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INFILTRATION OF WATER INTO MARSHALL SOILS AS RELATED TO SELECTED HYDROLOGIC CHARACTERISTICS

by

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INTRODUCTION

Water resources have received increased attention during recent years because of the continuously expanding demand upon existing supplies. The demand for water is increasing for human consumption, for industrial operations and for agricultural purposes. Stream and lake pollution, sedimentation of reservoirs and other similar problems are becoming more acute.

The problem of diminishing supplies of high quality water is related in part to runoff of surface water during rainstorms. Large quantities of water falling as rain and snow appear as surface runoff. This water carries much suspended and dissolved material which eventually finds its way into streams and reservoirs. In addition, large quantities of soil may be lost by erosion resulting in reduced soil productivity.

Various kinds of structures have been built and used in conjunction with watersheds to help contain runoff water and thus reduce some of the problems. Engineers are continually designing new water control structures for highways, for flood control and erosion control, and for other similar uses. Without adequate predictive information on the amounts of runoff to anticipate from various rainfall intensities and durations, such designs must be somewhat of a guess. Since surface runoff is universely related to water infiltration rate, estimates of infiltration could be useful in development of water control projects and water storage systems.

Several methods have been developed for measuring as well as for estimating the rate of water infiltration into soils. Many of the existing techniques are laborious and time consuming. A means of quickly estimating water infiltration into soils with a reasonable degree of accuracy is needed.

Numerous factors either directly or indirectly affect infiltration. A knowledge of the influence these factors have on infiltration characteristics of a soil would be a useful tool in estimating water infiltration rate. While some of these factors relate to elements other than the soil, the characteristics of the soil primarily determine the amounts of water that will infiltrate a soil in a specified length of time.

Soils vary considerably from one series to another and to a lesser extent within a series. It is therefore difficult to estimate infiltration without a precise knowledge of the soil in question and the relationship of its properties to water infiltration.

The present study is a part of a larger program investigating water infiltration and related soil characteristics as a possible tool in the development of water conservation programs. The objectives of the present study are:

1. to characterize the soils of a given soil series from various locations with respect to some physical and hydrologic factors relating to infiltration;
2. to determine the feasibility of estimating the infiltration rate of the soil at different initial soil moisture contents and of selecting the resulting infiltration curves to represent different portions of the year based on the probable soil moisture content for that time;
3. to determine the feasibility of using the probability of receiving rainfall exceeding the infiltration rate of the soil for the various periods of the year; and

4. to delineate some of the problems involved in using the infiltration estimation procedure to determine soil infiltration characteristics.

The Marshall soil series was selected for this study. The soils in the Marshall series have developed in loess parent material and therefore are likely to be less variable in their physical characteristics than soils developed in other kinds of parent materials.

REVIEW OF LITERATURE

Terms used to describe water movement into and through the soil have varied through the years. Horton (1933) defined infiltration capacity as "the maximum rate at which a given soil surface, when in a given condition, can absorb rain as it falls." Richards (1952) equated Horton's infiltration capacity with the presently used infiltration rate. However, he further defined infiltration rate as "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." Quantitatively he says it is the volume of water passing into the soil per unit of area per unit of time and has the dimensions of velocity.

Factors Affecting Infiltration

Arend and Horton (1943) state that there is a definite water infiltration rate for soil when rain begins. This infiltration rate value is determined wholly by antecedant conditions such as soil cover, soil structure, initial surface condition, and soil moisture content.

Fernandez and Wilkinson (1965) conclude that the problem of infiltration involves three highly dynamic and variable phases:

1. storm characteristics such ~~as~~ energy, intensity, and duration of rainfall;
2. vegetation present above, at, and beneath the soil surface; and
3. the state of the soil, especially the physical properties of the surface.

Using a sprinkling infiltrometer in the field they found that the mean weight-diameter of water stable aggregates was closely related with the wetrun equilibrium infiltration rate. Surface sealing resulting from the break-down of aggregates appeared to be the reason for decreased infiltration under corn as compared to crested wheatgrass.

Surface crusting

The role of soil surface sealing or crust formation in influencing infiltration has received much attention. Both erosion and surface sealing start with raindrop impact. When raindrops strike the soil they break down the clods and aggregates at the surface resulting in development of a single-grain structure. The soil particles are carried into the surface water and the soil surface becomes puddled. Both of these actions reduce infiltration.

McIntyre (1958b) proposed a mechanism for crust formation. He indicates that wet soil aggregates are broken down by raindrop impact and sometimes by slaking. If dispersion occurs the fine material is then washed into the surface pores and thus reduces their volume. After break-down of the surface soil aggregates, raindrop impact causes compaction of the surface producing a seal about 0.1 mm. thick. This prevents further washing-in unless the seal is removed by turbulence of the water passing over it. Washing-in may not occur, however, in soils having a stable structure where the amount of dispersion is low.

Lemos and Lutz (1957) reported that natural soil crusts had a much greater bulk density, a higher percentage of particles less than 0.10 mm. in diameter, and a lower degree of aggregation than the underlying soil.

McIntyre (1958a) found that the crust was a dense layer 0.1 mm. thick which contained no visible pores under high microscopic magnification. Below this very thin seal, porosity was considerably reduced compared to unaffected soil below. This washed-in zone occurred to a depth of about 1.5 to 3.0 mm.

Long (1964) in studies using Marshall silty clay loam from second-year corn reported a primary seal of up to 0.01 inches (0.254 mm.) thick and a secondary seal immediately below the primary extending from about 0.125 (3.17 mm.) to 0.25 inches (6.34 mm.) deep. He states that at high rainfall intensities the rainfall energy may be transmitted through the seal causing greater breakdown of aggregates below the seal.

McIntyre (1958a) also studied crust permeability (hydraulic conductivity). He calculated the permeability of crusts from experimental data using the Darcy equation: $Q = KA(h_1 - h_2)/L$, where Q is the quantity of water flow, A is the cross sectional area of the soil sample, $(h_1 - h_2)/L$ is the hydraulic gradient, and K is permeability (hydraulic conductivity). The average permeability for the underlying soils was about 1×10^{-3} cm. per sec. for cultivated soils and about 4×10^{-3} cm. per sec. for virgin soils. The permeability for the 0.1 mm. thick seal was 5×10^{-7} cm. per sec. whereas for the washed-in area it was 5×10^{-6} cm. per sec. This indicates a decrease in permeability for the seal of about 2×10^{5} times and it was about 2×10^{4} times less for the washed-in area.

Sor and Bertrand (1962) found that the greatest dispersion and compaction of soil by raindrop impact occurred in the top 1 mm. of soil. They also found that water permeability was changed only in the upper 1.5 cm. of soil by a rainfall intensity of 1.6 inches (4.05 cm.) per hour but that greater intensities also affected the second 1.5 cm. layer. There was some compaction to a depth of 3.0 cm. after 30 minutes of rainfall.

In infiltration tests on Marshall silt loam, Duley (1940) reported the formation of a crust which is accompanied by a rapid reduction in infiltration rate. He attributes formation of the crust in part to the beating effect of raindrops and in part to the sorting action of water as it flows over the soil surface. The fine particles are fitted around the larger ones to form a relatively non-pervious seal. When the crust was removed the infiltration rate was restored to the level of undamaged soil.

Moldenhauer and Long (1964) report that a soil which has been sealed by raindrop impact and then dried will quickly seal again when rainfall begins. Equilibrium infiltration is rapidly reached unless the seal is broken between rains.

Schmidt, Shrader, and Moldenhauer (1964) found a very rapid decrease in infiltration during the first 15 minutes of rainfall followed by a near constant rate of infiltration of about 0.18 inch (0.46 cm.) per hour after 30 minutes. The initial decrease was attributed to rapid surface sealing due to disintegration of the soil structure at the surface, surface compaction, and clogging of surface pores. The initial rate was greater than 2.5 inches (6.3 cm.) per hour which was the rate of rainfall application.

<u>Rainfall intensity</u>

Ellison (1945) relates that changes in drop velocity, in drop size, and in rainfall intensity all affect infiltration and the effect is greatest for changes in drop velocity and least for rainfall intensity.

He also found that as soil-splash increased, infiltration capacity decreased.

Rubin, Steinhardt, and Reiniger (1964) concluded from a wide range of rainfall intensities on sand and on 0.5 to 1.5 mm. clay aggregates that the higher the intensity applied, the larger is the wetting front advance rate.

Neal (1938), working in the laboratory, found that infiltrations were not affected by slopes over the range from 0 to 16 percent, nor by rainfall intensities over the range from 0.9 to 4.0 inches (2.28 to 10.2 cm.) per hour. Infiltration did, however, vary inversely with the initial soil moisture content.

Moldenhauer and Long (1964) working with a rainfall simulator on Marshall silty clay loam found a rapid decrease in infiltration rate as soon as runoff began and the equilibrium infiltration rate was reached shortly thereafter. They concluded that their "soil loss and infiltration rate curves with time are typical of rate curves for similar soils studied by Schmidt *et al.* (1964), Adams, *et al.* (1958), and others."

The order of infiltration rates for different textures of soil used by Moldenhauer and Long was fine sand, loam, silt, silty clay, and silty clay loam in descending order. Their results show that infiltration rate was essentially constant with different intensity on all soils except fine sand. They attribute this to a certain amount of kinetic energy being required as rainfall to effect surface sealing and to initiate runoff.

On pasture, wheat stubble, and corn stubble, Arend and Horton (1943) concluded that rainfall intensities in the range from 3 to 6 inches (7.6 to 15.2 cm.) per hour had no effect on the constant infiltration rate with change in intensity. Unless prevented either by vegetal cover or excessive erosion, the time required for the infiltration rate to become reasonably constant varies in an inverse ratio to the rain intensity.

Particle size and soil structure

Miller and Gardner (1962) investigated the effect of stratified layers on infiltration. They injected different sizes of materials into the soil columns in the laboratory. It was found that the infiltration rate vs. time curve changes drastically when the wetting front reaches the dissimilar layer. They state that "infiltrating water moves into and through the soil at a rate dependent upon the nature of the transmitting pores, their water content, and the potential gradients existing and developed as flow takes place." Pore size affects water movement in at least two ways. If pores are too large to contain water at a given suction, they do not allow liquid water movements through them. As pore size decreases the resistance to water movement through these pores increases rapidly. These factors have a marked effect on the movement of a wetting front when it comes into contact with a material in which the pores are either larger or smaller than those in which it has been moving. Their work also indicated that distance from the water source to the wetting front is involved.

The effect of texture on soil water movement into balls of soil on nursery trees when planted in a soil was investigated by Grover, Cahoon, and Hotchkiss (1964). They found that water penetration rate was determined to a large extent by texture and structure. The rate of wetting was greater for a loamy sand than for a loam. A clay soil that was used however, had a stable crumb structure and this overshadowed the effect of texture. The rate of wetting in the clay was greater than in either of the other two textures.

Texture and structure both determine the relative pore size distribution in a given soil. Aljibury and Evans (1965) studying air permeability of a soil by varying moisture content found that flow through a soil is controlled largely by or results from the large pores. They state, "the usual large reduction in capillary conductivity with increase in soil water suction shows this very plainly." Research conducted by them indicates that pores contributing most to flow, drain at suctions of less than 100 cm. of water. Ellison (1945) found that differences in infiltration capacity[1] are related to differences in aggregation and clay content. Soils having the highest percentages of small aggregates and clay were found to have the lowest infiltration capacities. In studying surface flow velocities he found that velocities from 0 to 6 feet per second had no effect on infiltration rates. If the flow caused a shifting of particles of soil, infiltration capacities would likely be changed and infiltration rates would also change. These changes would probably result from changes in porosity.

Rose (1962) found that soil with a good structural condition gave higher infiltration for both disturbed and undisturbed soil samples than did a soil having poorer structure.

Bertrand and Sor (1962) using a field rainfall infiltrometer found

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[1]Infiltration capacity is defined by Ellison as the maximum rate... at which water will pass through the least permeable plane of the surface of the soil.

that a rainfall intensity of 1.6 inches (4.05 cm.) per hour decreased aggregate stability, specific surface, clay, and organic matter contents of the surface 0 to 1.5 cm. layer less than intensities of 2.8 and 4.0 inches (7.1 and 10.2 cm.) per hour. The higher intensities also produced considerable changes in the properties of the 1.5 to 3.0 cm. layer of soil. Fine-textured soils were affected less by rainfall energy than were coarser textured soils. A possible reason may be that soil particles in coarse textured soils are not bound into aggregates and therefore are more easily eroded.

Capillary intake rate as an index of soil structure was investigated by Swartzendruber, DeBoodt, and Kirkham (1954). They found that the kind of organic matter and the organic matter content of the soil affected capillary intake. The significant factor is believed to be the action of organic matter on the wetting angle of the soil.

Rose (1961) found that both soil type and the size of structural aggregates had a considerable effect on the detachment of soil particles caused by rainfall. He further found the mass of soil detached increased gradually with the length of cultivation period.

Water infiltration rates were used by Williams and Doneen (1960) as a measure of the effects of leguminous and gramineous green manure crops, and corn and cotton residues on soil structure. They found that infiltration was increased by the addition of certain gramineous green manures and crop residues on medium textured soils. Legumes did not influence infiltration, whereas corn residues and to a lesser extent, cotton residues were effective in improving infiltration. Sandy loam soils did not respond to residue additions because they have a predominantly single-grain condition, thus structure is not influenced.

Sukharev and Sukhareva (1958) concluded that the amount and rate of infiltration by soils of good structure are affected by agricultural practices, tillage, prominence of structure, and looseness of soil. They noted that pasturing and excessive plowing reduce infiltration because they cause puddling and decrease permeability. They also concluded that soil moisture influences infiltration.

Using a mowed Steppe as unity, for water intake in 150 minutes, the relative intake rates range from 0.53 for a continuously-tilled field in fallow to 2.94 for a Steppe not mowed since 1882. The actual intake rates at the end of 150 minutes range from 0.8 mm. per minute for the continuously-tilled fallow field through 2.2 mm. per minute for the mowed Stepped to 6.3 mm. per minute for the Steppe not mowed since 1882.

Ligon and Johnson (1959) found that, in general, under a given set of conditions on Fayette silt loam there was an increase in infiltration rate with time going from continuous corn to corn in rotation to grain and finally to meadow.

Dortignac and Love (1960) using a sprinkling infiltrometer found that use of Arizona fescue resulted in an infiltration rate of 3.05 inches (7.7 cm.) per hour, use of Mountain muhly resulted in an infiltration rate of 1.55 inches (3.93 cm.) per hour, and use of Blue grama resulted in an infiltration rate of 1.29 inches (3.27 cm.) per hour. They state that infiltration rates were associated with vegetation type because the organic materials and physical soil properties varied with vegetation type. Pine litter had the most porous surface soil conditions and the greatest quantity of dead organic material. Litter and porosity of the surface soil were the two measured factors most highly and consistently correlated with infiltration rates.

Dortignac and Love also found that infiltration rates increased 1.31 inches (3.32 cm.) per hour in grassland and 1.01 inches (2.56 cm.) per hour in pinegrass after 14 years of protection from grazing.

Antecedent moisture

Jamison and Thornton (1959) state that "soil moisture intake rates are affected far more by antecedent soil moisture than by soil cover or soil management practices." They found, by use of hydrograph analysis, that intake rates of Shelby-Grundy soils varied from more than 2.0 inches (5.1 cm.) per hour for the first few minutes of rainfall on a very dry soil to less than 0.01 inches (0.025 cm.) per hour on very wet soil.

Dortignac and Love (1960) indicated that the infiltration rate for wet surface-soil conditions was lower than for dry soil conditions.

Fernandez and Wilkinson (1965) found that soil under corn absorbed more water than soil under wheatgrass during the first 30 minutes of infiltration when antecedent moisture was below about 25 percent. At high antecedent soil moisture contents, however, soil under wheatgrass absorbed more water than soil under corn. During the second 30 minutes of infiltration, and even more so during the third 30 minutes, wheatgrass cover resulted in more infiltration than corn cover. Even during the third 30 minute period of infiltration antecedent moisture had an effect on infiltration. They conclude that the crop may have an influence on aggregate stability. The equilibrium infiltration rate under wheatgrass was about two times that under two years of corn.

Bodman and Coleman (1944) using sectioned tubes of 5 mm. height each observed that no water flowed out between the sections of tube which indicated that all the pressure potentials within the soil columns were less than the atmospheric pressure. Therefore, when hydrostatic pressures in the field are low at the surface of the soil it would appear that unless large pores and other large holes opened to the surface of the soil, water will not move into them from the soil mass during infiltration. They will act as nonconductors unless water around them is under positive pressure.

Bodman and Colman conclude that a decrease in infiltration rate with time is not because of permeability changes in the upper soil layer, but rather to a decrease in moisture potential gradient within the transmission zone of the soil. The average gradient within this zone apparently approaches, as a limit, that of the gravitational potential. They suggest that the moisture potential conditions within the infiltration zone represent the primary factors influencing changes in infiltration rates and that the other factors operate as modifying influences.

Musgrave and Free (1936) made infiltration runs on Marshall silt loam (silty clay loam) soils containing average moisture contents of 19.6 percent initially and 33.2 percent at the start of the wet run. At the end of 5.5 hours, the difference between the total amounts of infiltration for the two runs is about 2.20 surface inches (5.59 cm.) of water. The difference of 13.6 percent moisture at the start of the two runs is equivalent to approximately 2.50 inches (6.35 cm.) of surface water. Musgrave and Free conclude that porosity is one of the most dominant factors affecting infiltration. The relatively high rates at the start of the initial runs are largely due to a greater volume of pore space being available for infiltration at that time. The actual infiltration rate varied from 8.16 inches (20.6 cm.) per hour at the end of five minutes to 0.31 inches (.74 cm.) per hour at the end of five hours. In a Marshall soil the reduction in infiltration rate apparently became appreciable at or slightly above a soil moisture content of 30 percent. Below 30 percent soil moisture content apparently had little effect on infiltration rate at the start of infiltration.

In summary, a great deal of research has been conducted to elucidate the factors affecting infiltration of water into soil. It appears from recent work that antecedent soil moisture is a major factor and can be used to calculate or predict infiltration rate. Other factors may serve to modify the effect of antecedent moisture on infiltration.

Methods of Determining Infiltration

Determination of water infiltration into soils has been approached from many angles. Some of these include methods employing field measurement, laboratory measurement, hydrograph analysis, and more recently estimates based on unsaturated flow theory.

Green (1962) discusses use of sprinkling infiltrometers, ring infiltrometers, hydrograph analysis, and natural rainfall analysis on runoff plots and small watersheds.

Methods employing natural rainfall require collection of data over a long period of time because of the low number of storms producing sufficient rainfall for adequate runoff analysis.

Sprinkling infiltrometers have been used quite extensively in infiltration measurements. Application of water by this method more nearly approximates natural rainfall and the intensity and duration of rainfall can be controlled.

Arend and Horton (1943) emphasize that rain intensities used in infiltrometer experiments often equal or exceed throughout the experiment the highest rain intensities encountered in nature in the same locality. They concluded that use of high, constant rain intensities tends to produce abnormally high apparent initial infiltration values, a rapid reduction of infiltration rate during the initial phase of the experiment, and the development of surging runoff. In some instances the formation of marked initial runoff surge was similar to that produced on natural areas only in cloudburst storms.

Bertoni, Larson, and Shrader (1958) using the hydrograph analysis technique of Sharp and Holton (1940) found that infiltration rates on Marshall soil varied considerably between storms and attributed this to variation in infiltration with season of the year. However, they also had variation between plots and indicated the method of estimation was not precise. In spite of the variation encountered, Bertoni, *et al.* felt that the results obtained were satisfactory. Kidder and Holton (1943) had previously used the same method and believed it merited further testing. Jamison and Thorton (1959) used hydrograph analysis to estimate water intake rates of Shelby-Grundy soils.

Parr and Bertrand (1960) have published a review of methods used in measuring and estimating water infiltration into soil.

With the development of unsaturated flow theory, interest in the relationship between soil moisture and infiltration has increased. Green (1962) reviewed the literature on the development and application of moisture diffusion theory. Parr and Bertrand (1960) published a review of theoretical means of estimating or calculating infiltration.

Jackson, van Bavel, and Reginato (1963) reported that Butijn and Wesseling (1959) replicated moisture outflow measurements on several soil cores. Using their outflow data, Gardner's method (1956), and a method utilizing initial outflow assuming a semi-infinite sample they calculated capillary conductivity values. Their data showed 100- to 1000- fold variations between replicates. Jackson, et al. think the assumption of constant diffusivity is the weak point in the outflow method. Sufficiently small increments are necessary to make the assumption valid, and from an experimental point of view this doesn't seem practical to them. They too were unable to satisfactorily reproduce capillary conductivity values on replicate samples.

Using the method of transient outflow of Gardner (1956) and modified by Kunze and Kirkham (1962), Amemiya (1965) found an increase in moisture retention with increasing aggregate size in a Nicollet silt loam. This was attributed to differences in relative pore size distribution between and within aggregates at low moisture suction. He concluded that soil capillary conductivity appears to be a function of moisture content and independent of aggregate size so long as moisture-suction relationships are relatively unaffected by aggregate size. It can be a function of size only if size affects the moisture-suction relationship of the soil.

Gupta and Staple (1964) compared laboratory infiltration rates with results predicted by the iterative procedure of Philip (1957) and with results estimated by an explicit finite difference method. They found that while Philip's method predicted the shape of the drier portion of the moisture profile satisfactorily, it did not accurately predict the moisture profile under conditions near saturation. If the high conductivities in the saturated zone near the surface were taken into account the finite difference method provided satisfactory estimates of the shape and depth of the moisture profile.

The estimation procedures used by Gupta and Staple required diffusivity and conductivity coefficients for the entire range of soil moisture contents from air-dry to saturation. They found that it was more convenient to measure diffusivity at intermediate and low moisture contents and to measure conductivity coefficients at high moisture contents. Combining the two procedures made it possible to obtain diffusivity and conductivity coefficients for the necessary range of moisture contents.

Gupta and Staple found about seven percent occluded air at saturation in their soil. The infiltration rate was determined by applying water to cylinders of surface soil under a constant hydrostatic pressure of 0.4 cm., then sectioning the soil core to obtain the moisture content with depth at a given time.

The affect of soil water content on infiltration is associated with variations in the diffusivity-water content relations according to Hanks and Bowers (1963). They report that conductivity for most soils is commonly 10^3 to 10^4 times greater at saturation than at water contents found at initiation of infiltration. They hypothesized that careful measurements of conductivity and pressure head at water contents near saturation would be needed to estimate infiltration. At lower water contents commonly found at the start of infiltration the measurements need not be so precise. The reason is that changes in diffusivity-water content relations near saturation have a large influence on infiltration but progressively less influence as moisture contents decrease.

Hanks and Gardner (1965) used the one dimensional flow equation to estimate evaporation losses. They found that even with evaporation estimates, evaporation was markedly influenced on the wet end of the scale with relatively small variations in the diffusivity-water content relations. On the dry end of the scale there was no significant effect on estimated evaporation.

Green (1962) and Green, Hanks, and Larson (1964) used the numerical procedure of Hanks and Bowers (1962) to solve the moisture flow equation for infiltration into soils. They found that in general the calculated and the field-measured infiltration rates compare quite well. Green, *et al.* (1964) conclude from their study that moisture flow theory may be used, at least in part, to provide reasonable estimates of water infiltration into soils.

Soil Moisture Estimation

Shaw (1963) developed an empirical water balance method to estimate the available soil moisture under corn and Dale and Hartley (1963) programmed the procedure for computer analysis. By use of the procedure it is possible to estimate the moisture content of a soil in 15-cm. increments to a depth of 1.5 m. An estimate of the soil moisture profile at the beginning of the cropping season, evaporation estimates using open pan evaporation as a base, and rainfall records are necessary for the estimation procedure. The procedure adds rainfall to the existing soil moisture content and subtracts evaporation and transpiration losses making allowances for the stage of crop root development. If the rainfall is above a given intensity, an allowance is also made for runoff.

Dale and Shaw (1965) also developed a technique for determining the frequency of occurrence of soil moisture contents within given ranges of available water based on a given period of years. For half-month periods during the growing season they determined the number of years out of a given number of years record when the soil moisture was a specified amount. The number of years were then reported as the frequency of occurrence of soil moisture contents for each half-month period.

At present no attempt has been made to combine estimated infiltration, estimated soil moisture contents, and probable soil moisture contents in order to predict the probability of a specified infiltration rate at a given time during the growing season.

EXPERIMENTAL METHODS AND PROCEDURES

Field Procedures

The Marshall soils are well-drained Brunizems that occur on upland divides and gently rolling to strongly sloping topography. They are slightly acid to medium acid soils that are high in available potassium and low to medium in available phosphorus. If not eroded they are high in organic matter. The texture of the A1 horizon ranges from a heavy silt loam to a silty clay loam. The subsoil is moderately permeable to air, moisture, and roots. Marshall soils have a high available water holding capacity.[1]

Ten Marshall soil sites were selected at random throughout the Marshall Soil Association in Iowa in order to obtain a range in characteristics for the soil series.

Sites 1, 2, and 3 are corn yield test sites.[2] Site number 8 is the runoff plots of the Soil Conservation Experiment farm near Shenandoah, Iowa. The remaining six sites were selected at random throughout the Marshall Soil Association in areas not represented by the other four sites.

Detailed profile descriptions were made at each site from pits dug approximately 2 feet by 4 feet in area and deep enough to include several inches of the C horizon. Additional information recorded for each site

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[1]Most of the information for this general description was taken from the Soil Survey of Shelby County, Iowa. U.S. Dept. of Agriculture, Soil Conservation Service. Soil Survey Series 1956, No. 16. 1961.

[2]The corn yield study sites were established by the Agronomy Department, Iowa State University and are supervised by Dr. L. C. Dumenil.

included location, date, percent slope, slope aspect, shape of slope, degree of erosion, and vegetation on the area at the time of sampling.

Soil samples for various analyses were collected from each horizon at the individual sites. Samples for bulk density determinations were taken using a core sampling tool of the Uhland (1949) type. The soil above the respective sampling depth was carefully removed to minimize disturbance of the soil. The core sample was then taken from the approximate middle of the horizon, removed from the sampling tool, trimmed, and placed in a soil moisture can. Samples from subsequent depths were taken at slightly different locations within the same general area of the pit to avoid errors resulting from disturbance of the soil by the previous samplings.

Core samples were taken from the 0 to 15 cm. depth and from the 30 to 38 cm. depth for capillary conductivity determinations. These samples were taken at sites 1, 3, 8, and 8a in the same manner as were the bulk density samples. The capillary conductivity samples were left in the aluminum rings and put in plastic bags. A few drops of formaldehyde were added to retard organism growth. The bagged samples were then sealed, put in pint ice cream cartons and stored at 4 to 5°C.

Undisturbed soil cores were taken from each horizon for determination of moisture content at 0.1, 0.3, and 1.0 bar suctions. These cores were taken similarly to the bulk density and capillary conductivity cores except that 2.54 cm. thick cores were taken instead of 7.62 cm. thick cores. These samples were placed in plastic bags and formaldehyde was added. The bagged samples were put in pint ice cream cartons and stored at 4 to 5°C.

Approximately 0.5 to 1.5 kgm. bulk samples of soil were taken from each horizon and stored in paper bags. These samples were for various laboratory analyses for characterization of the Marshall soils.

Figure 1 shows the location of the Marshall Soil Association in Iowa and the sampling sites within the Marshall Soil Association. Included on the map are six additional site locations for which data were acquired from other research. These sites (sites 11 through 16) were located and described by soil scientists of the Soil Conservation Service and Iowa State University as a part of soil survey work in the area.[1]

Laboratory Procedures

The bulk soil samples were spread out to air dry. Clods and larger chunks of soil were broken into smaller sizes. When the samples were air dry the entire sample was ground to pass a 2 mm. sieve. A subsample of 75 to 100 grams of material was ground to pass a 100-mesh sieve for organic carbon determination. The 2 mm. samples were used for all other laboratory determinations.

Particle size distribution

Particle size distribution was determined by the method of Kilmer and Alexander (1949). Four separates were determined. Percent clay (less than 0.002 mm.) and percent fine silt (0.002 to 0.02 mm.) were determined by pipette analysis. Percent sand (0.046 to 2 mm.) was determined by passing the sample suspension through a 300-mesh sieve and determining the amount

[1]The data for sites 11 through 16 were acquired from the Soil Survey Laboratory, Lincoln, Nebraska and are given in the Appendix.

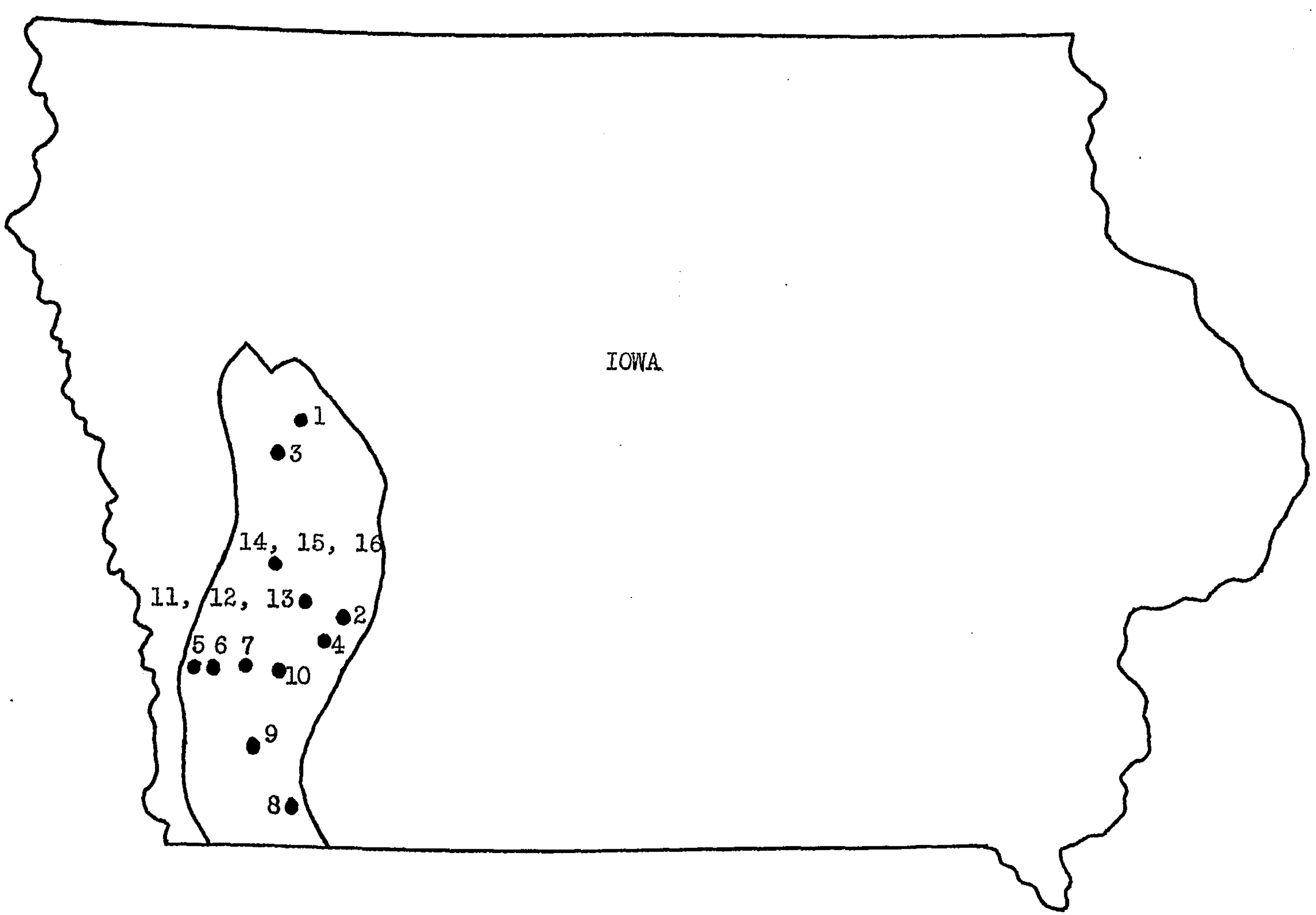

Figure 1. The location of the Marshall silty clay loam profiles in the Marshall Soil Association area

of sand remaining on the sieve. Percent coarse silt (0.02 to 0.046 mm.) was then found by difference.

Organic carbon

Organic carbon content was determined on all samples by the method of Mebius (1960) using soil passing a 100-mesh sieve. Duplicate samples were analyzed and the results were averaged. Variation between duplicate samples did not exceed 0.2 percent organic carbon for any of the samples and usually was less than 0.1 percent.

Moisture content-suction relationships

Moisture content-suction relationships at suctions of 0.1, 0.3, and 1.0 bar were determined by the porous plate method described by Richards (1954). Cores of undisturbed soil 2.54 cm. thick were used. Duplicate samples were run in different pressure units. The results of the duplicate samples were in good agreement. Because of an error in handling, samples at the 0.3 and 1.0 bar suctions for the Ap and A3 horizons of site 10 were inadvertently destroyed. No samples for the Ap horizon on plot number 8 at site 8 were taken for the 0.1, 0.3, and 1.0 bar suction. There are, therefore, no results for these observations.

