVIEW OF LITERATURE

DEFINITION OF TERMS USED

In order to make the meaning of words used in this thesis more clear the following definitions have been taken from the Report of the Subcommittee on Permeability and Infiltration, Committee on Terminology, of the Soil Science Society of America. (27)

"Capillary Conductivity (Qualitative). The physical property relating to the readiness with which unsaturated soils transmit water. Ordinarily this will include primarily the transfer of liquid and film water but not vapor diffusion which involves a different physical mechanism.

Drainage (soil). 1. The process of the discharge of water from an area of soil by sheet or stream flow (surface drainage) and the removal of excess water from within soil by downward flow through the soil (internal drainage). 2. The means for effecting the removal of water from the surface of soil and from within the soil, i.e., sloping topography or stream channels (surface drainage) and open ditches, underground tile lines, or pumped wells (artificial drainage).

Hydraulic Gradient (water in soil). A vector (macroscopic) point function which is equal to the decrease in the

hydraulic head per unit distance through the soil in the direction of the greatest rate of decrease. In isotropic soils, this will be in the direction of the flow velocity. The water moving force per unit of mass of water is represented both in direction and magnitude by the hydraulic gradient..... The hydraulic gradient is dimensionless...

Hydraulic Head (water in soil) (h). The elevation with respect to a standard datum at which water stands in a riser or manometer connected to the point in question in the soil. This will include gravitational head, pressure head, and velocity head, if the terminal opening of the sensing element is pointed upstream. For nonturbulent flow of water in soil, the velocity head is negligible. In unsaturated soil, a porous cup must be used for establishing hydraulic contact between the soil water and water in the manometer. Dimensionally, hydraulic head is a length,.....

Hydraulic Conductivity 1. The ratio of the flow velocity to the driving force for the viscous flow under saturated conditions of a specified liquid in a porous medium. Physical dimensions will depend on the equations selected to express the flow

Infiltration (soil). The downward entry of water into the soil.

Infiltration rate (soil). The maximum rate at which a soil, in a given condition at a given time, can absorb rain. Also, the maximum rate at which a soil will absorb water impounded on the surface at a shallow depth when adequate precautions are taken regarding border or fringe effects. Defined as the volume of water passing into the soil per unit of area per unit of time, it has the dimensions of velocity.

Percolation (soil water). A qualitative term applying to the downward movement of water through soil. Especially, the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1 or less.

Permeability (soil) 1. (Qualitative) The quality or state of a porous medium relating to the readiness with which such a medium conducts or transmits fluids. 2. (Quantitative). The specific property designating the rate or readiness with which a porous medium transmits fluids under standard conditions. The equation used for expressing the flow will take into account the properties of the fluid so that proper measurements on a given medium will give the same permeability value for all fluids which do not alter the medium. The physical dimensions of the

permeability unit will be determined by the equation used to express the flow.

Water conductivity (soil) 1. The ratio of flow velocity to the driving force for the viscous flow of water in soil. 2. (practical units) The ratio $V/i = k$, where V is the flow velocity and i is the hydraulic gradient in the Darcy equation $V = ki$.

Water Table (soil). The locus of points in the soil water at which the pressure is equal to atmospheric pressure."

THEORY

Kirkham and Gaskell (18) referred to the work of Darcy (6) of 1856 in which he found that the rate of water flow through a porous medium is proportional to the hydraulic gradient. He found on the basis of investigations using water flow through sand that this was true and came to the conclusion, now referred to as Darcy's law, which is expressed in the general formula:

$$V = ki$$

where V is the velocity of moving water; k is the permeability or transmission constant; and i is the hydraulic gradient.

The rate water moves through the soil and the water conductivity of the soil are not the same in all cases.

The amount of water that can be removed by the tile system depends on the rate that water moves through the soil. Evans, Kirkham, and Prevert (8 p.50) in 1950 discussed the relationship of water conductivity and infiltration rate. They stated that the water conductivity and infiltration will seldom be identical. The infiltration rate will be greater when water is applied to a dry soil than the rate given by the water conductivity. The infiltration rate will be greater because of some lateral movement and because, of necessity a head of surface water greater than zero must be maintained. There is also a downward capillary pull which initially is not negligible compared to the weight of the water column in the soil. As the water front moves downward lateral and vertical capillary movements becomes negligible, the hydraulic gradient will approach unity, and the infiltration rate will approach the value of the water conductivity. The infiltration rate will become less than the water conductivity only after a restricting layer is encountered by the water front.

FLOW INTO TILE DRAINS

Drain tiles commonly used to drain excess water from fields are kiln baked clay or concrete pipes, with dimensions of one inch or less in thickness, diameters of 3-8

inches, and usually about one foot long. Tiles are laid end to end in a trench dug to a desired depth, with the grade of the trench carefully controlled to insure correct fall. Because the tiles are not jointed or sealed together it is possible for the water to enter the tile line through the cracks between the tiles providing the pressure in the water surrounding the tile is greater than atmosphere pressure. The trench is filled above the pipes with various materials, often referred to as back-fill. Back-fill is usually the soil removed but is sometimes modified with layers of sand and gravel around the tiles or filling most of the trench.

Kirkham and Gaskell (18) quoted Flodquist (10) as stating in 1931 that because of the high conductivity of back-filled soil in a tile trench, a filled trench can act like an open ditch. Kirkham and Gaskell (18 p.39) in 1950 reported the same thing was observed at Iowa Agricultural Experiment Station, at least for the first year after back-filling the trench. Kirkham and Zeeuw (19 p.292) in 1952 concluded that the water conductivity of the back-filled trenches must have been high compared to that of the surrounding soil, and that back-filled trenches must have behaved like open ditches, because experimental results for soil similar to Dayton compared unfavorably with electrical

model and theoretical results for cases where the back-fill material was assumed to have the same water conductivity as the rest of the soil. Kirkham (17 p.442) in 1951 found that if the soil contains layers of three or more water conductivities the theory will be extremely involved. It is not considered worth while to extend the present theory (with homogeneous soils) to these soils where there are three or more water conductivities.

Kirkham and Gaskell (18 p.40) in 1950 described the water flow of tile drained soil and stated, "as the water table becomes low at the ditch edge the rate of fall near the center of the ditch increases". They recommended, for uniform soil overlying an impermeable layer, a spacing between tile lines of 10-20 times the distance from the soil surface to the impermeable layer (18 p.41). The time for the water table to drop one foot midway between ditches appears to vary as about the square of the ditch separation. This quadratic relationship should apply to tile drainage if the tile trench is back-filled with highly permeable material such as gravel.

Schwab, Kirkham, and Johnson (29 p.448) in 1957 stated that the water table, outflow, and hydraulic conductivity measurements for a planosol soil similar to Dayton seem to indicate that water movement to the tile

is largely through the more permeable back-fill over the drains. The initial water table midway between the drains a few hours after a rain is lower for the narrower spacings. Subsequently the rate of drop is nearly the same for all spacings. After the first day following rainfall evapotranspiration and other losses appear to influence the rate of drop more than the tile.

Luthin and Gaskill(20 p.598) in 1950 worked with a planosol similar to Dayton soil and found that layers of soil with different water conductivities are difficult or impossible problems to solve analytically, especially if the interface between the 2 layers is irregular. They concluded that if the soil had a conductivity ratio, between the top and restricting layer of at least 10, very little flow takes place through the subsoil when tile drains are placed at 4 feet depths and the distance from the soil surface to the restricting layer is 2 feet. Most of the water must flow laterally through the surface soil in order to reach the more permeable trench-fill material. They compared the amount of water removed at 2 depths, 2 feet and 4 feet. A reduction of 11.1 percent resulted when the tile was placed at the 2 feet depth. (20 p.601) They stated that the small increase in flow obtained by placing the tiles deeper probably did not justify the

additional cost of trench digging. Kirkham (16 p.59) in 1947 found that lowering the drains onto or into an impervious layer, although increasing the hydraulic head, decreases the flow rate, because the lower portion of the drain can not function effectively if at all. Drains should not be placed too near, on or in an impervious layer if a rapid initial draw-down of the water table is desired.

MEASUREMENT OF WATER CONDUCTIVITY

The water conductivity of each horizon of each soil is important when the discussion of water flow into tiles ensues. Because of this importance there is a need for methods of measuring the water conductivity. Reeve and Kirkham (28 p.582) in 1951 compared four methods that have been developed. These are the piezometer, tube, auger hole, and the conventional undisturbed-core method. The first three are field methods and require the presence of a water table above the depth to be measured. The undisturbed-core method is a laboratory method. The piezometer method measures a combination of the vertical and lateral conductivities of the soil. The tube measures primarily the vertical conductivity, and the auger hole measures primarily the lateral conductivity. The

conventional undisturbed-core method measures the vertical conductivity if the core is taken vertically, or lateral conductivity if so taken. Because of the lateral as well as the vertical movement of water to tile drains the piezometer method gives the truest picture of the water flow and water conductivity. Reeve and Kirkham showed with the values obtained on their tests that the piezometer and the undisturbed-core methods to be correlated closely. The range of water conductivity of their soils was between 39.1 and 0.13 inches per hour. Other discussions of methods for the determination of values for water conductivity were advanced by Luthin and Kirkham (20) in 1949, Van Bavel and Kirkham (31) in 1948, and Frevert and Kirkham (11) in 1948.

Johnson, Frevert, and Evans (14 p.284) in 1952 showed a simplified method of computing the water conductivity below the water table with the piezometer and gave an accurate method of determining the A-factor. The A-factor is a function of the geometry of the flow system which depends upon the size of the cavity augered below the pipe, the distance from the cavity to the impervious layer, and the distance below the water table. They gave the following formula to be used with the piezometer method for a cavity 4 inches long, 1 and 15/16 inches in diameter,

and the cavity must be 12 inches above the impervious layer.

$$K = \frac{625 \ln (h_1 - L_r) / (h_2 - L_r)}{t_1 - t_2}$$

where h_1 is the distance (feet) from the top of the pipe to the water at time t_1 (seconds); h_2 is the distance from the top of the pipe (feet) to the water at time t_2 (seconds); L_r is the distance from the top of the pipe to the water table (feet); K is the water conductivity in inches per hour; and the constant 625 combines R^2 (R = radius of the cavity), the A-factor, and 60 seconds.

There are many factors affecting the water conductivity of the soil. Reeve and Kirkham (28 p.588) in 1951 discussed the effect of root holes on water conductivity. These holes will cause a change in the vertical flow paths. Nikiforoff and Drosdoff (22 p.40) stated in 1943 that the numerous burrows of earthworms, partly filled with casts and partly empty, penetrate the whole A horizon and extend into the B horizon of the Dayton soils in the Willamette Valley. Schwab, Kirkham, and Johnson (29 p.448) in 1957 also stated that the actions of earthworms had affected the water conductivity of the planosol that they had worked with.

Fireman (9 p.338) in 1944 measured the water conductivity of disturbed samples by a method similar to

the method used on undisturbed-core samples in this study. The following formula was used to compute the water conductivity of samples:

$$K = \frac{QL}{TAh}$$

where K is the water conductivity, A is the cross-sectional area of the core, h is the loss in hydraulic head through length L, and Q is the volume of water passing through the core in time T.

Three-inch core samples were used in this study as explained in the procedure. Edminster, Turner, Lillard, and Steele (7 p.419) found in 1950 that there was no significant difference in the amount of water which percolated through 3-inch and 4-inch long cores. They stated that the Uhland type of sampler proved to be far more efficient for field work than other modifications tested. The Uhland sampler is described in detail in the experimental procedure of this thesis.

DESCRIPTION OF SOILS

The water conductivity of each of the soils, Willamette, Amity, and Dayton is different. Furthermore, the horizons of each soil have different water conductivities. Allison (1 p.12-13) in 1953 stated that the Willamette silts (the material moved into the valley by glacial water of

Pleistocene time) are composed of quartz, several different feldspars, and a variety of other common minerals, mostly in angular grains or cleavage fragments. The silts came chiefly from the Columbia River and are presently weathered to depths of 3 to 6 feet, mostly to Willamette, Amity, and Dayton soils. A claypan from a few inches to a foot or more thick has developed in areas of poor drainage.

Williams (32 p.28) described the Willamette series in 1955 as follows: "Willamette series consists of very deep brown soils of moderate profile development on old valley filling materials having their source mainly in basaltic and sedimentary rocks. They occur on gently sloping, nearly level to slightly undulating stream valley terraces and the valley floor. They have developed under moderate rainfall, mild wet winters and dry warm summers, with cover of scrub oak, hazel, and with occasional fir forests with open treeless prairie areas. The surface is well drained, fertile, moderately to slightly acid in reaction, occurring on level (0-3 percent) to steeply sloping (21-31+ percent) areas.

The surface soils are brown, friable, moderate subangular silt loams with a few iron and manganese concretions. The subsoils are lighter brown, firm, strong compact subangular blocky silty clay loams, slightly

mottled and having a few iron and manganese concretions. Willamette soils occur in association with Amity and Chehalis soils. They are better drained than the Amity soils which have more highly mottled subsoils and have a stronger developed profile, and occupy higher terraces above the Chehalis soil."

Williams (32 p.38) described Amity soil in 1955 as follows: "The Amity series is comprised of very deep light colored Podzolid soils developed under moderately high rainfall, wet mild winters and dry warm summers on old alluvial valley-filling materials having their source mainly in basaltic and sedimentary rocks under oak, fir, and open prairie vegetation. The soils are formed on valley floors and low terraces, relatively flat, or slightly undulating, including shallow basin-like areas generally above stream overflow. The surface and subdrainage is poor, due to level surface areas and heavy subsoils.

The soils are very deep, with fine-textured compact moderately slow permeable subsoils. The soils are moderately acid in reaction. The surface soils are dark brown, friable, moderately medium subangular blocky silt loam containing a few iron and manganese concretions. The subsoils are grayish-brown friable, compact, fine subangular blocky silty clay loam mottled with gray and yellowish

brown with a few iron and manganese concretions. The substratum is light-colored friable clay loam with better permeability."

Williams (32 p.49) described Dayton soils in 1955 as follows: "The Dayton soils are shallow poorly drained grayish-brown soils developed under moderately high rainfall, wet mild winters, and dry warm summers on old valley-filling material having their source in basaltic and sedimentary rocks under native vegetation of grasses with scattered scrub oak. The soils are formed on old terraces with flat smooth surfaces with few drainage channels. The surface drainage is poor and the subdrainage is very slow due to the compact fine-textured subsoils.

The soils are shallow (10-20 inches) to a claypan and have a low organic matter content. They are moderately to strongly acid in reaction, and for profitable use require drainage. The surface soils are grayish-brown, firm, slightly sticky silt loams with a few iron and manganese concretions."

