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Effect of Erosion on Water Infiltration Rates

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CONTENTS

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Effects of Erosion on Water Infiltration Rates

G. M. POWELL AND R. P. BEASLEY

INTRODUCTION

This problem was formulated for studying the water infiltration rates on various soils in Missouri and the effect erosion has on infiltration rates. If a definite relationship between the degree of topsoil erosion and the reduction in the amount of water taken into the soil can be established, this will strengthen the reasons for applying conservation measures, thus resulting in a reduction in erosion and downstream sedimentation.

Erosion caused by water runoff from the land influences the lives of all people. It carries away topsoil and reduces the fertility and the production potential of the land. It forms gullies and is a destructive force to the beauty of the land and the wildlife on that land.

Water erosion has been the major problem farmers have had to combat on cultivated land. Around 436 million acres are expected to be in cultivation in the United States in 1975. Of this amount, 179 million acres (approximately 42 percent of cultivated land) have a water erosion problem. The percentage of cultivated land with a water erosion problem ranges as high as 59 percent in the Appalacian States and as low as 24 percent in the Rocky Mountain States. (26)

Trends suggest that in the next 20 years the demand for water will more than double. (25) Thus if we are to continue to develop our society and advance technologically, as we have in recent years, an abundant supply of water will be necessary. It will be necessary also to make efficient use of that water. To accomplish these objectives requires that research be done today to learn more about the control of our water resources. Water infiltration rate, the rate at which water is taken into the soil, is an important factor to consider.

The rate of infiltration and total water intake are necessary tools required in the design of irrigation systems. Measurements of these are needed for determining the amount of water that will be available for crop growth, and for predicting the amount of surface runoff and peak rates of flow.

Horton (11), in 1933, pointed out the role of infiltration in the hydrologic cycle. Since that time a great deal of information has been accumulated on infiltration rates. Numerous studies, using many different procedures, have been made to determine the factors which affect infiltration and the degree of that effect. Much of the information now available is from specified soils or other specific conditions that limit the application of the information. Much of the data from which conclusions are drawn have failed to take into account all of the influencing factors. Methods employed in applying the water in many cases have failed to closely simulate actual rainfall. In addition, to this writer's knowledge, no work has been done on determining the effect erosion has on infiltration rates. It is desirable, then, that additional research be done in the area of water infiltration rates.

DEFINITIONS

Definition of Terms

Aggregate Stability. A value that, when compared with the degree of aggregation, shows a relative value to the stability of the aggregate.

Comminution Number. In this bulletin it shall mean the number of times the diameter is doubled in going from the smallest particle diameter to the largest. This may be expressed mathematically as

$$C = \frac{\log_{10}(\text{largest diameter}) - \log_{10}(\text{smallest diameter})}{\log_{10}(2)}$$

Degree of Aggregation. The percent by weight of silt and clay size particles which are held together to form a larger particle.

Front Slope of a Terrace. The slope immediately above the terrace channel.

Infiltration. Intake of water into a soil.

Infiltration Rate. The rate at which water is taken into the soil. This changes with time and conditions. Consequently a specific time and the specific conditions must be expressed.

Infiltrometer. An instrument or equipment which is employed to measure an infiltration rate.

pH. Logarithm of the reciprocal of the active hydrogen ion in grams per liter.

pH_w. pH of soil measured in distilled water.

pH_s. pH of soil measured in solution of 0.01 molar calcium.

Test Designation

I, II, III, IV, V. Location (indicates farm where testing was done).

A, B, C, E, F, X, Y. Site (indicates area or areas on farm where testing site was located).

S, M, N, D. Plot (indicates subsoil, medium topsoil, normal topsoil and double topsoil, respectively).

D, W. Run (indicates dry or first run and wet or second run, respectively).

Symbols Used

C	Comminution number.	
e	Base of natural logarithms.	
f	Instantaneous infiltration rate at a specific time.	in/hr.
f_o	Initial infiltration rate.	in/hr.
f_c	Final infiltration rate, a specific value for a particular soil-cover complex.	in/hr.
k	Constant depending primarily upon soils, and vegetation.	
I	Total infiltration.	

REVIEW OF LITERATURE

Factors Affecting Infiltration

A great deal of research has been done in establishing factors that influence infiltration rates and the degree of their effect. A general comprehensive summary of these factors was given by Musgrave. (21) For a more detailed description of the factors influencing infiltration, refer to Parr and Bertrand's review of literature. (23)

Methods for Measuring Infiltration

Previous methods for measuring infiltration rates have been of three main types: (1) a sprinkling device to simulate a rain storm; (2) a cylinder or ring which uses impounded water on the surface or a basin which is a cylinder on a large scale; or (3) a watershed hydrograph analysis which utilizes rainfall and runoff data from a particular watershed area.

The watershed hydrograph method is dependent on rainfall and is not realistic for comparison of such factors as vegetal cover or tillage practices. In addition, direct intrepretation of data is virtually impossible, making watershed hydrographs impractical for short term studies. Ring infiltrometers are limited because of air trapped inside the column, the method of placement of the ring in the soil, the unnatural seepage at the interface between the metal of the ring and the soil, and lateral movement of soil water below the ring. All of these conditions introduce errors; consequently, the sprinkling infiltrometer seems to be the most versatile research tool for making comparative studies of infiltration rates under natural conditions. A review of the important methods of measuring infiltration is given by Parr and Bertrand. (23)

Development of the Purdue Sprinkling Infiltrometer

The realization that the drop size has an effect on the infiltration rate and an even greater effect on erosion has led to the study of drop size, velocity, and kinetic energies produced by different nozzles in sprinkling infiltrometers. The study by Meyer (19) led to a study by Bertrand and Parr (4, 5) of 24 commercial nozzles. From preliminary tests on these nozzles, three nozzles were selected for final testing.