Soil moisture content at suctions of 3, 5, and 15 bars were determined by the pressure membrane method of Richards (1947) on samples ground to pass a 2 mm. sieve. Duplicate determinations were made in different pressure units and the results averaged. If the duplicate samples for the 3-, 5-, and 15-bar suctions did not agree to within approximately 2 percent moisture, new determinations were made on a new set of soil from the same sample.

Bulk density

The bulk densities were determined by oven drying the soil samples at approximately 110°C until all the water was removed. This usually required about 48 hours. The volume of the soil sample was known from the volume of the ring used in taking the core sample and the bulk density was then calculated.

Capillary conductivity

Capillary conductivity measurements were determined by the outflow method of Gardner (1956) as modified by Kunze and Kirkham (1962).

The soil cores that were used for these measurements were left in the aluminum cylinders in which they were taken and put in individual volumetric pressure plate extractors in a constant temperature room at approximately 22°C. The porous plate was wet from the underside by filling the entire water outflow system. After the porous plates were completely saturated, water was added to the inside of the unit around the soil core so that the core was saturated from the bottom. The water was added in small amounts and allowed to move into the soil core before adding more water. Sufficient water was added to bring the cores to zero suction.

After the cores were wetted to zero suction, the excess water was drawn off. A few drops of formaldehyde were added to each soil core and to the burets receiving the outflow to restrict organism growth. The units were then sealed. Because of the impedance of the porous plate, the initial outflow was measured by equilibrating the cores at .025 bar of pressure. This required approximately one month.

Maximum water content used in calculating infiltration was estimated by extrapolating from .025 bar back to zero suction. At zero suction about 10 percent occluded air remained in the surface soil.

After equilibration at a given pressure step, the pressure was increased to a new level chosen so as to keep outflow less than about 10 ml. This was attained by approximately doubling the pressure of each subsequent step over the previous pressure setting.

Each time the pressure was increased the outflow measuring system was flushed and new water and a few drops of formaldehyde were added.

Outflow readings were taken frequently at the beginning of a run and less frequently with time. After the first day, readings were taken every one to two days to determine when outflow ceased.

The maximum pressure used was approximately 2 bars. When outflow ceased at this pressure, the cores were removed and weighed for a moisture determination. Bulk density was also determined on the cores for use in calculating total pore space and approximate total water content at zero suction. Total outflow at each pressure step was used to determine the water content corresponding to a given pressure. Green (1962) gives a more complete discussion of the procedure and the factors involved.

Infiltration Estimates

Based on the results of Green (1962) who showed that estimated infiltration by the Hanks and Bowers (1962) method agreed reasonably well with field measured infiltration on Ida silt loam, a study was initiated to determine if the numerical procedure (Hanks and Bowers) could also be applied to data from Marshall soils.

The description of the infiltration of water into soils subject to specific boundary conditions requires that Darcy's relation is valid for water flow through unsaturated soils. The following is an analogous expression of Darcy's relation for saturated flow;

$$V = -K \frac{\partial \phi}{\partial x} \tag{1}$$

where V is the volume flux ($cm.^3/cm.^2$ sec.), K is the capillary conductivity (cm./sec.), ϕ is the total potential (cm.), and x is the distance (cm.).

The movement of water and change in water contents within a given volume of soil must obey the principle of conservation of matter as described by the equation of continuity for flow in the x direction;

$$\frac{\partial \theta}{\partial t} = - \frac{\partial V}{\partial x} \tag{2}$$

where θ is the volumetric water content ($cm.^3/cm.^3$) and t is the time (sec.).

The combining of equations (1) and (2) results in the following partial differential equation;

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} K\left(\frac{\partial \phi}{\partial x}\right) \tag{3}$$

Because the capillary conductivity, K, is dependent on the water content and/or water potential, the solution of equation (3) is difficult owing to its non-linearity. For this reason a numerical approach has been used. With the present existence of high speed computers the numerical solution is enhanced.

In equation (3) the total hydraulic head, ϕ, is the sum of the water potential and the gravity potential where $\phi = \psi - x$ and x is measured positive downward, and ψ is the water pressure. Substituting $\phi = \psi - x$

in equation (3) yields:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(K \frac{\partial \psi}{\partial x} - K \frac{\partial x}{\partial x}\right) = \frac{\partial}{\partial x}\left(K \frac{\partial \psi}{\partial x} - K\right) = \frac{\partial}{\partial x}\left(K \frac{\partial \psi}{\partial x}\right) - \frac{\partial K}{\partial x} \quad (4)$$

It is difficult to measure ψ in the soil at suctions above 800 cm. of water, therefore because ψ and θ are related and assumed, for this study, to be single valued the following holds:

$$\frac{\partial \psi}{\partial x} = \frac{\partial \psi}{\partial \theta} \quad \frac{\partial \theta}{\partial x} \quad (5)$$

thus:

$$K \frac{\partial \psi}{\partial x} = K \frac{\partial \psi}{\partial \theta} \quad \frac{\partial \theta}{\partial x} = D \frac{\partial \theta}{\partial x} \quad (6)$$

where $D = K \frac{\partial \psi}{\partial \theta}$ is the diffusivity in cm.^{2}/sec. Substituting equation (6) into equation (4) gives:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} \quad D\left(\frac{\partial \theta}{\partial x}\right) - \frac{\partial K}{\partial x} \quad (7)$$

Equation (7) can be solved numerically by a finite difference method as shown using Figure 2; where i = distance and j = time.

Let C be the specific moisture capacity defined as:

$$C = \frac{\partial \theta}{\partial \psi} \quad (8)$$

Then

$$\frac{K}{C} = \frac{K}{\partial \theta / \partial \psi} = K \frac{\partial \psi}{\partial \theta} = D \text{ or } K = DC \quad (9)$$

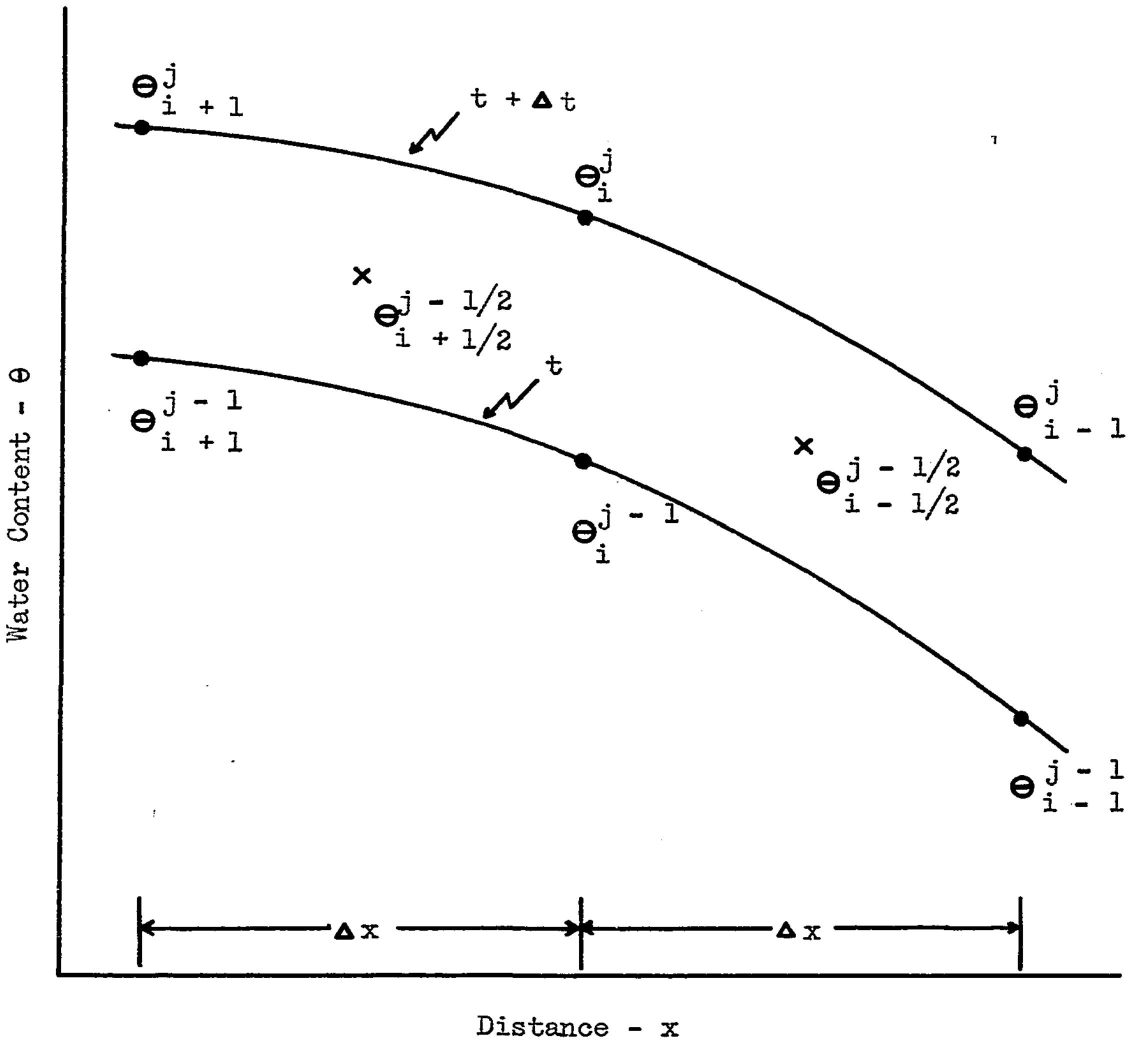

Figure 2. Diagram showing sections of two moisture distribution curves used to illustrate the derivation of the numerical form of the water flow equation

Returning to Darcy's Law and referring to Hanks and Bowers (1962):

$$V = -K\frac{\partial\phi}{\partial x} = -K\frac{\partial\psi}{\partial x} + K\frac{\partial x}{\partial x} = -D\frac{\partial\theta}{\partial x} + KG \tag{10}$$

where $\frac{\partial x}{\partial x}$ is the result of the gravity potential G.

In numerical form:

$$V_1 = -D^{j-1/2}_{i+1/2}\left(\frac{\theta^{j-1}_{i} - \theta^{j-1}_{i+1} + \theta^{j}_{i} - \theta^{j}_{i+1} + 2\,GC}{2\,\Delta x}\right) \tag{11}$$

and

$$V_2 = -D^{j-1/2}_{i-1/2}\left(\frac{\theta^{j-1}_{i-1} - \theta^{j-1}_{i} + \theta^{j}_{i-1} - \theta^{j}_{i} + 2GC}{2\,\Delta x}\right) \tag{12}$$

From equation (2)

$$\frac{\partial\theta}{\partial t} = -\frac{\partial V}{\partial x}$$

yields in numerical form:

$$\frac{\partial\theta}{\partial t} = \frac{\theta^{j}_{i} - \theta^{j-1}_{i}}{\Delta t}$$

and

$$-\frac{\partial V}{\partial x} = \frac{V_2 - V_1}{\Delta x}$$

therefore:

$$\frac{\theta_i^j - \theta_i^{j-1}}{\Delta t} = \frac{D_{i-1/2}^{j-1/2}\left(\frac{\theta_{i-1}^{j-1} - \theta_i^{j-1} + \theta_{i-1}^{j} - \theta_i^{j} + 2GC}{2\Delta x}\right)}{\Delta x}$$

$$- \frac{D_{i+1/2}^{j-1/2}\left(\frac{\theta_i^{j-1} - \theta_{i+1}^{j-1} + \theta_i^{j} - \theta_{i+1}^{j} + 2GC}{2\Delta x}\right)}{\Delta x} \qquad (13)$$

Since $D = \frac{K}{C}$ and since it is assumed there is a single valued ralationship between volumetric water content, θ and water pressure, ψ, these substitutions can be made in equation (13) and the result will be:

$$\frac{\psi_i^j - \psi_i^{j-1}}{\Delta t} = \frac{K_{i-1/2}^{j-1/2}\left(\frac{\psi_{i-1}^{j-1} - \psi_i^{j-1} + \psi_{i-1}^{j} - \psi_i^{j} + 2G}{2\Delta x}\right)}{C_i^{j-1/2}\,\Delta x}$$

$$- \frac{K_{i+1/2}^{j-1/2}\left(\frac{\psi_i^{j-1} - \psi_{i+1}^{j-1} + \psi_i^{j} - \psi_{i+1}^{j} + 2G}{2\Delta x}\right)}{C_i^{j-1/2}\,\Delta x} \qquad (14)$$

which is equation (4) of Hanks and Bowers (1962), where ψ in equation (14) is represented by h in Hanks' and Bowers' equation and $C_i^{j-1/2}$ is the average specific moisture content for the increment in question.

Capillary conductivity and suction-water content data from the 0 to 15 cm. depth and from the 30 to 38 cm. depth of four soil sites (site numbers 1, 3, 8, and 8a) were used in the infiltration estimates. The capillary conductivity vs. water content data from the four plots were averaged and the results plotted for each of the two depths and a smooth line was drawn through the points to represent each depth. The same procedure was followed for the suction vs. water content data. This gave one set of data for the 0 to 15 cm. depth and another set for the 30 to 38 cm. depth to be used in the infiltration estimates.

Water content-diffusivity and water content-suction relationships are used in the procedure for estimating infiltration. These data from each depth were, therefore, plotted and the necessary information was taken from the resulting graphs for use in the infiltration computations. For a more complete discussion of this procedure see Green (1962) or Green, Hanks and Larson (1964).

Infiltration rates were calculated for different initial soil water contents to supply results for varying soil water conditions. The infiltration rates were plotted against time to provide curves illustrating the change in infiltration rate with time. These curves were based upon specified initial soil water content ranges. From these curves it was possible to determine if a given curve could be used to represent the approximate infiltration rate for a given time of the year based upon the soil water content at that time.

In order to make infiltration estimates, the water content of the soil must be known for the time for which the estimates are desired. The actual soil water content may be used when available. However, since infiltration estimates could be used for many purposes including future planning, it is necessary to have some estimate of the soil water content from which the infiltration estimates can be made. The probability of having a given soil water content at a given time during the year would make possible the estimation of infiltration rates based on the probable soil water content at the specified time.

By use of Shaw's (1963) procedure as discussed in the "Literature Review," it is possible to estimate the water content of a soil in 15 cm. increments to a depth of 1.5 m.

Dale and Shaw (1965) report the frequency of soil water contents for Colo and Nicollet soils at Ames, Iowa within specified ranges of percent available water based on the period 1933 through 1962. The frequencies given are for the water content of the entire 1.5 m. soil profile and were developed from daily soil water estimates obtained by Shaw's method.

Dale[1] computed the estimated available daily soil water content for Marshall soil at Norwich, Iowa. His results cover the season, with a few exceptions, from April 1 through November 30 over the 18-year period from 1948 through 1965. The exceptions result from unavailability of measured soil water contents at the beginning of some seasons. These values are needed for the estimation procedure.

Using Dale's data for the Marshall soil and Dale and Shaw's method of determining the frequency of a given soil water content, frequencies were determined for the top 45 cm. of soil by 15 cm. increments. The frequencies were then converted to probabilities. Increments of soil water content directly comparable to Dale and Shaw's (1965) increments were used in the frequency determinations. However, the frequencies for the current study were determined for the average soil water contents during half-month periods rather than for soil water contents on given

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[1]Dale, R. F. Unpublished soil water estimates on Marshall soil at Norwich, Iowa.

dates as was done by Dale. These averages were calculated for each of the three 15 cm. depth increments. Because Dale and Shaw's results are in percent available water and because the infiltration procedure requires percent total water by volume, their figures for available water were converted to percent total water.

For the Marshall soil, Dale[1] used 1.1 inches (2.79 cm.) of available water in 15 cm. of soil as 100 percent available water in his selection of soil water increments. In the present study, assuming 0.3 bar suction as field capacity, the surface 15 cm. of soil would hold about .85 inches (2.16 cm.) of available water. To convert percent available to percent total water at field capacity, the average 15-bar water percentage for the particular depth increment involved was converted to cm. of water in 15 cm. of soil. This figure was then added to Dale's 1.1 inches (2.79 cm.) to obtain the total cm. of water at field capacity in 15 cm. of soil. The 15-bar percentages were obtained from laboratory data on field samples collected for the present study. The total cm. of water were expressed as percent water by volume for the present study.

Rainfall Probabilities

If water infiltration rates into soil are known or can be estimated, it would be desirable to also know the probability of receiving rainfall intensities exceeding infiltration.

The probability of occurrence of rainfall intensities of 1.26 cm. per

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[1]Dale, R. F. Unpublished soil water estimates on Marshall soil at Norwich, Iowa.

hour or greater were determined. The intensities were divided into classes of equal to or greater than 1.26, 2.54, 3.80, 5.08, 6.34, and 7.60 cm. per hour, respectively. The probability of receiving one or more and two or more rains of the specified intensities were calculated for half-month intervals beginning on April 1 and ending on November 15.

The data for calculating the probabilities came from hydrograph records of the U.S. Weather Bureau. These data were collected and analyzed for the cooperative Soil and Water Loss Experiments, Iowa State University Experiment Station and USDA, ARS, Soil and Water Conservation Research Division, Cornbelt Branch.[1]

Maximum 5-, 15-, 30-, and 60-minute intensities in inches per hour for every rain during the 1932 through 1963 period had been previously tabulated from the hydrographs. Maximum 30-minute rainfall intensities were used in the present study because according to Wischmeier (1959) they correlate best with erosion losses.

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[1]Moldenhauer, W. C. Unpublished data available at Iowa State University, Agronomy Department and at the USDA, ARS Statistical Laboratory, Department of Agricultural Engineering, Purdue University, Lafayette, Indiana.

RESULTS AND DISCUSSION

Profile Characteristics

Tables 1 and 2 contain the average values of the laboratory determinations for the various characteristics for profiles 1 through 10 and 11 through 16, respectively. Tables 6 and 7 in Appendix B show the results of the various laboratory determinations by horizon for profiles 1 through 10. It also gives the means, standard deviations, 95 percent confidence intervals, and the coefficients of variation for each horizon across the ten profiles sampled. Table 10 in Appendix B contains similar information for profiles 11 through 16.

Note that for profiles 1 through 10 the division between coarse silt and sand is 0.046 mm. whereas for profiles 11 through 16 the division is 0.050 mm. This may account for the higher percentages of coarse silt in profiles 11 through 16 but it does not account for the higher sand percentages in these profiles.

There is little variation in the percentages of the various soil fractions within each horizon as evidenced by the small coefficients of variation shown in Table 6 in Appendix B. They range from 0.55 percent up to 3.88 percent for the clay, fine silt, and coarse silt fraction. Sand, however, does exhibit more variability with coefficients of variation ranging from 4.50 percent up to 12.01 percent. Table 8 of Appendix B gives the particle size distribution by profile.

The average percentages of each soil fraction are shown as a function of depth in Figure 3.

Organic carbon content is highest in the A1 horizon and decreases

Table 1. Average values of the laboratory determinations for the various profile characteristics of profiles 1 through 10

Horizon	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.046 mm. (%)	Sand .046-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
Ap	32.4	29.8	35.4	2.3	1.9	1.20
A3	33.6	30.7	33.4	2.2	1.6	1.22
B1	34.3	30.8	32.8	2.0	1.3	1.25
B2	32.2	32.7	32.7	2.3	.74	1.22
B3	29.1	34.9	33.7	2.2	.50	1.22
C	26.5	34.8	36.2	2.4	.31	1.26

Table 2. Average values of the laboratory determinations for the various profile characteristics for profiles 11 through 16

Horizon	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.050 mm. (%)	Sand .050-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
Ap	30.2	28.1	38.8	2.9	2.3	1.34
A3	33.0	29.1	35.3	2.6	1.8	1.24
B1	32.7	29.4	35.1	2.8	1.3	1.23
B2	31.7	28.6	36.4	3.2	.74	1.22
B3	29.5	28.5	38.4	3.5	.47	1.23
C	28.2	28.2	39.7	3.9	.29	1.30

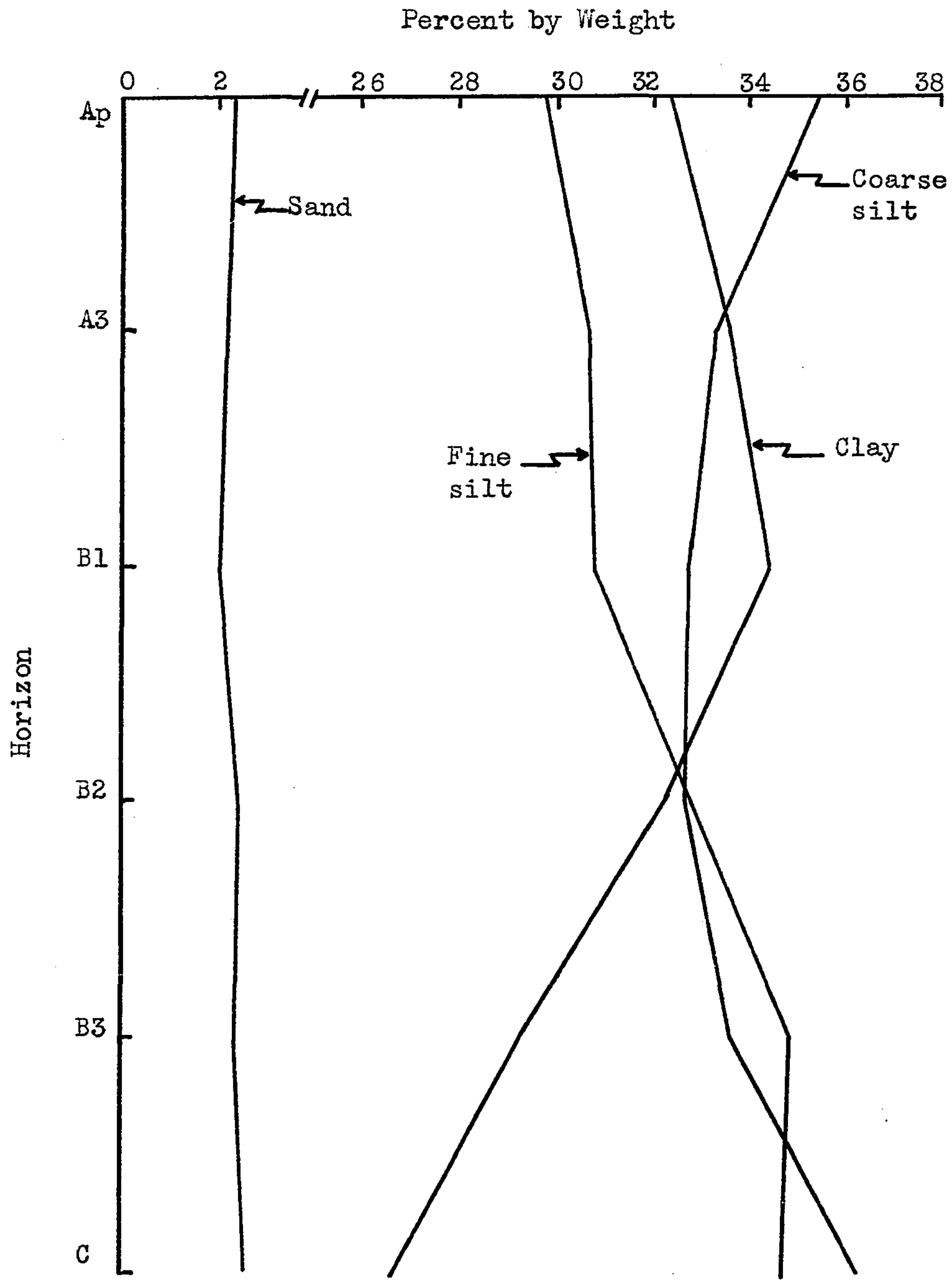

Figure 3. Average percentage distribution of the various size fractions with depth in the Marshall soil for profiles 1 through 10

rapidly with depth as shown in Figure 4.

Figure 5 shows the average soil water content as a function of suction for each horizon across the 10 profiles. Figure 6 illustrates the average soil water content as a function of horizon for each of six suctions. From Figure 6 it can be seen that the water contents tend to decrease slightly with depth at suctions above one bar. At the 0.3 and 0.1 bar suctions, however, this trend does not hold. Table 9 of Appendix B gives the water percentages at different suctions for the various horizons of each profile.

Water content at various suctions is related to pore size distribution. Pore size distribution is a function of texture and structure. At the higher suctions or lower soil water contents, soil water is probably related more to texture than to structure. Higher clay and fine silt contents would tend to result in a larger percentage of smaller pores which retain water at higher energy levels. Note in Figure 6 that at the 15 bar suction, soil moisture content is highest in the B1 horizon in which clay content is highest. It then decreases steadily with depth as does clay content. The 1-, 3-, and 5-bar suctions tend to exhibit, in a general way, this same relationship.

Soil structure, particularly granular structure, would be expected to play a larger role in water retention at lower suctions and higher soil water contents. Granular structure and/or high sand and coarse silt content would give rise to a higher percentage of larger pores. Water is held at lower energy levels in these pores, therefore the higher the percentage of them, the more water the soil would hold at lower suctions. In Figure 6 the water in the Ap horizon at 0.1 bar suction is high then decreases somewhat before increasing again in lower horizons. The higher

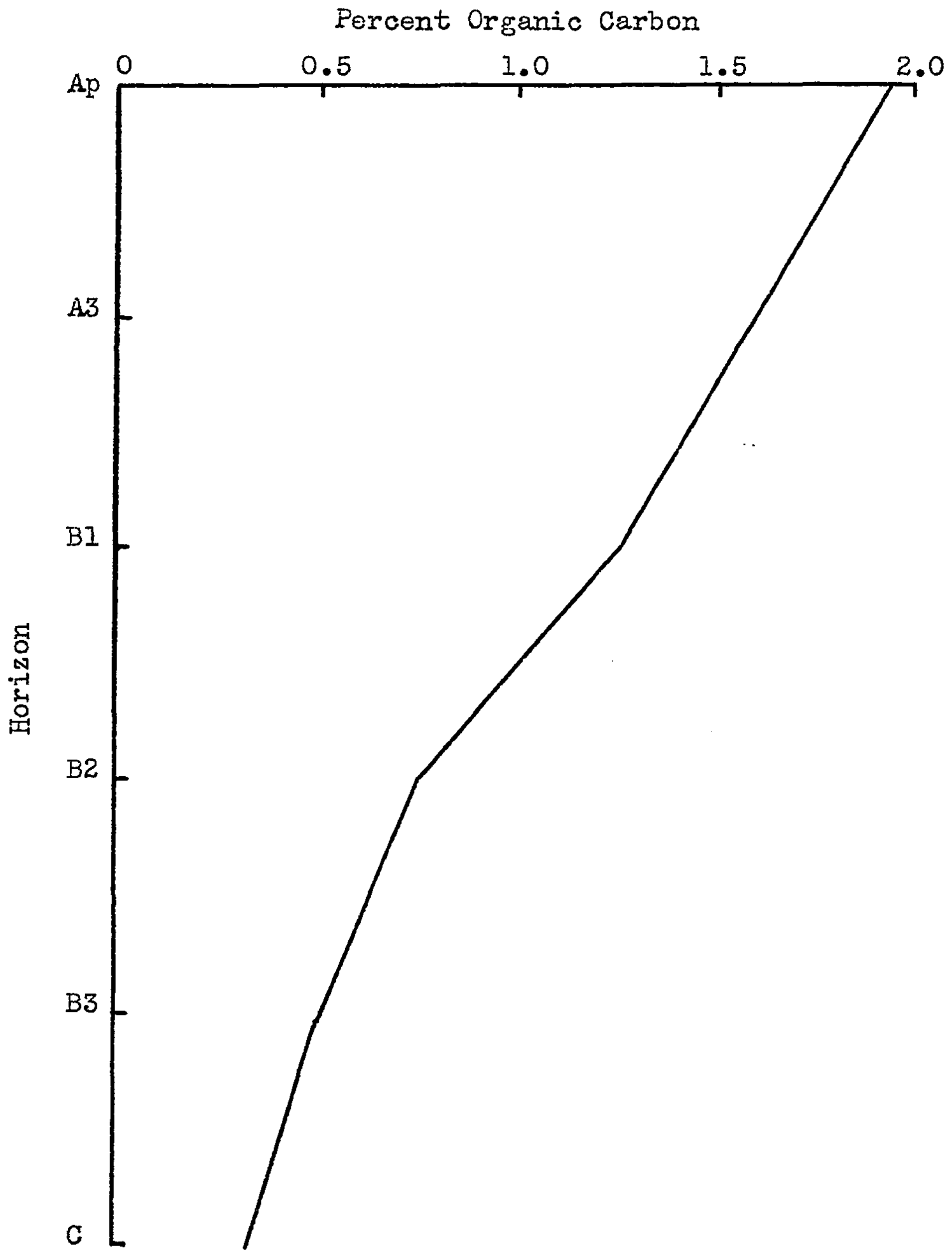

Figure 4. Distribution of average organic carbon content for the various horizons in Marshall soil for profiles 1 through 10

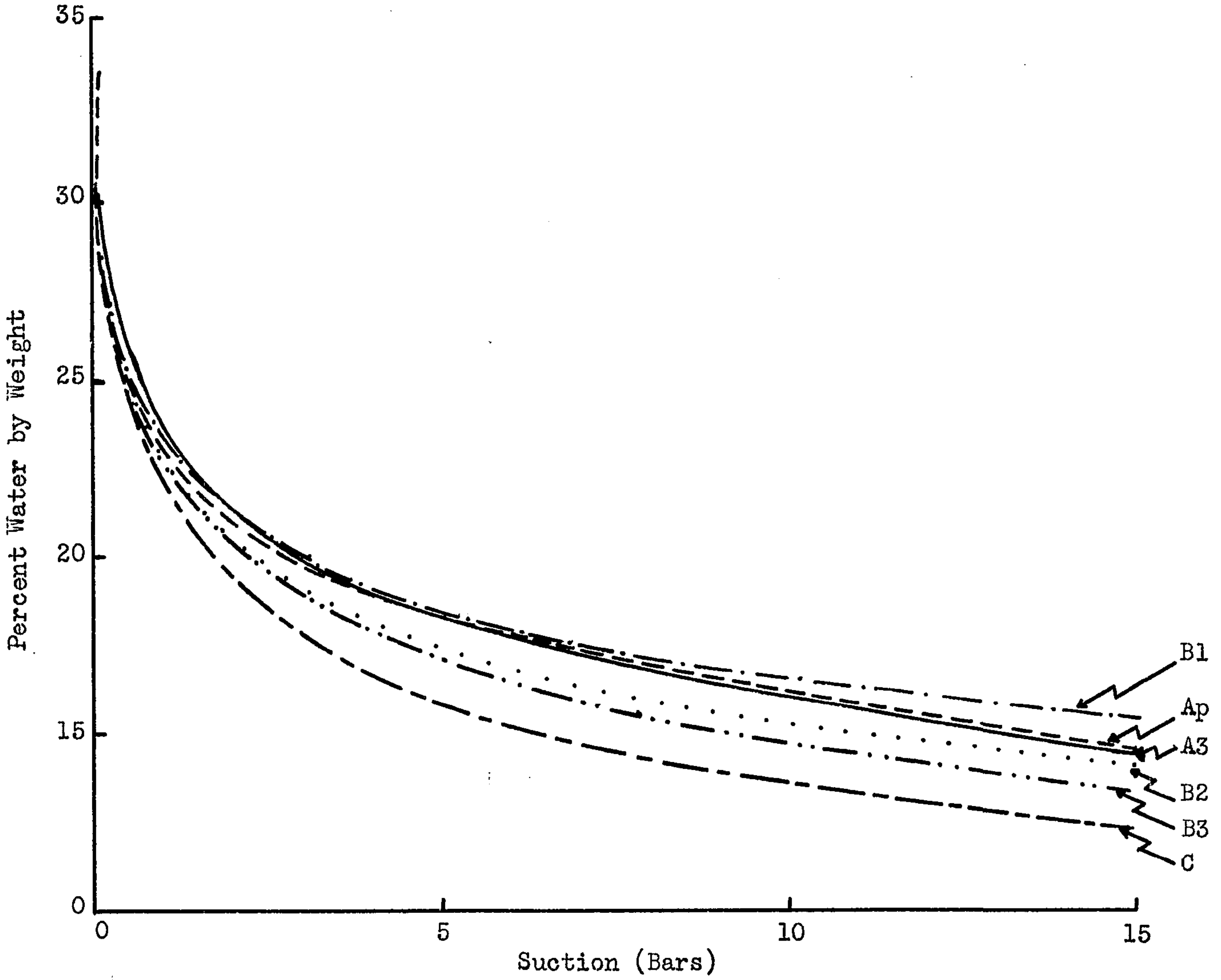

Figure 5. Average soil water content for the various horizons of Marshall soil as a function of suction for profiles 1 through 10

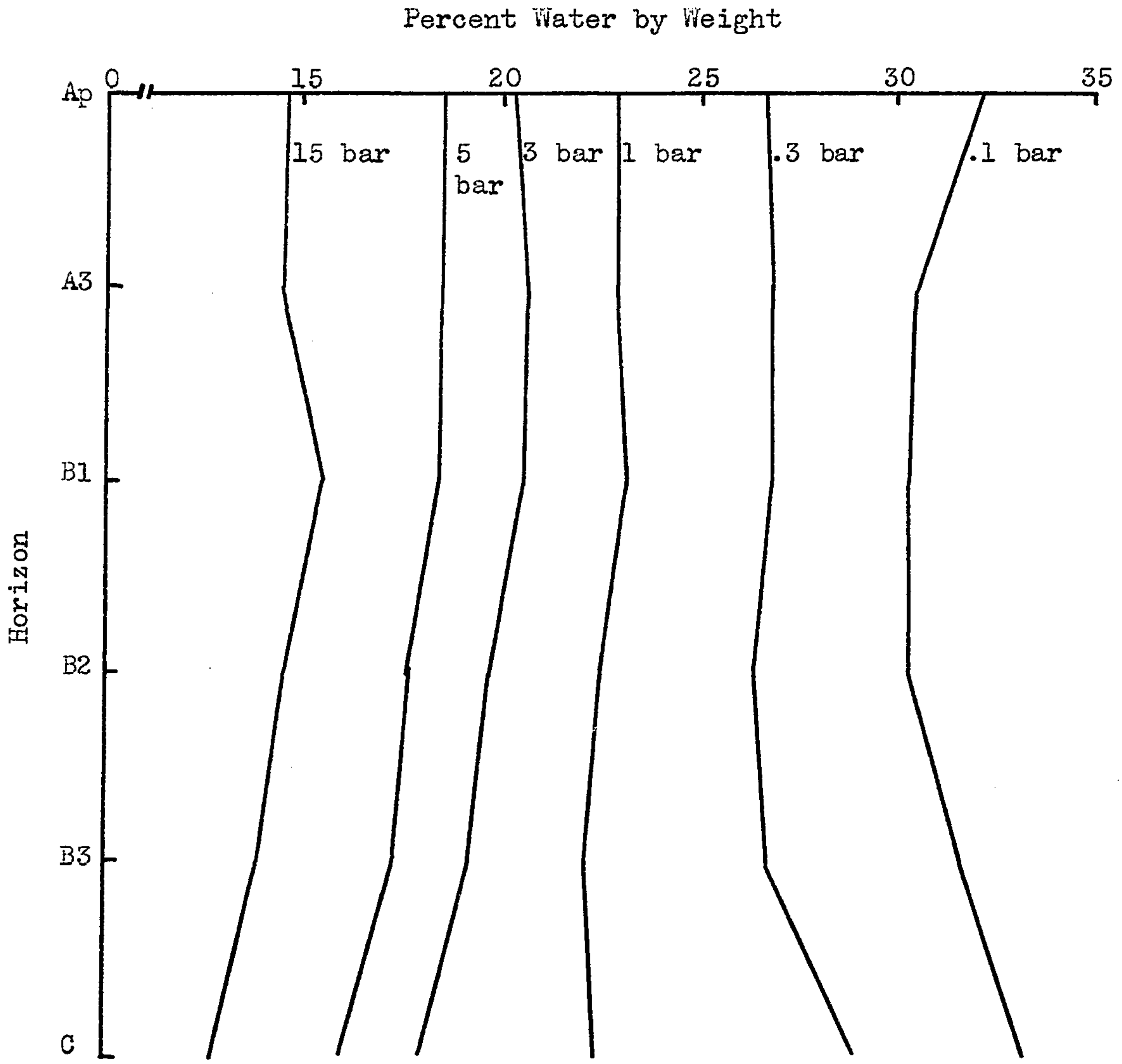

Figure 6. Average percent water by weight for each horizon at the various suctions for profiles 1 through 10

water percentage in the Ap horizon may be due to a more granular structure than is found in other horizons. Coarse silt content increases somewhat in the B3 horizon and considerably more in the C. This may explain the higher water content in the C horizon at the 0.1 bar suction.