PREVIOUS WORK IN THE WILLAMETTE VALLEY

Bloss (2 p.6) in 1893 estimated on the basis of his observations of Willamette Valley soils that "tiles should be placed 16 to 20 feet apart in some clayey ground, while

in certain loams equally good drainage may be secured at 40 to 50 feet apart." He recommended a depth of 40 inches.

Hedrick (12 p.12) in 1897 estimated that soil with an impervious subsurface in prune orchards in the Willamette Valley could be drained with tiles at a distance of 36 to 44 feet apart. The depth that he recommended was three feet. Powers and Teeter (25 p.24) discussed the work done by the U.S. Office of Drainage Investigations at Albany, Oregon, in 1908, in which they stated that the laterals were placed 60 feet apart. The depth was varied from $2\frac{1}{2}$ to $4\frac{1}{2}$ feet. They stated that "A study of water table conditions in the vicinity of these drains indicates that the drains laid $4\frac{1}{2}$ feet deep are less effective than those laid to a depth of 33-36 inches, for at least 2 weeks or more after heavy precipitation." No mention is made of the results from the $2\frac{1}{2}$ feet tile depths. Powers and Teeter (24 p.25) conducted an experiment dealing with tile spacing and depth in Dayton soil. The drainage experiments in 1914 conducted at Oregon State College were on an area of Dayton soil. The spacings between laterals on this experiment were 25, 50, 75, and 100 feet apart with depths averaging 33 inches. Test wells were maintained to check levels of the water table. The test wells were one rod from tile lines and one rod apart.

The conclusion was reached that tiles should be spaced at intervals of 60 to 66 feet. Powers and Teeters also stated "Laterals of this distance afford the most practical drainage for typical white land under present conditions. This distance may be increased in less retentive phases of this soil." (24 p.8) They state that the depth should be 33-36 inches, in the "gritty silty clay layer" that they found was more porous.

Powers and Teeters stated "A study should be made of the subsoil and ground water conditions and the drains so located as to encounter excess water in the most porous layers." The fact was recognized that water cannot pass through the soil fast enough to drain completely even though the tile is amply large, so that surface runs or surface inlets are needed.

It is obvious very little drainage research has been done on these important but poorly drained soils in the Willamette Valley. It is the authors hope that the data collected and correlated in the following pages will be an aid to future studies and to persons engaged in the drainage of excess water from their land.

SPECIFIC OBJECTIVES

Experiments conducted in 1908 and 1914 were performed at a limited number of locations. Water table levels were checked during the months of March and April in the 1914 experiments, at distances of 16 feet from the tiles. Speculation was made as to the rate of draw-down between tiles and the test wells 16 feet away.

The first objective of this study was to determine the status of the water table in tiled and non-tiled Dayton, Amity, and Willamette soils during the high rainfall months of December to April. It is a known fact that the water table is high during this time on Dayton and Amity soils and occasionally on tiled and non-tiled fields of Willamette soil. The level of the water table in relation to the distance from the tiles, the draw-down after precipitation ceases, and fluctuations due to daily precipitation during the season are not known. With this information about the water table an evaluation of the spacing's effectiveness can be made.

The second objective was to determine the water conductivity of the different horizons of the above mentioned soils. An understanding of the water conductivity of soils will give a more complete understanding of the functioning of the tile system as related to the soil. The water

conductivity of the various horizons of the soil should influence the depth to which tiles are placed.

EXPERIMENTAL PROCEDURES

Description of locations Studies were made on four fields near Corvallis. Two of these fields had soils which ranged from Dayton to Willamette; these were the Davis field which is approximately one mile southwest of the Corvallis Airport, and the Oregon Dairy Breeders Association field which is about one mile southwest of Granger, Oregon. The other two fields were chosen because they had tile systems installed in Dayton soils. These were the Hanson field which is about one mile east of the Corvallis Airport and the Kowalski field 2 miles north of Monroe, Oregon. The topography of the four fields is almost level with approximately 0.25 percent fall.

The Davis field was tiled in October, 1956. The three soil series intergrade from south to north through Willamette, Amity, and Dayton within a distance of 80 feet. The tile laterals are spaced 76 feet apart, in a grid pattern, and were placed at a depth of $4\frac{1}{2}$ feet. The laterals drain to the north where a main carries the water to the Muddy Creek which is west of the field. The field was in pasture during the winter and had approximately 50 sheep grazing on it during the months of February and March. The pasture was poor and did not furnish sufficient forage to sustain the flock, necessitating feeding of baled hay.

The field contained about 30 acres. A legal description of this field is NW $\frac{1}{4}$, NW $\frac{1}{4}$, sec. 32, T.12S. R.5W.

The Oregon Dairy Breeders Association field, which contained the three soil series also, did not intergrade as rapidly as the previous field. These soils were intergraded in a distance of 300 yards, with Dayton soil 200 yards north of the Amity soil, and the Amity soil 100 yards north of the Willamette soil. The drain system in this soil was partially installed in November, 1951 and finished in April 1952, to a depth of 4 feet. The tile laterals spaced 90 feet apart drain east to the main drain which drains the water south to the edge of the bench overlooking a Willamette river meander scar. The field was in ungrazed mixture of forage plants which did not have much growth until early April. Heavy applications of shavings and manure have been applied to this field every year from the animal pens south of the field. The legal description of this field is NE $\frac{1}{4}$, SW $\frac{1}{4}$ sec. 19, T.11S., R.4W.

The Hanson field was Dayton soil with the tile system installed in September 1952. The depth was approximately 2.7 feet with parallel laterals 70 feet apart. Lateral tiles drained to the north where they joined the main drain which carried the water to the east edge of the field where the bench overlooks a portion of the Willamette River.

The field was in pasture during the winter with the only grazing being done by some geese. A legal description of the field is SW $\frac{1}{4}$, SW $\frac{1}{4}$, sec.28, R.12S., R.5W.

The Kowalski field, 2 miles north of Monroe, Oregon, was Dayton soil with a tile system installed in November, 1956. The tiles were buried approximately 4 feet deep with spacing between parallel tile lines of 80 feet. The system drains to the south and east where it empties into a small creek. The field was in pasture during the winter with over 100 sheep grazing it during January and February. A legal description is SW $\frac{1}{4}$, NE $\frac{1}{4}$, sec16, T14S, R5W.

Water table measurements Test wells are holes dug in the soil that enable the observation of the water table in the soil. The test wells in this study was almost permanent in that they had pipes inserted to a depth of four feet below the surface for the duration of time readings were taken. The pipes were 4 $\frac{1}{2}$ -foot long, one-inch diameter steel boiler tubing, perforated with 3/8-inch holes eight inches apart, except for the 15 inches at the upper end. The top 6 inches were above the soil surface and a steel washer was placed 6 inches below the surface. The surface soil was packed and tamped around the pipe above the washer to prevent surface drainage into the test wells.

These test wells were placed a measured distance from the buried tile lines, which were located with a sharpened steel rod or tile probe, approximately 4 feet long. The spacings were measured using 100-foot engineer tapes. Test well sites at the Davis field were 2, 5, 10, 20, and 38 feet, the midpoint distance, from the tile laterals. Other spacings were $2\frac{1}{2}$, 5, 10, 20, and the midpoint distance, which was 45 feet for the Oregon Dairy Breeders Association field, 35 feet for the Hanson field, and 40 feet for the Kowalski field. The lateral distance between replications in each soil was 25 feet. Three replications of distances from tile lines of test wells were placed in each soil.

The holes for the pipes were dug with a one-inch King tube or a one-inch soil auger after a six-inch depth hole had been dug with a four-inch diameter orchard auger. The holes for the pipes were dug 4 feet deep. The King tube is a sharpened tube which is driven into the soil with a hammer and when revolved brings the soil that was forced inside the tube out also, leaving a hole. A soil auger is similar to a wood bit, which when turned cuts into the soil leaving a hole. The soil auger was the method used to cut most of the holes needed as it was faster in the soils of this study than the King tube.

The water table status was observed but not measured while the installation of the test wells was being done in November and December. Measurements and records were started in December 1956. The depth of the water table was measured with a common measuring stick which was marked at 1/10 foot intervals. Measurements continued until the first week of April.

Water conductivity measurements

Piezometer method The procedure for installing the tubes was identical to that described by Johnson, Frevert, and Evans. (14) They describe the procedure as follows: "A hole 1 15/16 inches in diameter is bored to a depth of 6 inches after trash and surface sod have been removed from the location chosen for a measurement. A sharpened section of 2 inch (inside diameter) thin-walled electrical conduit is driven axially into the hole to a depth of 5 inches using light blows from a maul. To prevent damage to the top of the tube it is desirable to use a driving head. The 1 15/16-inch soil auger is then inserted into the tube and the soil is removed to a depth 6 inches below the bottom of the tube. The tube is again driven 5 inches deeper. This procedure is continued until the tube point is at the depth desired for measurement. A cavity, 4 inches in length and 1 15/16 inches in diameter, is then

carefully augered below the bottom end of the tube. A stop may be attached to the auger shaft to make contact with the top of the tube when the cavity is drilled to proper depth.

The water seeping into the cavity is then pumped out two or three times to remove the effect of puddled soil on the cavity walls. To facilitate this, a hose attached to a small pitcher pump is inserted to the tube bottom. Reproducibility of results from an individual hole indicates that puddling effects have been minimized.

Soil water is then allowed to rise in the tube. The equilibrium water level is determined. In highly permeable soils as little as a few seconds may be required for the water table to reach equilibrium; in tight clay soils a longer time is required."

The data for calculating the water conductivity was obtained by measuring the distance from the top of the pipe to the level of the water table after equilibrium has been reached. The water is removed from the hole and the depth and time is recorded. At a later time the depth is measured and recorded along with the time. At least three increments of rise and time were taken in each tube at each position.

Measurements were made during the last week of March in non-tiled areas near the test wells at the Davis, Kowalski and Hanson fields. No measurements were made at the Oregon Dairy Breeders Association field due to a low water table.

Core method To determine the water conductivity of soil horizons that did not have a water table or where the soil was almost completely impervious it was necessary to collect soil in the undisturbed (as much so as possible) form. The use of the Uhland sampler allowed this. This sampler consists of an outside shell and cutting head into which is inserted a 3- by 3-inch aluminum cylinder sleeve. A cap is placed over this unit and the shell, with its inner sleeve, is driven into the soil through the use of a dropping weight. The sampler is removed from the soil and the sleeve with the enclosed soil is removed from the sampler. Cores are trimmed with a sharp knife and boxed in a waxed ice cream carton for transportation to the laboratory. By the collecting of cores and then forcing water thru them in the laboratory it is possible to measure their water conductivity.

The core samples were taken midway between tile laterals where water table measurements were conducted. Samples were taken from the Davis and Hanson fields in July and

from the Oregon Dairy Breeders Association and Kowalski fields in August. The samples from the undisturbed-core method were taken at different locations than where the piezometer water conductivity measurements were made. The soils were much drier in August and July, compared to the soils in March, when the piezometer measurements were taken.

The measurement of the water conductivity was done after the core samples had been moistened by capillarity for a period of at least 24 hours, and in some soils 7 days. The measurement was taken using 2 to 27 inches of hydraulic head differences.

The apparatus used to apply the hydraulic head difference across the core samples was similar to the apparatus described by Christiansen (4) and Fireman (9) in 1944. The apparatus differed from theirs in that the water moved through the core from the bottom to top instead of the reverse. The base of the apparatus is composed of an aluminum sheet and soldered to it are ten cylinders 1 inch long and 3 inches in diameter. Centrally located in each cylinder is an inlet hole to supply a source of water. A screen is held by a brass cylinder, to a height equal to that of the top of the aluminum cylinder. The core containers are placed upon

the base, being separated by a rubber washer. Another cylinder is placed on top of the core container and again separated by a rubber washer. The top cylinder has an outlet on the side which provides an overflow for the water that passes through the soil. The entire unit is clamped together by two bolts. The apparatus is shown in Figure 1.

A constant head is applied to the inlet and the overflow provides a constant head at the outlet. The water from the outlet is contained in a glass graduate cylinder for measurement.

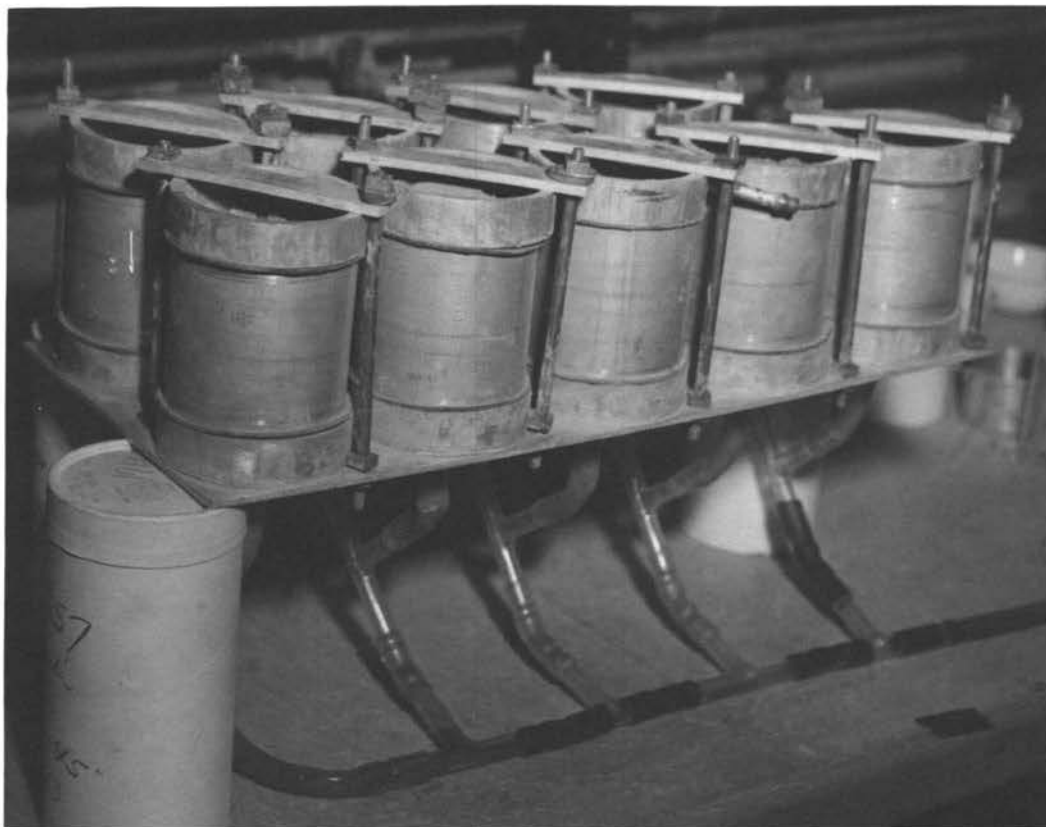


Figure 1. Photograph of apparatus for measuring water conductivity of undisturbed-core samples.