Bertrand and Parr followed the procedure of Meyer in testing the commercial spray nozzles for drop size, drop distribution, and kinetic energies at various combinations of pressure and height. The three nozzles finally selected have application rates of approximately 2.5, 3.25, and 4.5 inches per hour. This range is useful in that it increases the adaptability of the sprinkling infiltrometer.

After the nozzles were selected, the overall infiltrometer was designed on the basis of ease of handling and erecting, reproducibility of data, cost, ease of construction, and similarity to actual rainfall. (5) With this infiltrometer, simulated rainfall can be applied to any treatment at any time throughout the season and is therefore a useful research tool.

Dixon and Peterson of the University of Wisconsin have proposed changes which greatly improve the ease of setting up the equipment to run field tests. They also improve the east and efficiency of collecting runoff, and the reproducibility of the tests. (7) The major contributions of Dixon and Peterson were the redesign of the tower, making erection easier and faster, and the addition of the vacuum pump and vacuum collection tank in place of the circulating pump used by Bertrand and Parr. These improvements also improved the accuracy of the equipment. The sprinkling infiltrometer as modified consists of:

1. A pumping unit consisting of a centrifugal pressure pump to supply water to the nozzle and a vacuum pump to produce a vacuum on the collection tank. The pressure pump and the vacuum pump are driven from a single gasoline engine by a flexible coupling and a V-belt, respectively.
2. A pressure control system consiting of a low pressure spring loaded bypass valve and a pressure tank. The gasoline engine was slightly modfied to reduce the variations in engine speed. Pressure gauges were installed at the pressure tank and at the nozzle itself.
3. A plot frame and runoff collection system. The plot frame is 12 inches high and 45.75 inches square and is driven into the ground to a depth of eight inches. Four runoff tubes are located on one side of the frame and oriented on the downhill side. The runoff water is conveyed by a flexible tubing to a collection point where the vacuum line from the vacuum collection tank picks up the water and returns it to the collection tank.
4. The runoff measuring sytem consists of a runoff accumulation tank upon which a vacuum is maintained, a leveling stand, and a water stage recorder to record the level of the runoff water.
5. The tower is constructed of thin wall steel tubing with telescoping legs to facilitate adjusting the height and to aid in erection. The overall height of the tower is 10 feet and it has a 12-foot square base. The cover for the tower is made from a nylon parachute.
6. The spray nozzle assembly is attached to the top of the tower by means of a ball and socket trailer hitch so that the nozzle may easily be adjusted in a vertical position. The assembly is then locked in position by means of a set screw. The spray nozzle delivers an application rate of 4.71 inches per hour to the plot area.
7. A supply tank with a capacity of about a thousand gallons and a heavy duty carrier.

A detailed description of the construction of this sprinkling infiltrometer is given by Dixon and Peterson. (7)

DESIGN OF THE EXPERIMENT

The factors taken into account when designing this experiment were:

1. Surface condition and the amount of protection aginst the impact of rain (foliage density, stem density, surface roughness, surface bulk density, mulch, etc.).

2. Internal characteristics of the soil mass: including pore size, depth or thickness of soil horizons, degree of swelling of clay and colloids, organic matter content, degree of aggregation, and bulk density.

3. Soil moisture content and the degree of saturation at the beginning of the test.

4. Simulated rainfall characteristics; including duration, intensity, drop size, velocity, and kinetic energy.

5. Season of the year and temperature of the soil and water.

During this study all factors except the degree of erosion were held as nearly constant as possible for pairs of tests. In field tests it is of course impossible to keep all of these factors constant.

The type and condition of crop cover has one of the greatest effects on water intake rates. These factors will control the degree to which the compact surface layer is formed under raindrop impact. Due to the difficulty of evaluating crop cover and stem density, pairs of eroded and non-eroded plots were selected so that this factor would not enter as a variable for that pair of tests. Differences between surface conditions of the soil, within pairs such as surface roughness and surface bulk density, were also considered negligible since each pair of plots had had similar treatment. Plots were selected so that depression storage, caused by surface roughness, was not an influencing factor.

The internal charaecteristics of paired test plots were considered very similar in each case, with the exception that the topsoil was very thin on one plot as compared to the other. This difference in topsoil thickness, as a result of erosion, has an effect on the clay content at the surface and the pore size. The clay content, in turn, has an effect on the degree of aggregation and bulk density as well as the thickness of the permeable portion of the soil. The degree of aggregation and the bulk density were measured for all profiles. The particle size distribution and amount of organic matter were determined for each six-inch horizon to a total depth of two feet for each profile.

Soil moisture content was measured at the beginning of each test. The second, or wet, test was usually made 16 to 24 hours after the first, or dry test. Soil moisture was therefore known both before and after the dry test as well as before the wet test.

The same nozzle, nozzle pressure, and height were used for all tests to eliminate the influence of differences in drop size or rainfall intensity. All pairs of tests on one soil type were run within a week, thus eliminating any major differences due to season of the year (crop cover or soil characteristics), temperature of the water, and temperature of the soil.

The objective of this experiment was to determine the effct of topsoil erosion on infiltration rates.

Since infiltration rates may be affected a great deal by soil erosion on one soil type but relatively little on another, several soil types were included in this study.