Variation in bulk density within each horizon is relatively small across profiles as can be seen from the small coefficients of variation in Table 6 of Appendix B. No explanation can be given for the generally higher bulk density values in profile 4 as compared to all the other profiles.

Water Content-Suction-Diffusivity Relations

The numerical solution of the infiltration equation used by Hanks and Bowers (1962) and presented in this study requires a knowledge of the water content-suction and the water content-diffusivity relations. These relationships were determined by the method of Kunze and Kirkham (1962).

Figure 7 shows the average water content-suction relations for four locations on Marshall silty clay loam. Each datum point represents the average equilibrium point of four profiles in the stepwise desorption procedure. The values for each profile are given in Table 11 of Appendix C. The average values used in Figure 7 are shown in Table 12 of Appendix C. The data from which the average values were calculated for suctions up to approximately 2 bar and the water contents are given in Table 11 of the Appendix. Table 7 of the Appendix contains the 15-bar suctions and the related water percentages used in calculating the average values shown in Figure 7. The curve was extrapolated at the dry end to acquire the suction at the lowest water content used in the study. The data points at the

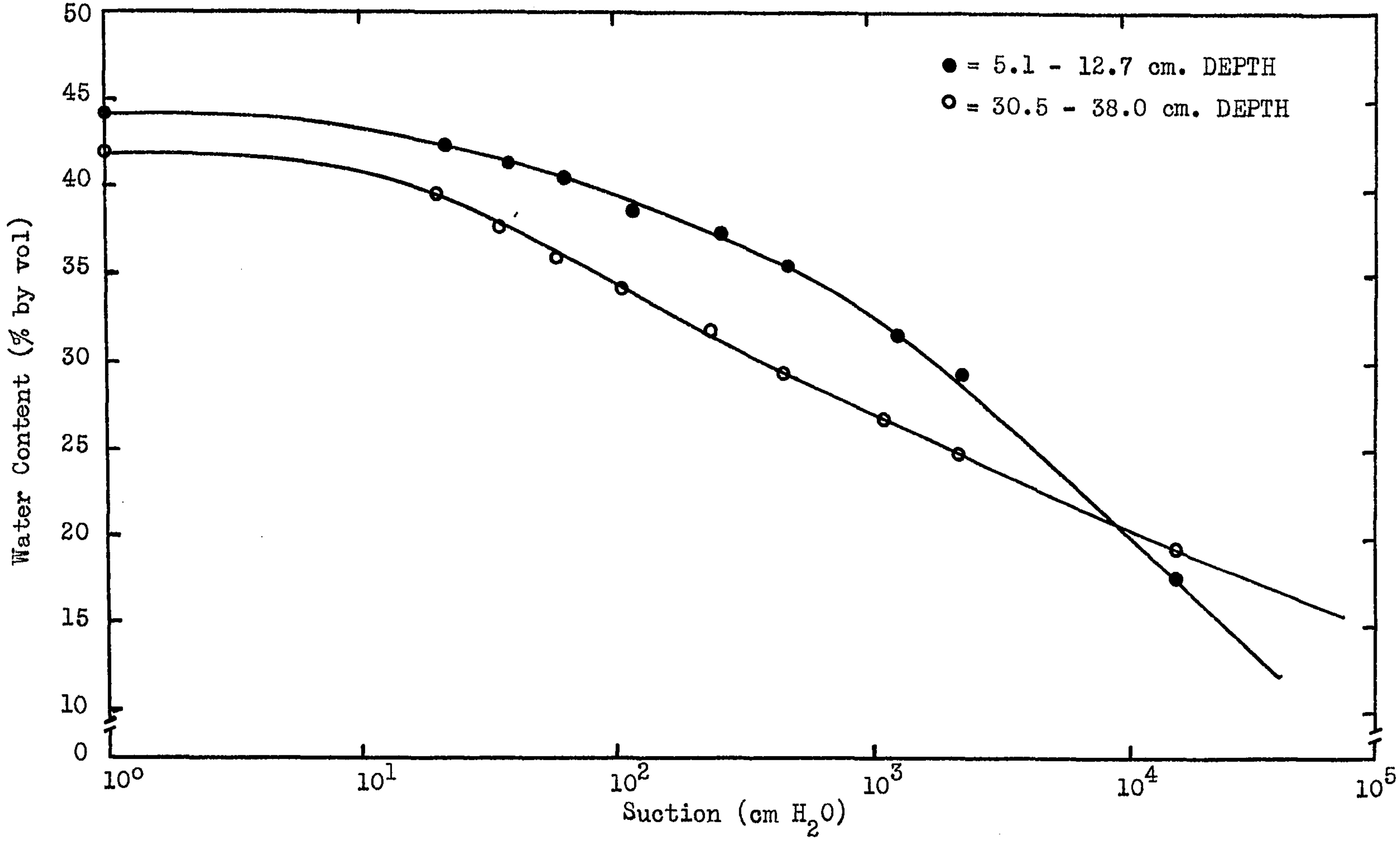

Figure 7. Average water content versus suction relations for four locations on Marshall silty clay loam

highest suction were taken from the results obtained by the pressure membrane procedure. The saturation water content shown in Figure 7 as 1 cm. suction was obtained by extrapolation of the data points on a linear scale.

The water content-suction relations used in the infiltration procedure were taken from the graphs in Figure 7.

Figure 8 shows the average water content-diffusivity relations for four locations. Complete data are given in Tables 11 and 12 of the Appendix. Extrapolation at the dry end of the curve has been shown by Hanks and Bowers (1962) to have little effect on estimated infiltration. In the present study, $D(\theta)$ values of 0 at suctions greater than 100 cm. had only small effects on estimated infiltration. The diffusivity values at the saturated water content were arbitrarily selected to correspond to saturated conductivities of 1 cm./hr. and 0.75 cm./hr. for the surface and subsoils, respectively. The conductivities were selected on the basis of results on Marshall soils of previous workers. Musgrave, et al. (1936) report equilibrium rates ranging from 0.8 to 1.2 cm./hr. Duley (1939) reports similar values. Schmidt, et al. (1964) showed an equilibrium infiltration rate after 30 minutes of 0.58 and 0.73 cm./hr. depending upon rainfall intensity. Green[1] using a rainfall simulator reported final intake rates of slightly over 2.5 cm./hr. on Marshall soils.

Each datum point on the graphs in Figure 7 is the average value for four profiles. Table 12 in the Appendix shows the actual values of the plotted points.

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[1]Green, R. E., Project 1356 Water Infiltration into Soils, Project Report. Unpublished. 1960.

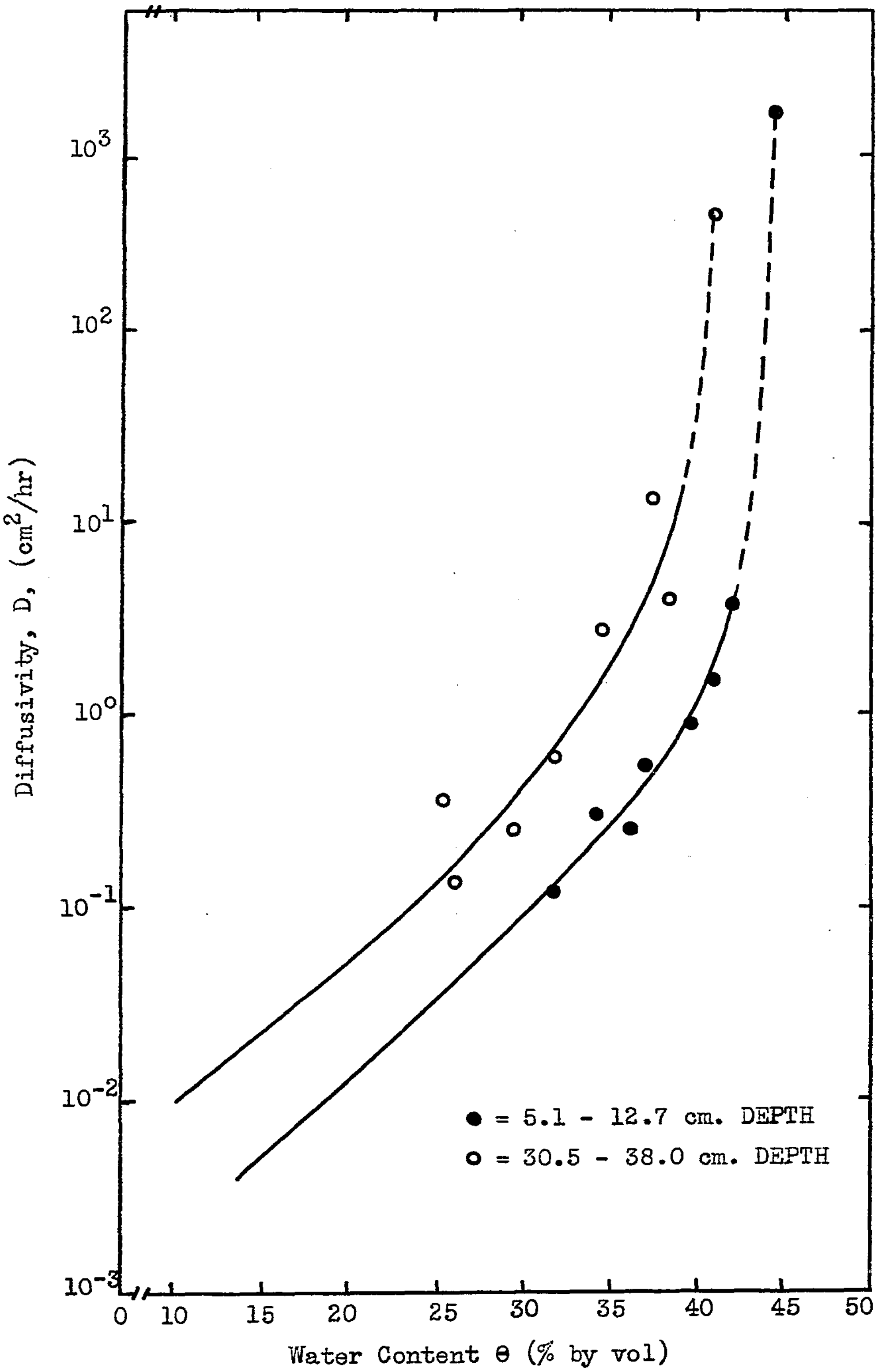

Figure 8. Average D versus θ for undisturbed soil cores from four locations

Estimating Infiltration into a Soil

The numerical solution of the water flow equation (Hanks and Bowers, 1962) will estimate infiltration into a two-layered soil. In this study infiltration was estimated based on surface soil conditions only.

In the course of making infiltration estimates, certain problems were encountered which indicated some of the limitations of the estimation procedure. Some of these limitations and problems were investigated.

Figure 9 shows both cumulative infiltration and infiltration rate for a Marshall silty clay loam using depth increments of 0.25 cm., 0.5 cm., and 1.0 cm. The differences in the results shown indicate that the selected depth increment used for making infiltration estimates may have a marked effect on the results. This should be expected since the numerical procedure uses a finite difference method rather than the infinitely small units used in normal integration procedures. It would therefore appear that smaller increments would give more precise results; however the problem is to select a sufficiently small increment that is still practical to consider in the numerical procedure.

The infiltration results presented in Figures 9 and 10 were estimated on a soil profile containing 16 percent water by volume throughout the depth considered.

The difference in initial conditions for the results shown in Figure 10 are the diffusivity values. The bottom lines on the graph are the result of using a diffusivity value of zero for all suctions greater than 100 cm. of water whereas the top lines represent actual measured values. The results are not greatly different but they do indicate that diffusivity

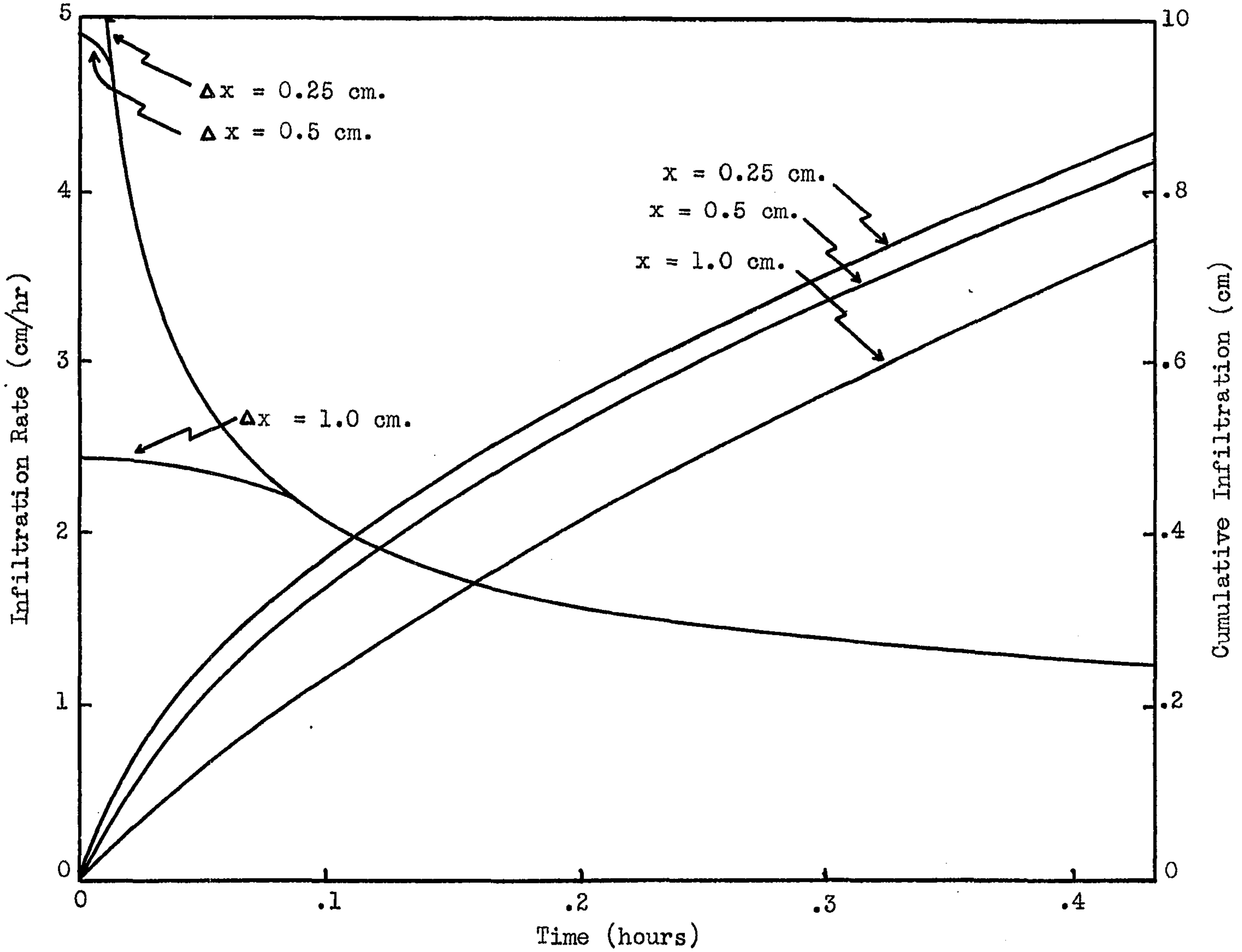

Figure 9. Infiltration rate (decreasing) and cumulative infiltration (increasing) into Marshall silty clay loam with an antecedent water content of 16 percent constant with depth and three different depth increments

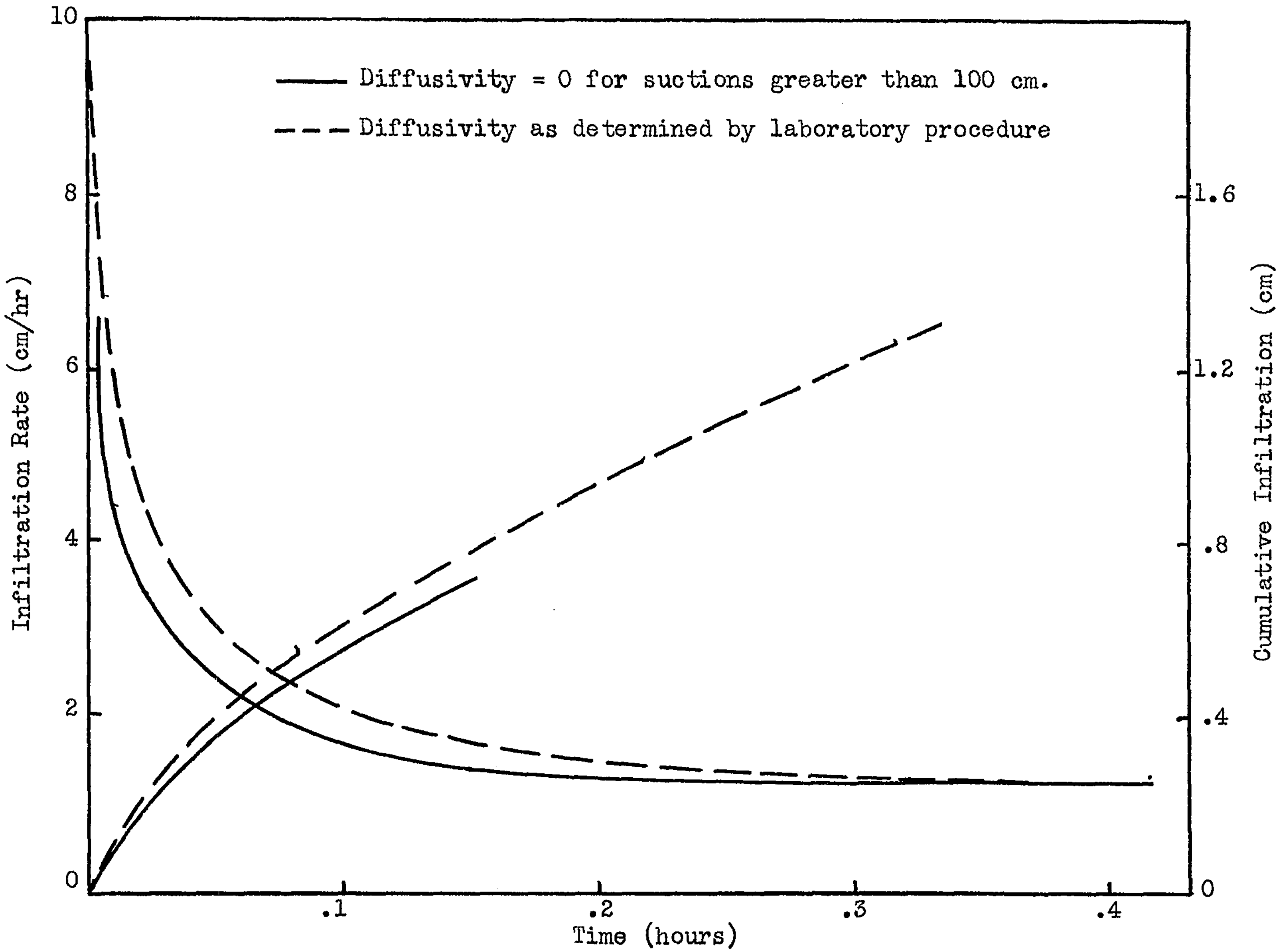

Figure 10. Infiltration rate (decreasing) and cumulative infiltration (increasing) into Marshall silty clay loam with an antecedent water content of 16 percent constant with depth, a depth increment of 0.25 cm. and two different suction-diffusivity relations

should be considered in soils drier than those represented by a suction of 100 cm. of water.

Table 13 in the Appendix gives the general input data used for all the infiltration estimates. Differences are noted in the text.

Figure 11 shows the results for a soil with an antecedent moisture content considerably higher than that in Figures 9 and 10. The top line for infiltration rate and for cumulative infiltration are the result of an initial water content of 36 percent constant with depth. The infiltration rate decreases much more rapidly and the equilibrium infiltration rate is slightly lower for the wetter soil as compared to the drier soil.

The depth increment was variable for the results obtained in Figure 11. During the initial stages of infiltration the depth increment is 0.25 cm., the same as in Figure 10. However, the depth increment is increased to 0.5 cm. then to 1.0 cm. as infiltration continues. Figure 9 shows that the size of the depth increment is important only during the initial stages of infiltration and the use of an increasing depth increment is therefore justified.

The lower lines for infiltration rate and for cumulative infiltration in Figure 11 result from variable antecedent water contents in the top 20 cm. of soil as given in the figure. Below this depth the soil contains 36 percent water.

The results of the various depth increments indicate that antecedent water content in the surface few cm. of soil may have a pronounced effect on the infiltration estimates. This is significant from the standpoint of one of the stated objectives of this study. Objective 2 refers to estimating infiltration rates based on probable soil water contents at

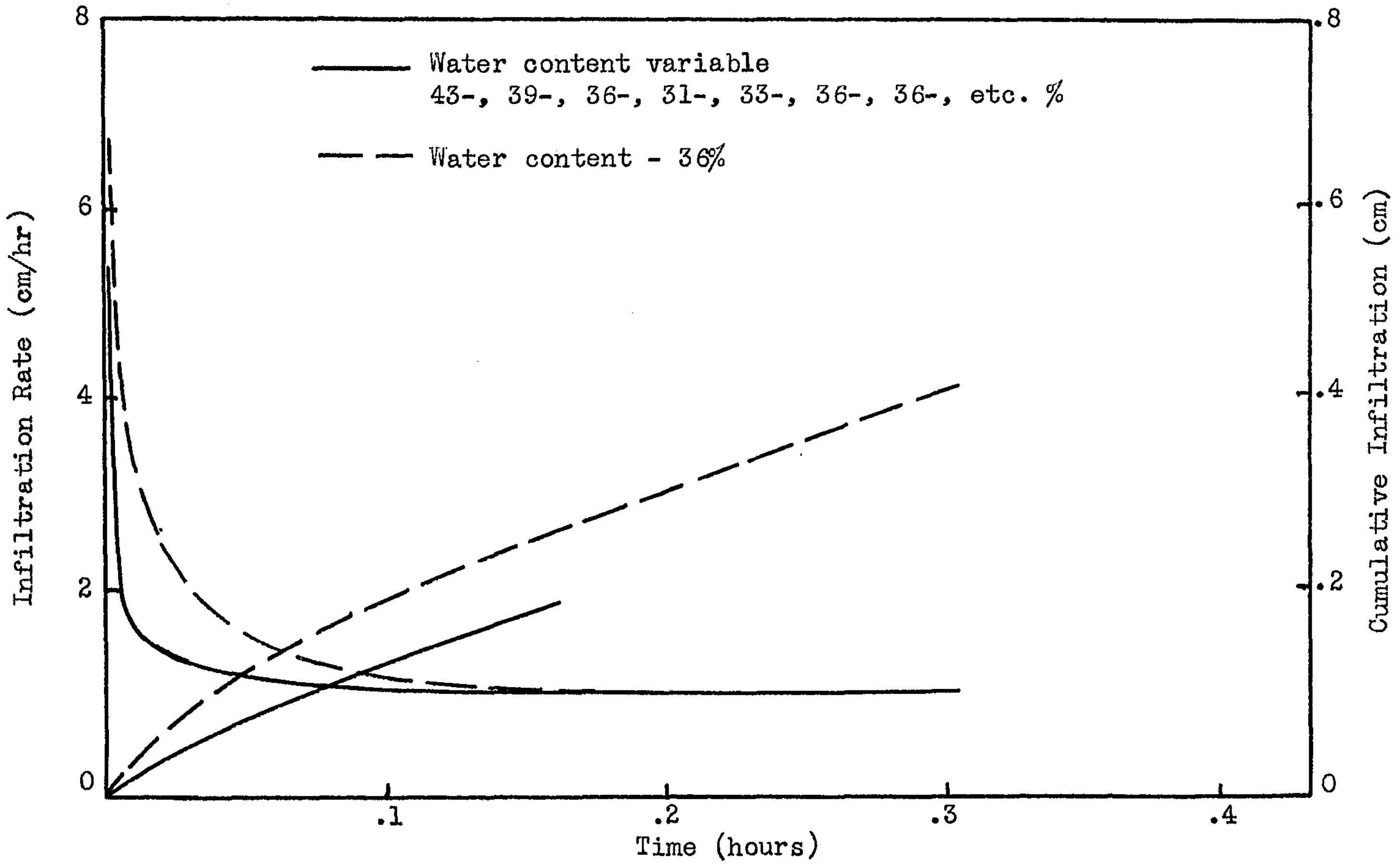

Figure 11. Infiltration rate (decreasing) and cumulative infiltration (increasing) into Marshall silty clay loam with depth increments variable and different antecedent soil water contents

different periods of the year. At present the best known technique for determining soil water probability is that of Shaw and Dale (1965), but the smallest depth increment that can be used by their technique is 15 cm. Averaging soil water contents over such a large depth increment could result in serious errors when estimating infiltration. If a means of estimating soil water content in smaller increments could be found, the danger of serious error in estimating infiltration may be greatly reduced.

Edwards (1966) developed a means for evaluating the effects of surface crusting on infiltration. He showed that crusting reduced considerably the infiltration rate of an Ida silt loam. Surface crusting was not investigated in the present study, but it would be expected to influence the infiltration rates obtained for a Marshall silty clay loam.

Figures 12 through 14 indicate the progression of the wetting front under various conditions. In general the wetting front is quite abrupt for the lower antecedent soil water content. The thickness of the depth increment used in the calculations appears to have some effect on the wetting front as shown in Figure 12. This effect seems to be more pronounced in the early stages of infiltration.

Figure 13 indicates that the soil water content-diffusivity relations at suctions greater than 100 cm. may also have some effect on the wetting front. The wetting front is sharper in the case where the diffusivity was maintained at zero for suctions greater than 100 cm. of water.