RESULTS

Rainfall Data Rainfall data collected at the Corvallis Station of the U.S. Department of Commerce, Weather Bureau, located at Granger, Oregon, are used to show the daily rainfall and are shown in Figure 2 and Table I. These show the fairly uniform distribution of rainfall during the last 2 days of February and the first 2 days of March, when no additional rain fell. This break in the precipitation permitted the measurement of draw-down of the water table during the highest rainfall period.

It would have been more desirable if daily data on precipitation could have been collected at each of the locations where studies were conducted. This would present a more accurate picture of the rainfall received at each location instead of a general picture such as the case here. It was not possible to collect these data as it was not possible to visit each field daily because of time limitations.

Water Table Measurements

Davis field. The non-tiled areas at the Davis field had a water table during the time that measurements were

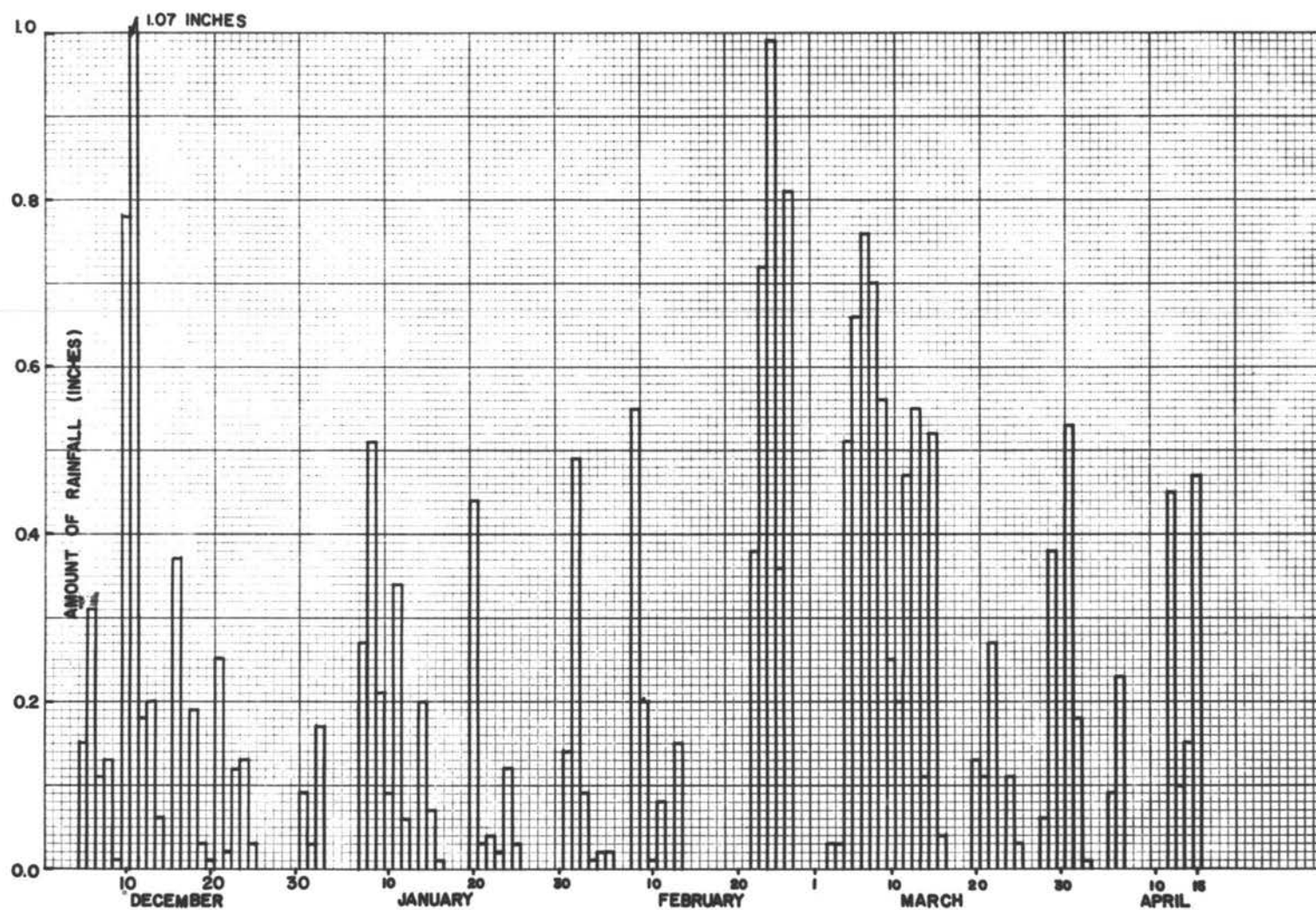


Figure 2. Daily precipitation recorded at Granger, Oregon, during the months water table measurements were made.

Table I. The rainfall distribution in inches at the Corvallis Weather Station, during the five months when water table measurements were made.

DAY	MONTH				
	December	January	February	March	April
1		0.03	0.49		0.18
2		0.17	0.09		0.01
3			0.01	0.03	
4	0.32		0.02	0.03	
5	0.15		0.02	0.51	0.09
6	0.31			0.66	0.23
7	0.11	0.27		0.76	
8	0.13	0.51	0.55	0.70	
9	0.01	0.21	0.20	0.56	
10	0.78	0.09	0.01	0.25	
11	1.07	0.34	0.08	0.20	
12	0.18	0.06		0.47	0.45
13	0.20		0.15	0.55	0.10
14	0.06	0.20		0.11	0.15
15		0.07		0.52	0.47
16	0.37	0.01		0.04	
17					
18	0.19				
19	0.03				
20	0.01	0.44		0.13	
21	0.25	0.03		0.11	
22	0.02	0.04	0.38	0.27	
23	0.12	0.02	0.72		
24	0.13	0.12	0.99	0.11	
25	0.03	0.03	0.36	0.03	
26			0.81		
27					
28				0.06	
29				0.38	
30					
31	0.09	0.14		0.53	
TOTALS	4.56	2.78	4.88	7.01	1.68

Grand total = 20.91

taken. The measurements on the non-tiled area were taken between January 31 and April 8, 1957. The average for the non-tiled Amity soil was 2.27 feet below the surface and the Dayton soil average was 0.39 feet below the surface. The average for the non-tiled Willamette soil area was not computed as the water table was too low to be read on three dates, which would cause the average of the remaining values to be too high.

A graphic picture for comparing the three areas of non-tiled soil at the Davis field is shown in Figure 3. Figure 3 and other figures showing depth of the water table will show the depth as the ordinate, and time or distance from the tile line as the abscissa. The upper line in Figure 3 shows the levels of the water table in the Dayton soil; the middle line shows the levels of the water table in the Amity soil; and the bottom line shows the levels of the water table in Willamette soil. The dotted line at the right side of the bottom line is used to indicate the level of the water table was lower than 4.0 feet below the surface on these last three dates of measurement. The water table in Dayton non-tiled soil was above the soil surface on all dates measurements were made except two. The water table in the Amity and Willamette soils in non-tiled areas was always lower than

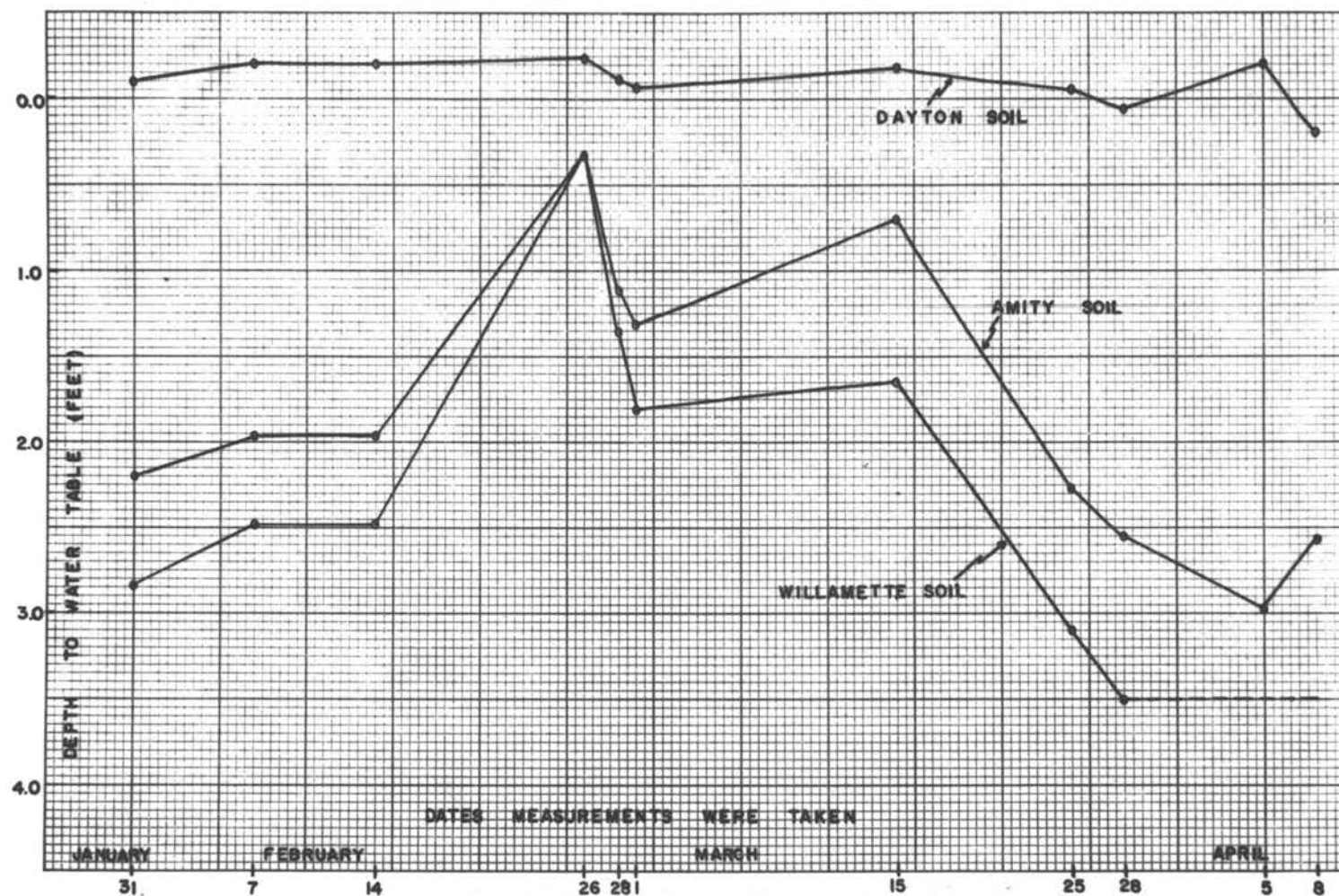


Figure 3. Water table status in non-tiled areas for the Davis field.

the water table in the Dayton soil areas. The water table in the Amity soil was always higher than the water table in the Willamette soil.

Measurements on the Willamette soil at the Davis field in the tiled area indicate that the water table was generally low with an average reading of 2.64 feet below the surface. This average includes all test wells for the 15 dates readings were recorded. The water table depth was usually between 2 and 3 feet below the soil surface. The water table level in the tiled Willamette between December 12 and April 8 is shown in Figure 4. The three lines show the effect upon the level of the water table due to distance from the tile lines. The distances of the test wells from the tiles, used for this graph, were 2 and 10 feet from the east tile line and the mid-point distance of 38 feet. The line connecting the 38-foot points is broken to prevent the loss of continuity where the lines cross. The upper lines cross because of a soil difference found between the tile laterals. The soil near the west lateral appeared more conductive to water than the soil near the east lateral. The effects of soil difference may also be seen in Figure 5, which shows the level of the water table at nine distances from the tile laterals on Willamette soil between two

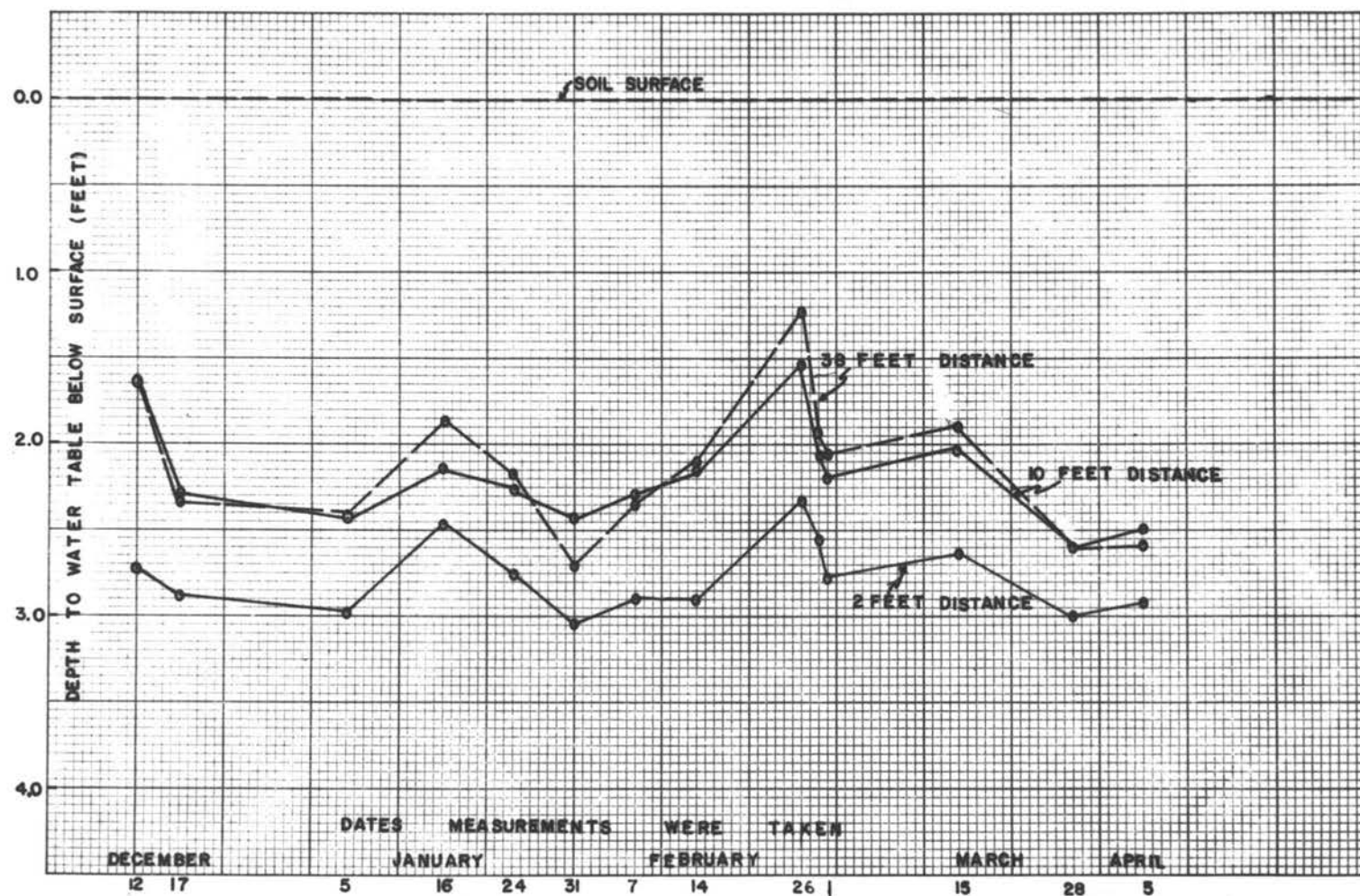


Figure 4. Water table status in Willamette soil for the Davis field at three distances from a tile line.