Where possible, tests were made on naturally eroded and non-eroded plots. This, however, was not feasible if the eroded field had not been cropped or treated the same as a non-eroded field. In such cases it was necessary to simulate erosion of the topsoil by removing it by mechanical means. This was done only when no other practical alternative was available. In the case of the University's South Farm (location I, site A), the Soils Department had removed the topsoil from one plot and placed it on another. This resulted in three adjacent plots having surface material consisting of a double topsoil layer, a normal layer, and a subsoil. This had been done about 1940 so that differences in organic matter and other factors had had an opportunity to equalize. In the case of the University Horticulture Farm (location V) and South Farm (location I, site B), the front slope of a terrace channel was used for the subsoil plot. Both fields had been farmed several years since terracing, thus giving the subsoil an opportunity to acquire organic matter and equalize in that way with the topsoiil.

It was decided that because antecedent moisture conditions influence the infiltration rate, two tests would be made on the same plot. The first test was under dry conditions (e.g. before water had been applied). The second test was made the following day under wet antecedent conditions: after water had been applied and allowed to remain over night and thus to equalize at what was assumed to be at, or very near, field capacity.

PROCEDURE

Selection of Test Plots

All test locations were selected on the basis of contrasts in the extent of soil erosion. Proximity of the location to Columbia and availability by access roads were also considered. Several locations were selected so that different soil types would be used. A variety of crops and cover conditions were also present.

The particular site at each location was selected on the basis of uniformity of cover and cropping history of that site. In most cases, an effort was made to choose a site which had been cropped in the same way for several years. Here again, it was necessary to keep in mind the necessity of an eroded and a non-eroded plot at each site.

The individual test plots at each site were selected on the basis of the extent of erosion while trying to keep such factors as slope, variations in crop cover, and soil type the same. Since erosion is affected a great deal by slope, this objective was very hard to achieve. In some cases, the only alternative was to select the plots and measure the slope of the individual plots. However, since previous experiments have shown that slope has very little effect on the infiltration rate, this did not present a problem.

Plot Location and Description

Location I—University of Missouri South Farm

This farm is located four miles southeast of Columbia, Mo. Three sites were selected as follows:

Site A. This site was on the Soils Department subsoil plots, which are located about 200 yards southwest of the Central Farms office at the south farm. The legal description of this site is the SW ¼ of the SW ¼ of Section 28, Township 48 North, Range 12 West of the 5th Principal Meridian in Boone County, Mo.

These plots were constructed by removing the topsoil from one plot and placing it on top of another, leaving a normal plot in between. This was done about 1940 and the plots were cropped with corn until about 1960. Since that time, the plots have been in grass. Soil tests indicate that from the standpoint of fertility, the subsoil should be at a production potential equal to the normal or double topsoil plots. These plots were given no special treatment for this experiment. Soil type at this site is the Mexico silt loam, light gray variant.

Site B. This site was in Field A which is located southwest of the shop on the south farm. Subsoil plots were selected in the front slope of terraces. This site has been cropped in corn and has been farmed for several years since the construction of terraces. No difference in organic matter content of these plots is evident at the surface, but is quite evident at lower levels of the profile. No treatment was made on these plots except that the corn was cut off at the ground surface just prior to the test. All grass was also cut so that the ground surface was left bare.

Site C. This site is also located in Field A; however, it had not been cropped for a number of years. It was decided that it would be advantageous to mechanically "erode" the topsoil from a plot on at least one location. This area was selected on the basis of accessibility and availability, as well as its lack of a crop. About seven inches of soil, all the topsoil, was removed, thus forming the subsoil plot. Three to four inches of soil were removed from the medium topsoil plot. The only special treatment made on these plots, including the normal plot, was tandem disking and harrowing several times to kill vegetation and equalize surface conditions.

Sites B and C are located in W ½ of the NE ¼ and the E ½ of the NW ¼ of Section 33, Township 48 North, Range 12 west of the 5th Principal Meridian in Boone County. The soil type for both of these sites is a Mexico silt loam with the exception that the second subsoil plot at site C was a Gara clay loam.

Location II—The University of Missouri Bradford Farm

Site X. This site was a vegetated area covered with crab grass, blue grass, and some weeds. The site had been mowed. The amount of vegetation on both the normal and subsoil plots was relatively consistent. No treatment was made of this site.

Site Y. Site Y was a non-vegetated area very close to Site X. The subsoil and topsoil plots were hoed by hand to remove the scattered vegetation and to leave the surface in approximately the same condition. Freezing and thawing over the winter had left the first subsoil plot (S1) in a loose, well-aggregated state. No farming operations or equipment had disturbed this condition at the time of the first set of tests.

The eroded or subsoil plots had had the soil removed by mechanical means the year before. Some relatively large differences were therefore present, other than depth of topsoil, which affect infiltration. For example, organic matter and soil fertility were not equal for the subsoil and topsoil plots.

Location III—The University of Missouri Dairy Farm

This farm is one mile west of Midway in the SW ¼ of Section 31, Township 49 North, Range 14 West of the 5th Principal Meridan in Boone County. The site at this location was chosen in a pasture. This land had been cropped to corn until about 1958. The grass was in bunches and the ground surface was quite dense because of heavy grazing. Vegetation and surface conditions of the soil were approximately the same. The soil type was Weldon silt loam.

Location IV—The Coy Again Farm

This farm is two and one-half miles southwest of Woodlandville in the SE ¼ of Section 16, Township 49 Range 14 West of the 5th Principal Meridian in Boone County. Two sites were selected at this location. Both were in fields that had been in corn for several years.

Site E. This site was in field one, directly north of the farmstead. The normal plot had at one time been part of a livestock area but several years of cropping had probably reduced any effects of that condition.

Site F. This site was in field two, one-half mile northwest of the farmstead.

Both Sites E and F were located on the Seymour silt loam soil type. The density of the soil was quite high. The only treatment on either of these sites was the removing of the corn and other vegetation by cutting it at the ground level. The soil was then left in a bare condition for all tests.