The abrupt wetting front at the lower antecedent water content may be the result of the good aggregation of Marshall soils. The larger pores existing between the aggregates reduces the opportunity for water movement downward by film adjustment around individual soil particles and

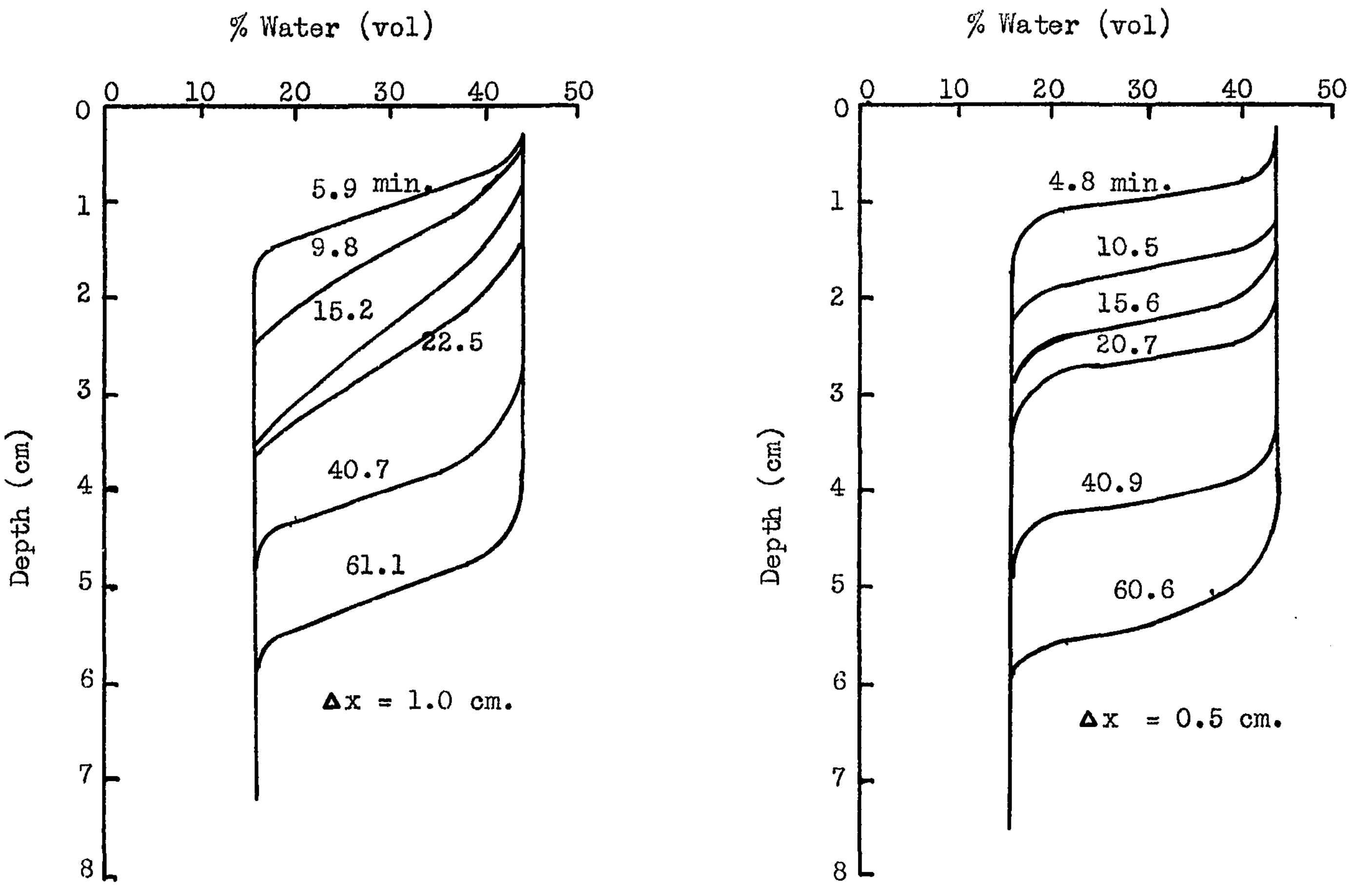

Figure 12. Progression of the wetting through Marshall silty clay loam during infiltration for two different depth increments and an antecedent water content of 16 percent constant with depth

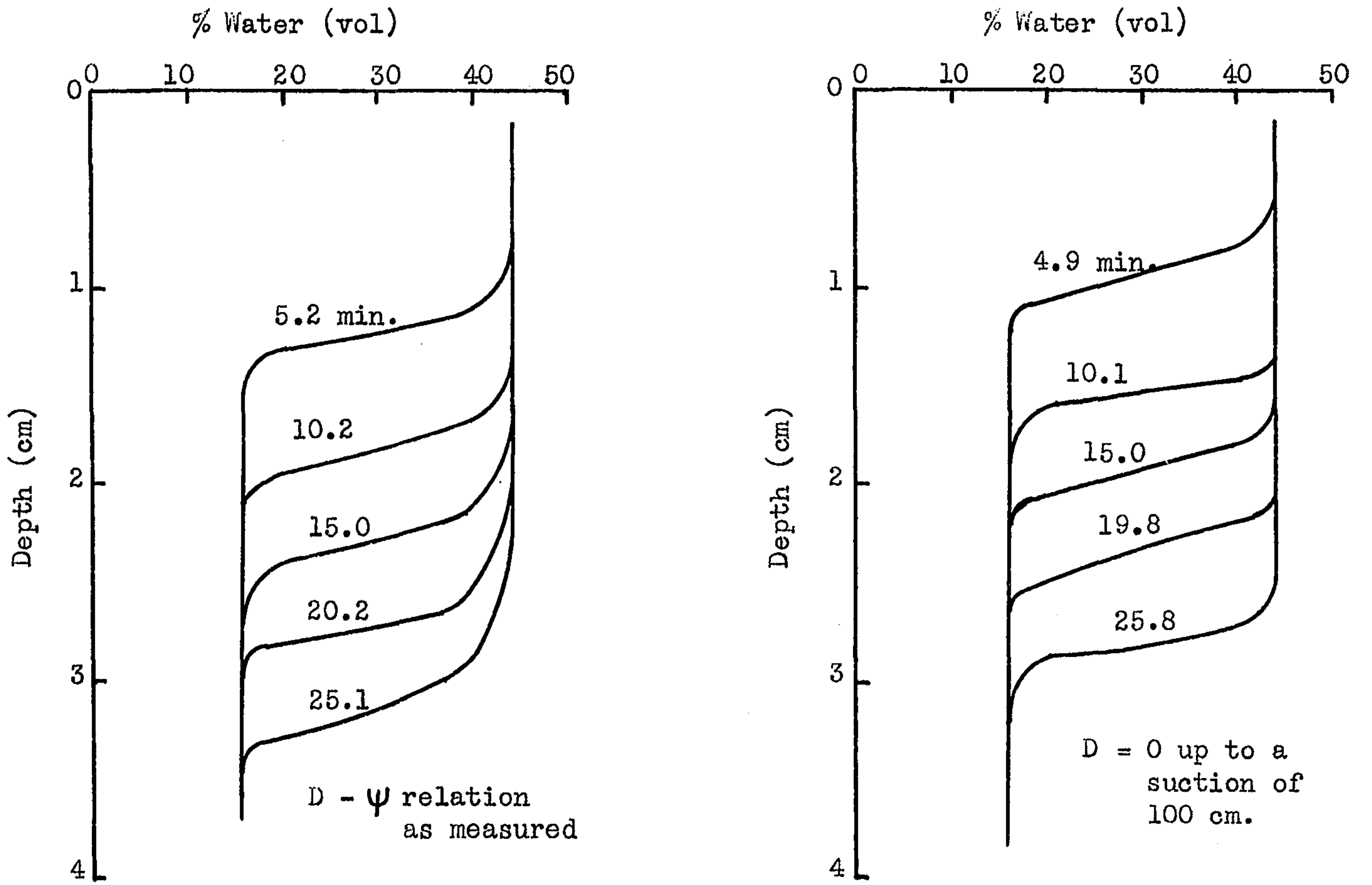

Figure 13. Progression of the wetting front through Marshall silty clay loam during infiltration for a depth increment of 0.25 cm. and a water content of 16 percent constant with depth, and at two different diffusivity-suction (D - ψ) relations

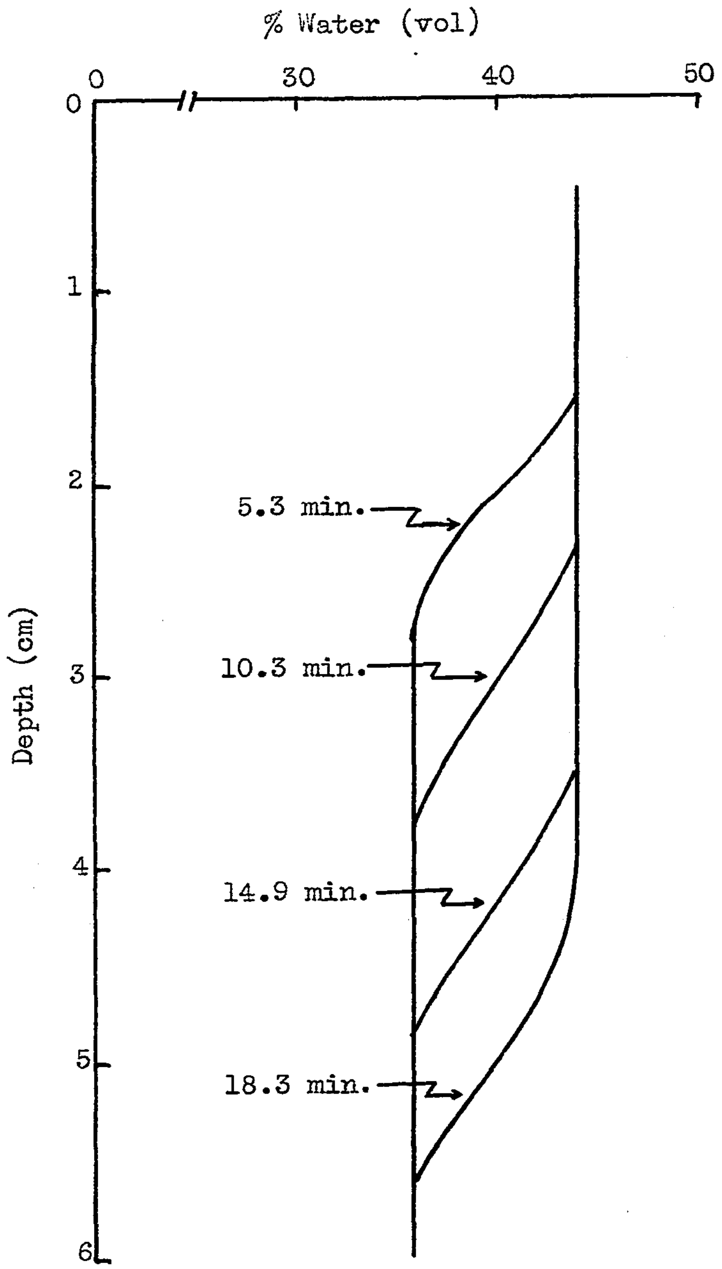

Figure 14. Progression of the wetting front through Marshall silty clay loam during infiltration for a variable depth increment and a water content of 36 percent constant with depth

through micropores between particles on a suction gradient.

Figure 14 illustrates the wetting fronts at an antecedent water content of 36 percent by volume. At this higher water content the wetting front is much less abrupt. Where the water content of the surface few cm. is variable the wetting front is very poorly defined.

One of the problems encountered in using the numerical procedure is that of determining the conductivity-suction relations at low suctions or high soil water contents. Figure 15 illustrates two hypothetical conductivity-suction relations for suctions less than 25 cm. The values at suctions greater than 25 cm. are measured values. The data are plotted as step functions which is the way they are used by the computer. The complete data are given in Tables 14 and 15 of Appendix D.

The two sets of data shown in Figure 15 were used to calculate infiltrations. Figure 16 shows the results obtained from use of the two different sets of input data. The resulting infiltration differences indicate the importance of being able to measure the conductivity-suction relations at several points between 0 and 25 cm. suction. Methods for making such measurements need to be developed for more precise infiltration estimates.

The effect of limiting rainfall during infiltration was investigated. Figure 17 shows the calculated infiltration results at three different rainfall rates. The 1.0 cm. per hour rainfall rate is equal to the saturated conductivity used in the infiltration estimates and therefore appears as a straight line. The 1.5 cm. per hour rainfall rate is considerably less than the initial infiltration rate, but converges with the infiltration rate curve where rainfall is not limiting at times over about 0.2 hours. The infiltration curve for a rainfall rate of 100 cm. per hour is

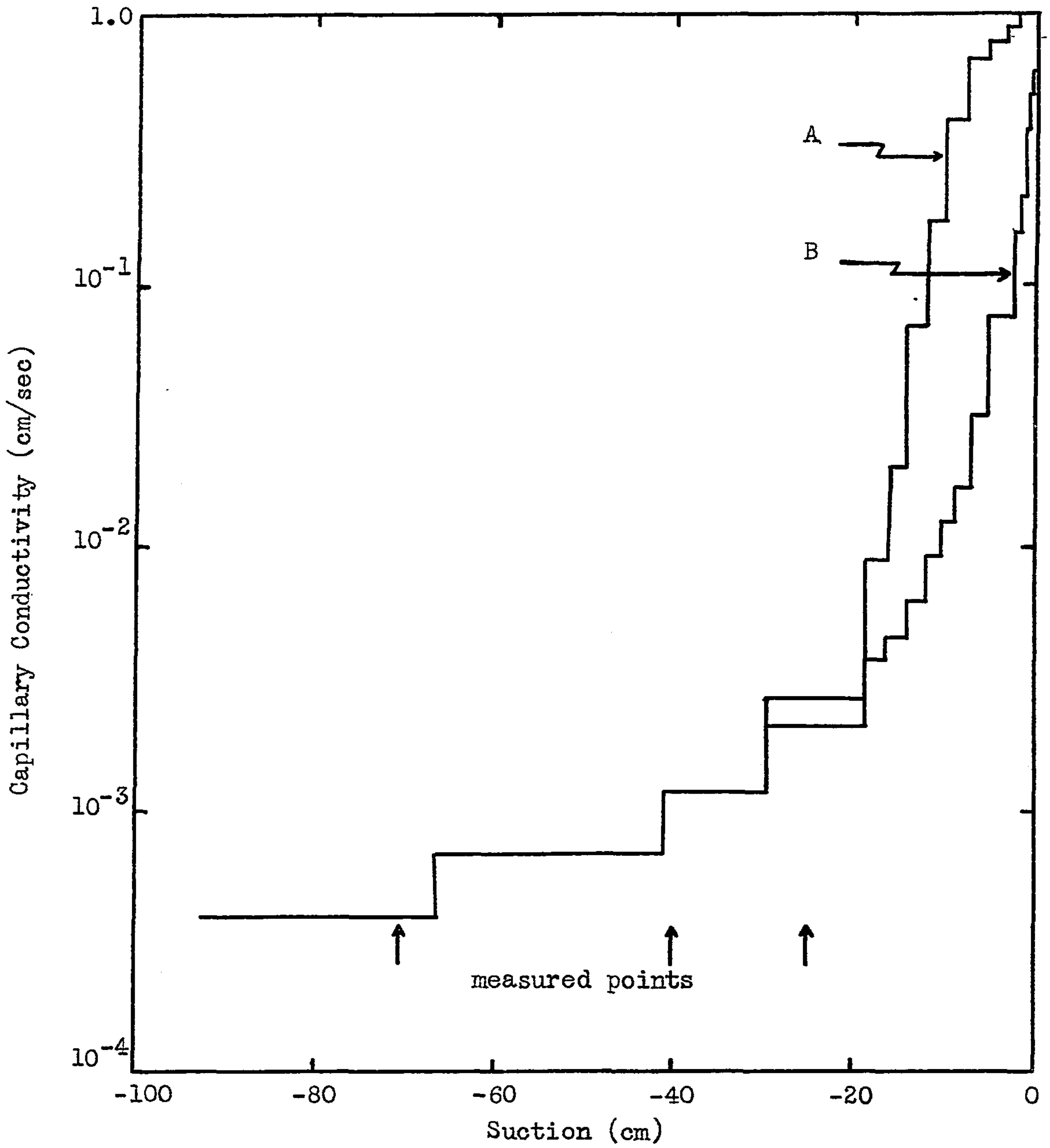

Figure 15. Two curves extrapolated from 25 to 0 cm. suction from which data were used to illustrate the effect of conductivity-suction relations at suctions less than 25 cm.

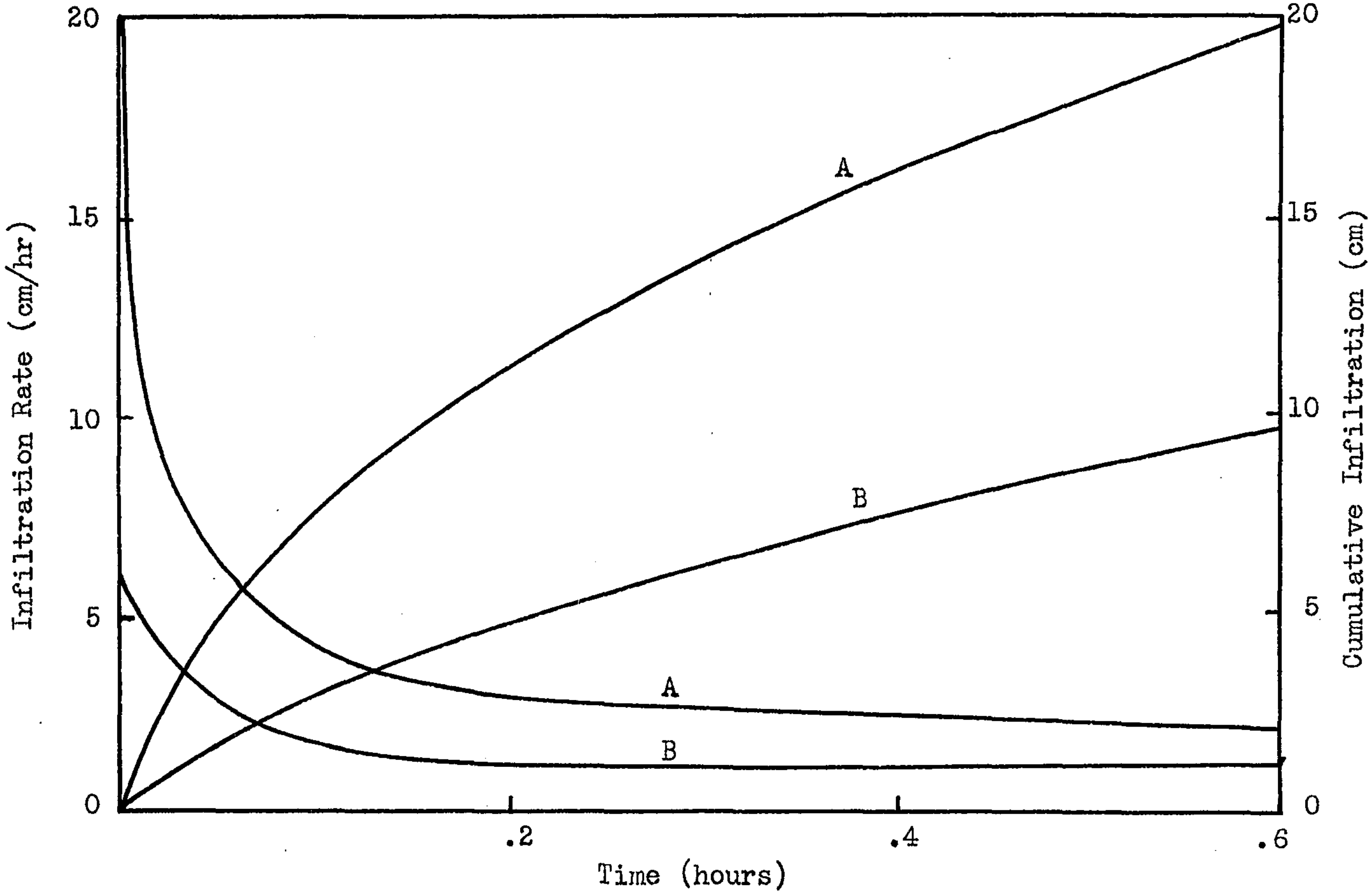

Figure 16. Infiltration rate (decreasing) and cumulative infiltration (increasing) into Marshall silty clay loam based on two different conductivity-suction relations for suctions less than 25 cm. (curves A and B in this graph correspond to curves A and B in Figure 14)

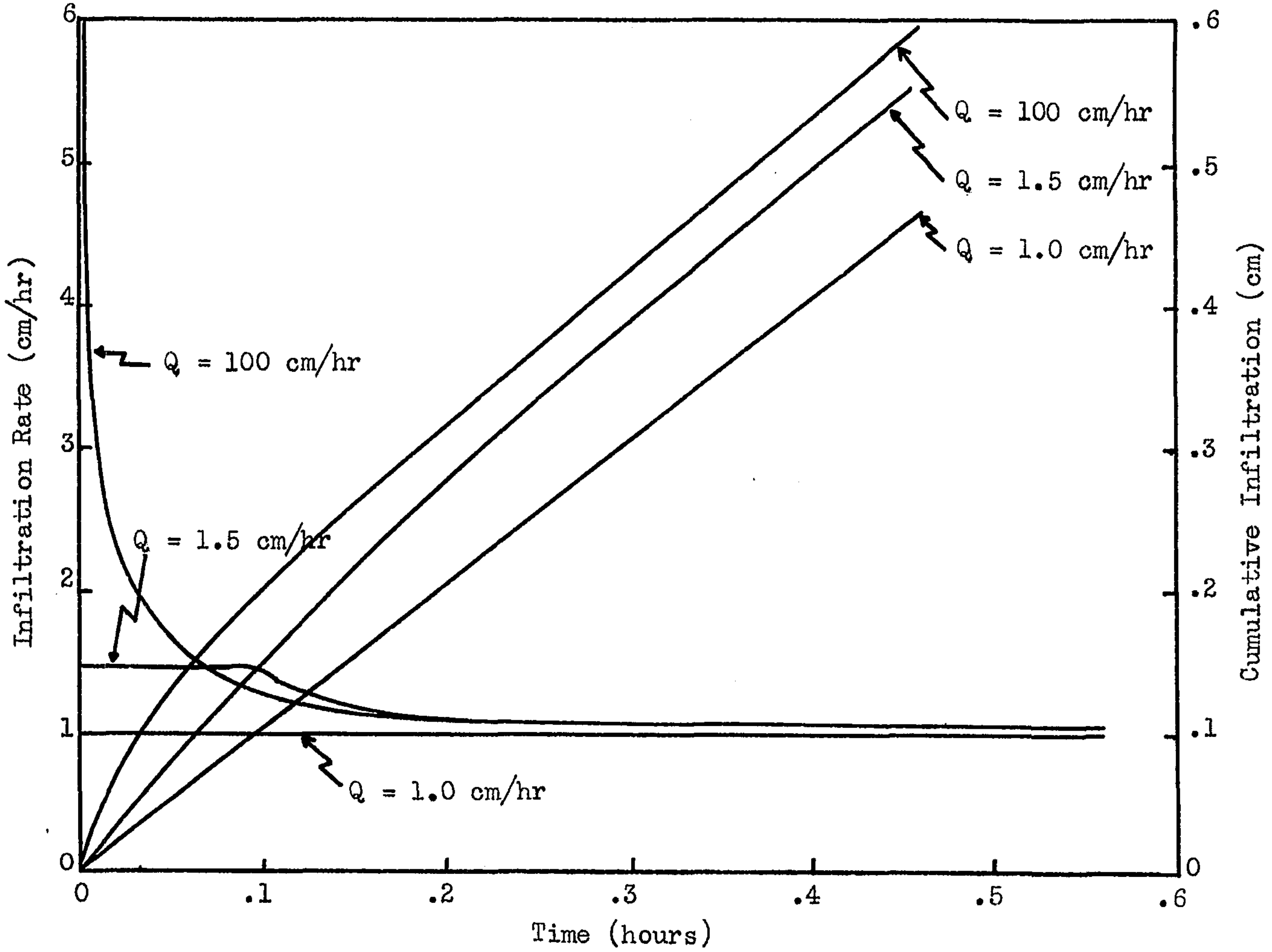

Figure 17. Infiltration rate (decreasing) and cumulative infiltration (increasing) into Marshall silty clay loam at three different rainfall rates, Q

one that would be obtained from an unlimited rainfall rate.

Estimated Soil Water Contents

Table 3 gives the average estimated soil water contents at Norwich, Iowa during half-month periods for the 0 to 15, 15 to 30, and 30 to 45 cm. soil depths. During the spring and fall the average soil water content tends to be lower in the 0 to 15 cm. depth than in either of the other two depths. However, during the summer months it tends to be higher in the 0 to 15 cm. depth than in the 15 to 30 cm. depth but about equal to the water content of the 30 to 45 cm. depth.

Table 3 also shows the frequency of the various soil water contents for the period 1948 through 1965. The maximum soil water percentage shown corresponds to the field capacity value used by Dale and Shaw (1965) in their estimation of soil water content.

The frequencies given in Table 3 were converted to probabilities and the values are shown in Table 4. The probabilities for the half-month periods are based on the 18-year period 1948-1965. The period April 1 through April 15 is based on a 14-year period and the periods April 16 through April 30 and May 1 through May 15 are based on a 17-year period. This resulted from lack of data from some of the years.

The probability for any given soil water content is most variable for the 0 to 15 cm. depth. This would be somewhat expected since the surface 15 cm. of soil is influenced by precipitation and evaporation more than soil at greater depths.

The probability of having a high soil water content (32.5-36.0 percent) in the 0 to 15 cm. depth is greatest during the last half of June

Table 3. Average soil water contents and number of years out of total years studied for occurrence of the indicated soil water contents during half-month periods for Marshall soil at Norwich, Iowa, 1948-1965[a]

Percent water by volume	April		May		June		July		August		Sept.		October		Nov.
	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-15	16-31	1-15
0-15 cm. depth															
32.5-36.0	2	1	0	4	5	10	11	4	7	7	6	8	7	4	6
28.8-32.4	6	4	7	5	4	6	3	5	3	2	9	5	2	3	4
25.1-28.7	5	5	4	4	3	2	2	4	4	5	1	2	3	4	3
21.5-25.0	0	1	5	1	2	0	1	4	1	1	1	1	1	3	1
17.7-21.4	0	6	1	4	4	0	1	0	3	3	1	1	4	3	1
<17.7	1	0	0	0	0	0	0	1	0	0	0	1	1	1	3
Average	28.5	25.0	27.4	28.0	28.0	32.4	31.0	28.2	28.5	28.3	30.6	30.2	28.0	26.3	28.0
15-30 cm. depth															
32.5-36.0	10	14	14	15	12	6	5	1	1	6	4	7	13	15	16
28.8-32.4	2	2	2	2	4	5	4	5	3	4	6	5	2	0	0
25.1-28.7	1	0	0	0	1	2	6	3	5	2	5	3	2	2	1
21.5-25.0	0	0	0	0	0	4	0	2	3	0	1	3	1	1	1
17.7-21.4	1	1	1	1	1	1	3	5	4	4	1	0	0	0	0
<17.7	0	0	0	0	0	0	0	2	2	2	1	0	0	0	0
Average	33.3	34.4	34.4	34.5	32.5	29.5	28.6	23.8	24.6	27.4	29.4	30.8	33.0	34.0	34.5
30-45 cm. depth															
34.2-37.7	8	11	13	15	16	11	9	6	4	7	9	11	12	14	15
30.5-34.1	3	4	2	2	1	6	3	5	4	0	1	3	2	0	0
26.8-30.4	2	1	1	0	0	0	4	3	2	3	2	0	0	0	1
23.2-26.7	0	0	0	0	0	0	2	2	3	2	2	1	1	1	0
19.4-23.1	1	1	1	1	1	1	0	2	5	3	1	0	0	0	0
<19.4	0	0	0	0	0	0	0	0	0	3	3	3	3	3	2
Average	33.3	34.5	35.4	35.6	35.9	34.0	33.0	30.5	28.2	28.3	30.2	32.2	33.2	33.5	34.9

[a]Calculated from unpublished data of Dale.

Table 4. Probabilities of specified average soil water contents during half-month periods for Marshall soil at Norwich, Iowa, 1948-1965

Percent water by volume	April		May		June		July		August		Sept.		October		Nov.
	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-15	16-31	1-15
							0-15 cm. depth								
32.5-36.0	.143	.059	0	.222	.278	.556	.611	.222	.389	.389	.333	.445	.389	.222	.333
28.8-32.4	.428	.235	.411	.278	.222	.333	.167	.278	.167	.111	.500	.278	.111	.167	.222
25.1-28.7	.357	.294	.235	.222	.167	.111	.111	.222	.222	.278	.056	.111	.167	.222	.167
21.5-25.0	0	.059	.294	.056	.111	0	.056	.222	.056	.056	.056	.056	.056	.167	.056
17.7-21.4	0	.353	.059	.222	.222	0	.056	0	.167	.167	.056	.056	.222	.167	.056
<17.7	.071	0	0	0	0	0	0	.056	0	0	0	.056	.056	.056	.167
							15-30 cm. depth								
32.5-36.0	.713	.825	.825	.835	.667	.333	.278	.056	.056	.333	.222	.389	.722	.835	.890
28.8-32.4	.143	.118	.118	.111	.222	.278	.222	.278	.167	.222	.333	.278	.111	0	0
25.1-28.7	.071	0	0	0	.056	.111	.333	.167	.278	.111	.278	.167	.111	.111	.056
21.5-25.0	0	0	0	0	0	.222	0	.111	.167	0	.056	.167	.056	.056	.056
17.7-21.4	.071	.059	.059	.056	.056	.056	.167	.278	.222	.222	.056	0	0	0	0
<17.7	0	0	0	0	0	0	0	.111	.111	.111	.056	0	0	0	0
							30-45 cm. depth								
34.2-37.7	.571	.648	.766	.835	.890	.611	.500	.333	.222	.389	.500	.611	.667	.779	.835
30.5-34.1	.214	.235	.118	.111	.056	.333	.167	.278	.222	0	.056	.167	.111	0	0
26.8-30.4	.143	.059	.059	0	0	0	.222	.167	.111	.167	.111	0	0	0	.056
23.2-26.7	0	0	0	0	0	0	.111	.111	.167	.111	.111	.056	.056	.056	0
19.4-23.1	.071	.059	.059	.056	.056	.056	0	.111	.278	.167	.056	0	0	0	0
<19.4	0	0	0	0	0	0	0	0	0	.167	.167	.167	.167	.167	.111

and the first half of July. There are probably three major reasons for this. The first is that the highest probability of rainfall occurs during the last half of June, thus soil water in general should be high. The second reason is that a canopy is beginning to develop and some shading is occurring. Finally, in the estimation procedure Dale assumes the radiant energy is used by the plant to remove water from the root zone, thus there is less energy available for evaporating it from the soil surface and his estimation procedure therefore removes water from the root zone.

Figures 18 through 21 illustrate the probabilities of having equivalent soil water contents at each of the three depths. In Figure 18 it will be noticed that the least erratic soil water distribution with time is at the 30 to 45 cm. soil depth. This graph shows water contents near field capacity. Note that the surface zone, 0 to 15 cm. depth, has the lowest probability of being at or near field capacity during April and May. During this period evaporation is occurring from the surface. The estimation procedure used by Dale does not remove water from the soil at a depth greater than 15 cm. during this period. Therefore, the probability of having a high soil water content at the 15 to 30 cm. and 30 to 45 cm. depths is high compared to the 0 to 15 cm. depth.