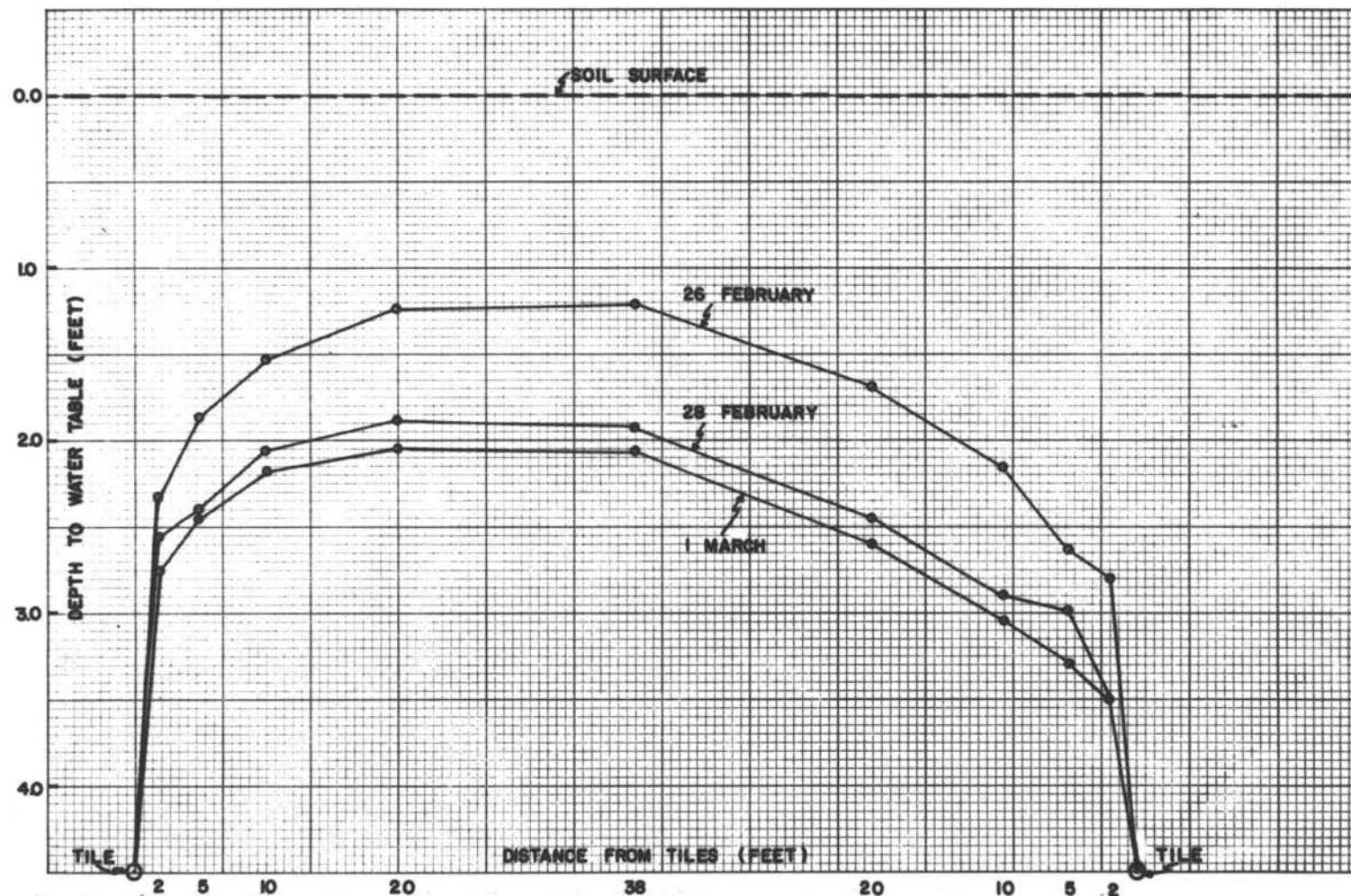


Figure 5. The depth of the water table in Willamette soil between parallel tile lines on three dates at the Davis field.

tile laterals. The three curves are for three consecutive readings during a single period of draw-down which occurred between February 26 and March 2 when no additional rain was received and the initial water table status was high. The three different levels represent three measurement dates, with the upper line connecting the water table measurements obtained the day rain ceased, or February 26, the middle line shows the water table measurements of February 28, and the bottom line shows the water table measurements of March 1. The water table was higher the greater the distance from the tile lines. The highest measured water table in this tiled Willamette soil was on February 26 when the readings were taken within 6 hours after rain ceased. It should be noted that the scale for the ordinate and the abscissa are different which distorts the actual shape of the water table. Lines on this graph and other graphs showing relationship of water tables to tile spacing were drawn as straight lines between the tile and the water table level 2 or $2\frac{1}{2}$ feet distance from the buried tile lines. This is an assumption based on a general opinion expressed in the literature review. The large circles on the graph indicate the location of the center of the tiles but were not drawn to scale.

The results from the tiled Amity soil of the Davis field during the season are shown in Figure 6. The three

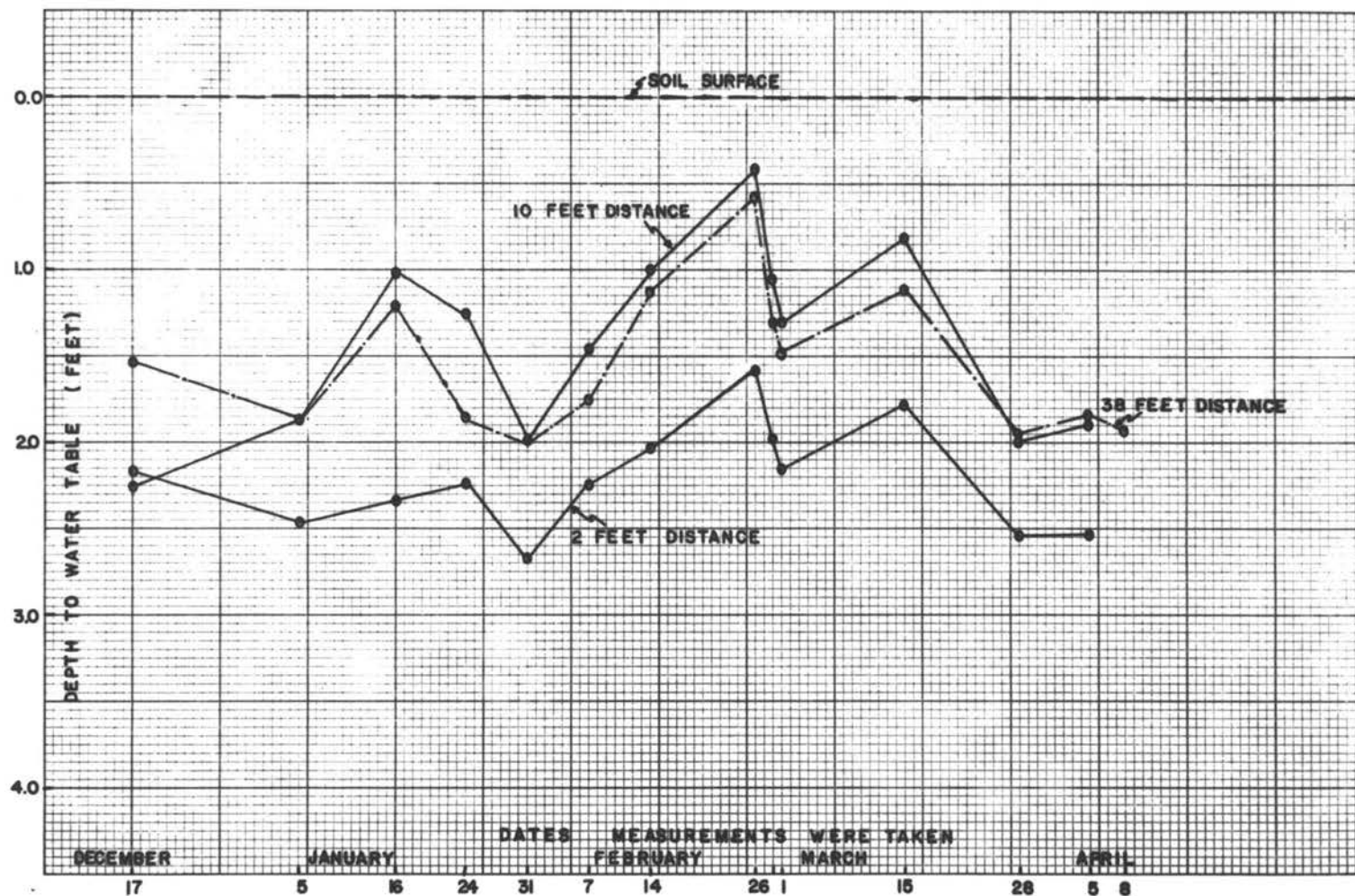


Figure 6. Water table status in Amity soil for the Davis field at three distances from a tile line.

lines show the level of the water table on the different dates during the winter at the specified distances from the tile laterals. The distances of the test wells from the tile laterals used in this graph are the same as for the Willamette soil, 2, 10, and 38 feet. The distances from the tile laterals were measured from the east lateral. The 38-foot distance is shown by the broken lines. The water table was generally higher in the Amity soil than in the Willamette soil, with the water table between 1 and $2\frac{1}{2}$ feet for most of the season. The water table depth was greater than one foot except for the periods of late February and early March. The water table dropped very rapidly whenever rain ceased.

The level of the water table of Amity soil at the nine measured distances from the tile laterals is shown in Figure 7. The three curves are for the same three consecutive measurement dates discussed previously showing a single draw-down period. The measurements obtained for the Amity soil on February 26 (upper line) were the highest readings obtained on this soil during the measurement season. The rate of draw-down of the Amity and Willamette soils was observed to be about the same but the water table in the Amity soil was the higher of the two for all dates. The water table was lower near one tile

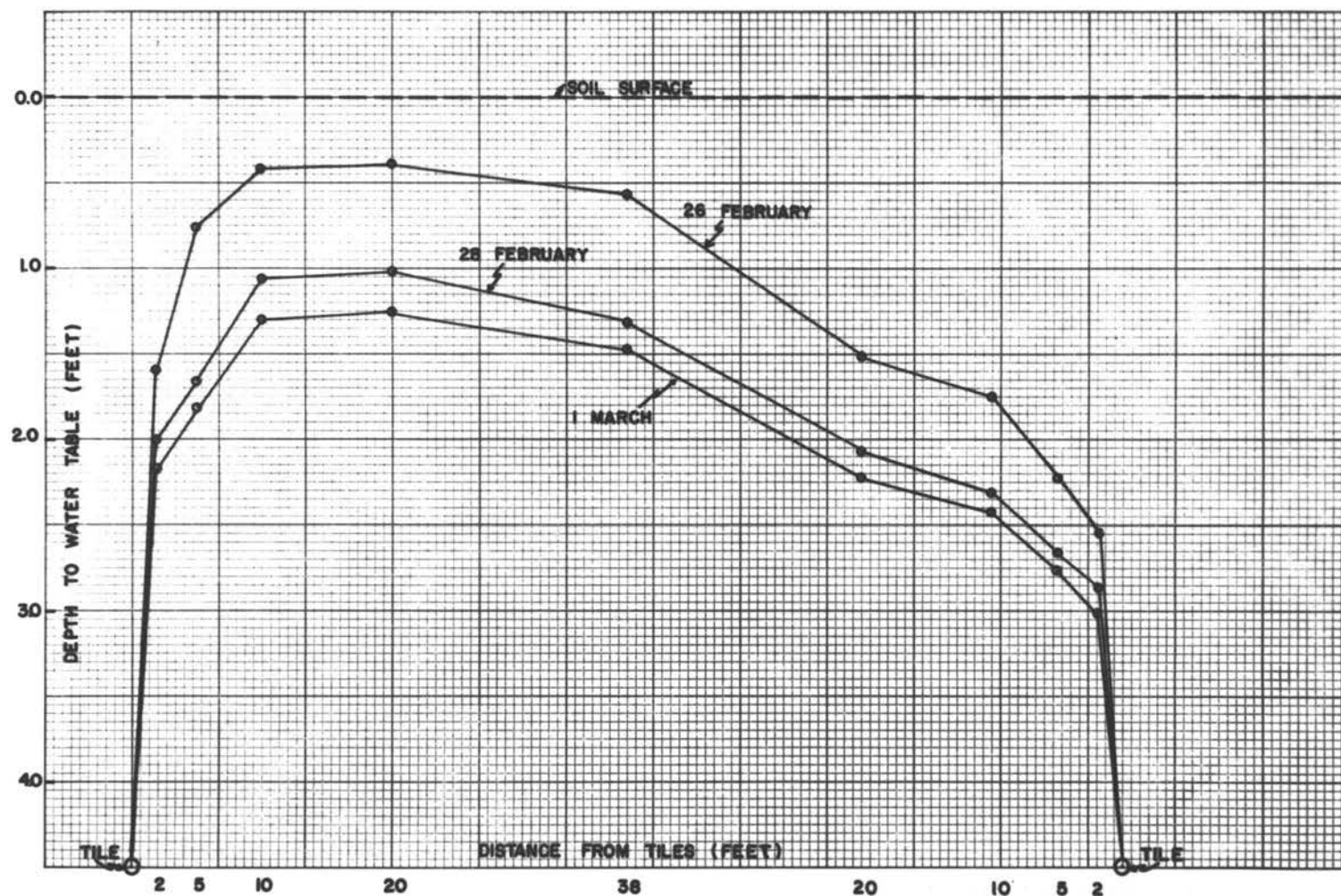


Figure 7. The depth of the water table in Amity soil between tile lines on three dates at the Davis field.

than it was at the other, which indicates a variation in soil water conductivity within the experimental site. The east tile is in the lower left corner of Figure 7.