Location V—The University of Missouri Horticulture Farm

The location of this farm, one mile west of New Franklin in the SE ¼ of Section 30, Township 49 North, Range 16 West of the 5th Principal Meridian in Howard County, is in the river hills area and is charaecterized by steep slopes and hills. The soil type is a Menfro silt loam. Two sites were selected on this farm.

Site X. This site was in a terraced alfalfa field. The normal topsoil plot was on top of a terrace ridge and the subsoil plot was located in the front slope of the terrace channel. No treatment of this site was made for this experiment. The area has been cropped several years since terraces were constructed.

Site Y. This site was located on bare cultivated soil. The normal topsoil plot was located on a ridge, and the subsoil plot was on the side of a hill in the front slope of a terrace channel. Cultivation had occurred and the soil allowed to remain undisturbed except for rain with no special treatment made for this experiment.

Setting Up Equipment

A complete flow diagram of the equipment is shown in Figure 1. This figure shows the relationship of components of the sprinkling infiltrometer which was described earlier in the review of literateure. Following are a description of the procedure used in setting up this equipment and additional figures showing the plot frame and tower.

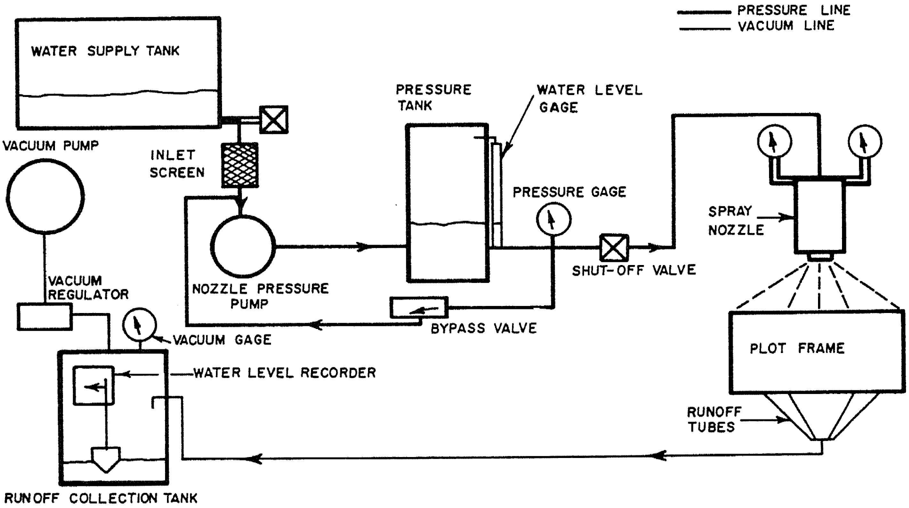

Fig. 1—Flow diagram of sprinkling infiltrometer components.

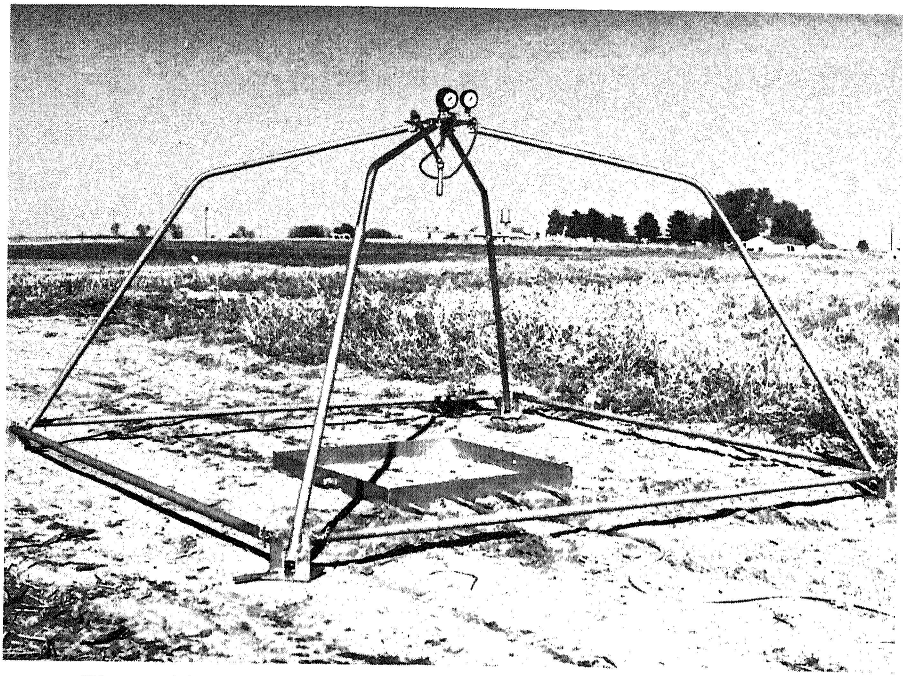

Fig. 2—Tower erected with telescoping legs in the contracted position.

The infiltrometer was transported to the location by loading all of the equipment on a two and one-half ton truck. When the test site was reached, the plot frame was unloaded and placed over the area that had been selected for that test. The frame then was driven into the ground by specially constructed hammers and angle iron driving frame. Figure 2 shows the plot frame after it had been driven into the ground.

After the plot frame had been driven, the tower was unloaded and assembled over it. Figure 2 shows the tower, erected, with the telescoping legs in the contracted position, making the nozzle height about five feet. With the tower at this height, the pressure gauges were attached and the tower canopy (which was made from a parachute) was placed over the tower and the water supply hose was connected to the nozzle assembly. The telescoping legs were then extended to give a nozzle height of nine feet. The canopy was tied down to the base of the frame. The equipment is shown in the operating position in Figure 3.

After the tower had been set up in operation position, the nozzle was adjusted to a vertical position and the tower moved to center the nozzle over the center of the plot, making the tower ready for operation.