Note in Table 4 that the probability of having at least 25 percent soil water by volume in the 0 to 15 cm. depth is greatest during the last half of June and least during the last half of April. The probability of the soil containing at least 25 percent water in the 15 to 30 cm. depth as seen in Table 4, is greatest during the first half of June and again during October and the first half of November. The probability is lowest

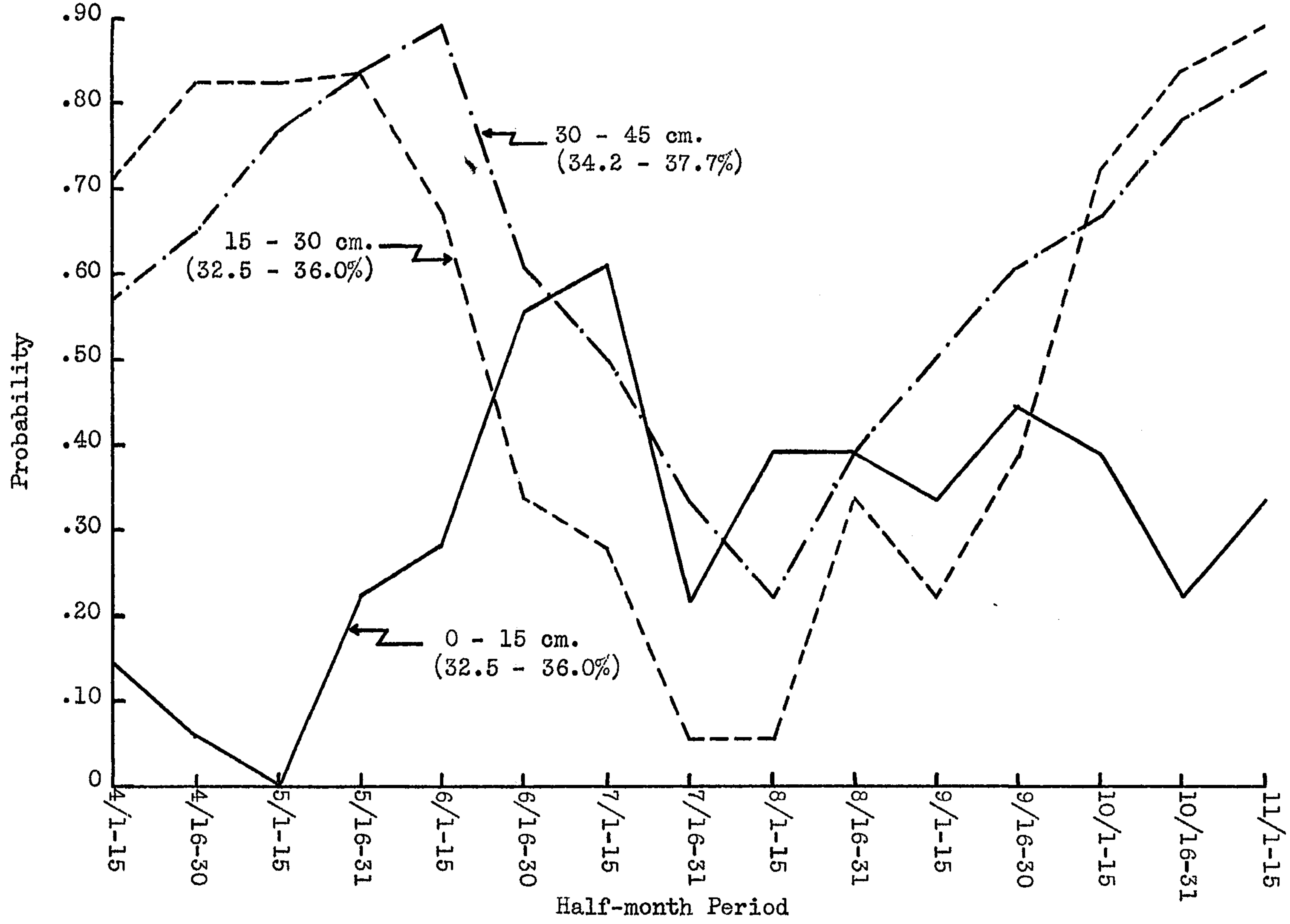

Figure 18. The probabilities of having the average half-month soil water contents shown in parentheses for different soil depths in Marshall soil based on the period 1948-1965 at Norwich, Iowa

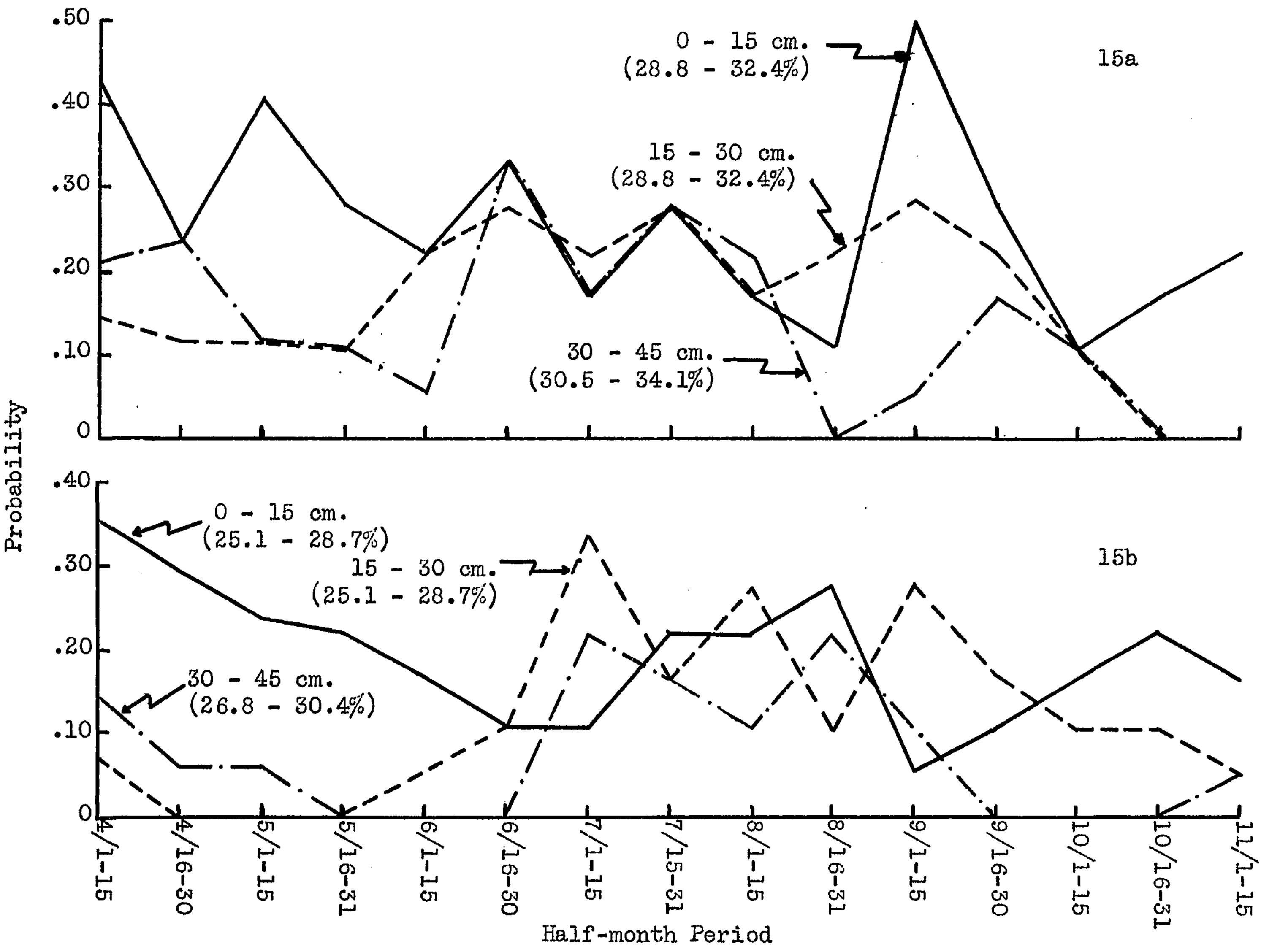

Figure 19. The probabilities of having the average half-month soil water contents shown in parentheses for different soil depths in Marshall soil based on the period 1948-1965 at Norwich, Iowa

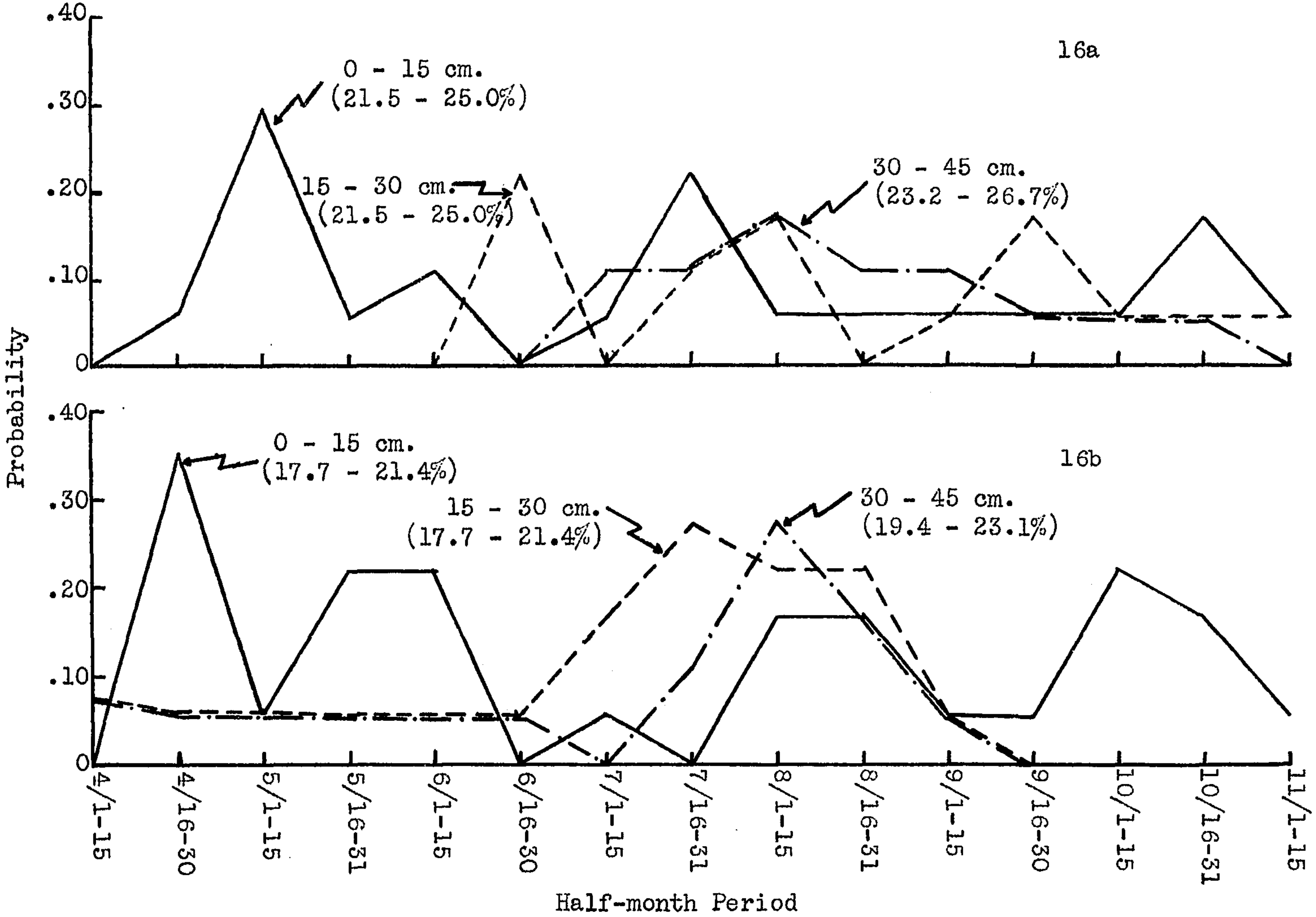

Figure 20. The probabilities of having the average half-month soil water contents shown in parentheses for different soil depths in Marshall soil based on the period 1948-1965 at Norwich, Iowa

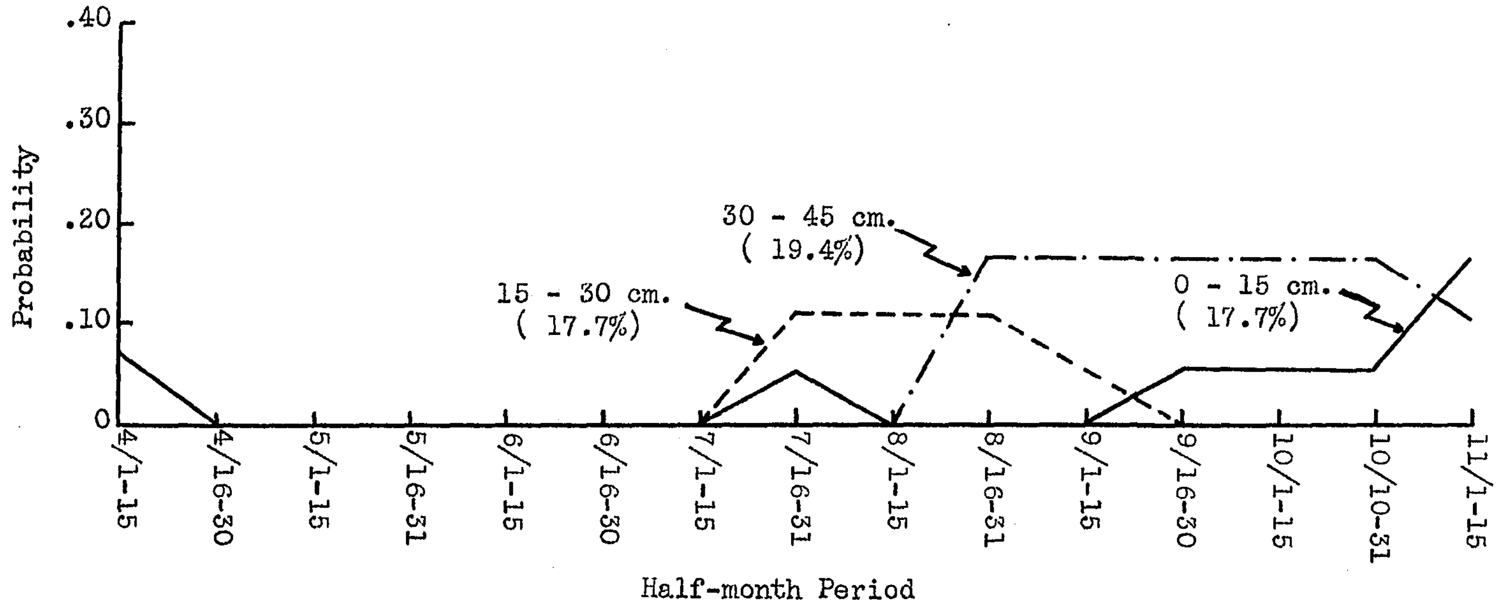

Figure 21. The probabilities of having average half-month soil water contents less than the 15-bar percentage for different soil depths in Marshall soil based on the period 1948-1965 at Norwich, Iowa

during the last half of July and the first half of August. As seen in Table 4, the probability of having a corresponding soil water content (greater than 26.7 percent by volume) in the 30 to 45 cm. depth is greatest during the entire period of April 1 through June 30 and lowest during the month of August. It is during July and August that water loss is generally greatest from this zone because of the greater root development.

Figures 19a through 20b show the probabilities of having progressively lower soil water contents at each of the three soil depths. Figure 21 shows the probability of having a soil water content less than the permanent wilting percentage of the soil. This probability is greatest in general, for all three soil depths during the latter part of the summer and during the autumn months. Water demand is greatest during the summer when the plant root system is well-developed and radiant energy is high. This results in a high water loss through transpiration, particularly from the rooting zone. During this time rainfall is generally lower, therefore less water is available which results in the higher probability of low soil water contents. Note the same trend in Figures 20a and 20b.

Rainfall Probabilities

Table 5 gives the probabilities of receiving one or more and two or more rains of specified 30-minute intensities for the 32-year period 1932 through 1963 at Norwich, Iowa. These probabilities are plotted in Figures 22 and 23. Figure 22 illustrates the probability of receiving one or more rains and Figure 23 illustrates the probability of receiving two or more rains.

The probability of receiving the higher intensity rains is greatest

Table 5. The probability of receiving one or more and two or more rains of specified 30-minute intensities during half-month periods based on the period 1932-1963 at Norwich, Iowa

Period	Intensity											
	≥7.60 cm./hr.		≥6.34 cm./hr.		≥5.08 cm./hr.		≥3.80 cm./hr.		≥2.54 cm./hr.		≥1.26 cm./hr.	
	1 or more rains	2 or more rains	1 or more rains	2 or more rains	1 or more rains	2 or more rains	1 or more rains	2 or more rains	1 or more rains	2 or more rains	1 or more rains	2 or more rains
4/1 - 4/15	0	0	0	0	0	0	0	0	.125	0	.250	.031
4/16 - 4/30	0	0	0	0	0	0	.031	0	.125	0	.468	.166
5/1 - 5/15	0	0	.031	0	.031	0	.125	0	.281	.031	.625	.250
5/16 - 5/31	0	0	0	0	0	0	.031	0	.281	.156	.688	.375
6/1 - 6/15	.031	0	.188	0	.219	.031	.375	.156	.594	.344	.719	.561
6/16 - 6/30	.063	0	.094	.031	.188	.063	.344	.094	.626	.219	.731	.688
7/1 - 7/15	.063	0	.094	0	.094	0	.156	.031	.313	.125	.561	.406
7/16 - 7/31	.031	0	.063	0	.156	.063	.250	.094	.469	.125	.593	.313
8/1 - 8/15	.031	0	.031	0	.156	0	.250	.031	.469	.188	.688	.531
8/16 - 8/31	0	0	0	0	.094	0	.219	0	.500	.094	.688	.281
9/1 - 9/15	0	0	.031	.031	.063	.031	.125	.031	.281	.063	.531	.281
9/16 - 9/30	0	0	0	0	0	0	.031	0	.188	0	.500	.063
10/1 - 10/15	0	0	0	0	.031	0	.031	0	.031	.031	.250	.094
10/16 - 10/31	0	0	0	0	0	0	.063	0	.063	0	.250	.125
11/1 - 11/15	0	0	0	0	0	0	0	0	.031	0	.094	0

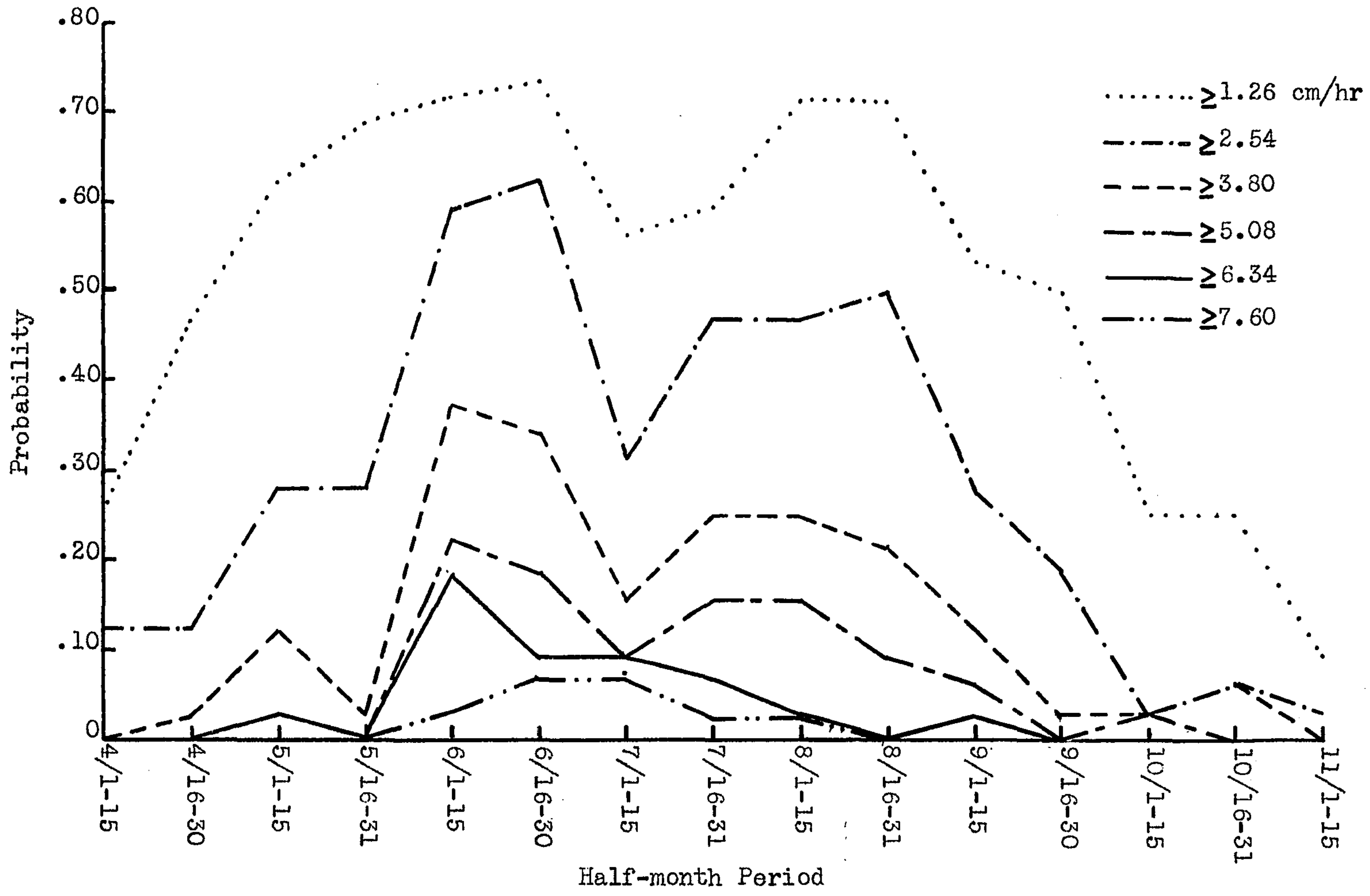

Figure 22. The probability of receiving one or more rains of specified 30-minute intensities during half-month periods based on the period 1932-1963 at Norwich, Iowa

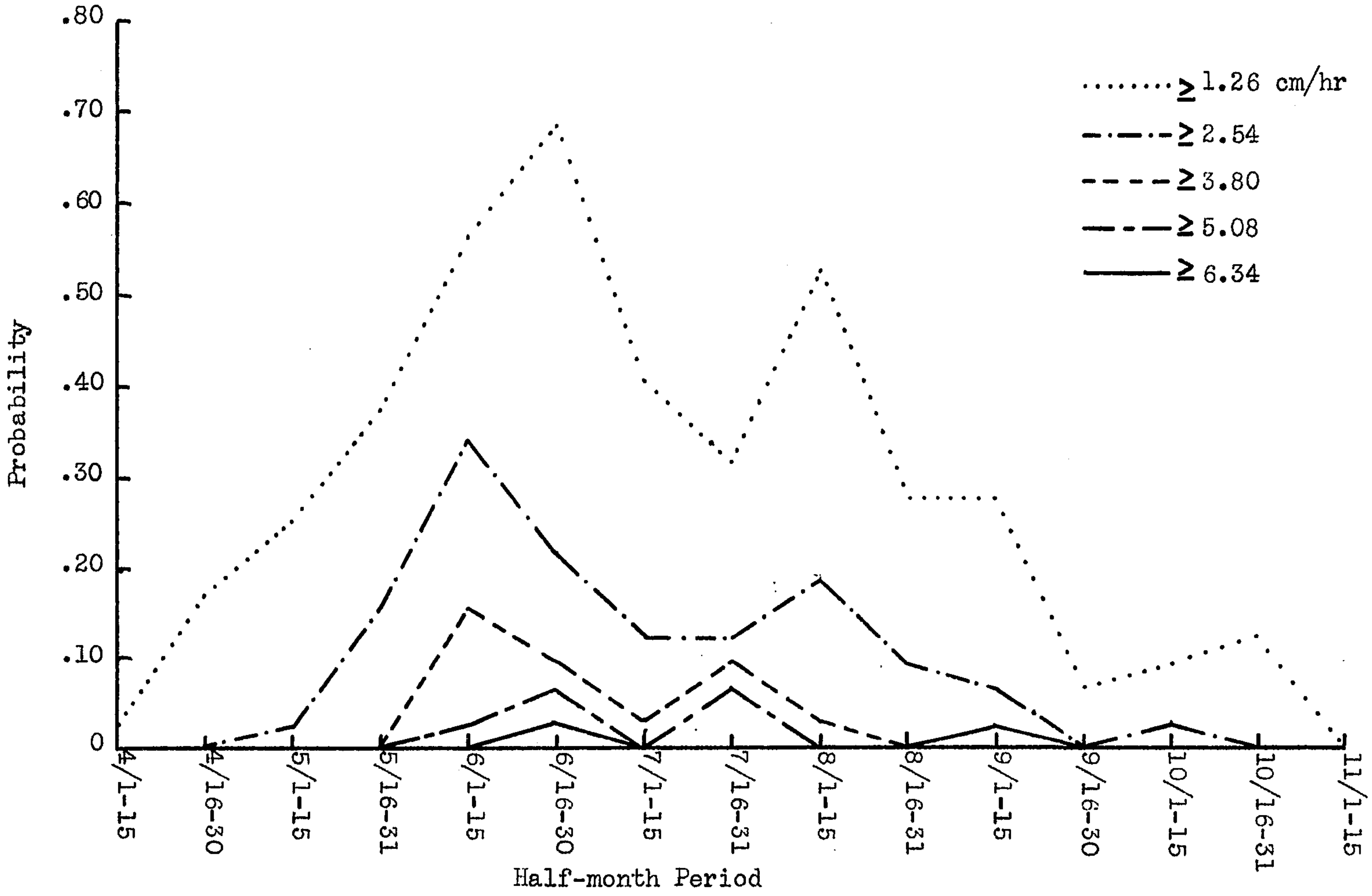

Figure 23. The probability of receiving two or more rains of specified 30-minute intensities during half-month periods based on the period 1932-1963 at Norwich, Iowa

during June. The probability of receiving a higher number of high intensity rains is also greatest in June as can be seen in Figure 23. Rainfall probability decreases during the first half of July then increases again and remains relatively high until about the first half of October. The highest probability of receiving two or more rains of at least 1.26 cm. per hour over a 30-minute period occurs during the last half of June.

Figures 22 and 23 reveal a generally well-defined pattern of rainfall probabilities throughout the season from April 1 through November 15 regardless of the intensity.

One of the stated objectives of this study was to determine the probability of receiving rainfall rates greater than the infiltration rate of the soil for given periods of the year. Since the infiltration rate is dependent upon the antecedent soil water content, it is necessary to know the probability of having the specified soil water content to determine the probability of receiving a rainfall rate exceeding infiltration rate for a selected period of time.

As an example, if the probability for receiving a rainfall rate exceeding infiltration were desired for the period July 16 through July 31 and for an antecedent soil water content of 16 percent the infiltration rate-time relationship shown in Figure 10 would be used. Figure 21 shows the probability of having a soil water content less than 17.7 percent for the surface 15 cm. of soil. For the period July 16 through July 31 there is a 5 percent probability of having a soil water content less than 17.7 percent. Referring to Figure 22, the probability of receiving a rainfall rate greater than 1.25 cm./hr., which is the equilibrium infiltration rate for a soil containing 16 percent water, would be about 59 percent during the period July 16 through July 31. Combining the two probabilities (5 percent x 59 percent) results in a 2.95 percent probability of receiving a rainfall rate greater than the soil infiltration rate for the specified set of conditions.

For an antecedent soil water content of 36 percent, the probability of receiving rainfall exceeding the infiltration rate would be 13.3 percent (22.5 percent from Figure 18 multiplied by 59 percent from Figure 22) for the period July 16 through July 31. The infiltration rate for an antecedent soil water content of 36 percent is shown in Figure 11. If the period selected were July 1 through July 15 the probability of receiving a rainfall rate exceeding the infiltration rate would be 36.0 percent (61 percent x 59 percent) because of the higher probability of having a 36 percent antecedent soil water content for this period.

Infiltration rates were estimated for only two antecedent soil water contents, 16 percent and 36 percent, except for the variable water contents of the surface few cm. shown in Figure 11. These infiltration estimates were sufficient to illustrate the method of using the information presented in this study. As was indicated earlier, the weakest part of determining the probability of rainfall exceeding infiltration is probably the estimation of the soil water content of the surface few cm. of soil.

Granting some of the weaknesses discussed, this study does indicate a very real possibility of combining estimated infiltration rate, estimated soil water content, and rainfall probabilities to determine the probability of runoff from rainfall for a specified period of the year. Further studies may be made to solve some of the problems encountered in this study and perhaps to refine some of the techniques that were used.

SUMMARY AND CONCLUSIONS

A study was initiated to:

1. characterize the Marshall soil series from various locations within the Marshall Soil Association area with respect to various physical and hydrologic factors relating to infiltration;
2. estimate infiltration rates and cumulative infiltrations at different antecedent water contents on Marshall silty clay loam soil;
3. relate probable antecedent soil water content, estimated infiltration, and rainfall probability of selected intensities for different periods of the year as a means of determining the probability of runoff producing rainfall; and
4. delineate some of the problems involved in using the numerical procedure of Hanks and Bowers (1962) for estimating infiltration into a soil.

Ten sites within the Marshall Soil Association area were selected at random to characterize the series. Data for six additional sites were obtained from the Soil Survey Laboratory, Lincoln, Nebraska. Profile descriptions for the 16 sites are given in Appendix A. The results of the various laboratory analyses given in Tables 6, 7, and 10 of the Appendix indicate small variations between the soils analyzed.

Four sites were sampled for capillary conductivity determinations to be used in estimating infiltration. Because of the small amount of variation in characteristics of the soil, the data from the four sites used in the infiltration estimates were averaged to represent the Marshall soil series.

Infiltration estimates were made for different antecedent soil water contents representing a dry soil, a wet soil, and two wet soils with varying water contents in the surface layer. Different depth increments were also investigated and found to influence infiltration estimates.

Diffusivities measured at suctions greater than 100 cm. have an effect on infiltration estimates but the effect is large only for large differences in diffusivity.

Soil water contents for several years were estimated by the procedure of Shaw (1963) and computer programmed by Dale and Hartley (1963) and a probability distribution was determined. Table 4 shows the probabilities for Norwich, Iowa.

Probabilities for rainfall of specified intensities were calculated for half-month periods at Norwich, Iowa. Figure 22 shows the probabilities of receiving one or more rains of specified intensities.

A system was devised for determining the probability of runoff occurring under a given set of conditions for half-month periods during the growing season. Since infiltration is dependent upon antecedent soil water content, the probability of a given infiltration rate can be determined from the probability of the soil water content corresponding to the given infiltration rate. Combining probability for the given infiltration rate with the probability of receiving a rain greater than the infiltration rate results in a probability for having runoff.

One of the weaknesses of the method discussed is the procedure for estimating soil water content. The procedure of Shaw (1963) and Dale and Hartley (1963) estimates the water content by 15 cm. increments. Variations in water content within the top 15 cm. of soil may significantly affect the resulting infiltration rate. Therefore, averaging the soil water content across the 15 cm. increment may result in serious errors in estimating infiltration. A means of estimating soil water content on much smaller increments is necessary for more accurate infiltration estimates in calculating runoff probabilities.

Another factor affecting infiltration is surface crusting. Edwards (1967) developed a means to assess the effect of crusting on infiltration. He showed that surface crusting can have a marked effect on infiltration.

The present study has indicated a means by which soil water probabilities, estimated infiltration, and rainfall probability can all be used to determine the probability of having runoff under a given set of conditions.

Future studies need to be conducted to refine the soil water estimation parameter and to develop a means of combining the procedure for determining the effect of crusting on infiltration with the estimation procedure of Hanks and Bowers (1962).

Refinement of the procedures used in this study and discussed above should help lead to an effective means of determining the runoff probabilities for soils without vegetation. The runoff probabilities could then be used to aid in development of watersheds for flood control and water storage.

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APPENDIX A

Descriptions and locations of Marshall profiles used in this study.

In the descriptions of profiles 1 through 10, the Munsell colors are for moist soil. Field pH was determined by use of Parstains solutions. Representatives of the Iowa soil survey staff of the Soil Conservation Service and Iowa State University consider grayish colored mottles in the B and C horizons of Marshall soils to be relict features.

Profile 1. Location: 1090 feet east and 335 feet north of the southwest corner of SW 1/4, SE 1/4, Section 33, T. 85 N., R. 37 W., Crawford County, Iowa (corn yield site No. 15).

This profile is located on a convex, south-southwest facing 8 percent slope. The soil at the site has suffered slight erosion. Corn was growing on the site at the time of sampling, August, 1964.

Ap 0 to 7 inches, very dark brown (10YR 2/2, moist) silty clay loam; moderate medium granular structure; friable when moist; roots; abrupt smooth lower boundary.

B1 7 to 12 inches, brown to dark brown (10YR 4/3, moist), silty clay loam, moderate medium subangular blocky structure; friable when moist; few fine roots; gradual smooth lower boundary.

B2 12 to 21 inches, yellowish brown to dark yellowish brown (10YR 4.5/4, moist) silty clay loam; few faint olive gray (5Y 5/2, moist) and yellowish brown (10YR 5/6, moist) mottles; weak medium subangular blocky structure; slightly firm when moist; few fine roots; gradual smooth lower boundary.

B3 21 to 31 inches, grayish brown (2.5Y 5/2, moist) light silty clay loam; few coarse prominent strong brown (7.5YR 4/6, moist) mottles; weak coarse subangular blocky structure; thin continuous dark grayish brown (2.5Y 4/2, moist) clay coatings on vertical ped surfaces; friable when moist, slightly plastic when wet; pH 6.4; abrupt smooth lower boundary.

C 31 to 40 inches +, grayish brown (2.5Y 5/2, moist) light silty clay loam; common medium distinct yellowish brown (10YR 5/4, moist) mottles; massive; friable when moist; slightly plastic when wet; pH 6.8.

Profile 2. Location: 235 feet west and 765 feet north of the southeast corner of SE 1/4, SW 1/4, Section 1, T. 76 N., R. 36 W., Cass County, Iowa (corn yield site No. 16).

This profile is located on a slightly convex, south facing 8 percent slope. The soil is moderately well drained and erosion has been slight at this site. Corn was being grown on the area at the time of sampling, August, 1964.

Ap 0 to 7 inches, very dark grayish brown (10YR 3/2, moist) silty clay loam; weak fine subangular blocky structure that breaks into very weak fine granules; friable when moist, slightly sticky and slightly plastic when wet; plentiful fine roots; many fine and common medium pores; pH 6.4; abrupt smooth lower boundary.

A3 7 to 13 inches, dark grayish brown (10YR 4/2, moist) silty clay loam; weak fine subangular blocky structure; thin continuous very dark gray (10YR 3/1, moist) coatings on ped surfaces; friable when moist, slightly sticky and plastic when wet; plentiful fine roots; many very fine and common fine pores; pH 6.6; clear wavy lower boundary.

B1 13 to 17 inches, light olive brown (2.5Y 5/3, moist) silty clay loam; moderate fine subangular blocky structure; thin continuous dark gray (10YR 4/1, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and plastic when wet; plentiful fine roots; many very fine and common fine pores; pH 6.6; clear wavy lower boundary.

B2 17 to 24 inches, light olive brown (2.5Y 5/3, moist) silty clay loam; few fine distinct yellowish brown (10YR 5/6, moist) mottles; very weak medium prismatic structure that breaks into moderate coarse angular blocks; thin continuous dark grayish brown (2.5Y 4/2, moist) coatings on ped and pore surfaces; firm when moist, slightly sticky and plastic when wet; plentiful fine roots; many very fine and common fine pores; pH 6.7; abrupt wavy lower boundary.

B3 24 to 31 inches, light yellowish brown (2.5Y 6/3, moist) light silty clay loam; common medium distinct strong brown (7.5YR 5/6, moist) mottles; weak medium subangular blocky structure; thin discontinuous grayish brown (2.5Y 5/2, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and plastic when wet; plentiful fine roots; many very fine and common fine pores; pH 6.8; gradual wavy lower boundary.

C 31 to 45 inches +, light brownish gray (2.5Y 6/2, moist) heavy silt loam; common medium distinct strong brown (7.5YR 5/6, moist) mottles; massive; friable when moist, slightly sticky and slightly plastic when wet; few fine roots; many very fine pores; pH 7.0.

Profile 3. Location: 340 feet east and 745 feet south of the northwest corner of NW 1/4, NW 1/4, Section 29, T. 84 N., R. 37 W., Crawford County, Iowa (corn yield site No. 30; described by K. L. Wells, R. L. Warren, and E. C. A. Runge).

This profile is located on a slightly convex, west facing 8 percent slope. The soil at the site has suffered moderate erosion. There were numerous medium roots throughout the profile. A large krotovina was found at a depth of 11 to 18 inches. Corn was growing on the area at the time of sampling.

Ap 0 to 6 inches, very dark brown (10YR 2/2, moist) light silty clay loam; medium granular structure; friable when moist; clear lower boundary.

A3B1 6 to 11 inches, very dark grayish brown (10YR 3/2, moist) silty clay loam; weak medium subangular blocky structure that breaks into medium granules; friable when moist; gradual lower boundary.

B21 11 to 18 inches, dark yellowish brown (10YR 3/4, moist) silty clay loam; weak medium subangular blocky structure; slightly firm when moist; gradual lower boundary.

B22 18 to 28 inches, dark yellowish brown (10YR 3.5/4, moist) silty clay loam; weak medium subangular blocky structure; slightly firm when moist; gradual lower boundary.