Similar curves are shown for the Dayton soil in Figures 8 and 9, at the Davis field. The Dayton soil water tables were higher than the Amity soil's. There was a greater difference between the water table depth 2 feet and 10 feet from the tiles than on the Amity or Willamette soils. At distances over 10 feet from the tile the water table was within $1\frac{1}{2}$ feet of the surface during the season. Figure 9 shows that the draw-down is slight near the east lateral but greater toward the west tile lateral (lower right hand corner) but not as great as in the Amity soil.

Because the three soil series intergrade at the Davis field it is possible to show the water table as it is influenced by the soil changes. The distance between test wells in the direction of soil intergradation was 25 feet. Figure 10 is a graph of the water table as related to type of soil at three dates. The distances from the tile laterals were 2 feet, and 38 feet, with the 2 feet measured from the east tile line. The two lines for February 26 show the variation of depth to the water table as influenced by distance from tile lines and in the different soils. The two lines at the 2 feet distance show the effects of

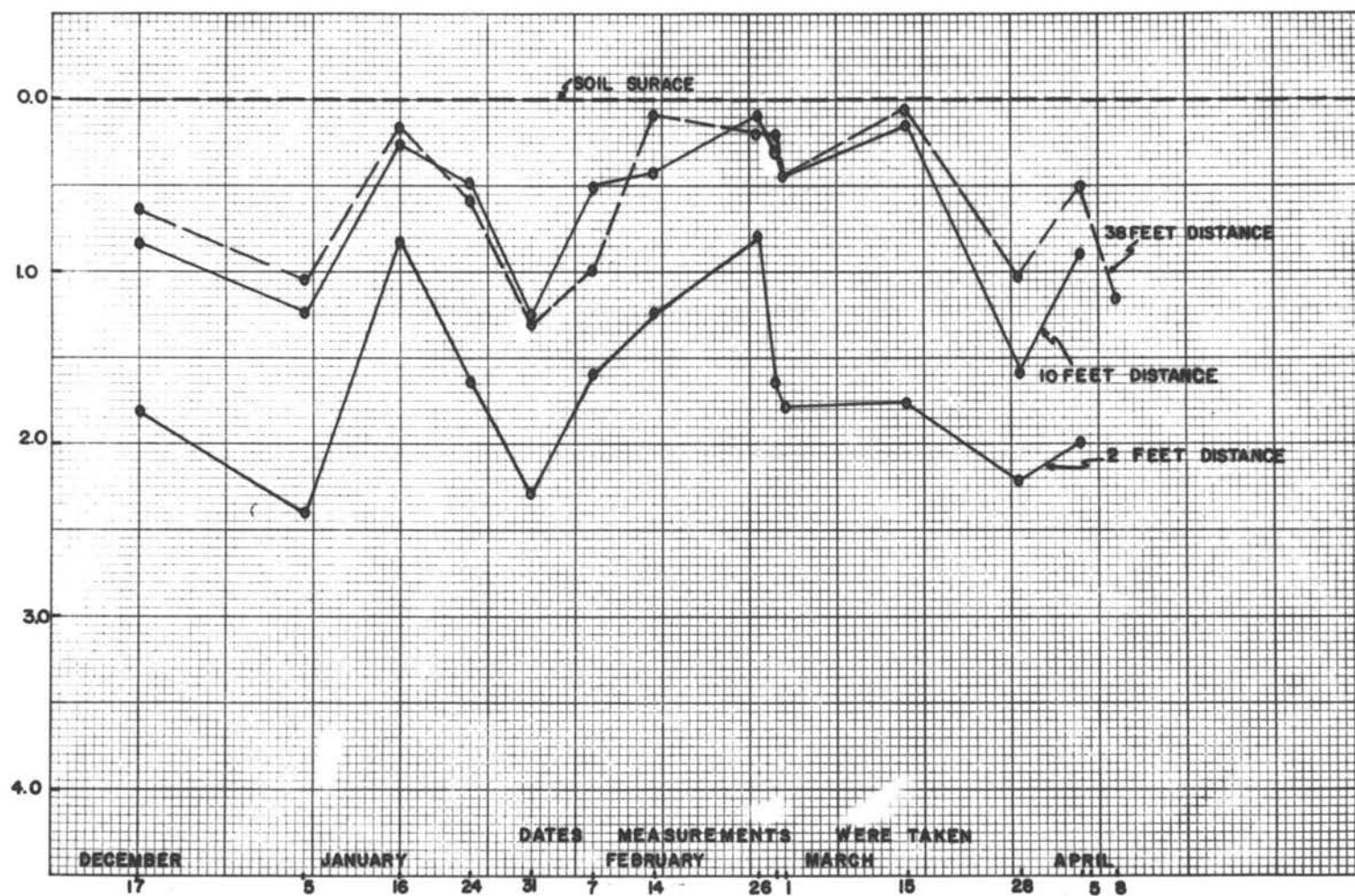


Figure 8. Water table status in Dayton soil for the Davis field at three distances from a tile line.

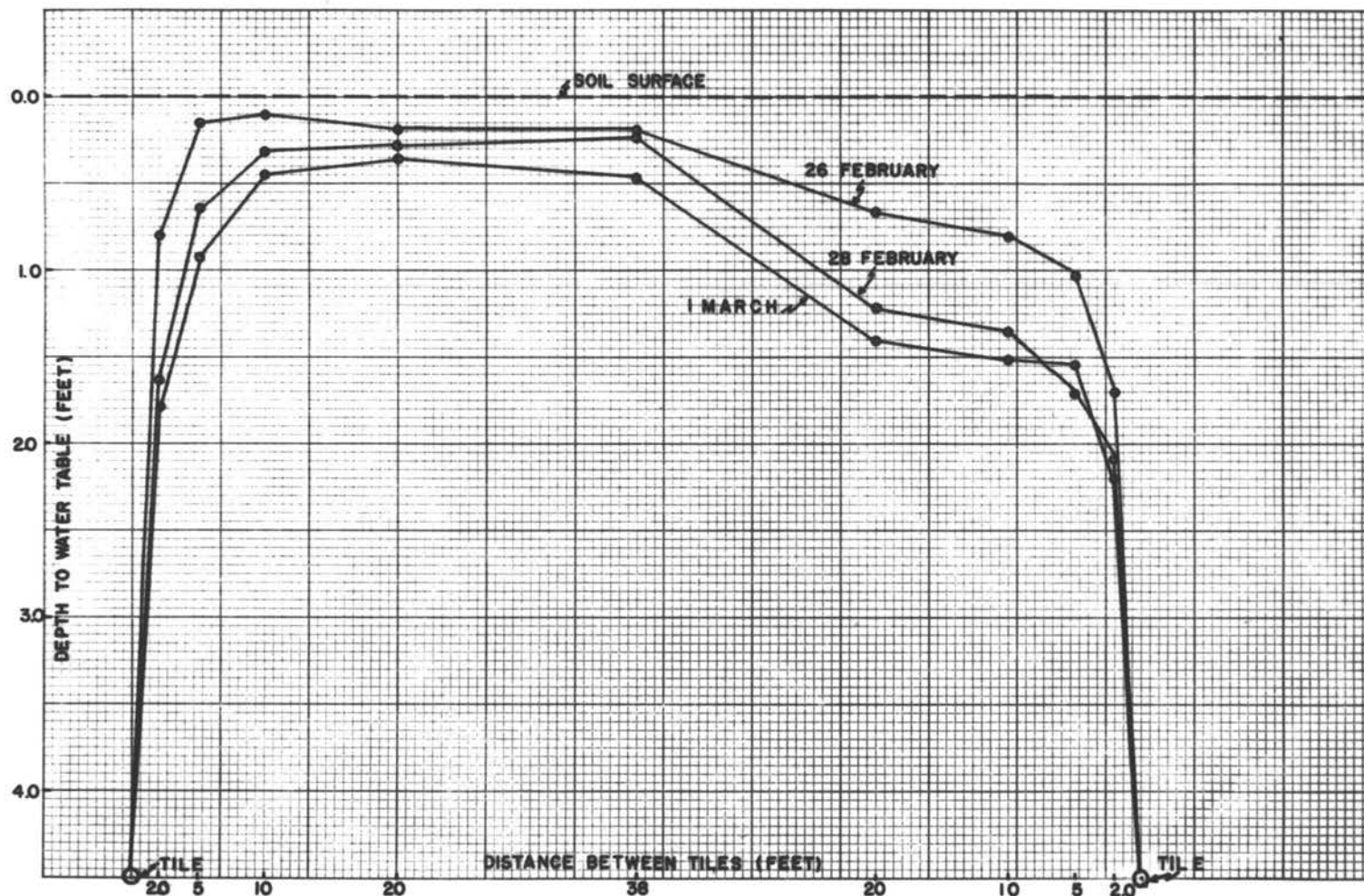


Figure 9. The depth of the water table in Dayton soil between parallel tile lines on three dates at the Davis field.

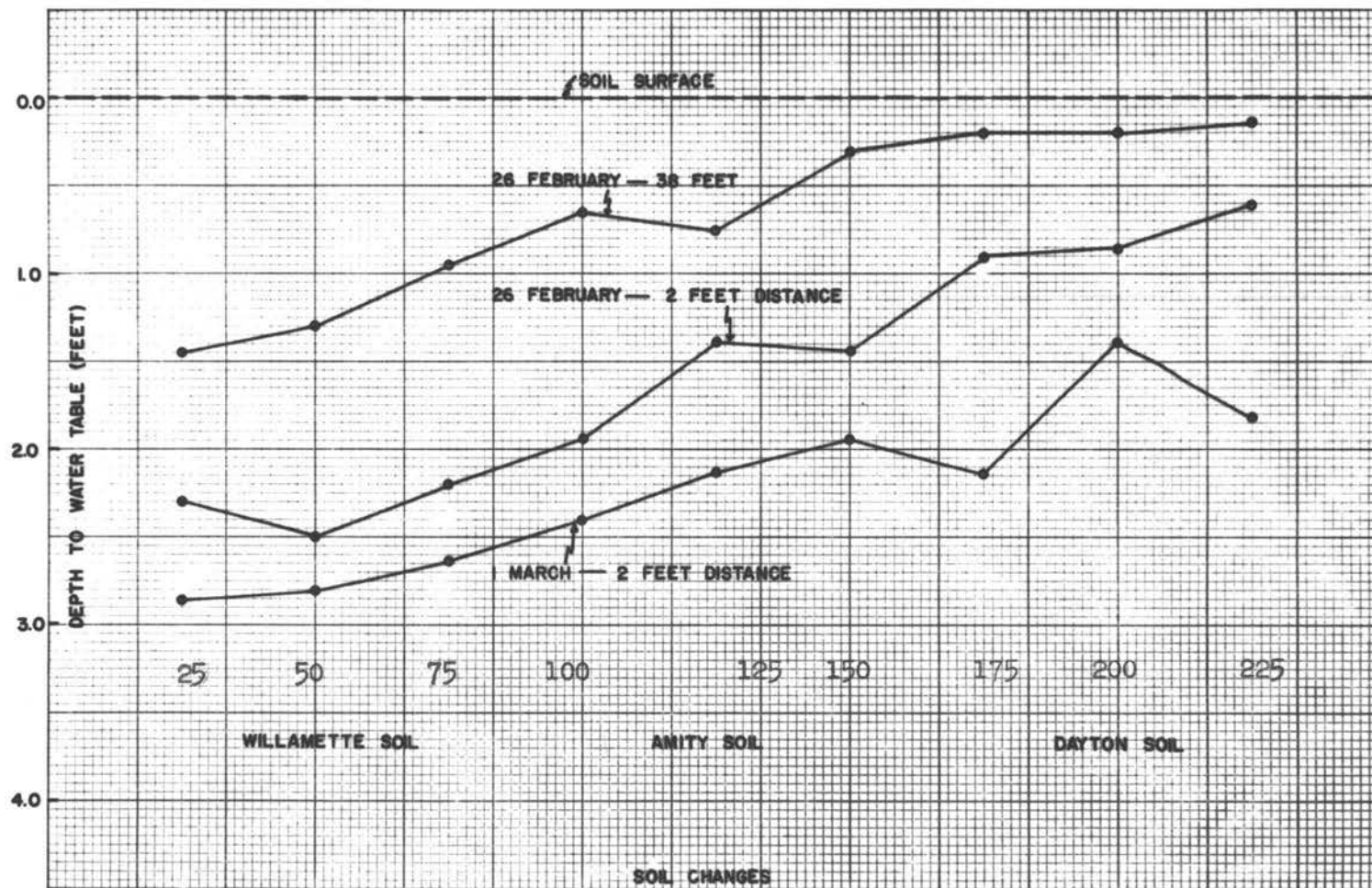


Figure 10. The depth of the water table as influenced by soil gradation, distance to tile, and time.

draw-down at that distance between February 26 and March 1. The draw-down between these two dates was greater in the Dayton soil (at the 2 feet distance) than in the Willamette soil. The opposite was found at distances of 38 feet. The graph does not show the depth of the tile lines, which was $4\frac{1}{2}$ feet.

Oregon Dairy Breeders Association field. The water table levels in the non-tiled areas of Dayton soil of the Oregon Dairy Breeders Association field and also the non-tiled areas of the Hanson and Kowalski fields are graphed in Figure 11. They are shown to indicate the status of the water table in these Dayton soils during the season. The water table was less than 1 foot below the surface at all times other than in early April.