If a calibration test was to be made, the calibration pan was set on top of the plot frame. The vacuum line was then connected to the outlet of the calibra-

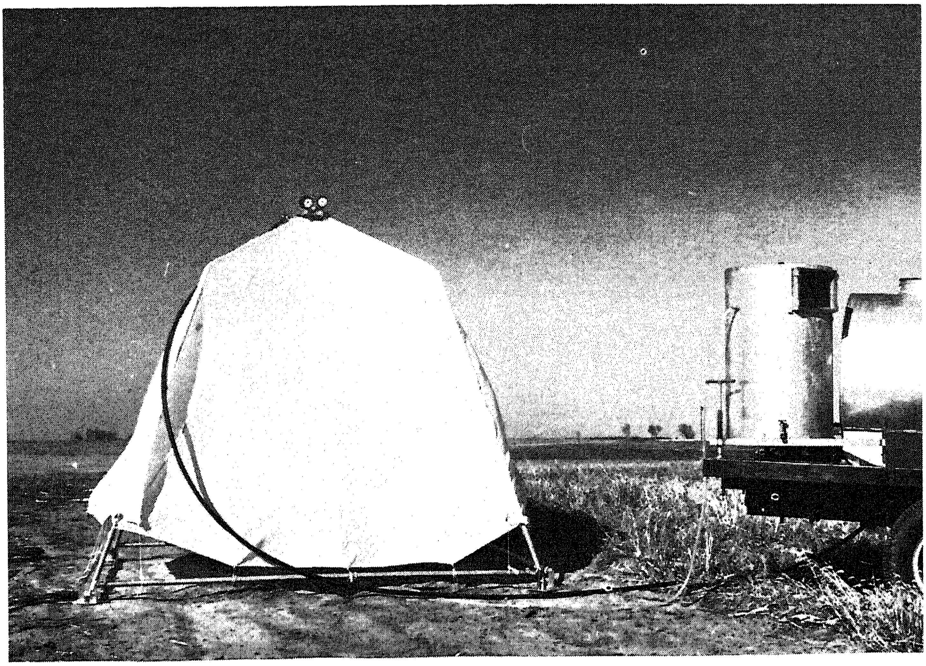

Fig. 3—Infiltrometer set up in operating position with vacuum and pressure lines in place.

tion pan instead of the runoff tubes of the plot frame. When no calibration test was to be made, the vacuum line was connected to the runoff tubes as in Figure 2.

When the tower had been made ready for operation, the strip chart was placed on the water level recorder. The recorder was then placed inside of the collection tank through the plexiglass door shown in Figure 3. The equipment was then ready to begin the test and the next step of the procedure was to take moisture samples.

The nozzle at the operation height of nine feet sprinkles water over an area approximately ten feet in diameter, when the nozzle is centered over the plot. The result is that a buffered area of approximately three feet in width surrounds the plot frame. This buffered area, it is hoped, reduces the effect of lateral movement of subsurface water from the plot frame area to a minimum.

Measurement of Variables

Soil moisture. Soil moisture on a volume basis was determined from data of soil moisture on a weight basis. The soil moisture by weight was determined by taking soil samples prior to running each test. Soil samples were taken either by a soil sampling tube or by a soil auger and put in one pound ointment boxes.

These were weighed in a wet condition and dried at 105°C and weighed again to determine the weight of the moisture. The weight of the moisture divided by the weight of the oven dry soil times 100 gives the soil moisture in percent by weight (dry basis). Samples were taken from each six-inch layer to a total depth of two feet. A composite sample from three sampling sites immediately outside the plot frame was used.

Soil moisture by volume is determined by multiplying the percent moisture by weight by the bulk density of the soil. A description of bulk density sampling procedures will be given later.

Application rate. The application rate was measured by placing the calibration pan on the plot frame and determining the runoff rate from the recorder chart. In this case, the application rate is equal to the runoff rate.

Runoff. Runoff was measured and recorded continuously by the liquid level recorder. This was accomplished by recording the height of the water on a chart to the scale, five inches equal one foot of depth. Time was the other dimension on the chart and was to the scale, one inch equals 25 minutes. Infiltration rates were determined by subtracting the runoff rate from the application rate. Total infiltration was determined by subtracting the total runoff from the total application.

Time, weather conditions, etc. Time at the beginning and at the end of the test was recorded. Weather conditions were recorded for each day. Rain within two days prior to the test was recorded. Since slope of the area was not considered to be an influencing factor, it was not recorded.

Bulk density. Bulk densities were determined from soil cores taken with a hydraulic soil probe mounted on a pick-up truck. The probe takes an undisturbed core approximately three inches in diameter. The core to a depth of two feet was cut into six-inch lengths. Bulk densities were determined for each of these horizons. Soil moisture at sampling time was also determined. The bulk density was calculated by determining the oven-dry weight in grams and dividing by the volume of the six-inch-length section of core in cubic centimeters.

Soil testing data. Soil testing was done by the Soils Department of the University of Missouri. The data were obtained on the same samples which had been used for the bulk density determinations. Organic matter was measured for all horizon levels. In addition, an analysis was made on the surface horizon to determine phosphorus, potassium, magnesium, calcium, pH and milliequivalents of hydrogen per 100 grams.

Degree of aggregation. The percent of aggregated silt and clay (greater than .05 mm) was divided by the percent of total silt and clay and multiplied by 100. Fifty grams of dry soil which had passed through a 2-mm sieve was weighed out. This soil was inverted 10 times in a one-liter cylinder with distilled water. The hydrometer reading at 40 seconds, times two, equals the percent unaggregated silt and clay. When subtracted from 100, this gives the aggregated silt and clay.