C1 28 to 36 inches +, dark yellowish brown (10YR 4/4, moist) light silty clay loam; few fine faint olive gray (5Y 5/2, moist) and yellowish brown (10YR 5/6, moist) mottles; massive; friable when moist.

Profile 4. Location: 640 feet west and 210 feet north of the southeast corner of NE 1/4, NW 1/4, Section 5, T. 75 N., R. 35 W., Cass County, Iowa.

This profile is located on a convex, southwest facing 4 percent slope. The soil has been slightly eroded and internal drainage is good. A plow sole was found in the A3 horizon. Corn was growing on the area at the time of sampling, August, 1964.

Ap 0 to 5 inches, very dark grayish brown (10YR 3/2, moist) silty clay loam; weak fine subangular blocky structure that breaks into weak fine granules; friable when moist, slightly sticky and slightly plastic when wet; plentiful fine roots; many fine pores; pH 6.4; abrupt smooth lower boundary.

A3 5 to 10 inches, very dark grayish brown (10YR 3/2, moist) silty clay loam; weak medium angular blocky structure; friable when moist; slightly sticky and plastic when wet; plentiful fine roots; common fine pores; pH 6.4; abrupt wavy lower boundary.

B1 10 to 15 inches, dark grayish brown (10YR 4/2, moist) silty clay loam; moderate very fine subangular blocky structure; thin discontinuous very dark grayish brown (10YR 3/2, moist) coatings on ped and pore surfaces; firm when moist, sticky and plastic when wet; plentiful fine roots; many very fine and fine pores; pH 6.4; clear wavy lower boundary.

B2 15 to 29 inches, olive brown (2.5Y 4/3, moist) silty clay loam; weak medium prismatic structure that breaks into moderate medium angular blocks; thin continuous dark grayish brown (10YR 4/2, moist) coatings on ped and pore surfaces; firm when moist, sticky and plastic when wet; plentiful fine roots; many very fine and common fine pores; pH 6.6; clear wavy lower boundary.

B3 29 to 38 inches, grayish brown (2.5Y 5/2, moist) light silty clay loam; common medium distinct black (5YR 2/1, moist) and common fine distinct dark brown (7.5YR 4/4, moist) mottles; moderate medium subangular blocky structure; thin discontinuous dark grayish brown (10YR 4/2, moist) coatings on ped and pore surfaces; firm when moist, slightly sticky and plastic when wet; few fine roots; many very fine and common fine pores; pH 6.6; gradual wavy lower boundary.

C 38 to 49 inches +, grayish brown (2.5Y 5/2, moist) light silty clay loam; common medium distinct black (5YR 2/1, moist) and common fine distinct dark brown (7.5YR 4/4, moist) mottles; massive; firm when moist, slightly sticky and plastic when wet; few fine roots; many very fine and common fine pores; pH 6.8.

Profile 5. Location: 450 feet west and 85 feet north of the southeast corner of SE 1/4, SW 1/4, Section 14, T. 74 N., R. 42 W., Pottawattamie County, Iowa (USDA Watershed at Treynor).

This profile is located on a convex, west facing 6 percent slope. The soil is slightly eroded and well drained internally. A plow sole was found in the A3 horizon. Corn was growing on the area at the time of sampling, August, 1964.

Ap 0 to 6 inches, very dark grayish brown (10YR 3/2, moist) light silty clay loam; moderate fine granular structure; friable when moist, slightly sticky and slightly plastic when wet; plentiful fine roots; many fine pores; pH 6.6; abrupt smooth lower boundary.

A3 6 to 14 inches, very dark grayish brown (10YR 3/2, moist) light silty clay loam; massive; firm when moist, slightly sticky and slightly plastic when wet; few fine roots; few very fine to fine pores; pH 6.7; clear wavy lower boundary.

B1 14 to 18 inches, dark grayish brown (10YR 4/2, moist) light silty clay loam; weak to moderate fine angular blocky structure; thin continuous very dark grayish brown (10YR 3/2, moist) coatings; firm when moist, slightly sticky and plastic when wet; plentiful fine roots; common very fine and few medium pores; pH 6.8; abrupt wavy lower boundary.

B2 18 to 33 inches, olive brown (2.5Y 4/3, moist) silty clay loam; weak medium prismatic structure that breaks into weak medium angular blocks; thin continuous dark gray (10YR 4/1, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and plastic when wet; few fine roots; many very fine and few fine pores; pH 6.9; gradual wavy lower boundary.

B3 33 to 40 inches, light olive brown (2.5Y 5/3, moist) light silty clay loam; common fine distinct dark brown (7.5YR 4/4, moist) mottles; weak medium subangular blocky structure; thin distinct dark grayish brown (10YR 4/2, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and plastic when wet; few very fine roots; many very fine and common fine pores; pH 7.0; gradual wavy lower boundary.

C 40 to 48 inches +, grayish brown (2.5Y 5/2, moist) silt loam; many medium distinct dark brown (7.5YR 4/4, moist) and few fine prominent black (5YR 2/1, moist) mottles; massive; friable when moist, slightly sticky and slightly plastic when wet; many very fine and common fine pores; pH 7.0.

Profile 6. Location: 660 feet north and 100 feet west of the southeast corner of SE 1/4, SE 1/4, Section 14, T. 74 N., R. 42 W., Pottawattamie County, Iowa (USDA Watershed at Treynor).

This profile is located on a slightly convex, southeast facing 6 percent slope. Erosion has been slight and the soil at this site is well-drained. There were rodent mounds nearby and a krotovina was found near the bottom of the profile. Bromegrass was growing on the site at the time of sampling, August, 1964.

Ap 0 to 5 inches, very dark grayish brown (10YR 3/2, moist) light silty clay loam; moderate fine granular structure; friable when moist, slightly sticky and slightly plastic when wet; many fine to medium roots; many fine pores; pH 6.8; abrupt smooth lower boundary.

A3 5 to 10 inches, dark grayish brown (10YR 4/2, moist) silty clay loam; moderate fine angular blocky structure; thin continuous very dark gray (10YR 3/1, moist) coatings; firm when moist, slightly sticky and slightly plastic when wet; pH 7.0; clear smooth lower boundary.

B1 10 to 16 inches, brown (10YR 5/3, moist) silty clay loam; moderate fine subangular blocky structure; thin discontinuous very dark gray (10YR 3/1, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and slightly plastic when wet; pH 7.0; gradual wavy lower boundary.

B2 16 to 25 inches, brown (10YR 5/3, moist) silty clay loam; weak coarse prismatic structure that breaks into weak medium subangular blocks; thin discontinuous very dark grayish brown (10YR 3/2, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and plastic when wet; pH 7.0; gradual wavy lower boundary.

B3 25 to 34 inches, light olive brown (2.5Y 5/3, moist) light silty clay loam; weak medium subangular blocky structure; thin discontinuous dark gray (10YR 4/1, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and slightly plastic when wet; pH 7.0; gradual wavy lower boundary.

C 34 to 46 inches +, light olive brown (2.5Y 5/3, moist) silt loam; few fine distinct yellowish brown (10YR 5/6, moist) mottles; massive; friable when moist, slightly sticky and slightly plastic when wet; pH 7.0.

Profile 7. Location: 1030 feet east and 140 feet north of the southwest corner of NE 1/4, NE 1/4, Section 14, T. 74 N., R. 40 W., Pottawattamie County, Iowa.

This profile is located on a slightly convex east-northeast facing 8 percent slope. The soil at this site has suffered slight erosion and it is moderately well drained. A krotovina was found in the lower part of the profile. Corn was growing on the area at the time of sampling, August, 1964.

Ap 0 to 6 inches, very dark grayish brown (10YR 3/2, moist) light silty clay loam; weak very fine subangular blocky structure that breaks into weak to moderate fine granules; friable when moist, slightly sticky and slightly plastic when wet; plentiful fine roots; many fine pores; pH 6.6; abrupt smooth lower boundary.

A3 6 to 10 inches, dark grayish brown (10YR 4/2, moist) silty clay loam; weak medium angular blocky structure; thin continuous very dark gray (10YR 3/1, moist) coatings; firm when moist, slightly sticky and plastic when wet; plentiful fine roots; common fine pores; pH 6.7; clear wavy lower boundary.

B1 10 to 16 inches, grayish brown (2.5Y 5/2, moist) silty clay loam; weak to moderate medium subangular blocky structure; thin discontinuous dark grayish brown (10YR 4/2, moist) coatings on ped and pore surfaces; firm when moist, slightly sticky and plastic when wet; plentiful fine roots; common fine pores; pH 6.7; clear wavy lower boundary.

B2 16 to 28 inches, olive brown (2.5Y 4/3, moist) silty clay loam; few fine distinct strong brown (7.5YR 5/6, moist) mottles; weak coarse prismatic structure that breaks into weak medium angular blocks; thin continuous dark grayish brown (10YR 4/2, moist) coatings on ped and pore surfaces; firm when moist, slightly sticky and plastic when wet; plentiful fine roots; common fine pores; pH 6.8; gradual wavy lower boundary.

B3 28 to 38 inches, grayish brown (2.5Y 5/2, moist) light silty clay loam; common fine distinct strong brown (7.5YR 5/6, moist) mottles; weak medium subangular blocky structure; thin discontinuous dark grayish brown (2.5Y 4/2, moist) coatings on ped and pore surfaces; firm when moist, slightly sticky and plastic when wet; few fine roots; common fine pores; pH 6.8; clear wavy lower boundary.

C 34 to 43 inches +, light brownish gray (2.5Y 6/2, moist) light silty clay loam; many medium distinct strong brown (7.5YR 5/6, moist) mottles; massive; firm when moist, slightly sticky and plastic when wet; few fine roots; common fine pores; pH 7.0.

Profile 8. Location: 725 feet west and 180 feet north of the southeast corner of SE 1/4, SE 1/4, Section 28, T. 69 N., R. 38 W., Page County, Iowa (runoff plots on Soil Conservation Farm).

This profile is located on a planar southwest facing 9 percent slope. It is a moderately well drained soil and erosion has been slight. The plot was fallow at the time of sampling, August, 1964.

Ap 0 to 5 inches, very dark grayish brown (10YR 3/2, moist) silty clay loam; puddled; very hard when dry, friable when moist, slightly sticky and slightly plastic when wet; plentiful fine roots; many very fine and common medium pores; pH 6.7; abrupt wavy lower boundary.

A3 5 to 9 inches, dark grayish brown (10YR 4/2, moist) silty clay loam; weak to moderate very fine angular blocky structure; thin continuous very dark gray (10YR 3/1, moist) coatings; friable when moist, slightly sticky and plastic when wet; few fine roots; many very fine and common fine pores; pH 6.6; clear smooth lower boundary.

B1 9 to 13 inches, dark grayish brown (10YR 4/2, moist) silty clay loam; moderate very fine angular blocky structure; thin continuous very dark grayish brown (10YR 3/2, moist) coatings on ped and pore surfaces; firm when moist, slightly sticky and plastic when wet; few fine roots; many very fine and common fine pores; pH 6.4; clear wavy lower boundary.

B2 13 to 24 inches, olive brown (2.5Y 4/3, moist) silty clay loam; weak medium prismatic structure that breaks into moderate fine angular blocks; thin continuous dark grayish brown (10YR 4/2, moist) coatings on ped and pore surfaces; firm when moist, sticky and plastic when wet; few very fine roots; many very fine and common fine pores; pH 6.5; gradual wavy lower boundary.

B3 24 to 29 inches, olive brown (2.5Y 4/3, moist) light silty clay loam; weak medium subangular blocky structure; thin continuous dark grayish brown (10YR 4/2, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and plastic when wet; few very fine roots; many very fine and common fine pores; pH 6.5; gradual wavy lower boundary.

C 29 to 35 inches +, olive brown (2.5Y 4/3, moist) heavy silt loam; common fine distinct yellowish red (5YR 4/6, moist) and few fine prominent black (5YR 2/1, moist) mottles; massive; friable when moist, slightly sticky and slightly plastic when wet; common fine pores; pH 6.5.

Profile 9. Location: 920 feet north and 170 feet east of the southwest corner of NE 1/4, NW 1/4, Section 34, T. 71 N., R. 39 W., Montgomery County, Iowa.

This profile is located on a convex southwest facing 7 percent slope. It is moderately well drained. Erosion has been slight. The area was in pasture at the time of sampling, August, 1964.

Ap 0 to 6 inches, very dark grayish brown (10YR 3/2, moist) silty clay loam; moderate fine angular blocky structure, except weak medium granular structure in top inch; firm when moist, slightly sticky and plastic when wet; abundant fine roots; common fine pores; pH 6.7; clear smooth lower boundary.

A3 6 to 10 inches, dark grayish brown (10YR 4/2, moist) silty clay loam; weak medium prismatic structure that breaks into moderate very fine angular blocks; thin continuous very dark gray (10YR 3/1, moist) coatings; firm when moist, slightly sticky and plastic when wet; abundant fine roots; common fine pores; pH 6.7; clear smooth lower boundary.

B1 10 to 14 inches, dark grayish brown (10YR 4/2, moist) silty clay loam; very weak medium prismatic structure that breaks into moderate fine angular blocks; thin continuous very dark grayish brown (10YR 3/2, moist) coatings on ped and pore surfaces; firm when moist, sticky and plastic when wet; plentiful fine roots; common fine pores; pH 6.7; clear wavy lower boundary.

B21 14 to 20 inches, olive brown (2.5Y 4/3, moist) silty clay loam; weak medium prismatic structure that breaks into moderate fine angular blocks; thin continuous dark grayish brown (10YR 4/2, moist) coatings on ped and pore surfaces; firm when moist, sticky and plastic when wet; plentiful fine roots; common fine pores; pH 6.8; gradual smooth lower boundary.

B22 20 to 30 inches, grayish brown (2.5Y 5/2, moist) light silty clay loam; few fine prominent black (5YR 2/1, moist) and common fine distinct brown to dark brown (7.5YR 4/4, moist) mottles; weak to moderate medium prismatic structure that breaks into weak to moderate medium angular blocks; thin continuous dark grayish brown (2.5Y 4/2, moist) coatings on ped and pore surfaces; firm when moist, sticky and plastic when wet; plentiful fine roots; common fine pores; pH 6.9; gradual wavy lower boundary.

B3 30 to 37 inches, grayish brown (2.5Y 5/2, moist) light silty clay loam; common fine distinct brown to dark brown (7.5YR 4/4, moist) and few fine prominent black (5YR 2/1, moist) mottles; very weak coarse prismatic structure that breaks into weak coarse subangular blocks; fine discontinuous dark grayish brown (2.5Y 4/2, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and slightly plastic when wet; few fine roots; common fine pores; pH 7.0; gradual wavy lower boundary.

C 37 to 42 inches +, grayish brown (2.5Y 5/2, moist) heavy silt loam; many fine distinct brown to dark brown (7.5YR 4/4; moist) and common fine prominent very dark gray (5YR 3/1, moist) mottles; massive; friable when moist, slightly sticky and slightly plastic when wet; few very fine roots; common fine pores; pH 7.0.

Profile 10. Location: 100 feet east and 1180 feet south of the northwest corner of NW 1/4, NW 1/4, Section 16, T. 74 N., R. 38 W., Pottawattamie County, Iowa.

This profile is located on a slightly convex west facing 8 percent slope. The soil at this site is moderately well drained and has suffered slight erosion. Corn was growing on the area at the time of sampling, August, 1964.

Ap 0 to 6 inches, very dark grayish brown (10YR 3/2, moist) silty clay loam; weak fine subangular blocky structure; firm when moist, slightly sticky and slightly plastic when wet; few very fine roots; common fine pores; pH 7.6; abrupt smooth lower boundary.

A3 6 to 10 inches, dark grayish brown (10YR 4/2, moist) silty clay loam; weak fine subangular blocky structure; thin continuous very dark gray (10YR 3/1, moist) coatings; friable when moist, slightly sticky and slightly plastic when wet; few very fine roots; common fine pores; pH 7.4; clear smooth lower boundary.

B1 10 to 15 inches, olive brown (2.5Y 4/3, moist) silty clay loam; weak medium prismatic structure that breaks into weak fine subangular blocks; thin discontinuous very dark gray (10YR 3/1, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and slightly plastic when wet; few very fine roots; common fine pores; pH 7.2; gradual smooth lower boundary.

B2 15 to 31 inches, olive brown (2.5Y 4/3, moist) silty clay loam; weak medium prismatic structure that breaks into weak coarse angular blocks; thin continuous very dark grayish brown (2.5Y 3/2, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and plastic when wet; few very fine roots; common fine pores; pH 6.8; gradual wavy lower boundary.

B3 31 to 39 inches, grayish brown (2.5Y 5/2, moist) light silty clay loam; common fine distinct brown to dark brown (7.5YR 4/4, moist) and few fine prominent very dark gray (5YR 3/1, moist) mottles; weak medium subangular blocky structure; thin discontinuous dark grayish brown (2.5Y 4/2, moist) coatings on ped and pore surfaces; friable when moist, slightly sticky and slightly plastic when wet; few very fine roots; many very fine and common fine pores; pH 6.9; gradual wavy lower boundary.

C 39 to 45 inches +, grayish brown (2.5Y 5/2, moist) silt loam; common fine distinct brown to dark brown (7.5YR 4/4, moist) and few fine prominent very dark gray (5YR 3/1, moist) mottles; massive; friable when moist, slightly sticky and slightly plastic when wet; many very fine and common fine pores, pH 7.0.

Descriptions of profiles 11 through 16 were obtained from the Soil Survey Laboratory, Lincoln, Nebraska and are tentative descriptions. The Munsell colors and consistence are for moist soil. The field pH was determined by use of LaMotte solutions.

Profile 11. Location: 642 feet south of road center and 719 feet east of the northwest corner of the NW 1/4, SE 1/4, Section 34, T. 77 N., R. 37 W., Cass County, Iowa (approximately 3 miles northwest of Atlantic, Iowa).

This profile is located on a west or southwest facing less than 1 percent slope. It is a well drained moderately permeable soil. Clover was growing on the area at the time of sampling, May, 1963. (Described by R. I. Dideriksen, W. M. Jury)

Alp 0 to 7 inches, black (10YR 2/1) light silty clay loam, dark gray (10YR 4/1) when dry; weak medium subangular blocky breaking to weak fine granular structure; friable; common fine and medium root channels; black (10YR 2/1) to very dark drown (10YR 2/2) when kneaded; weak plow sole at 6 to 7 inches; pH 5.6; abrupt smooth boundary.

A12 7 to 16 inches, black (10YR 2/1) light silty clay loam, dark gray (10YR 4/1) when dry; very weak fine subangular blocky and moderate fine granular structure; friable; common fine and medium root channels; black (10YR 2/1) to very dark brown (10YR 2/2) when kneaded; pH 5.8; gradual smooth boundary.

A3 16 to 23 inches, very dark brown (10YR 2/2) with some very dark grayish brown (10YR 3/2) light to medium silty clay loam, dark gray (10YR 4/1) and dark grayish brown (10YR 4/2) when dry; weak fine subangular blocky structure; friable; few fine and medium root channels; very dark grayish brown (10YR 3/2) when kneaded; few moisture films on some peds; pH 5.8; clear smooth boundary.

B21 23 to 28 inches, mixed dark brown to brown (10YR 4/3) and very dark grayish brown (10YR 3/2) medium silty clay loam; pale brown (10YR 6/3) and light brownish gray (10YR 6/2) when dry; weak to moderate fine subangular blocky structure; ped exteriors are dark brown (10YR 4/3) and very dark grayish brown (10YR 3/2), ped interiors are dark brown to brown (10YR 4/3); friable; common fine and medium inped tubular pores; dark brown to brown (10YR 4/3) when kneaded; very few thin discontinuous clay films on some peds; very few, very fine soft dark brown concretions of an oxide; common 1/8-inch root fills of black material from above; pH 6.0; clear smooth boundary.

B22 28 to 36 inches, dark brown to brown (10YR 4/3) medium silty clay loam; weak medium prismatic breaking to moderate fine subangular blocky structure; friable; few fine and medium inped tubular pores; yellowish brown (10YR 5/4) when kneaded; very few, very fine soft dark brown concretions of an oxide; few thin discontinuous clay films on some peds; few black (10YR 2/1) root fills from above horizons; pH 6.0; gradual smooth boundary.

B23 36 to 44 inches, yellowish brown (10YR 5/4) light silty clay loam; weak medium prismatic breaking to moderate to weak medium subangular blocky structure; common (5%) fine grayish brown (2.5Y 5/2) mottles; friable to firm; common fine inped tubular pores; very few thin discontinuous clay films on some vertical ped faced; few fine dark brown and yellowish brown soft concretions of an oxide; pH 6.2; gradual smooth boundary.

B31 44 to 52 inches, mottled yellowish brown (10YR 5/4) and grayish brown (2.5Y 5/2) to olive gray (5Y 5/2) light silty clay loam to heavy silt loam; weak medium prismatic breaking to weak medium and coarse subangular blocky structure; many fine dark brown (7.5YR 4/4) and yellowish brown (10YR 5/6) mottles; friable to firm; pores same as above; few thin indistinct grainy silt coats and very few thin discontinuous clay films on some vertical ped faces; common very fine soft dark brown concretions of an oxide; pH 6.4; diffuse smooth boundary.

B32 52 to 60 inches, colors same as above but with a slight decrease in the brown (7.5YR 4/4) mottles; heavy silt loam; some vertical cleavage; friable; pores as above; few indistinct silt coats on cleavage faces; oxides same as above horizon; pH 6.8; diffuse smooth boundary.

C1 60 to 72 inches, mottled dark yellowish brown (10YR 4/4) to yellowish brown (10YR 5/6) and grayish brown (2.5Y 5/2) to olive gray (5Y 5/2) medium silt loam; massive; pores same as above; oxides same; pH 6.8.

Remarks: Roots common from 0 to 23 inches, few from 23 to 52 inches, nearly absent below 57 inches. One 2 x 4-inch oval fill of black material at 30 inches in pit; some mixing of 10YR 3/2 material at 13 to 23 inches by rodents; few distinct 1/2-inch spherical voids at 44 to 72 inches. The grayish brown (2.5Y 5/2) to olive gray (5Y 5/2) mottles below 36 inches appear to be a relict feature. The depth to a deoxidized olive gray zone decreased with increasing slope (see Marshall description on 7 percent slope).

Profile 12. Location: 829 feet south of road center and 500 feet east of the northwest corner of the NW 1/4, SE 1/4, Section 34, T. 77 N., R. 37 W., Cass County, Iowa (approximately 3 miles northwest of Atlantic, Iowa).

This profile is located on west facing 3 percent slope. It is a well drained moderately permeable soil. Clower was growing on the site at the time of sampling, May, 1963. (Described by R. I. Dideriksen, W. M. Jury).

A1p 0 to 7 inches, black (10YR 2/1) to very dark brown (10YR 2/2) light silty clay loam, dark gray (10YR 4/1) to grayish brown (10YR 5/2) when dry; weak medium subangular blocky breaking to weak fine granular structure; friable; common fine and medium root channels; very dark brown (10YR 2/2) when kneaded; few very dark grayish brown (10YR 3/2) worm casts; pH 5.8; clear smooth boundary.

A12 7 to 13 inches, very dark brown (10YR 2/2) light silty clay loam, grayish brown (10YR 5/2) when dry; weak fine granular with some weak fine subangular blocky structure; friable; common fine and medium root channels; very dark brown (10YR 2/2) to very dark grayish brown (10YR 3/2) when kneaded; few worm casts as above; pH 5.8; gradual smooth boundary.

A3 13 to 18 inches, very dark grayish brown (10YR 3/2) medium silty clay loam; grayish brown (10YR 5/2) with some pale brown (10YR 6/3) peds when dry; weak fine subangular blocky structure; friable; common fine inped tubular pores and some medium root channels; few peds; pore fills and worm casts of dark brown to brown (10YR 4/3); pH 5.8; clear wavy boundary.

B21 18 to 26 inches, dark brown to brown (10YR 4/3) medium silty clay loam, pale brown (10YR 6/3) when dry; weak to moderate fine subangular blocky structure; friable; pores as above; some oriented thin discontinuous very dark grayish brown (10YR 3/2) stains on a few peds; few black (10YR 2/1) fills in fine vertical channels; very few very fine soft dark brown concretions of an oxide; kneaded color the same; pH 6.0; gradual smooth boundary.

B22 26 to 34 inches, dark brown to brown (10YR 4/3) light to medium silty clay loam; weak medium prismatic breaking to moderate fine subangular blocky structure; few fine grayish brown (2.5Y 5/2) mottles; friable; many fine inped tubular pores; thin discontinuous clay films on some peds; kneaded color the same; few fine soft dark brown and yellowish brown concretions of an oxide; pH 6.0; clear smooth boundary.

B31 34 to 41 inches, yellowish brown (10YR 5/4) and dark brown to brown (10YR 4/3) light silty clay loam; weak medium prismatic breaking to moderate to weak medium subangular blocky structure; common fine grayish brown (2.5Y 5/2) and common fine yellowish brown (10YR 5/6) grading to dark brown to brown (7.5YR 4/4) mottles; friable; pores as above; thin discontinuous clay films on vertical ped faces; oxides as above; pH 6.2; gradual smooth boundary.

B32 41 to 47 inches, mottled yellowish brown (10YR 5/4), grayish brown (2.5Y 5/2), and some dark brown to brown (10YR 4/3) light silty clay loam; weak medium prismatic breaking to weak medium subangular blocky structure; common fine yellowish brown (10YR 5/6) and dark brown to brown (7.5YR 4/4) mottles; friable to firm; many fine and medium inped tubular pores; few thin discontinuous films on some vertical faces (may be clay); slight increase in grayish brown color in ped interiors; pores as above; very few very fine soft black concretions of an oxide; pH 6.4; gradual smooth boundary.

B33 47 to 58 inches, color same as above except the grayish brown colors grade to olive gray (5Y 5/2) light silty clay loam to heavy silt loam; weak medium to coarse prismatic breaking to weak medium subangular blocky structure; mottles as above; friable to firm; oxides and pores as above; very few indistinct grainy silt coats on a few vertical faces; pH 6.6; diffuse smooth boundary.

C1 58 to 68 inches, mottled yellowish brown (10YR 5/4 to 5/6) and olive gray (5Y 5/2) silt loam; massive with some vertical cleavage; friable; many fine and very fine tubular pores; few indistinct grainy silt coats on vertical faces; few fine soft dark brown to black concretions of an oxide; pH 6.8; clear smooth boundary.

C2 68 to 72 inches, mottled dark brown to brown (7.5YR 4/4), strong brown (7.5YR 5/6) and some olive gray (5Y 5/2); silt loam; massive with some vertical cleavage; friable; pores and grainy silt coats as above; common fine soft dark brown to black concretions of an oxide; pH 6.8; clear smooth boundary.

C3 72 to 76 inches, mottled dark yellowish brown (10YR 4/4), yellowish brown (10YR 5/6), and olive gray (5Y 5/2); silt loam; massive; friable; oxides as above; pH 7.0.

Remarks: Roots common from 0 to 26 inches, few from 26 to 58 inches, and nearly absent below. Mottled subsoil has a higher percentage of olive gray colors but doesn't appear to be a distinct deoxidized zone; mottles from 26 inches plus, however, appear to be relict and related to the more gray zone below. The 68- to 72-inch layer represents a weak iron zone. At 18 to 26 inches there is faint tonguing of very dark grayish brown stains to 24 inches and about 6 inches wide in places; one 8-inch burrow hole filled with black soil material at 34 inches in pit 5 feet in diameter.

Profile 13. Location: 798 feet south of road center and 379 feet east of the northwest corner of the NW 1/4, SE 1/4, Section 34, T. 77 N., R. 37 W., Cass County, Iowa (approximately 3 miles northwest of Atlantic, Iowa).

This profile is located on a 6 to 7 percent west-northwest facing slope. It is a well drained moderately permeable soil. The site was plowed at the time of sampling, May, 1963 and was to be in corn in 1963. (Described by R. I. Dideriksen)

A1p 0 to 6 inches, very dark brown (10YR 2/2) to very dark grayish brown (10YR 3/2) light to medium silty clay loam; grayish brown (10YR 5/2) when dry; weak medium subangular blocky breaking to weak fine granular structure; friable; few medium root channels; kneaded color the same; pH 5.4; abrupt smooth boundary.

A3 6 to 10 inches, very dark grayish brown (10YR 3/2), grayish brown (10YR 5/2) and some pale brown (10YR 6/3) when dry; medium silty clay loam; weak fine subangular blocky breaking to weak fine granular structure; friable; common fine and medium root channels; some mixing of dark brown to brown (10YR 4/3) peds; few very dark brown (10YR 2/2) fills in vertical pores; very dark grayish brown (10YR 3/2) to dark brown (10YR 3/3) when kneaded; pH 5.6; clear smooth boundary.

B21 10 to 18 inches, dark brown to brown (10YR 4/3), pale brown (10YR 6/3) when dry; light to medium silty clay loam; weak to moderate fine subangular blocky structure; friable; common fine and medium inped tubular pores; few peds have thin discontinuous stains of very dark grayish brown (10YR 3/2) color; yellowish brown (10YR 5/4) when kneaded; few 1/8-inch fills in pores of very dark brown to very dark grayish brown material from above; pH 6.4; gradual smooth boundary.

B22 18 to 25 inches, dark brown to brown (10YR 4/3) and yellowish brown (10YR 5/4) light silty clay loam; weak medium prismatic breaking to weak fine subangular blocky structure; very few fine grayish brown (2.5Y 5/2) mottles; friable; pores as above; few very thin discontinuous clay films on some vertical faces; ped exteriors are dark brown to brown (10YR 4/3) and ped interiors are yellowish brown (10YR 5/4), slight increase in mottles in ped interiors; distinct 1/2-inch spherical voids in this horizon; pH 6.4; clear smooth boundary.

B31 25 to 32 inches, color, texture, and structure same as above; common fine grayish brown (2.5Y 5/2), dark yellowish brown (10YR 4/4), and yellowish brown (10YR 5/6) mottles; friable; pores as above; very few thin discontinuous clay films on some vertical faces; pH 6.4; gradual smooth boundary.

B32 32 to 39 inches, mottled yellowish brown (10YR 5/4), dark brown to brown (10YR 4/3), and olive gray (5Y 5/2) heavy silt loam to light silty clay loam; weak medium prismatic breaking to weak medium subangular blocky structure; friable to firm; many fine and medium inped tubular pores; common fine soft dark brown to black concretions of an oxide; few indistinct grainy silt coats on some peds; pH 6.4; gradual smooth boundary.

B33 39 to 44 inches, mottled dark brown (10YR 4/3 to 7.5YR 4/3) and olive gray (5Y 5/2) heavy silt loam; weak medium to coarse prismatic breaking to very weak medium subangular blocky structure; many fine strong brown (7.5YR 5/6) to yellowish brown (10YR 5/6) mottles; friable to firm; pores as above; oxides as above; few 1/2-inch spherical voids; few indistinct grainy silt coats on vertical ped faces; pH 6.6; abrupt smooth boundary.

B34 44 to 47 inches, dark brown to brown (7.5YR 4/4) and strong brown (7.5YR 5/8) silt loam; weak coarse prismatic structure; common fine olive gray (5Y 5/2) mottles; friable to firm; pores as above; dark brown to brown (7.5YR 4/4) ped exteriors and strong brown (7.5YR 5/8) ped interiors; some thin discontinuous films on vertical ped faces; zone of iron accumulation; pH 6.4; abrupt smooth boundary.

C1 47 to 53 inches, olive gray (5Y 5/2) silt loam; massive with some vertical cleavage; many fine and very fine tubular pores; many 1/4- to 1/2-inch soft to moderately hard "pipestems" of strong brown (7.5YR 5/8) and dark brown to brown (7.5YR 4/4) iron concretions; friable; few 1/2-inch spherical voids; deoxidized zone with iron segregations; pH 6.4; gradual wavy boundary.

C2 53 to 58 inches, mottled light olive brown (2.5Y 5/4) to yellowish brown (10YR 5/4) and olive gray (5Y 5/2) silt loam; massive; friable; pores as above; common very fine soft dark brown to black concretions of an oxide; pH 6.4; abrupt smooth boundary.

C3 58 to 60 inches, yellowish brown (10YR 5/6) silt loam; massive; common medium, olive gray (5Y 5/2) and few fine dark brown to brown (7.5YR 4/4) mottles; friable; pores as above; few moderately hard "pipestems" of strong brown (7.5YR 5/8); weak zone of iron accumulation; pH 6.6; abrupt smooth boundary.

C4 60 to 63 inches, olive gray (5Y 5/2) silt loam; massive; common fine yellowish brown (10YR 5/6) mottles; friable; pores as above; few 1/4-inch soft "pipestems" as above; pH 6.6; clear smooth boundary.

C5 63 to 69 inches, mottled light olive brown (2.5Y 5/4) silt loam; massive; common medium yellowish brown (10YR 5/6) and common medium and fine olive gray (5Y 5/2) mottles; friable; pores as above; common dark brown to brown (7.5YR 4/4) moderately hard "pipestems"; zone of iron accumulation; pH 6.6; clear irregular boundary.