The water table levels in the Amity and Willamette soils at the Oregon Dairy Breeders Association field were not plotted for the season because they were below the depth of the pipe most of the season. However, readings from the Willamette soil in tiled areas during the dates of highest measurement of the season were plotted as shown in Figure 12. The water level was occasionally observed to be higher beside the tiles than at the midpoint between the tile laterals. This is an indication that

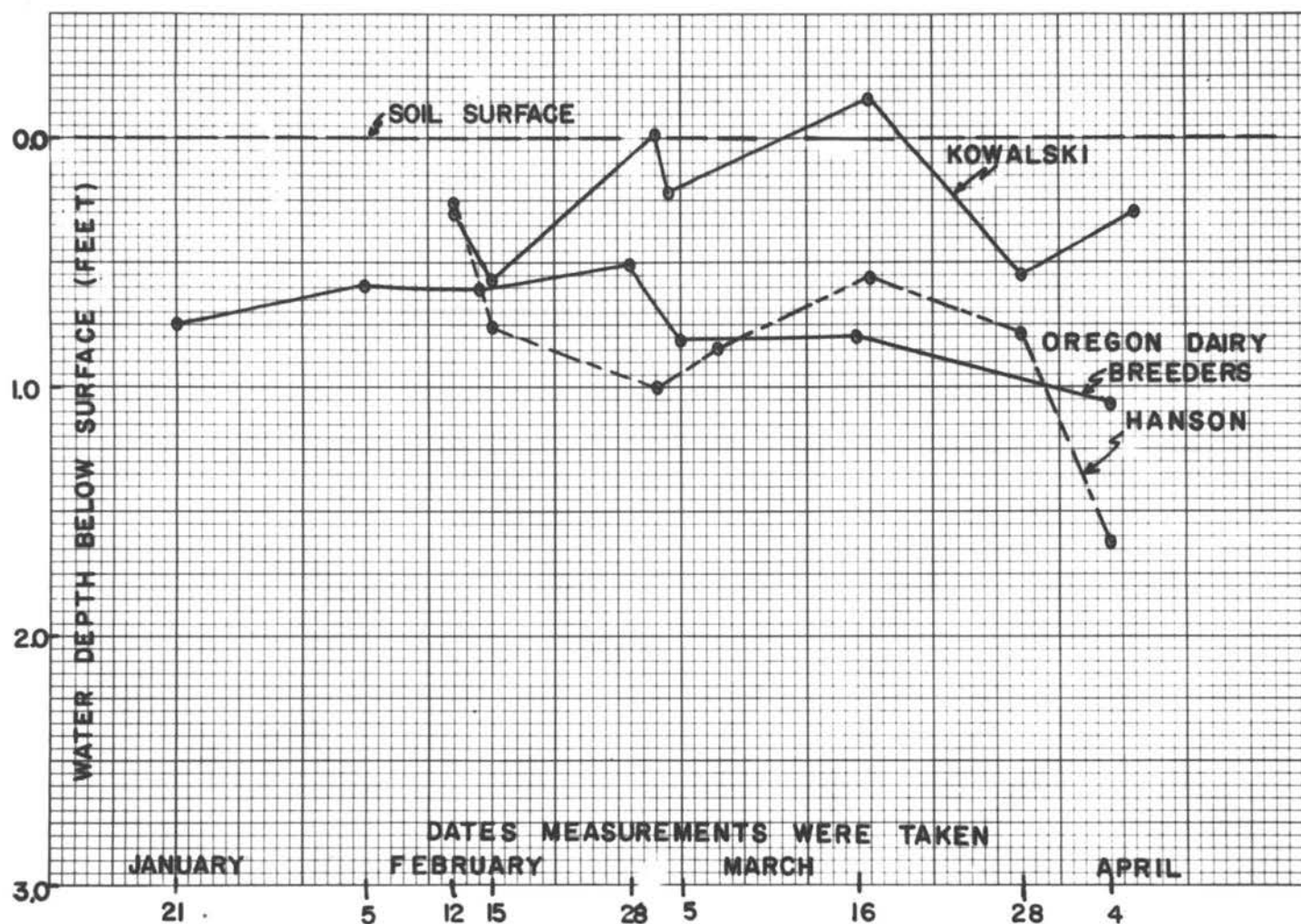


Figure 11. Water table status in non-tiled Dayton areas at three fields.

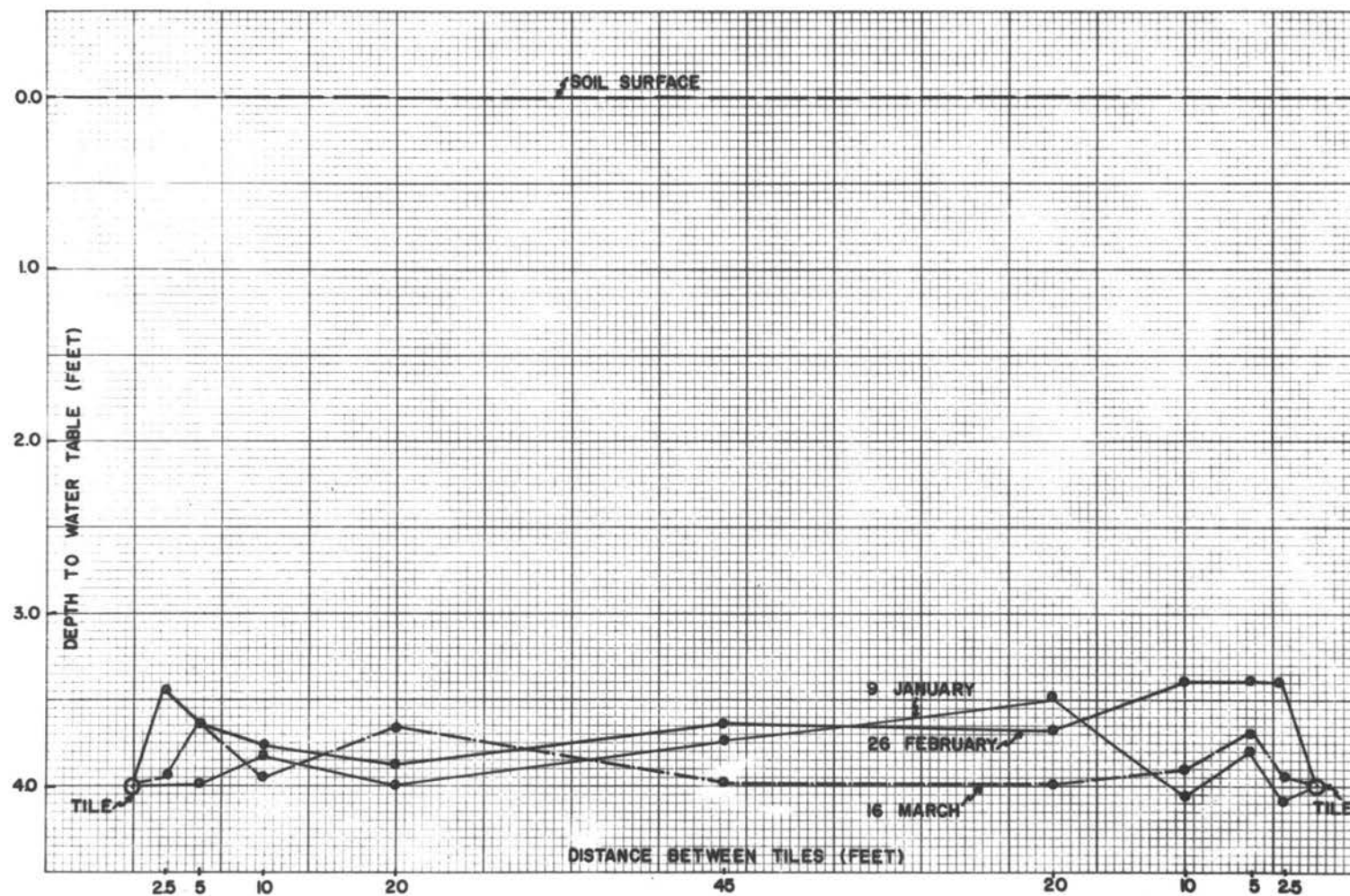


Figure 12. The depth of the water table in Willamette soil between tile lines on three dates at the Oregon Dairy Breeders Association field.

water could be entering the soil from the tile lines. Similar curves were obtained for Amity soils but are not presented.

Results for the tiled Dayton soil area at the Oregon Dairy Breeders Association field are shown in Figure 13, with the three lines connecting the levels of the water table at the specified distances from the tiles. The water table was above the surface of the soil a portion of the season between test wells, especially near the north lateral (NL) in Figure 13, where the soil was more restricting to water flow as evidenced by soil examination. There was very little difference between the water table depth at distances of 45 feet and $2\frac{1}{2}$ feet from the north lateral. However, there was over 1 foot difference in depth to the water table at distances of $2\frac{1}{2}$ and 45 feet from the south tile lateral. The effects of this difference in water conductivity may also be seen in Figure 14, which shows the water table depth as influenced by distance from tile lines. The three lines show the shape of the water table on different dates of the season. The rate of the water table draw-down following heavy rains is shown by the lines for February 26 and March 2. The line for April 5 represents the status of the water table the last day measurements were taken.

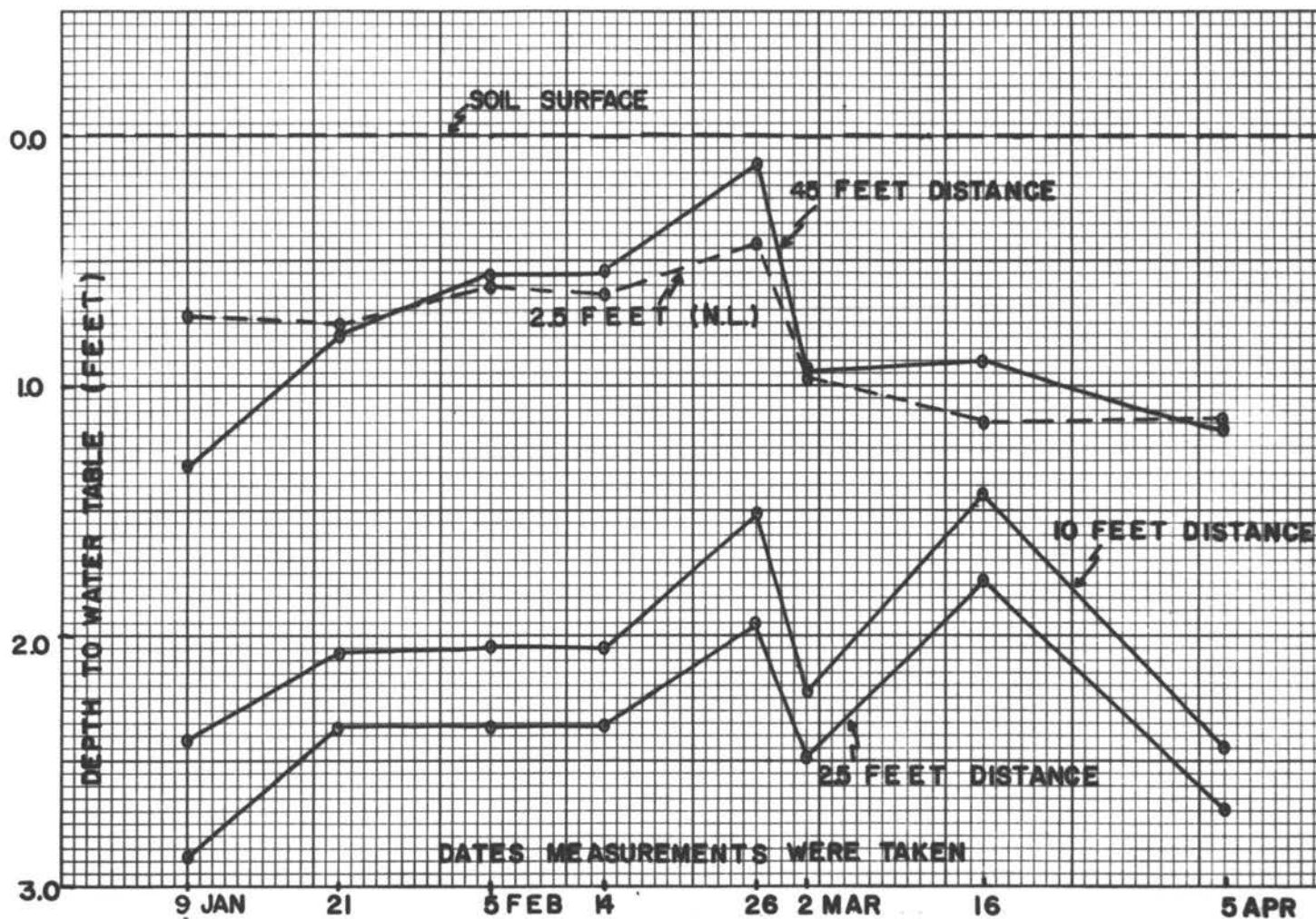


Figure 13. Water table status in Dayton soil for the Oregon Dairy Breeders Association field at three distances from a tile line.

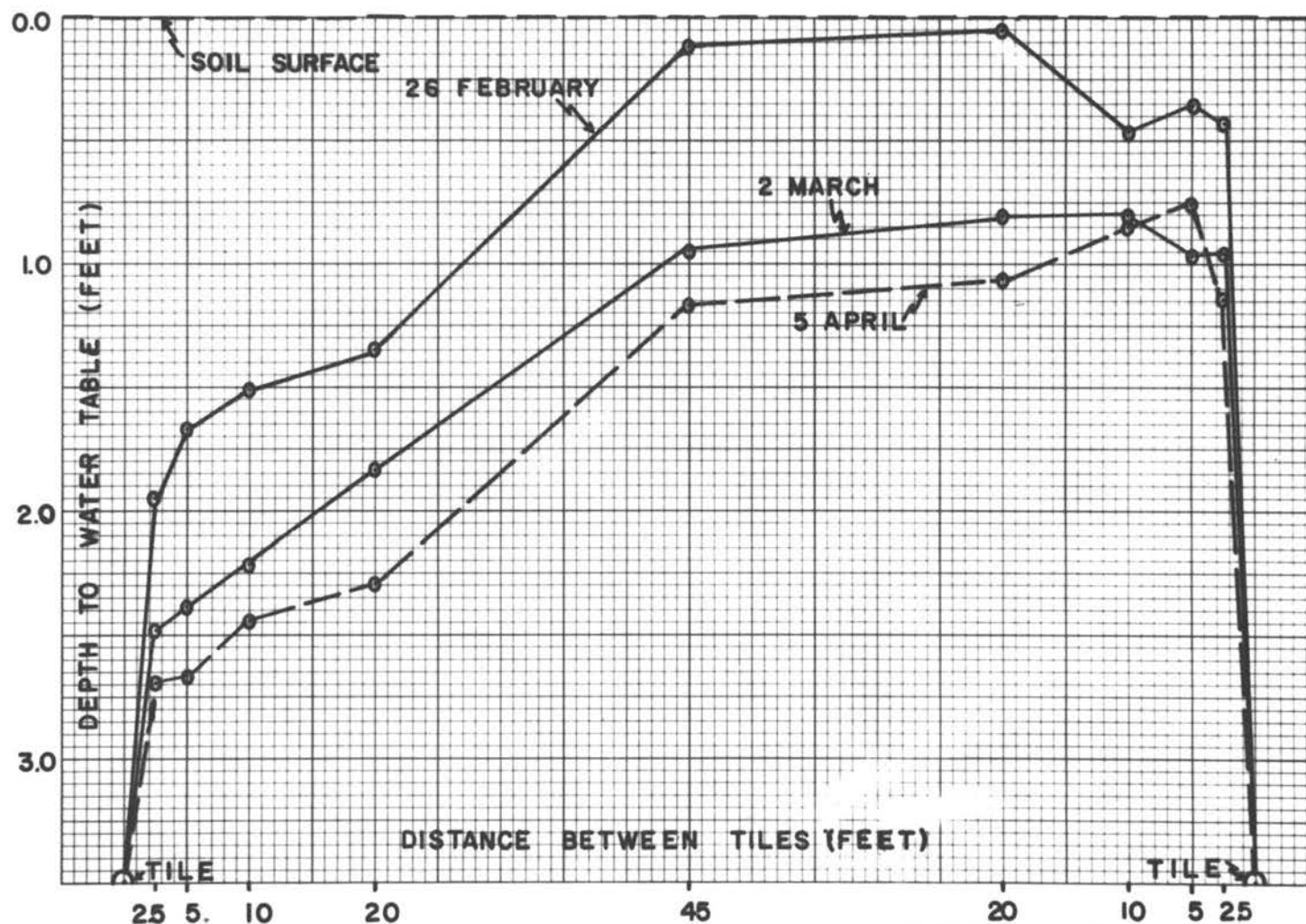


Figure 14. The depth of the water table in Dayton soil between parallel tile lines at the Oregon Dairy Breeders Association field on three dates.