At the end of an hour, the inversion procedure was repeated and a reading was taken at 40 seconds, from which a second determination was made to show some relative value of the stability of the aggregates. The degree of aggregation was determined for all profile depths.

Soil type. Soil type was determined from soil survey maps. (13)

Particle size analysis. A particle size analysis for each six-inch horizon depth was made. The results of the analysis are expressed by a summation curve of accumulated percent settled out versus the log of the diameter in mm. This curve may be approximated by a straight line through the 16.7 and 83.3 percent points of this curve. This includes two-thirds of the sample or one standard deviation on either side of median. A summary of the results can be expressed, as in Table V of the Appendix, as percent gravel, percent sand and silt, median diameter, communition number and percent clay. This procedure may be found in Powell's unpublished Master of Science Thesis. (24) The size fractions were determined by a modified Bouyoucos method. (2) (6)

RESULTS

Results of Tests

During the test the water runoff was recorded on strip charts by the water level recorder. An analysis as described in the procedure was used to determine runoff rates and total infiltration. The infiltration rates versus time were plotted and a curve was drawn. These infiltration rate curves are shown in Figures 4 through 23. Factors which may have an influence on the infiltration rates are: antecedent soil moisture (Table I), bulk density (Table II), soil fertility (Table III), and the particle size and degree of aggregation (both in Table IV). These tables are included in the Appendix.

In some cases tests were made at the same site at more than one time during the summer. When this was done all tests of the same general time at a particular site were designated by the same set number. In some cases more than one test was made on the same plot area. These tests are shown by a subscripted plot designation.

Location I—Site A

Figures 4 through 9 show water infiltration rates versus time for this site at three times during the summer (designated by the set number). The first figure of each set shows the infiltration curve when low antecedent moisture was present. The second figure shows the infiltration curve for the high antecedent moisture condition present after the first run.

From the tests at this location it is evident that the antecedent moisture affects the infiltration rates a great deal, particularly during the first part of the test.

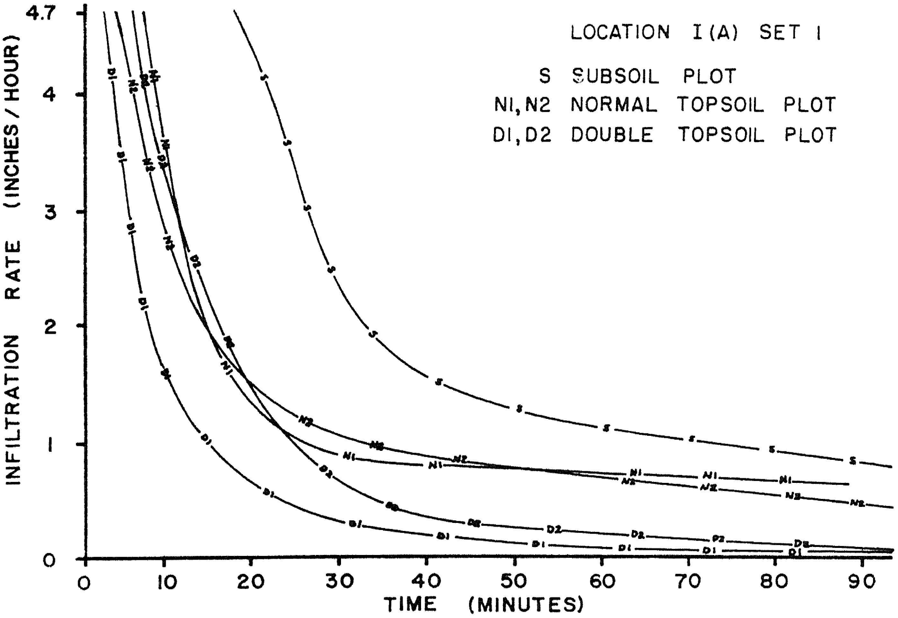

Fig. 4—Mexico soil in grass under low antecedent moisture.

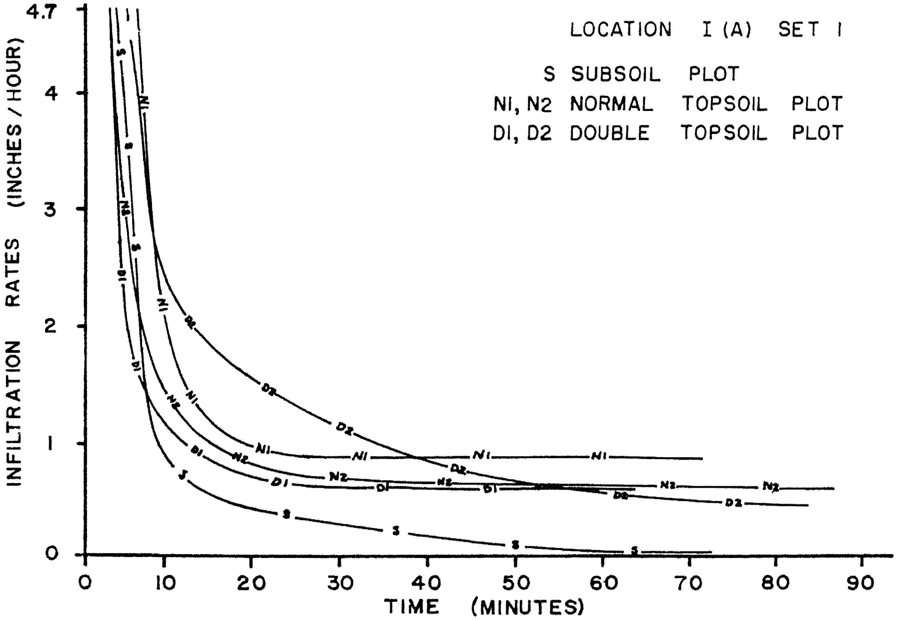

Fig. 5—Mexico soil in grass under high antecedent moisture.