C6 69 to 77 inches, gray (5Y 5/1) to olive gray (5Y 5/2) silt loam; massive; few fine light olive gray mottles; friable; pores as above; common 1/4-inch to 1/2-inch moderately hard to hard "pipestems" of dark brown to brown (7.5YR 4/4) color; distinct deoxidized zone; pH 6.6.

Remarks: Root distribution not determined--plowed field; zones of iron accumulation 44 to 47 inches distinct, 58 to 60 inches moderate, and 63 to 69 inches weak; 3-inch rodent fill at 10 inches, another at 18 inches, and one at 25 inches. Iron band at 44 to 47 inches is continuous around pit and slopes slightly to the west-northwest. Mottles at 18 inches plus are considered to be relict and related to the deoxidized zone below.

Profile 14. Location: 362 feet south and 968 feet west of the center of road corner in the NE 1/4, NW 1/4, Section 28, T. 78 N., R. 38 W., Shelby County, Iowa (approximately 3 miles north of Walnut, Iowa). Area located on field sheet No. 93 of the Shelby County Soil Survey Report.

This profile is located on a west facing slope of less than 1 percent. It is a well drained moderately permeable soil. Alfalfa was growing on the site at the time of sampling, May, 1953. (Described by R. I. Dideriksen, C. S. Fisher)

A1p 0 to 7 inches, black (10YR 2/1) light silty clay loam, dark gray (10YR 4/1) when dry; weak medium subangular blocky breaking to weak fine granular structure; friable; common fine and medium root channels; weak plow sole at 6 to 7 inches; black (10YR 2/1) to very dark brown (10YR 2/2) when kneaded; few very dark brown worm casts; pH 6.4; abrupt smooth boundary.

A12 7 to 16 inches, black (10YR 2/1) light silty clay loam; dark gray (10YR 4/1) when dry; weak fine subangular blocky and fine granular structure; friable; root channels as above; few fine peds of brown to dark brown (10YR 4/3) in lower part; common very dark brown worm casts; very dark brown (10YR 2/2) when kneaded; pH 6.2; gradual smooth boundary.

A3 16 to 23 inches, very dark grayish brown (10YR 3/2) light to medium silty clay loam; dark gray (10YR 4/1) and some grayish brown (10YR 5/2) when dry; weak fine subangular blocky structure; friable; few fine and medium inped tubular pores; dark brown to brown (10YR 4/3) peds are common; some 1/8-inch channel fills of very dark brown (10YR 2/2) material; kneaded color same; pH 6.2; clear smooth boundary.

B21 23 to 33 inches, dark brown to brown (10YR 4/3) medium silty clay loam; pale brown (10YR 6/3) when dry; weak fine subangular blocky structure; friable; few fine inped tubular pores; few very thin discontinuous clay films; hue of horizon toward 2.5Y; few ped exteriors are very dark grayish brown (10YR 3/2); few worn casts as above; some 1/2-inch spherical voids; pH 6.4; gradual smooth boundary.

B22 33 to 38 inches, dark brown to brown (10YR 4/3) light to medium silty clay loam; weak medium prismatic breaking to weak medium subangular blocky structure; very few very fine grayish brown (2.5Y 5/2) and very few fine dark brown to brown (7.5YR 4/4) mottles; many fine inped tubular pores; yellowish brown (10YR 5/4) when kneaded; thin discontinuous clay films on vertical ped faces; very few very fine soft dark brown to black concretions of an oxide; pH 6.6; clear smooth boundary.

B23 38 to 45 inches, mottled dark brown to brown (10YR 4/3) and grayish brown (2.5Y 5/2) to olive gray (5Y 5/2) light silty clay loam; weak medium prismatic breaking to weak medium subangular blocky structure; common fine dark brown to brown (7.5YR 4/4) and strong brown (7.5YR 5/6) mottles; friable to firm; pores as above; yellowish brown (10YR 5/4) when kneaded; very few very thin discontinuous clay films on some vertical ped faces; very few 1/2-inch spherical voids; few fine soft dark brown to black concretions of an oxide; pH 6.6; gradual smooth boundary.

B31 45 to 56 inches, mottled yellowish brown (10YR 5/4) and olive gray (5Y 5/2) heavy silt loam; structure as above; many medium yellowish brown (10YR 5/6 to 5/8) mottles; friable to firm; pores as above; common fine soft dark brown to black concretions of an oxide; pH 6.4; diffuse smooth boundary.

B32 56 to 63 inches, color, texture, and mottles as above; massive with some vertical cleavage; very few indistinct grainy silt coats on some cleavage faces; pores and concretions as above; pH 6.4; diffuse smooth boundary.

C1 63 to 72 inches, same as horizon above but vertical cleavage may be absent.

Remarks: Roots are abundant at 0 to 16 inches, common at 16 to 33 inches, and few at 33 to 56 inches. Two-inch rodent burrow filled with dark materials at 40 inches. Mottles of 2.5Y to 5Y hue below 33 inches appear to be a relict feature. No distinct deoxidized zone observed in pit but about 50 percent of the colors are olive gray below 45 inches.

Profile 15. Location: 434 feet south and 1224 feet west of center of road corner in the NE 1/4, NW 1/4, Section 28, T. 78 N., R. 38 W., Shelby County, Iowa (approximately 3 miles north of Walnut, Iowa). Area located on field sheet No. 93 of the Shelby County Soil Survey Report.

This profile is located on a west facing 3 percent slope. The soil at this site is well drained and moderately permeable. Alfalfa was growing on the site at the time of sampling, May, 1963. (Described by R. I. Dideriksen, C. S. Fisher)

A1p 0 to 7 inches, very dark brown (10YR 2/2) light silty clay loam, dark gray (10YR 4/1) to grayish brown (10YR 5/2) when dry; weak medium subangular blocky breaking to weak fine granular structure; friable; common fine and medium root channels; kneaded color the same; weak plow sole at 6 to 8 inches; pH 6.4; clear smooth boundary.

A12 7 to 13 inches, very dark brown (10YR 2/2) light silty clay loam, grayish brown (10YR 5/2) when dry; weak fine subangular blocky and fine granular structure; friable; root channels as above; common dark brown to brown peds in lower part; very dark grayish brown (10YR 3/2) when kneaded; few dark worm casts; pH 6.4; clear smooth boundary.

A3 13 to 18 inches, very dark grayish brown (10YR 3/2) and dark brown to brown (10YR 4/3) light to medium silty clay loam, grayish brown (10YR 5/2) and some pale brown (10YR 6/3) when dry; weak fine subangular blocky structure; friable; common fine and very fine inped tubular pores; very few thin discontinuous stains on some peds; ped exteriors are very dark grayish brown (10YR 3/2) with 30% dark brown to brown (10YR 4/3) and ped interiors are dark brown to brown (10YR 4/3); dark brown (10YR 3/3) to very dark grayish brown (10YR 3/2) when kneaded; few dark worm casts and fills in old root channels; pH 6.4; clear smooth boundary.

B21 18 to 27 inches, dark brown to brown (10YR 4/3) and yellowish brown (10YR 5/4) medium silty clay loam, pale brown (10YR 6/3) when dry; weak fine subangular blocky structure; friable; pores as above; ped exteriors are dark brown to brown (10YR 4/3) and ped interiors are yellowish brown (10YR 5/4); yellowish brown (10YR 5/4) when kneaded; thin discontinuous clay films on some peds; a very few dark fills in old root channels; pH 6.5; gradual smooth boundary.

B22 27 to 34 inches, dark brown to brown (10YR 5/4) light silty clay loam; weak medium prismatic breaking to weak medium subangular blocky structure; common fine grayish brown (2.5Y 5/2) and a few fine dark yellowish brown (10YR 4/4) mottles; friable; pores as above; interiors are yellowish brown (10YR 5/4) with a slight increase in grayish brown mottles; a few very thin discontinuous clay films on some vertical ped faces; few very fine soft dark brown to black concretions of an oxide; pH 6.5; gradual smooth boundary.

B31 34 to 44 inches, yellowish brown (10YR 5/4) light silty clay loam to heavy silt loam; structure and consistence as above; many fine and very fine inped tubular pores; many medium grayish brown (2.5Y 5/2) and common fine dark brown to brown (7.5YR to 10YR 4/4) mottles; less clay films than above; common fine soft dark brown to black concretions of an oxide; yellowish brown (10YR 5/4) when kneaded; pH 6.6; gradual smooth boundary.

B32 44 to 50 inches, mottled yellowish brown (10YR 5/4) and olive gray (5Y 5/2) heavy silt loam; weak medium prismatic breaking to very weak medium subangular blocky structure; common fine dark brown to brown (7.5YR 4/4) mottles; friable; pores as above; some darker fills in vertical channels; very few indistinct grainy silt coats on some vertical ped faces; oxides as above; pH 6.5; diffuse smooth boundary.

C1 50 to 58 inches, mottled dark brown to brown (10YR to 7.5YR 4/4) and olive gray (5Y 5/2) silt loam; massive with some vertical cleavage; friable; common fine and very fine tubular pores; grainy silt coats as above; slight increase in concretions of an oxide; pH 6.6; diffuse smooth boundary.

C2 58 to 68 inches, mottled yellowish brown (10YR 5/6) and olive gray (5Y 5/2) silt loam; massive with some vertical cleavage; friable; pores as above; some indistinct grainy coats on cleavage faces; oxides same as C1 horizon; pH 6.8; diffuse smooth boundary.

C3 68 to 76 inches, same as above horizon but no cleavage noted.

Remarks: Roots abundant from 0 to 18 inches, common from 18 to 34 inches, few from 34 to 58 inches; rodent burrows at 10 inches, at 24 inches, and one at 54 inches; grayish brown mottles at 27 inches appear to be relict. Not a distinct deoxidized zone at 44 inches and below but 50% of material is olive gray.

Profile 16. Location: 605 feet south and 1432 feet west of center of road corner in the NE 1/4, NW 1/4, Section 28, T. 78 N., R. 38 W., Shelby County, Iowa (approximately 3 miles north of Walnut, Iowa). Area located on field sheet No. 93 of the Shelby County Soil Survey Report.

This profile is located on a 6 to 7 percent west-northwest facing slope. The soil at this site is well drained and moderately permeable. Alfalfa was growing on the site at the time of sampling, May, 1963. (Described by R. I. Dideriksen, C. S. Fisher)

A1p 0 to 7 inches, very dark brown (10YR 2/2) light silty clay loam, dark gray (10YR 4/1) to grayish brown (10YR 5/2) when dry; weak medium subangular blocky breaking to weak fine granular structure; friable; few fine and medium root channels; very dark grayish brown (10YR 3/2) when kneaded; weak plow sole at 5 to 7 inches; pH 6.2; clear smooth boundary.

A3 7 to 12 inches, very dark grayish brown (10YR 3/2) light to medium silty clay loam, grayish brown (10YR 5/2) when dry; weak fine subangular blocky and fine granular structure; friable; many fine and very fine root channels; few dark brown to brown (10YR 4/3) peds; very dark grayish brown (10YR 3/2) to dark brown (10YR 3/3) when kneaded; few root fills of dark material from above; pH 6.4; clear smooth boundary.

B1 12 to 16 inches, dark brown (10YR 3/3) and dark brown to brown (10YR 4/3) medium silty clay loam, grayish brown (10YR 5/2) and pale brown (10YR 6/3) when dry; weak fine subangular blocky structure; friable; some very dark grayish brown (10YR 3/2) stains on ped exteriors; few dark root fills and worm casts; kneaded color the same; common fine and very fine inped tubular pores; pH 6.4; clear smooth boundary.

B21 16 to 22 inches, dark brown to brown (10YR 4/3) light to medium silty clay loam; pale brown (10YR 6/3) when dry; weak fine subangular blocky structure; friable; pores as above; few very thin discontinuous clay films of dark brown (10YR 3/3); few darker worm casts; dark brown to brown (10YR 4/3) to yellowish brown (10YR 5/4) when kneaded; pH 6.4; gradual smooth boundary.

B22 22 to 27 inches, dark brown to brown (10YR 4/3) light silty clay loam; weak fine subangular blocky structure; few fine grayish brown (2.5Y 5/2) mottles; friable; pores as above; few thin discontinuous clay films on some peds; yellowish brown (10YR 5/4) when kneaded; pH 6.4; clear smooth boundary.

B23 27 to 34 inches, dark brown to brown (10YR 4/3) light silty clay loam; weak medium prismatic breaking to weak medium and fine subangular blocky structure; many medium grayish brown (2.5Y 5/2) to olive gray (5Y 5/2) and few fine dark brown to brown (7.5YR 4/4) mottles; friable; pores as above; few thin discontinuous clay films on vertical ped faces; yellowish brown (10YR 5/4) when kneaded; few very fine soft dark brown to black concretions of an oxide; few dark worm casts; few 1/2-inch spherical voids; pH 6.4; gradual smooth boundary.

B31 34 to 42 inches, mottled dark brown to brown (10YR 4/3) and grayish brown (2.5Y 5/2) to olive gray (5Y 5/2) light silty clay loam; weak medium prismatic breaking to weak medium subangular blocky structure; common fine dark brown to brown (7.5YR 4/4) to dark yellowish brown (10YR 4/4) mottles; friable; pores as above; yellowish brown (10YR 5/4) when kneaded; slight decrease in clay films from above but more distinctly oriented on vertical ped faces; few to common fine soft dark brown to black concretions of an oxide; few 1/2-inch spherical voids; pH 6.6; gradual smooth boundary.

B32 42 to 49 inches, same color and structure as above; heavy silt loam to light silty clay loam; clay films nearly absent; common fine dark yellowish brown (10YR 4/4) mottles; friable; many fine and very fine inped tubular pores; oxides as above; pH 6.5; gradual smooth boundary.

C1 49 to 57 inches, mottled yellowish brown (10YR 5/4) and olive gray (5Y 5/2) to gray (5Y 5/1) heavy silt loam; massive with some weak vertical cleavage; common fine dark brown to brown (7.5YR 4/4) and dark yellowish brown (10YR 4/4) mottles; friable; many fine and medium tubular pores; many fine and medium soft dark brown to black concretions of an oxide; pH 6.4; diffuse smooth boundary.

C2 57 to 68 inches, mottled yellowish brown (10YR 5/4) and gray (5Y 5/1) silt loam; massive with some vertical cleavage; mottled as above; few indistinct films on part of cleavage faces; pores and oxides as above; pH 6.6; diffuse smooth boundary.

C3 68 to 74 inches, same as above except for a slight increase in dark brown to brown (7.5YR 4/4) mottles; pH 6.6; diffuse smooth boundary.

C4 74 to 79 inches, same as above except an increase in mottling of strong brown (7.5YR 5/6) colors; slight increase in oxides; clear smooth boundary.

C5 79 to 81 inches, strong brown (7.5YR 5/6) to yellowish brown (10YR 5/6) silt loam; massive; common medium olive gray (5Y 5/2) around pores and on some faces; friable; pores as above; few dark brown to brown (7.5YR 4/4) soft 1/4-inch "pipestems," a zone of iron accumulation; pH 6.4; abrupt smooth boundary.

C6 81 to 87 inches, gray (5Y 5/1) silt loam; massive; few fine light olive brown (2.5Y 5/4) mottles; some dark brown to brown (7.5Y 4/4) to strong brown (7.5YR 5/6) moderately hard "pipestems"; friable; pores as above; considered to be a deoxidized zone; pH 6.6.

Remarks: Roots are abundant from 0 to 12 inches, common from 12 to 34 inches, and few from 34 to 68 inches; rodent burrows at 24 and 40 inches filled with darker material. Grayish brown mottles start at 22 inches and they are considered relict; olive gray colors are present at 34 inches and below; a distinct deoxidized gray zone at 81 inches plus; distinct iron band at 79 to 81 inches. A3 and B1 horizon depths were redefined at time of sampling to determine the zone of maximum clay; the original description of this profile did not have a B1 horizon.

APPENDIX B

Table 6. Horizon depth, particle size distribution, organic carbon content, and bulk density of each horizon at the various locations for Marshall soil

Profile number	Horizon	Depth (cm.)	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.046 mm. (%)	Sand .046-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
1	Ap	0-18	34.9	30.3	32.5	2.3	1.62	1.21
2	Ap	0-18	32.9	28.3	36.8	2.0	1.45	1.20
3	Ap	0-15	31.0	31.4	34.9	2.7	1.76	0.95
4	Ap	0-13	33.0	31.6	33.8	1.7	1.92	1.40
5	Ap	0-15	29.9	32.9	34.7	2.5	1.82	1.11
6	Ap	0-13	31.0	28.4	38.4	2.2	1.72	1.17
7	Ap	0-15	29.8	30.1	37.9	2.1	2.38	1.09
8[a]	Ap	0-13	33.4	28.9	35.7	2.0	1.70	1.33
8a	Ap	0-13	34.1	28.0	35.0	2.9	1.75	1.26
9	Ap	0-15	34.2	28.0	35.6	2.3	2.40	1.22
10	Ap	0-15	32.8	30.4	34.5	2.4	2.83	1.26
Mean			32.45	29.84	35.44	2.28	1.94	1.20
Standard deviation			1.76	1.66	1.74	0.34	0.42	0.12
95% Confid. inter.; mean ±			1.18	1.11	1.16	0.23	0.28	0.08
Coeff. of var. (%)			1.63	1.68	1.47	4.50	6.46	3.05
2	A3	18-33	33.5	30.4	33.7	2.3	.97	1.25
3	A3B1[b]	15-28	34.2	28.4	33.9	2.5	1.21	1.11
4	A3	13-25	33.7	31.3	33.4	1.6	1.84	1.34
5	A3	15-36	29.8	31.3	37.0	2.0	1.82	1.20

[a]Profiles 8 and 8a are on runoff plots 2 and 8, respectively, on the Soil Conservation Experiment Farm. Every horizon in Profile 8 was sampled whereas only the Ap was sampled in Profile 8a.

[b]In this table and in Table 2 the A3B1, B21, and B22 horizons are included in the A3 and B2 horizons, respectively, for purpose of analysis.

Table 6. (Continued)

Profile number	Horizon	Depth (cm.)	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.046 mm. (%)	Sand .046-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
6	A3	13-25	32.4	26.9	38.5	2.2	1.77	1.17
7	A3	15-25	33.4	28.8	35.6	2.3	2.24	1.24
8	A3	13-23	33.5	33.7	30.7	2.1	1.53	1.20
9	A3	15-25	36.6	31.9	28.7	2.8	1.51	1.21
10	A3	15-25	35.5	33.3	29.3	1.9	1.48	1.26
Mean			33.60	30.67	33.42	2.19	1.60	1.22
Standard deviation			1.90	2.27	3.36	0.35	0.38	.06
95% Confid. inter.; mean ±			1.46	2.09	2.58	0.27	0.29	0.05
Coeff. of var. (%)			1.88	2.47	3.35	5.25	7.81	1.72
1	B1	18-30	37.1	28.5	31.8	2.6	1.46	1.18
2	B1	33-43	30.8	27.0	39.6	2.6	.782	1.25
4	B1	25-38	35.4	33.0	30.2	1.4	1.39	1.41
5	B1	36-46	31.6	30.1	35.9	2.3	1.76	1.33
6	B1	25-41	33.2	29.5	34.9	2.4	1.37	1.19
7	B1	25-41	33.6	30.9	33.6	2.0	1.35	1.23
8	B1	23-33	37.0	32.3	29.0	1.7	1.17	1.24
9	B1	25-36	37.2	30.1	30.6	2.1	1.10	1.24
10	B1	25-38	33.2	35.8	29.7	1.3	1.02	1.18
Mean			34.34	30.80	32.81	2.04	1.27	1.25
Standard deviation			2.43	2.61	3.49	0.49	0.28	0.08
95% Confid. inter.; mean ±			1.86	2.01	2.68	0.38	0.22	0.06
Coeff. of var. (%)			2.36	2.82	3.55	7.99	7.46	2.10
1	B2	30-53	29.0	37.3	31.1	2.6	.531	1.25
2	B2	43-61	29.5	29.8	37.8	2.9	.554	1.27
4	B2	38-74	35.2	34.0	29.0	1.8	.806	1.40
5	B2	46-84	32.1	32.0	34.1	1.7	.975	1.18

Table 6. (Continued)

Profile number	Horizon	Depth (cm.)	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.046 mm. (%)	Sand .046-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
6	B2	41-64	29.8	31.4	35.8	3.0	.700	1.20
7	B2	41-71	33.8	26.9	36.5	2.8	1.15	1.22
8	B2	33-61	36.9	35.3	26.4	1.4	.978	1.20
10	B2	38-79	31.4	40.9	26.3	1.4	.556	1.21
3[b]	B21	28-46	33.6	30.6	32.7	3.1	.803	1.13
9[b]	B21	36-51	33.7	30.2	33.6	2.4	.716	1.16
3[b]	B22	46-71	31.1	31.8	34.9	2.3	.530	1.24
9[b]	B22	51-76	30.7	32.4	34.2	2.7	.550	1.24
Mean			32.23	32.72	32.70	2.34	0.737	1.22
Standard deviation			2.44	3.72	3.78	0.62	0.044	0.07
95% Confid. inter.; mean ±			1.55	2.37	2.40	0.39	0.133	0.04
Coeff. of var. (%)			2.18	3.28	3.33	7.64	8.21	1.60
1	B3	53-79	27.7	31.5	38.5	2.3	.486	1.23
2	B3	61-79	28.0	30.9	38.2	2.9	.352	1.33
4	B3	74-96	29.2	38.0	31.2	1.6	.368	1.45
5	B3	84-102	29.5	38.3	30.5	1.7	.409	1.17
6	B3	64-86	29.0	31.9	36.4	2.6	.708	1.11
7	B3	71-96	31.0	31.2	35.5	2.2	1.04	1.20
8	B3	61-74	29.5	34.6	34.5	1.4	.508	1.27
9	B3	76-94	30.3	35.4	30.6	3.7	.334	1.28
10	B3	79-99	28.1	42.7	27.9	1.3	.334	1.20
Mean			29.14	34.94	33.70	2.19	0.504	1.25
Standard deviation			1.09	4.07	3.78	0.79	0.234	0.10
95% Confid. inter.; mean ±			0.84	3.13	2.90	0.61	0.180	0.08
Coeff. of var. (%)			1.24	3.88	3.74	12.01	15.48	2.66

Table 6. (Continued)

Profile number	Horizon	Depth (cm.)	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.046 mm. (%)	Sand .046-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
1	C	79-102	29.4	33.6	34.9	2.1	.252	1.23
2	C	79-114	26.3	37.0	35.0	1.7	.296	1.41
3	C	71-91	30.6	30.7	35.6	3.1	.411	1.28
4	C	96-124	28.7	39.6	29.7	2.0	.287	1.44
5	C	102-122	24.0	34.6	38.9	2.5	.314	1.08
6	C	86-117	24.4	32.5	39.6	3.5	.333	1.11
7	C	86-109	27.5	31.1	38.9	2.5	.285	1.30
8	C	74-89	27.0	35.8	35.9	1.2	.400	1.20
9	C	94-107	25.8	31.3	40.2	2.7	.322	1.33
10	C	99-114	21.7	41.9	33.8	2.6	.202	1.27
Mean			26.54	34.81	36.25	2.39	0.310	1.26
Standard deviation			2.70	3.78	3.23	0.67	0.063	0.12
95% Confid. inter.; mean ±			1.93	2.70	2.31	0.48	0.045	0.08
Coeff. of var. (%)			3.22	3.44	2.81	8.87	6.39	2.90

Table 7. Water percentages by weight and by volume at different suctions for each horizon at the various locations for Marshall soil

Profile number	Horizon	Percent water by weight						Percent water by volume					
		.1	.3	1	3	5	15	.1	.3	1	3	5	15
		atm.						atm.					
1	Ap	31.0	26.1	21.1	20.4	18.4	16.8	37.5	31.6	25.5	24.7	22.3	20.3
2	Ap	30.7	27.8	24.6	21.0	19.0	14.6	36.8	33.4	29.5	25.2	22.8	17.5
3	Ap	29.2	25.9	23.6	19.7	18.0	13.3	27.7	24.6	22.4	18.7	17.1	12.6
4	Ap	32.2	25.1	21.8	19.1	17.4	13.5	45.2	35.1	30.5	26.7	24.4	18.9
5	Ap	30.8	26.6	21.7	18.3	16.3	12.7	34.2	29.5	24.1	20.3	18.1	14.1
6	Ap	27.7	26.8	24.2	19.1	17.8	13.2	32.4	31.3	28.3	22.3	20.8	15.4
7	Ap	33.3	29.4	24.9	20.5	18.6	14.2	36.3	32.0	27.1	22.3	20.3	15.5
8	Ap	34.1	26.6	23.4	20.5	18.1	13.8	45.4	35.4	31.1	27.3	24.1	18.4
8a	Ap				19.0	17.1	13.1				23.9	21.5	16.5
9	Ap	40.7	26.8	22.0	23.4	21.5	18.1	49.6	32.7	26.8	28.5	26.2	22.1
10	Ap	32.9			23.9	22.0	18.3	41.5			30.1	27.7	23.1
Mean		32.27	26.79	23.03	20.44	18.56	14.69	37.66	31.73	27.26	24.54	22.30	17.67
Std. Dev.		3.54	1.23	1.41	1.78	1.74	2.06	6.33	3.25	2.92	3.49	3.22	3.28
95% C.I.; mean ±		2.53	0.94	1.09	1.20	1.17	1.38	4.53	2.50	2.25	2.34	2.16	2.20
C.V. (%)		3.47	1.53	2.05	2.63	2.83	4.22	5.32	3.42	3.58	4.28	4.37	5.25
2	A3	30.1	27.9	24.5	20.2	17.9	14.1	37.6	34.9	30.6	25.2	22.4	17.6
3	A3B1	31.8	27.7	22.8	19.8	17.7	13.5	35.3	30.7	25.3	22.0	19.6	15.0
4	A3	29.7	25.6	21.9	19.9	17.6	13.9	39.8	34.3	29.3	26.7	23.5	18.6
5	A3	30.8	25.0	21.1	18.8	16.1	12.5	37.0	30.0	25.3	22.6	19.3	15.0
6	A3	30.3	25.0	21.1	19.5	17.4	13.4	35.4	29.3	24.7	22.8	20.4	15.7
7	A3	30.4	28.0	23.2	22.0	20.1	14.8	37.7	34.7	28.8	27.4	24.9	18.4
8	A3	29.8	27.5	24.7	21.2	19.8	15.3	35.8	33.0	29.7	25.5	23.8	18.4
9	A3	31.0	28.1	24.8	23.4	21.4	17.3	37.5	34.0	30.0	28.3	25.9	20.9
10	A3	31.6			21.9	18.6	16.0	39.8			27.6	23.4	20.2
Mean		30.61	26.85	23.01	20.74	18.51	14.53	37.32	32.61	27.96	25.23	22.58	17.76
Std. Dev.		0.742	1.39	1.55	1.48	1.64	1.48	1.69	2.27	2.43	2.38	2.34	2.15
95% C.I.; mean ±		0.57	1.16	1.30	1.14	1.26	1.14	1.30	1.90	2.03	1.82	1.80	1.65
C.V. (%)		0.81	1.83	2.38	2.38	2.96	3.37	1.51	2.46	3.07	3.14	3.45	4.03

Table 7. (Continued)

Profile number	Horizon	Percent water by weight .1 atm.	.3	1	3	5	15	Percent water by volume .1 atm.	.3	1	3	5	15
1	B1	31.6	26.0	23.7	21.4	19.3	15.2	37.3	30.7	28.0	25.2	22.8	17.9
2	B1	29.7	27.2	23.3	19.1	17.3	13.9	37.1	34.0	29.1	23.9	21.6	17.4
4	B1	31.3	26.4	23.7	20.6	18.4	15.4	44.1	37.2	33.4	29.6	26.0	21.7
5	B1	29.1	25.3	21.1	19.0	16.6	14.7	38.7	33.6	28.1	25.2	22.1	19.6
6	B1	31.7	28.5	22.0	19.6	17.9	14.6	37.7	33.9	26.2	23.4	21.3	17.4
7	B1	30.9	27.2	23.0	20.1	17.9	15.3	38.0	33.4	28.3	24.7	22.0	18.8
8	B1	29.9	27.4	24.8	23.1	21.1	18.2	37.1	34.0	30.8	28.6	26.2	22.6
9	B1	30.2	26.8	24.4	22.7	19.5	17.2	37.4	33.2	30.2	28.1	24.1	21.3
10	B1	29.5	27.5	23.3	20.3	18.2	15.0	34.8	32.5	27.5	24.0	21.5	17.7
Mean		30.43	26.92	23.26	20.66	18.47	15.50	38.02	33.61	29.07	25.86	23.07	19.38
Std. Dev.		0.968	0.936	1.14	1.48	1.33	1.35	6.31	1.70	2.13	2.29	1.92	2.02
95% C.I.; mean ±		0.74	0.72	0.88	1.13	1.02	1.04	1.93	1.31	1.64	1.76	1.47	1.55
C.V. (%)		1.06	1.16	1.63	2.38	2.40	2.90	2.20	1.69	2.44	2.95	2.77	3.48
1	B2	29.4	28.3	23.9	19.3	17.6	14.9	36.7	35.4	29.9	24.1	22.0	18.6
2	B2	28.3	25.1	21.9	17.4	15.3	13.1	35.9	31.9	27.8	22.1	19.4	16.6
4	B2	29.3	26.0	23.1	20.4	18.6	15.2	41.0	36.4	32.3	28.6	26.0	21.3
5	B2	29.6	26.6	22.2	19.4	17.4	14.2	34.9	31.4	26.2	22.9	20.5	16.8
6	B2	33.5	25.5	21.1	18.3	16.2	12.9	40.2	30.6	25.3	22.0	19.4	15.5
7	B2	30.8	26.8	23.2	20.7	18.7	15.2	37.6	32.7	28.3	25.2	22.8	18.5
8	B2	30.2	28.1	25.3	22.8	20.4	16.3	36.2	33.7	30.4	27.4	24.5	19.6
10	B2	32.2	26.5	22.0	19.7	17.7	15.0	39.0	32.1	26.6	23.8	21.4	18.2
3	B21	30.2	25.6	21.2	19.2	16.9	13.5	34.1	28.9	24.0	21.7	19.1	15.2
9	B21	30.7	26.8	22.9	21.4	17.9	16.3	38.1	33.2	28.4	26.5	22.2	20.2
3	B22	30.4	25.3	21.8	18.9	16.9	13.6	37.7	31.4	27.0	23.4	21.0	16.9
9	B22	29.0	26.0	23.6	19.8	17.8	14.4	36.0	32.3	29.3	24.5	22.1	17.8
Mean		30.30	26.38	22.68	19.78	17.62	14.55	37.28	32.50	28.79	24.35	21.70	17.93
Std. Dev.		1.42	1.02	1.22	1.42	1.29	1.14	2.07	2.02	3.36	2.21	2.08	1.85
95% C.I.; mean ±		0.91	0.65	0.78	0.90	0.82	0.72	1.32	1.29	2.13	1.40	1.32	1.18
C.V. (%)		1.36	1.12	1.56	2.08	2.12	2.26	1.60	1.80	3.36	2.62	2.76	2.98

Table 7. (Continued)

Profile number	Horizon	Percent water by weight .1 atm.	.3	1	3	5	15	Percent water by volume .1 atm.	.3	1	3	5	15
1	B3	32.0	26.5	21.0	18.9	17.8	13.4	39.4	32.6	25.8	23.2	22.0	16.5
2	B3	28.6	25.5	21.0	17.5	15.2	12.1	38.0	33.9	27.9	23.3	20.2	16.1
4	B3	29.8	20.8	23.2	19.8	17.7	14.4	43.2	30.2	33.6	28.8	25.6	20.9
5	B3	31.7	27.8	22.7	19.7	17.7	15.1	37.1	32.5	26.6	23.0	20.7	17.7
6	B3	32.1	25.8	20.3	17.9	16.4	12.5	35.6	29.7	22.5	19.9	18.2	13.9
7	B3	31.8	28.6	23.0	20.3	18.1	15.6	38.2	34.3	27.6	24.4	21.7	18.7
8	B3	31.5	27.9	24.3	20.5	18.5	14.2	40.0	35.4	29.2	26.0	23.5	18.0
9	B3	34.2	26.4	20.8	19.2	17.4	14.1	43.8	33.8	26.6	24.6	22.3	18.0
10	B3	33.7	32.5	23.2	18.3	16.5	13.6	40.4	39.0	27.8	22.0	19.8	16.3
Mean		31.71	26.87	22.17	19.12	17.26	13.89	39.52	33.49	27.51	23.91	21.56	17.34
Std. Dev.		1.72	3.10	1.41	1.06	1.03	1.14	2.70	2.78	2.95	2.51	2.17	1.96
95% C.I.; mean ±		1.32	2.38	1.08	0.82	0.79	0.87	2.07	2.14	2.27	1.93	1.67	1.51
C.V. (%)		1.81	3.84	2.12	1.85	1.99	2.72	2.27	2.77	3.58	3.50	3.36	3.76
1	C	33.6	29.7	23.0	18.5	16.6	13.4	41.3	36.5	28.3	22.8	20.4	16.5
2	C	27.8	25.7	23.7	17.3	15.6	12.1	39.2	36.2	33.4	24.4	22.0	17.1
3	C	33.5	28.2	22.1	18.8	16.7	13.5	42.9	36.1	28.3	24.1	21.4	17.3
4	C	33.6	31.5	25.8	19.4	17.6	13.5	48.4	45.4	37.2	27.9	25.3	19.5
5	C	34.6	29.6	21.7	16.8	15.1	12.0	37.4	32.0	23.4	18.2	16.3	12.9
6	C	38.0	29.0	18.8	15.1	13.8	10.9	42.2	32.1	20.8	16.7	15.3	12.1
7	C	30.3	27.4	20.5	19.4	16.8	12.7	39.4	35.6	26.6	25.2	21.9	16.5
8	C	30.4	28.1	25.0	19.1	16.3	13.4	36.5	33.7	30.0	22.9	19.6	16.1
9	C	32.5	28.1	21.0	18.3	16.6	13.1	43.2	37.4	27.9	24.4	22.1	17.4
10	C	38.1	32.9	22.4	16.8	14.8	11.9	48.4	41.8	28.4	21.3	18.8	15.1
Mean		33.24	29.02	22.40	17.95	15.99	12.65	41.89	36.68	28.43	22.79	20.31	16.05
Std. Dev.		3.26	2.06	2.10	1.41	1.14	0.89	4.09	4.17	4.61	3.32	2.96	2.19
95% C.I.; mean ±		2.33	1.47	1.50	1.01	0.82	0.64	2.92	2.98	3.30	2.37	2.11	1.57
C.V. (%)		3.10	2.24	2.96	2.48	2.26	2.24	3.09	3.59	5.13	4.61	4.60	4.31