Hanson field. The water table at the Hanson field was high with an average for all measurements of the tiled Dayton soil of 0.72 feet below the surface. Figure 15 shows the level of the water table for the dates readings were taken. The depth of the water table below the surface was almost the same at the midpoint distance and the $2\frac{1}{2}$ -foot distance from the tile lateral. The three lines connect the water table levels at measured distances from the tile laterals. The drainage pattern as it is influenced by the distance from the tiles can be seen in Figure 16, which shows the depth of the water table at three dates of measurements, January 8, February 28, and March 4. These dates were chosen as they best show the fluctuation of the water table during the season, and not because they represent one continuous draw-down of the water table. The measurements of January 8 were taken just after considerable rain had fallen and the water table had risen. The measurements of February 28 were taken two days after rain had ceased while March 4 was near the end of the same rainless period, only 0.06 inches of rain fell between the last two dates. The water level $2\frac{1}{2}$ feet from the tile line is not connected to the drain as the water table was observed to be high (at times water was ponded) over the drains indicating that the tiles were probably not acting as open

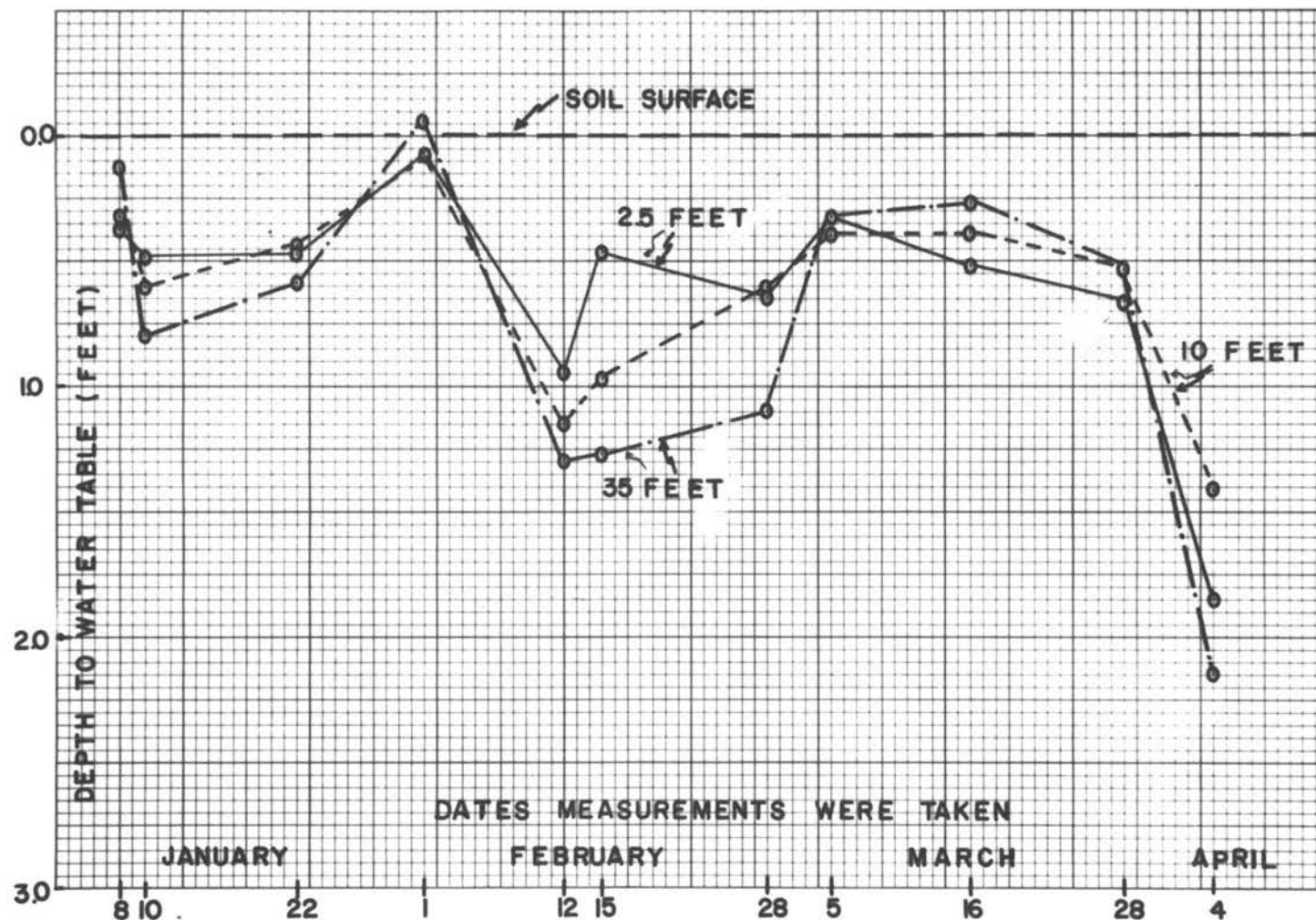


Figure 15. Water table status in Dayton soil for the Hanson field at three distances from a tile line.

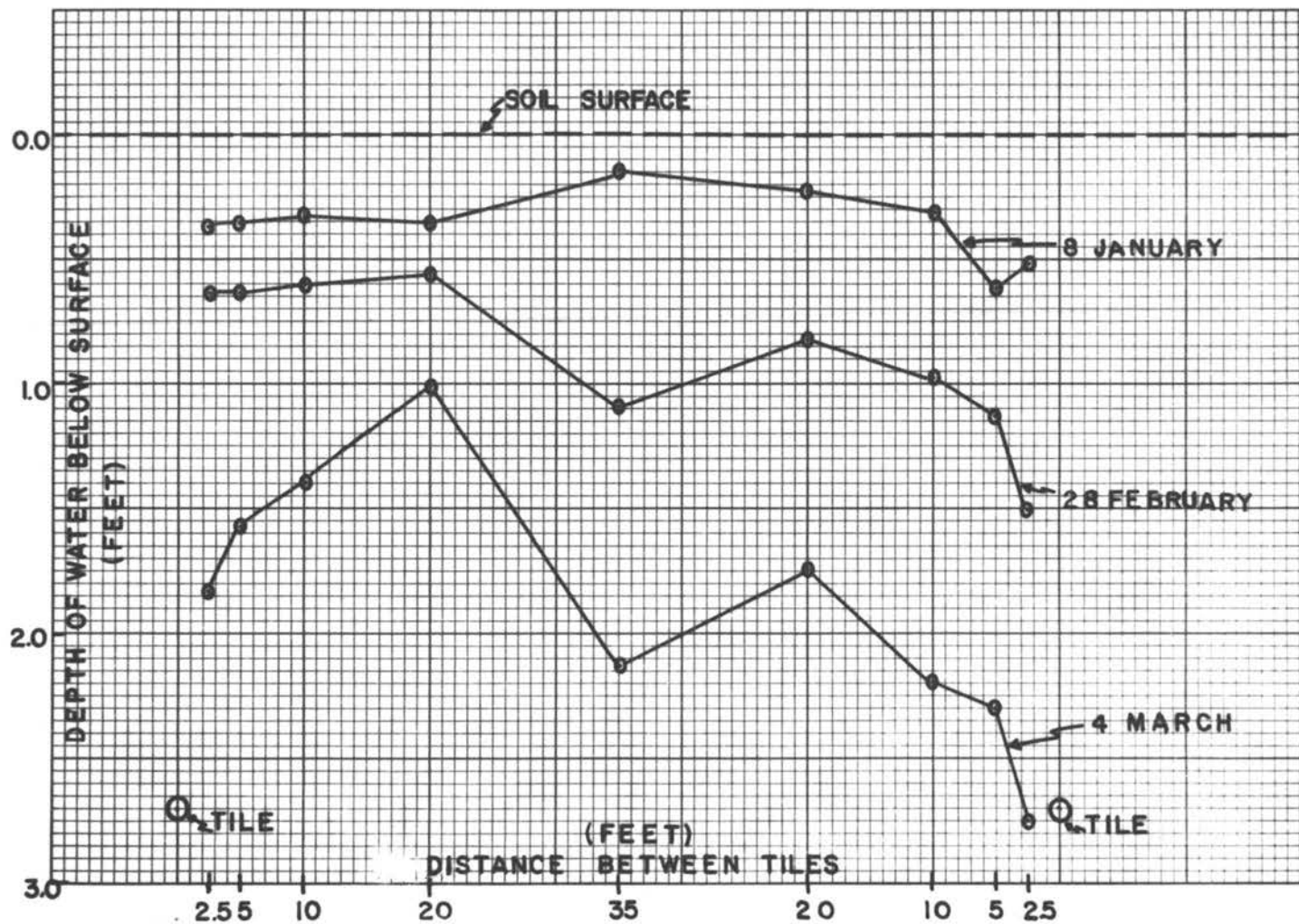


Figure 16. The depth of the water table in Dayton soil between parallel tile lines on three dates at the Hanson field.

ditches as mentioned in the review of literature on page 9 of this thesis.

Kowalski field. The water table at the Kowalski field was high with an average for all measurements for the season on the tiled area of 0.69 feet below the surface. The average for the non-tiled area was 0.25 feet below the surface. Figure 17 shows the measurements of the water table for the season in this Dayton soil. At distances greater than 10 feet from the tile the depth was never over $1\frac{1}{2}$ feet to the water table. The three lines show the effects that the presence of tiles have upon the level of the water table at distances of $2\frac{1}{2}$, 10, and 40 feet. There was very little difference between the level of the water table 10 feet from the tile and the water table 40 feet from the tile. The graph in Figure 18 shows the level of the water table between the two tile laterals on three different dates. The water table level of January 29 was the highest water table measured in this field during the season and was plotted for this reason. February 15 was selected for plotting because it represents the shape and depth of the water table when it was near the lowest measured. April 6 was the last day measurements were made. The draw-down

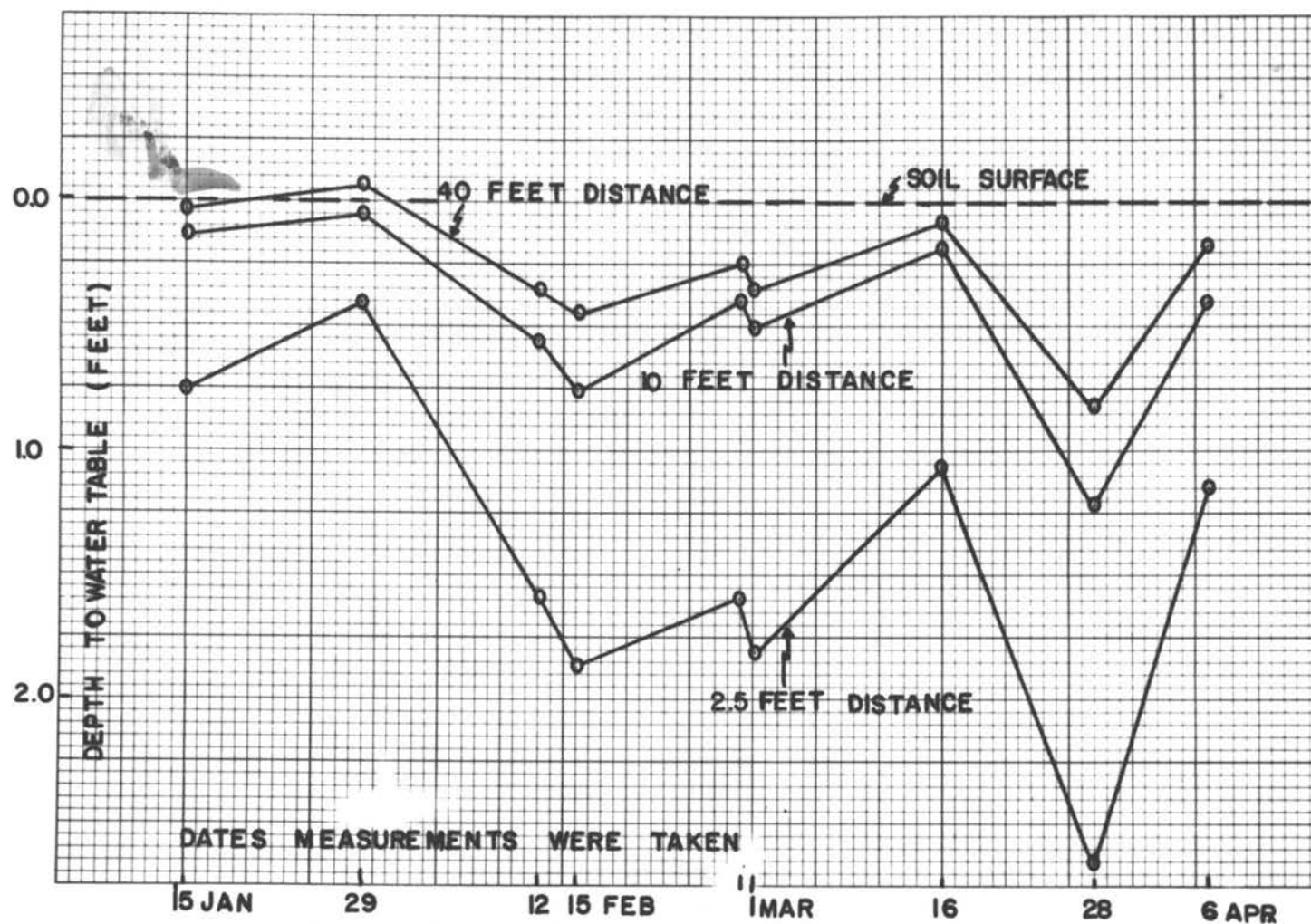


Figure 17. Water table status in Dayton soil for the Kowalski field at three distances from a tile line.