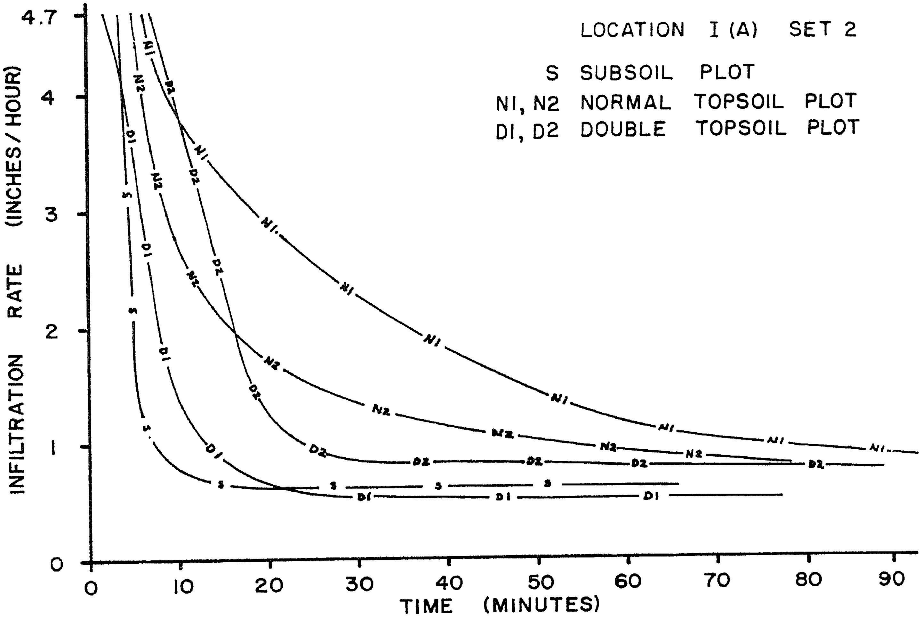

Fig. 6—Mexico soil in grass under low antecedent moisture.

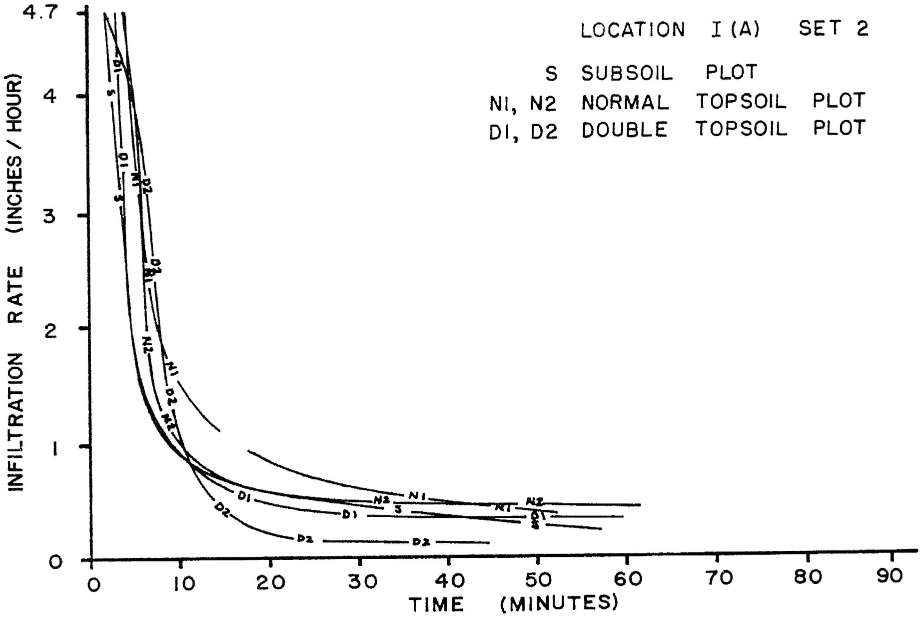

Fig. 7—Mexico soil in grass under high antecedent moisture.

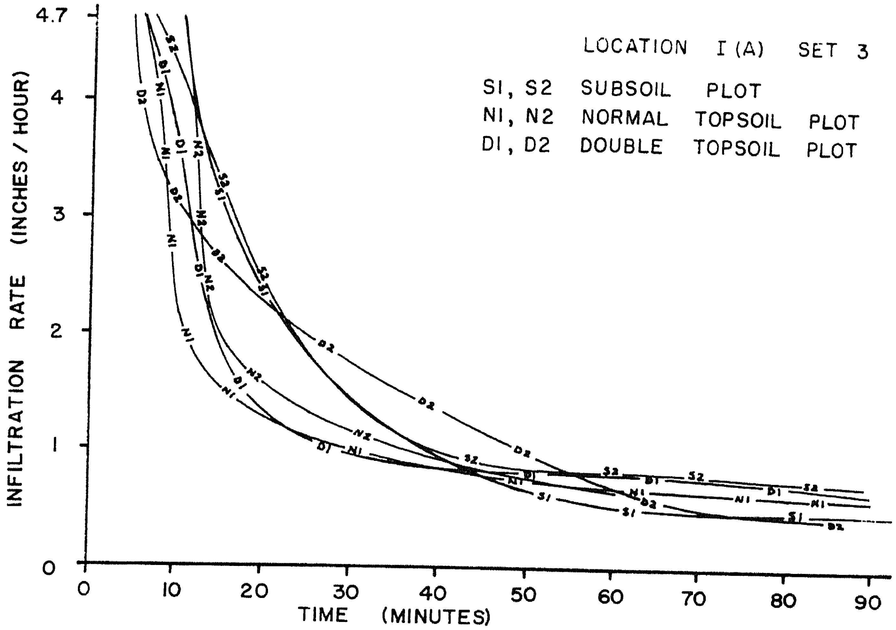

Fig. 8—Mexico soil in grass under low antecedent moisture.