Table 8. Horizon depth, particle size distribution, organic carbon content, and bulk density of the various horizons at each location for Marshall soil

Horizon	Depth (cm.)	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.046 mm. (%)	Sand .046-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
				Site 1			
Ap	0-18	34.9	30.3	32.5	2.3	1.62	1.21
B1	18-30	37.1	28.5	31.8	2.6	1.46	1.18
B2	30-53	29.0	37.3	31.1	2.6	.531	1.25
B3	53-79	27.7	31.5	38.5	2.3	.486	1.23
C	79-102	29.4	33.6	34.9	2.1	.252	1.23
				Site 2			
Ap	0-18	32.9	28.3	36.8	2.0	1.45	1.20
A3	18-33	33.5	30.4	33.7	2.3	.966	1.25
B1	33-43	30.8	27.0	39.6	2.6	.782	1.25
B2	43-61	29.5	29.8	37.8	2.9	.554	1.27
B3	61-79	28.0	30.9	38.2	2.9	.352	1.33
C	79-114	26.3	37.0	35.0	1.7	.296	1.41
				Site 3			
Ap	0-15	31.0	31.4	34.9	2.7	1.76	0.95
A3B1	15-28	34.2	28.4	33.9	2.5	1.21	1.11
B21	28-46	33.6	30.6	32.7	3.1	.803	1.13
B22	46-71	31.1	31.8	34.9	2.3	.530	1.24
C	71-91	30.6	30.7	35.6	3.1	.411	1.28

Table 8. (Continued)

Horizon	Depth (cm.)	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.046 mm. (%)	Sand .046-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
				Site 4			
Ap	0-13	33.0	31.6	33.8	1.7	1.92	1.40
A3	13-25	33.7	31.3	33.4	1.6	1.84	1.34
B1	25-38	35.4	33.0	30.2	1.4	1.39	1.41
B2	38-74	35.2	34.0	29.0	1.8	.806	1.40
B3	74-96	29.2	38.0	31.2	1.6	.368	1.45
C	96-124	28.7	39.6	29.7	2.0	.287	1.44
				Site 5			
Ap	0-15	29.9	32.9	34.7	2.5	1.82	1.11
A3	15-36	29.8	31.3	37.0	2.0	1.82	1.20
B1	36-46	31.6	30.1	35.9	2.3	1.76	1.33
B2	46-84	32.1	32.0	34.1	1.7	.975	1.18
B3	84-102	29.5	38.3	30.5	1.7	.409	1.17
C	102-122	24.0	34.6	38.9	2.5	.314	1.08
				Site 6			
Ap	0-13	31.0	28.4	38.4	2.2	1.72	1.17
A3	13-25	32.4	26.9	38.5	2.2	1.77	1.17
B1	25-41	33.2	29.5	34.9	2.4	1.37	1.19
B2	41-64	29.8	31.4	35.8	3.0	.700	1.20
B3	64-86	29.0	31.9	36.4	2.6	.708	1.11
C	86-117	24.4	32.5	39.6	3.5	.333	1.11

Table 8. (Continued)

Horizon	Depth (cm.)	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.046 mm. (%)	Sand .046-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
				Site 7			
Ap	0-15	29.8	30.1	37.9	2.1	2.38	1.09
A3	15-25	33.4	28.8	35.6	2.3	2.24	1.24
B1	25-41	33.6	30.9	33.6	2.0	1.35	1.23
B2	41-71	33.8	26.9	36.5	2.8	1.15	1.22
B3	71-96	31.0	31.2	35.5	2.2	1.04	1.20
C	86-109	27.5	31.1	38.9	2.5	.285	1.30
				Site 8			
Ap	0-13	33.4	28.9	35.7	2.0	1.70	1.33
A3	13-23	33.5	33.7	30.7	2.1	1.53	1.20
B1	23-33	37.0	32.3	29.0	1.7	1.17	1.24
B2	33-61	36.9	35.3	26.4	1.4	.978	1.20
B3	61-74	29.5	34.6	34.5	1.4	.508	1.27
C	74-89	27.0	35.8	35.9	1.2	.400	1.20
				Site 8a			
Ap	0-13	34.1	28.0	35.0	2.9	1.75	1.26

Table 8. (Continued)

Horizon	Depth (cm.)	Clay <.002 mm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.046 mm. (%)	Sand .046-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
				Site 9			
Ap	0-15	34.2	28.0	35.6	2.3	2.40	1.22
A3	15-25	36.6	31.9	28.7	2.8	1.51	1.21
B1	25-36	37.2	30.1	30.6	2.1	1.10	1.24
B21	36-51	33.7	30.2	33.6	2.4	.716	1.16
B22	51-76	30.7	32.4	34.2	2.7	.550	1.24
B3	76-94	30.3	35.4	30.6	3.7	.334	1.28
C	94-107	25.8	31.3	40.2	2.7	.322	1.33
				Site 10			
Ap	0-15	32.8	30.4	34.5	2.4	2.83	1.26
A3	15-25	35.5	33.3	29.3	1.9	1.48	1.26
B1	25-38	33.2	35.8	29.7	1.3	1.02	1.18
B2	38-79	31.4	40.9	26.3	1.4	.556	1.21
B3	79-99	28.1	42.7	27.9	1.3	.334	1.20
C	99-114	21.7	41.9	33.8	2.6	.202	1.27

Table 9. Water percentages by weight and by volume at different suctions for the various horizons at each location for Marshall soil

Horizon	Percent water by weight						Percent water by volume					
	.1	.3	1	3	5	15	.1	.3	1	3	5	15
	atm.						atm.					
Site 1												
Ap	31.0	26.1	21.1	20.4	18.4	16.8	37.5	31.6	25.5	24.7	22.3	20.3
B1	31.6	26.0	23.7	21.4	19.3	15.2	37.3	30.7	28.0	25.2	22.8	17.9
B2	29.4	28.3	23.9	19.3	17.6	14.9	36.7	35.4	29.9	24.1	22.0	18.6
B3	32.0	26.5	21.0	18.9	17.8	13.4	39.4	32.6	25.8	23.2	22.0	16.5
C	33.6	29.7	23.0	18.5	16.6	13.4	41.3	36.5	28.3	22.8	20.4	16.5
Site 2												
Ap	30.7	27.8	24.6	21.0	19.0	14.6	36.8	33.4	29.5	25.2	22.8	17.5
A3	30.1	27.9	24.5	20.2	17.9	14.1	37.6	34.9	30.6	25.2	22.4	17.6
B1	29.7	27.2	23.3	19.1	17.3	13.9	37.1	34.0	29.1	23.9	21.6	17.4
B2	28.3	25.1	21.9	17.4	15.3	13.1	35.9	31.9	27.8	22.1	19.4	16.6
B3	28.6	25.5	21.0	17.5	15.2	12.1	38.0	33.9	27.9	23.3	20.2	16.1
C	27.8	25.7	23.7	17.3	15.6	12.1	39.2	36.2	33.4	24.4	22.0	17.1
Site 3												
Ap	29.2	25.9	23.6	19.7	18.0	13.3	27.7	24.6	22.4	18.7	17.1	12.6
A3B1	31.8	27.7	22.8	19.8	17.7	13.5	35.3	30.7	25.3	22.0	19.6	15.0
B21	30.2	25.6	21.2	19.2	16.9	13.5	34.1	28.9	24.0	21.7	19.1	15.2
B22	30.4	25.3	21.8	18.9	16.9	13.6	37.7	31.4	27.0	23.4	21.0	16.9
C	33.5	28.2	22.1	18.8	16.7	13.5	42.9	36.1	28.3	24.1	21.4	17.3

Table 9. (Continued)

Horizon	Percent water by weight						Percent water by volume					
	.1	.3	1	3	5	15	.1	.3	1	3	5	15
	atm.						atm.					
						Site 4						
Ap	32.3	25.1	21.8	19.1	17.4	13.5	45.2	35.1	30.5	26.7	24.4	18.9
A3	29.7	25.6	21.9	19.9	17.6	13.9	39.8	34.3	29.3	26.7	23.5	18.6
B1	31.3	26.4	23.7	20.6	18.4	15.4	44.1	37.2	33.4	29.6	26.0	21.7
B2	29.3	26.0	23.1	20.4	18.6	15.2	41.0	36.4	32.3	28.6	26.0	21.3
B3	29.8	20.8	23.2	19.8	17.7	14.4	43.2	30.2	33.6	28.8	25.6	20.9
C	33.6	31.5	25.8	19.4	17.6	13.5	48.4	45.4	37.2	27.9	25.3	19.5
						Site 5						
Ap	30.8	26.6	21.7	18.3	16.3	12.7	34.2	29.5	24.1	20.3	18.1	14.1
A3	30.8	25.0	21.1	18.8	16.1	12.5	37.0	30.0	25.3	22.6	19.3	15.0
B1	29.1	25.3	21.1	19.0	16.6	14.7	38.7	33.6	28.1	25.2	22.1	19.6
B2	29.6	26.6	22.2	19.4	17.4	14.2	34.9	31.4	26.2	22.9	20.5	16.8
B3	31.7	27.8	22.7	19.7	17.7	15.1	37.1	32.5	26.6	23.0	20.7	17.7
C	34.6	29.6	21.7	16.8	15.1	12.0	37.4	32.0	23.4	18.2	16.3	12.9
						Site 6						
Ap	27.7	26.8	24.2	19.1	17.8	13.2	32.4	31.3	28.3	22.3	20.8	15.4
A3	30.3	25.0	21.1	19.5	17.4	13.4	35.4	29.3	24.7	22.8	20.4	15.7
B1	31.7	28.5	22.0	19.6	17.9	14.6	37.7	33.9	26.2	23.4	21.3	17.4
B2	33.5	25.5	21.1	18.3	16.2	12.9	40.2	30.6	25.3	22.0	19.4	15.5
B3	32.1	25.8	20.3	17.9	16.4	12.5	35.6	29.7	22.5	19.9	18.2	13.9
C	38.0	29.0	18.8	15.1	13.8	10.9	42.2	32.1	20.8	16.7	15.3	12.1

Table 9. (Continued)

Horizon	Percent water by weight						Percent water by volume					
	.1	.3	1	3	5	15	.1	.3	1	3	5	15
	atm.						atm.					
						Site 7						
Ap	33.3	29.4	24.9	20.5	18.6	14.2	36.3	32.0	27.1	22.3	20.3	15.5
A3	30.4	28.0	23.2	22.0	20.1	14.8	37.7	34.7	28.8	27.4	24.9	18.4
B1	30.9	27.2	23.0	20.1	17.9	15.3	38.0	33.4	28.3	24.7	22.0	18.8
B2	30.8	26.8	23.2	20.7	18.7	15.2	37.6	32.7	28.3	25.2	22.8	18.5
B3	31.8	28.6	23.0	20.3	18.1	15.6	38.2	34.3	27.6	24.4	21.7	18.7
C	30.3	27.4	20.5	19.4	16.8	12.7	39.4	35.6	26.6	25.2	21.9	16.5
						Site 8						
Ap	34.1	26.6	23.4	20.5	18.1	13.8	45.4	35.4	31.1	27.3	24.1	18.4
A3	29.8	27.5	24.7	21.2	19.8	15.3	35.8	33.0	29.7	25.5	23.8	18.4
B1	29.9	27.4	24.8	23.1	21.1	18.2	37.1	34.0	30.8	28.6	26.2	22.6
B2	30.2	28.1	25.3	22.8	20.4	16.3	36.2	33.7	30.4	27.4	24.5	19.6
B3	31.5	27.9	24.3	20.5	18.5	14.2	40.0	35.4	29.2	26.0	23.5	18.0
C	30.4	28.1	25.0	19.1	16.3	13.4	36.5	33.7	30.0	22.9	19.6	16.1
						Site 8a						
Ap				19.0	17.1	13.1				23.9	21.5	16.5

Table 9. (Continued)

Horizon	Percent water by weight						Percent water by volume					
	.1	.3	1	3	5	15	.1	.3	1	3	5	15
	atm.						atm.					
					Site 9							
Ap	40.7	26.8	22.0	23.4	21.5	18.1	49.6	32.7	26.8	28.5	26.2	22.1
A3	31.0	28.1	24.8	23.4	21.4	17.3	37.5	34.0	30.0	28.3	25.9	20.9
B1	30.2	26.8	24.4	22.7	19.5	17.2	37.4	33.2	30.2	28.1	24.1	21.3
B21	30.7	26.8	22.9	21.4	17.9	16.3	38.1	33.2	28.4	26.5	22.2	20.2
B22	29.0	26.0	23.6	19.8	17.8	14.4	36.0	32.3	29.3	24.5	22.1	17.8
B3	34.2	26.4	20.8	19.2	17.4	14.1	43.8	33.8	26.6	24.6	22.3	18.0
C	32.5	28.1	21.0	18.3	16.6	13.1	43.2	37.4	27.9	24.4	22.1	17.4
					Site 10							
Ap	32.9			23.9	22.0	18.3	41.5			30.1	27.7	23.1
A3	31.6			21.9	18.6	16.0	39.8			27.6	23.4	20.2
B1	29.5	27.5	23.3	20.3	18.2	15.0	34.8	32.5	27.5	24.0	21.5	17.7
B2	32.2	26.5	22.0	19.7	17.7	15.0	39.0	32.1	26.6	23.8	21.4	18.2
B3	33.7	32.5	23.2	18.3	16.5	13.6	40.4	39.0	27.8	22.0	19.8	16.3
C	38.1	32.9	22.4	16.8	14.8	11.9	48.4	41.8	28.4	21.3	18.8	15.1

Table 10. Horizon depth, particle size distribution, organic carbon content, and bulk density of each horizon at locations 11 through 16[a]

Profile number	Horizon	Horizon SCS	Depth (cm.)	Clay <.002 cm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.05 mm. (%)	Sand .05-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
11	Ap	Ap	0-18	28.6	31.2	37.9	2.3	2.46	1.34
12	Ap	Ap	0-18	30.9	27.9	38.4	2.8	2.14	1.42
13	Ap	Ap	0-15	31.7	25.5	39.5	3.3	2.05	1.39
14	Ap	Ap	0-18	29.0	30.8	37.6	2.6	2.61	1.28
15	Ap	Ap	0-18	30.4	27.9	38.7	3.0	2.20	1.32
16	Ap	Ap	0-18	30.6	25.4	40.4	3.6	2.31	1.26
Mean				30.20	28.12	38.75	2.93	2.30	1.34
Standard deviation				1.18	2.49	1.04	0.47	0.21	0.06
95% Confid. inter.; mean ±				1.24	2.61	1.09	0.49	0.22	0.07
Coeff. of variation (%)				1.60	3.61	1.09	6.55	3.72	1.92
11	A3	A12	18-41	33.0	31.1	33.9	2.0	2.14	1.19
12	A3	A12	18-33	33.0	28.4	36.1	2.5	1.82	1.23
13	A3	A3	15-25	33.3	27.4	36.3	3.0	1.45	1.23
14	A3	A13	18-41	32.4	30.7	34.7	2.2	2.16	1.30
15	A3	A13	18-33	33.5	28.2	35.7	2.6	1.87	1.26
16	A3	A31	18-30	32.5	28.9	35.2	3.4	1.48	1.24
Mean				32.95	29.12	35.32	2.62	1.82	1.24
Standard deviation				0.45	2.16	0.91	0.52	0.31	0.04
95% Confid. inter.; mean ±				0.47	1.54	0.95	0.54	0.32	0.04
Coeff. of variation (%)				0.55	2.06	1.05	8.04	6.90	1.23

[a]Data for these profiles were obtained from the Soil Survey Laboratory, Lincoln, Nebraska. The horizon designations have been changed to correspond more closely with the other 10 profiles. The SCS horizon designation is also given.

Table 10. (Continued)

Profile number	Horizon	Horizon SCS	Depth (cm.)	Clay <.002 cm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.05 mm. (%)	Sand .05-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
11	B1	A3	41-58	33.4	31.2	33.2	2.2	1.61	1.22
12	B1	A3	33-46	33.2	28.6	35.5	2.7	1.37	1.24
14	B1	A3	41-58	32.9	31.3	33.3	2.5	1.45	1.22
15	B1	A3	33-46	32.8	28.3	36.1	2.8	1.11	1.24
16	B1	A32	30-41	31.3	27.7	37.4	3.6	1.08	----
Mean				32.72	29.42	35.10	2.76	1.32	1.23
Standard deviation				0.83	1.70	1.82	0.53	0.23	0.01
95% Confid. inter.; mean ±				1.03	2.11	2.26	0.65	0.28	0.02
Coeff. of variation (%)				1.13	2.59	2.32	8.55	7.73	0.46
11	B2	B21	58-71	34.0	30.3	33.0	2.7	1.00	1.26
12	B2	B21	46-66	31.8	27.8	36.7	3.7	0.62	1.20
13	B2	B21	25-46	31.3	29.2	36.6	2.9	0.86	1.22
14	B2	B21	58-84	32.8	29.2	35.0	3.0	0.78	1.22
15	B2	B21	46-71	30.4	27.5	38.9	3.2	0.58	1.24
16	B2	B21	41-56	30.1	27.7	38.2	4.0	0.63	1.20
Mean				31.73	28.62	36.40	3.25	0.745	1.22
Standard deviation				1.48	1.12	2.15	0.50	0.164	0.02
95% Confid. inter.; mean ±				1.55	1.18	2.26	0.52	0.172	0.03
Coeff. of variation (%)				1.90	1.60	2.41	6.28	9.01	0.82

Table 10. (Continued)

Profile number	Horizon	Horizon SCS	Depth (cm.)	Clay <.002 cm. (%)	Fine silt .002-.02 mm. (%)	Coarse silt .02-.05 mm. (%)	Sand .05-2.0 mm. (%)	Organic carbon (%)	Bulk density (g/cc)
11	B3	B22	71-91	32.5	27.9	36.4	3.2	0.58	1.28
12	B3	B22	66-86	27.8	30.4	38.1	3.7	0.46	1.22
13	B3	B22	46-64	30.0	30.3	36.9	2.8	0.54	1.20
14	B3	B22	84-96	29.7	26.7	40.3	3.3	0.38	----
15	B3	B22	71-86	28.2	28.0	39.7	4.1	0.33	1.25
16	B3	B22	56-69	28.9	27.9	39.2	4.0	0.51	1.20
Mean				29.52	28.53	38.43	3.52	0.470	1.23
Standard deviation				1.69	1.49	1.57	0.50	0.10	0.03
95% Confid. inter.; mean ±				1.77	1.56	1.65	0.53	0.10	0.04
Coeff. of variation (%)				2.33	2.12	1.66	5.85	8.32	1.26
11	C	B23	91-112	30.1	28.1	38.2	3.6	0.33	1.38
12	C	B23	86-104	28.2	28.3	39.4	4.1	0.33	1.29
13	C	B23	64-81	29.6	29.6	37.8	3.0	0.33	1.22
14	C	B31	96-114	27.0	28.9	40.1	4.0	0.25	1.30
15	C	B31	86-112	26.9	27.4	41.6	4.1	0.21	----
16	C	B31	69-86	27.2	27.2	41.2	4.4	0.29	----
Mean				28.17	28.25	39.72	3.87	0.290	1.30
Standard deviation				1.39	0.90	1.54	0.50	0.05	0.07
95% Confid. inter.; mean ±				1.46	0.95	1.62	0.52	0.05	0.10
Coeff. of variation (%)				2.02	1.31	1.58	5.23	7.12	2.52

.APPENDIX C

Table 11. Suction, water content, diffusivity and conductivity relations for each of two depths at four locations on Marshall silty clay loam

Suction (cm H_2O)	Water content (% by vol)	Diffusivity (cm^2/hr)	Conductivity (cm/hr)
	Profile 1		
	(5.1 - 12.7 cm. depth)		
0			
25	44.1	1.63	4.5×10^{-4}
40	43.7	4.4×10^{-1}	1.1×10^{-4}
70	42.9	1.0×10^{-2}	1.1×10^{-5}
136	36.0	6.5×10^{-1}	9.3×10^{-6}
340	35.7	5.8×10^{-2}	2.5×10^{-6}
680	34.2	7.0×10^{-2}	1.8×10^{-6}
1224	32.8	4.6×10^{-2}	1.3×10^{-6}
2040	30.6		
	(30.5 - 38.0 cm. depth)		
0			
25	38.9	6.29	8.2×10^{-3}
40	37.0	5.41	3.2×10^{-3}
70	35.2	3.47	9.5×10^{-4}
136	33.4	1.00	1.1×10^{-4}
340	31.1	4.0×10^{-1}	2.8×10^{-5}
680	28.7	1.6×10^{-1}	6.8×10^{-6}
1224	26.3	4.9×10^{-2}	1.4×10^{-6}
2040	24.1		
	Profile 3		
	(5.1 - 12.7 cm. depth)		
0			
25	43.7	2.69	3.1×10^{-3}
40	42.0	1.45	6.1×10^{-4}
90	39.9	5.2×10^{-1}	1.2×10^{-4}
170	38.1	5.5×10^{-1}	6.1×10^{-5}
340	36.2	4.7×10^{-1}	2.0×10^{-5}
680	34.0	3.8×10^{-1}	1.3×10^{-5}
1224	32.0	2.8×10^{-1}	6.2×10^{-6}
2040	30.4		

Table 11. (Continued)

Suction (cm H_2O)	Water content (% by vol)	Diffusivity (cm^2/hr)	Conductivity (cm/hr)
	(30.5 - 38.0 cm. depth)		
0			
25	41.4	6.9×10^{-1}	1.2×10^{-3}
40	38.8	36.3	2.4×10^{-2}
90	35.4	1.49	3.5×10^{-4}
170	33.6	1.24	1.2×10^{-4}
340	31.8	7.5×10^{-1}	4.7×10^{-5}
680	29.7	3.0×10^{-1}	1.2×10^{-5}
1224	27.5	8.2×10^{-1}	2.2×10^{-6}
2040	25.4		
	Profile 8		
	(5.1 - 12.7 cm. depth)		
0			
25	41.2	1.78	4.8×10^{-4}
40	40.8	1.88	2.4×10^{-4}
70	40.5	5.2×10^{-1}	9.3×10^{-5}
136	39.3	2.9×10^{-1}	4.0×10^{-5}
340	36.5	1.8×10^{-1}	1.4×10^{-5}
680	33.6	1.5×10^{-1}	5.6×10^{-6}
1224	31.7	1.4×10^{-1}	2.8×10^{-6}
2040	30.0		
	(30.5 - 38.0 cm. depth)		
0			
25	39.6	1.29	1.1×10^{-3}
40	38.3	1.56	8.2×10^{-4}
70	36.7	5.7×10^{-1}	1.2×10^{-4}
136	35.4	1.9×10^{-1}	2.0×10^{-5}
340	33.2	3.0×10^{-2}	4.6×10^{-5}
680	28.0	8.9×10^{-2}	3.5×10^{-6}
1224	25.8	4.5×10^{-2}	6.3×10^{-7}
2040	24.8		

Table 11. (Continued)

Suction (cm H_2O)	Water content (% by vol)	Diffusivity (cm^2/hr)	Conductivity (cm/hr)
	Profile 8a		
	(5.1 - 12.7 cm. depth)		
0			
25	41.5	4.62	1.0×10^{-3}
40	41.2	1.61	5.8×10^{-4}
70	40.1	2.40	7.5×10^{-4}
136	38.0	9.6×10^{-1}	1.6×10^{-4}
340	34.6	3.7×10^{-1}	3.6×10^{-5}
680	31.3	5.2×10^{-1}	2.7×10^{-5}
1224	28.5	8.6×10^{-2}	3.2×10^{-6}
2040	25.5		
	(30.5 - 38.0 cm. depth)		
0			
25	36.5	5.95	8.2×10^{-3}
40	34.4	3.07	1.6×10^{-3}
70	32.8	8.2×10^{-1}	1.3×10^{-4}
136	31.5	4.4×10^{-1}	4.0×10^{-5}
340	29.7	1.1×10^{-1}	7.8×10^{-6}
680	27.2	6.2×10^{-2}	2.0×10^{-6}
1224	25.4	1.3	9.7×10^{-6}
2040	24.8		

Table 12. Average suction, water content, diffusivity, and conductivity relations at each of two depths for four locations

Suction ($cm\ H_2O$)	Water content (% by vol)	Diffusivity (cm^2/hr)	Conductivity (cm/hr)
	5.1 - 12.7 cm. depth		
0	43.8		
25	42.6	2.68	1.2×10^{-3}
40	41.9	1.34	3.9×10^{-4}
70	41.0	9.8×10^{-1}	2.9×10^{-4}
136	38.0	6.5×10^{-1}	7.1×10^{-5}
340	35.8	2.7×10^{-1}	1.8×10^{-5}
680	33.3	2.8×10^{-1}	1.2×10^{-5}
1224	31.3	1.4×10^{-1}	3.4×10^{-6}
2040	29.1		
	30.5 - 38.0 cm. depth		
0	41.4		
25	39.1	3.56	4.7×10^{-3}
40	37.1	11.58	7.5×10^{-3}
70	35.0	2.66	4.0×10^{-4}
136	33.5	7.3×10^{-1}	5.8×10^{-5}
340	31.4	3.2×10^{-1}	3.2×10^{-5}
680	28.4	1.5×10^{-1}	6.1×10^{-6}
1224	26.2	3.7×10^{-1}	3.5×10^{-6}
2040	24.8		

APPENDIX D

Table 13. General input data for all infiltration estimates

Top soil				Bottom soil		
Moisture content (% vol)	Suction (cm)	Diffusivity (cm^2/sec)	Conductivity (cm/hr)	Moisture content (% vol)	Suction (cm)	Diffusivity (cm^2/sec)
0.1400	-27000.00	0.01	2.0×10^{-8}	0.1400	-74000.00	0.02
0.1600	-20000.00	0.01	3.0×10^{-8}	0.1600	-43000.00	0.02
0.1800	-14700.00	0.01	4.0×10^{-8}	0.1800	-23500.00	0.03
0.2000	-11000.00	0.02	1.0×10^{-7}	0.2000	-12900.00	0.05
0.2200	-8100.00	0.03	2.1×10^{-7}	0.2200	-6800.00	0.07
0.2400	-5900.00	0.04	3.6×10^{-7}	0.2400	-3500.00	0.10
0.2600	-4250.00	0.05	5.0×10^{-7}	0.2600	-1600.00	0.14
0.2800	-3000.00	0.10	1.6×10^{-6}	0.2800	-800.00	0.22
0.3000	-1900.00	0.10	1.8×10^{-6}	0.3000	-470.00	0.34
0.3200	-1100.00	0.20	5.0×10^{-6}	0.3200	-270.00	0.55
0.3400	-580.00	0.20	7.8×10^{-6}	0.3400	-124.00	0.93
0.3600	-325.00	0.40	3.1×10^{-5}	0.3600	-60.00	1.75
0.3800	-162.00	0.60	7.2×10^{-5}	0.3700	-45.00	2.70
0.4000	-92.00	0.90	3.6×10^{-4}	0.3800	-34.00	4.50
0.4100	-66.00	1.10	4.2×10^{-4}	0.3900	-25.00	9.00
0.4200	-41.00	1.60	6.4×10^{-4}	0.3950	-21.00	14.00
0.4250	-30.00	2.60	1.2×10^{-3}	0.4000	-16.50	24.00
0.4300	-19.50	3.70	1.9×10^{-3}	0.4050	-12.50	50.00
0.4310	-17.40	8.00	3.8×10^{-3}	0.4100	-8.60	150.00
0.4320	-15.40	10.00	5.0×10^{-3}	0.4150	-4.80	310.00
0.4330	-13.40	14.00	7.0×10^{-3}	0.4160	-4.40	340.00
0.4340	-11.40	19.00	9.5×10^{-3}	0.4170	-3.80	360.00
0.4350	-9.44	27.00	1.4×10^{-2}	0.4172	-3.45	380.00
0.4360	-7.50	40.00	2.0×10^{-2}	0.4174	-1.90	410.00
0.4370	-5.56	68.00	3.5×10^{-2}	0.4176	-1.10	440.00
0.4380	-3.70	137.00	7.4×10^{-2}	0.4178	-0.40	470.00
0.4385	-2.77	185.00	1.0×10^{-1}	0.4180	-0.0	490.00
0.4390	-1.85	277.00	1.5×10^{-1}	0.4182	5.00	0.0
0.4392	-1.48	370.00	2.1×10^{-1}			
0.4394	-1.11	648.00	3.5×10^{-1}			
0.4396	-0.74	926.00	5.0×10^{-1}			
0.4398	-0.37	1370.00	7.4×10^{-1}			
0.4400	-0.0	1852.00	1.0			
0.4402	5.00	0.0				

Table 14. Hypothetical data used to determine the effect of the diffusivity-water content relation below 25 cm. suction on infiltration for curve A of Figures 14 and 15

Suction ($cm\ H_2O$)	Water content (% by vol)	Diffusivity (cm^2/hr)	Conductivity (cm/hr)
0	44.0	1852.00	1.00
3.7	43.8	1720.00	.93
5.56	43.7	1600.00	.85
7.50	43.6	1350.00	.71
9.44	43.5	797.00	.43
11.40	43.4	390.00	.175
13.40	43.3	137.00	.07
15.40	43.2	36.00	.018
17.40	43.1	18.00	.0088
19.50	43.0	5.80	.0029
30.00	42.5	2.60	.0012
41.00	42.0	1.60	.0007
66.00	41.0	1.10	.0004
92.00	40.0	.90	.0003
162.00	38.0	.60	.0001
325.00	36.0	.40	.00003
580.00	34.0	.20	.000008
1100.00	32.0	.20	.000005
1900.00	30.0	.10	.000002
3000.00	28.0	.10	.000002
4250.00	26.0	.05	.0000005
5900.00	24.0	.04	.0000004
8100.00	22.0	.03	.0000002
11000.00	20.0	.02	.0000001
14700.00	18.0	.01	.00000004
20000.00	16.0	.01	.00000003
21000.00	14.0	.01	.00000002

Table 15. Hypothetical data used to determine the effect of the diffusivity-water content relation below 25 cm. suction on infiltration for curve B of Figures 14 and 15

Suction (cm H_2O)	Water content (% by vol)	Diffusivity (cm^2/hr)	Conductivity (cm/hr)
0	44.00	1852.00	1.0
.37	43.98	1370.00	.74
.74	43.96	926.00	.50
1.11	43.94	648.00	.35
1.48	43.92	370.00	.20
1.85	43.90	277.00	.15
2.77	43.85	185.00	.10
3.70	43.80	137.00	.074
5.56	43.70	68.00	.036
7.50	43.60	40.00	.021
9.44	43.50	27.00	.014
11.40	43.40	19.00	.0096
13.40	43.30	14.00	.0070
15.40	43.20	10.00	.0050
17.40	43.10	8.00	.0040
19.50	43.00	3.70	.0023
30.00	42.50	2.60	.0012
41.00	42.00	1.60	.0007
66.00	41.00	1.10	.0004
92.00	40.00	.90	.0003
162.00	38.00	.60	.0001
325.00	36.00	.40	.00003
580.00	34.00	.20	.000008
1100.00	32.00	.20	.000005
1900.00	30.00	.10	.000002
3000.00	28.00	.10	.000002
4250.00	26.00	.05	.0000005
5900.00	24.00	.04	.0000004
8100.00	22.00	.03	.0000002
11000.00	20.00	.02	.0000001
14700.00	18.00	.01	.00000004
20000.00	16.00	.01	.00000003
21000.00	14.00	.01	.00000002