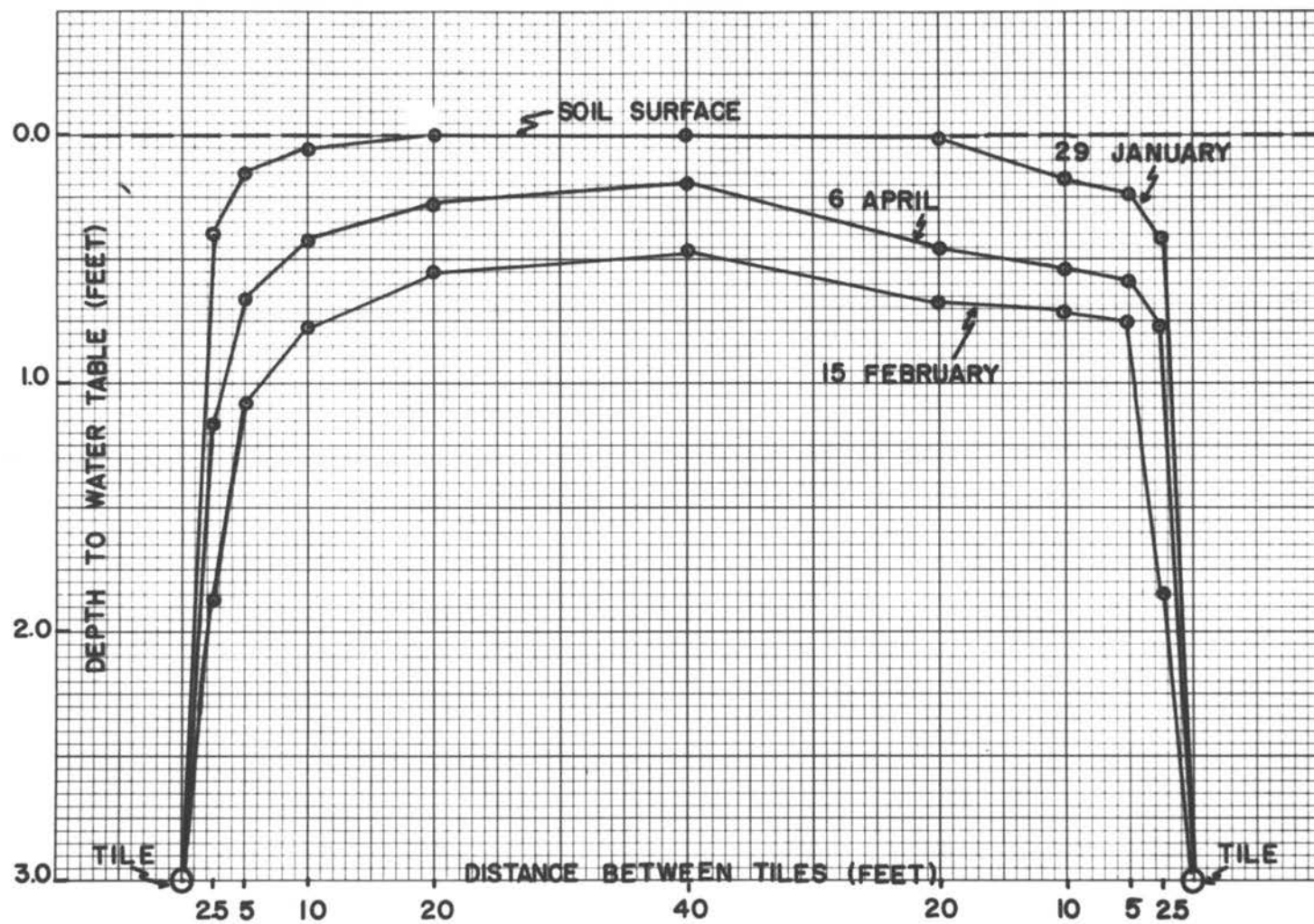


Figure 18. The depth of the water table in Dayton soil for the Kowlski field between parallel tile lines on three dates.

pattern for the east tile was almost identical with the draw-down pattern for the west lateral (right hand corner of Figure 18).

WATER CONDUCTIVITY MEASUREMENTS

Water conductivities were measured for each soil and their values are shown in the following tables. These tables show which method of measurement was employed with each sample. The values obtained using the piezometer method are marked with an asterisk. All other values were obtained using the undisturbed-core method. All values are in inches per hour.

Davis field. The water conductivity of Willamette soil at the Davis field was highest in the A-3 horizon (with 12.92 and 22.03* averages, shown in Table II) and about the same values in the A-p horizon (3.78) and B-1 horizon (4.07 and 6.06*). The variation was greatest in the B-1 horizon. Generally, higher values were obtained using the piezometer method because the measurements with the piezometer were conducted at non-tiled locations while the core method measurements were conducted at tiled locations.

The Amity soil had about the same water conductivities as the Willamette soil and were generally in the same order, but were slightly lower in each horizon.

Table II. Water conductivity values of soils in the Davis field.

SOIL	HORIZON	DEPTH	WATER CONDUCTIVITY, INCHES PER HOUR						Average
			Sample No.						
			1	2	3	4	5	6	
Willamette	A-p	3"	8.49	5.83	3.10	2.21	1.90	1.16	3.78
	A-3	17"	13.92	13.78	11.07				12.92
			35.19*	14.73*	15.18*				22.03*
Amity	B-1	25"	10.04	1.38	0.78				4.07
			15.42*	10.82*	1.46*	1.33*	1.29*		6.06*
	A-p	3"	5.00	3.17	2.15	1.15	1.23	1.05	
			0.92	0.71	0.66	0.56	0.37		1.54
Dayton	A-3	19"	14.68	12.04	11.56	10.56	9.52	8.02	11.06
	B-1	29"	7.29	3.47	3.08	1.54	1.46		3.42
	A-p	3"	2.15	1.89	0.27	0.11	0.03		0.89
		4½"	4.10*	5.55*	5.79*				5.15*
	A-2	8"	3.13	2.78	1.04	0.27	0.17	0.11	1.25
	B-1	17"	1.46	1.19	0.47	0.11	0.07		0.66
	B-2	24"	1.66	1.18	1.43	0.94	0.82	0.21	1.04

* Values were obtained using the Piezometer method. All other values were obtained with the undisturbed-core method.

The Dayton soil water conductivities ranged from 1.25 inches per hour in the A-2 horizon to 0.66 inches per hour in the B-1 horizon. These values are lower than those for the Amity or Willamette soil. The water conductivities measured by the piezometer method were again higher than those obtained by the core method.

Oregon Dairy Breeders Association field. The water conductivity of the Willamette soil at the Oregon Dairy Breeders Association field had the lowest conductivity in the B-1 horizon at a depth of 23 inches. These values are shown in Table III. The A-p and A-3 horizons had the highest water conductivities measured, which were 25.74 and 27.40 inches per hour.

In the Amity soil the lowest water conductivities were also in the B-1 horizon at a depth of 25 inches. The highest water conductivities were measured in the A-p horizon.

The water conductivities of the Dayton soil showed that the water conductivity of the B-1 horizon, in the center of the claypan, was the lowest. The highest values were found in the A-p horizon.

Table III. Water conductivity values for the three soils in the Oregon Dairy Breeders Association field

SOIL	HORIZON	DEPTH	WATER CONDUCTIVITY, INCHES PER HOUR						Averages
			Sample No.						
			1	2	3	4	5	6	
Willamette	A-p	3"	328.05	123.20	45.42	33.39	16.70	7.46	25.71 [#]
	A-3	17"	38.08	30.28	13.84				27.40
	B-1	23"	9.08	2.86	2.23				4.72
	B-1	33"	32.58	17.40	2.23				17.40
Amity	A-p	3"	8.31	7.21	6.15	1.90	1.83	1.39	4.47
	A-3	17"	4.91	1.43	1.27	0.77	0.70	0.59	1.61
	B-1	25"	1.21	0.26	0.30	0.30	0.30		0.30
	B-1	33"	10.43	3.48	2.42	1.98	1.83	0.66	3.47
Dayton	A-p	3"	12.04	6.77	6.15	1.42	1.39		5.55
	A-2	7"	1.90	1.86	1.35				1.70
	B-1	16"	0.22	0.16	0.09	0.07	0.10		0.13
	B-2	29"	0.80	0.73	0.51				0.68

Average does not include first two water conductivities.

Hanson and Kowalski fields. The water conductivities of the Dayton soils at the Hanson and Kowalski fields are shown in Tables IV and V. The highest conductivities were obtained from soil samples from the A horizons of both fields. The lowest measured water conductivity for the Kowalski field was in the B-2 horizon at a depth of 33 inches.

Many of the samples had water conductivities which were very difficult to measure and accurate values could not be obtained as the values for these core samples were observed to be less than 0.017 inches per hour. How much less than 0.017 inches per hour could not be determined with the apparatus used.

The values obtained using the piezometer method were lower than the values obtained using the core method, which is just the opposite from the results at the Davis field. This may be partly attributed to insufficient time of soaking the cores prior to measurement and to soil differences of the different test sites as explained earlier. Soil samples were taken when the soil was almost dry and considerable time, as much as one week, was required for the cores to expand.

Table IV. Water conductivity values obtained at the Hanson field.

SOIL	HORIZON	DEPTH	WATER CONDUCTIVITY, INCHES PER HOUR						
			Sample No.						
			1	2	3	4	5	6	Average
Dayton	A-p	3"	13.92 4.07*	4.66 3.46*	4.01 3.78*	0.47	0.33		4.68 3.77*
	A-2	10"	< 0.017	< 0.017	< 0.017				< 0.017
	B-1	15"	< 0.017	< 0.017					< 0.017
	B-2	30"	< 0.017	< 0.017					< 0.017

Table V. Water conductivity values obtained at the Kowalski field.

SOIL	HORIZON	DEPTH	WATER CONDUCTIVITY, INCHES PER HOUR						
			Sample No.						Average
			1	2	3	4	5	6	
Dayton	A-p	3"	47.52	35.22	0.84	0.81	0.40	0.35	12.21
			0.33	3.22*	1.43*				2.32*
	A-2	10"	1.24	1.12	0.51	0.51	0.44	<0.017	<0.76
			5.04*	1.49*					3.26*
	B-1	16"	2.93	2.90	1.35	0.51	0.18	0.09	1.33
	B-2	33"	0.71	0.59					0.63

* Values were obtained using the piezometer method. All other values were undisturbed-core values.

DISCUSSION

The rainfall during the winter months was sufficient to cause a water table to form at all locations where pipes were installed. Water tables occurred within the depth of measurement at most of the sites following the heavy rain on December 11. At most of the locations the water table was above the 4-foot depth from December 11 until readings ceased in April. The four day period in February and March without rain, and following a period of heavy rainfall gave an opportunity to measure the rate of draw-down in tiled and untiled areas. During the rest of the time the rainfall distribution was such that draw-down measurements were not possible with the nearly continuous additions of water from rain. It was impossible to follow the water table levels further into the spring since the installations interfered with farming operations.

The results from non-tiled areas may not be comparable to the results from nearby tiled areas. In some cases the water table was lower in the non-tiled area than the tiled area, which suggests that the poorer drained areas of the fields were tiled and the better drained soil was left untiled.

Another form of bias in the data is in the average depth of the water table over an extended period of time. Readings were usually made more frequently just after a rain when the water table was higher, rather than when the water table was low. This irregularity of readings tends to make the averages higher than the true average.

The matter of degree of drainage required in the Willamette Valley for the growth of crops has not been established. This would involve comprehensive experiments with various crops and perhaps fertility practices, with an economic analysis of the results. In the Midwest states a "rule of thumb" is often used which states that the water table should be lowered one foot per day. Conditions are different in the Willamette Valley from those in the Midwest since the period of high water tables is during a different season. In the Valley the water table is high in the winter when plant growth is small, while in the Midwest the rainfall during the summer is sufficient to cause a high water table in poorly drained soils. During this time plants are growing rapidly and a brief submergence of the plant roots may be quite detrimental to the crop.

The degree of drainage obtained in the three soils studied by tile spacings of around 70 feet was as expected; Willamette, the best drained; Amity, the next best; and

Dayton, the poorest. The measured water conductivities indicate the same order. It is obvious from the figures presented earlier that very little improved drainage by the use of tiles is obtained in Dayton soil at the four locations. The water table is nearly level between tile lines and to improve the draw-down of the water table significantly, tile lines would need to have a spacing of approximately 20 feet. It is doubtful if such a spacing would be economically feasible in such soils. Perhaps a combination of tile drains and bedding would be more feasible. However, no experimental results are available on this aspect.

The water conducting properties of Amity soils are better than those of the Dayton soils at the two locations. The results show that spacings of 76 feet in Amity soil had very little effect on the water table mid-way between tile lines, at the Davis field. A spacing of 40 feet is indicated as being necessary to have a significant effect upon the water table mid-way between the lines. At the Oregon Dairy Breeders Association field, a spacing of 90 feet was adequate. This may be attributed to the numerous worm holes and wood shavings present in the soil, as discussed previously.

At both locations, the Willamette soil is adequately drained with the present spacings, where the distances are 76 and 90 feet. It is felt that in soil with water conductivities like the Davis field, more effective drainage could be obtained if the spacing were reduced to 60 feet.

The results show the importance of taking into consideration the soil series present when designing a drainage system. Also, there is a range of variability within a given soil series.

SUMMARY AND CONCLUSION

A study was performed during the winter of 1956-57 to evaluate the water table status at certain locations near Corvallis, Oregon. At two of the locations tile systems had been installed in Willamette, Amity, and Dayton soils. At the other two locations tile systems had been installed in Dayton soil. In addition the water conductivities of certain soil horizons were measured at each location.

To measure the water table level perforated pipes were installed in augered holes to a depth of four feet. These pipes were located at distances from the tile lines of 2½, 5, 10, 20 feet and the midpoint distance, which varied from 35 to 45 feet. Measurements were made from December 12 to April 8 at irregular intervals.

Water conductivity measurements were made by the piezometer method and the undisturbed-core method.

The following conclusions were drawn from the study:

1. The Willamette, Amity, and Dayton soils vary greatly in water conducting properties as one would expect by examining their morphological characteristics. The Willamette soil has been shown to be the best drained, followed by Amity and then Dayton, the poorest drained of the three.

2. Although drainage requirements have not been established in the Willamette Valley, the Willamette soils studied appeared to be adequately drained at spacings of 76 and 90 feet. For Amity soils the spacings would need to be 40 feet to get significant effect on the water table midway between tile lines. For Dayton, the spacing required appears to be not more than 20 feet.

3. The water conductivity measurements for Dayton soil show that almost all of the water movement to tiles occurs through the surface 12 inches of soil.

4. In certain cases the backfill material had low water conducting properties which resulted in the ponding of water immediately over the tile lines. The nature of the backfill should be given careful consideration when installing tile systems.

5. The results indicate the need for taking into consideration the soil series present when designing a drainage system. It is doubtful whether some soils can be economically drained by tiles alone.

6. The study must be considered preliminary and emphasizes the need for further research on the drainage problems of the Willamette Valley.

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