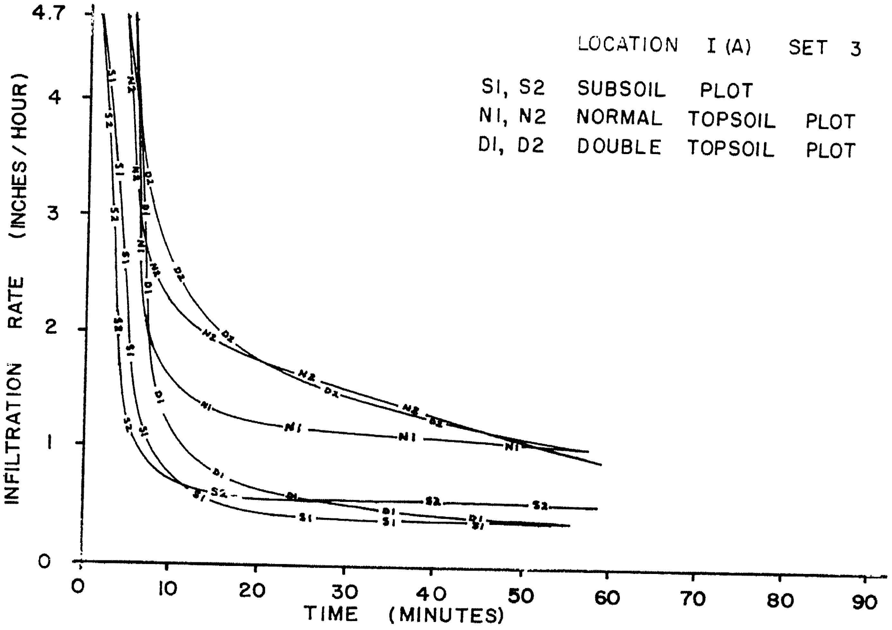

Fig. 9—Mexico soil in grass under high antecedent moisture.

This is evident when comparing the two figures of the same set. The infiltration rates during the latter part of the tests are not affected as much by high antecedent moistures as those at the beginning.

The final infiltration rate under relatively high antecedent moisture on the normal topsoil plot was higher than either the rate from the double topsoil or subsoil plots. This is shown by Figures 5, 7, and 9. Thus, when the soil is wet, the higher infiltration rates of the normal topsoil show the adverse effect that erosion and excessive deposition can have.

In most cases test results have shown that the infiltration rate under high antecedent moisture conditions is higher for the normal topsoil than for the double topsoil. There are two reasons which may explain this occurrence. First, the particle size analysis shows a smaller median diameter for the double topsoil and therefore smaller capillary size pores, and second, the degree of aggregation of the double topsoil is less than that of the normal topsoil.

Figure 4 shows a very high infiltration rate for the subsoil plot, both at the beginning of the test and as a final rate. The antecedent moisture was very low, as shown by Table 1. The subsoil plot contained 40 percent clay (Table V), which was almost twice as much as for the normal and double topsoil plots. As a result of the high percentage of swelling clay and low soil moisture, the soil shrinks and cracks. Cracks up to one inch wide developed. The normal plot was cracked some but not as extensively as the subsoil plot. The double topsoil plot cracked very little. The final infiltration rates seem to be in proportion to the extent of cracking, with the subsoil highest, normal in the middle, and double topsoil plots lowest.

Figure 5 shows the rates from the same plots as Figure 4 with a high antecedent moisture. The final infiltration rate for the subsoil is much lower under high antecedent moisture. The reduction in infiltration rate is due to the swelling action of the clay and, consequently, the closing of all but the capillary pores which take up water at a very slow rate.

When the soil is dry the high initial infiltration rate is primarily the result of the filling of the pore spaces larger than capillary size. Once these pores are filled the infiltration rate is due to the advance of water as capillary movement. The very high intake rates of the dry subsoil are a result of the formation of a large number of pores by the shrinking and cracking of the clay. When the plot was wetted and allowed to remain over night the intake rate the following day was much lower because the clay colloids had swelled and closed a large number if not all of the non-capillary pores.

It was noticed while making tests at this site that soil moisture after the first run varied a great deal from one side of the plot area to the other. It was also observed that bulk density also varied a great deal in this same manner. This variation was probably due to the crop cover and the lack of regular cultivation. In a grassed area small animals such as mice make holes in the ground which can greatly change surface characteristics and influence the intake rates of water. These local variations account for some of the differences between the infiltration rates from the different tests. The differences between the length of time required for the infiltration rate to decrease to a relatively constant value for the different tests is attributed to these inconsistencies. Slight differences in the degree of saturation may also account for part of the difference.

Location I—Site B

This test site is on Mexico silt loam which is quite similar to the soil type at site A, with the exception that the second subsoil plot is a Gara clay loam. The results of the test at low antecedent moisture are shown in Figure 10 and at high antecent moisture in Figure 11.

At this location the most interesting observation is the slower decline in the infiltration rate of the second subsoil plot (S2) but the much lower final value. A possible explanation of this is the high degree of aggregation and the higher bulk densities, particularly at the lower horizons. The high degree of aggregation accounts for the slow decline; the high bulk densities indicate tight fitting of these aggregates and explain the low final value.

The average final infiltration rate of the normal topsoil plots is higher than that of the subsoil plots. Observe, also, the influence of the high antecedent moisture on reduction of the infiltration rates (Figure 11).

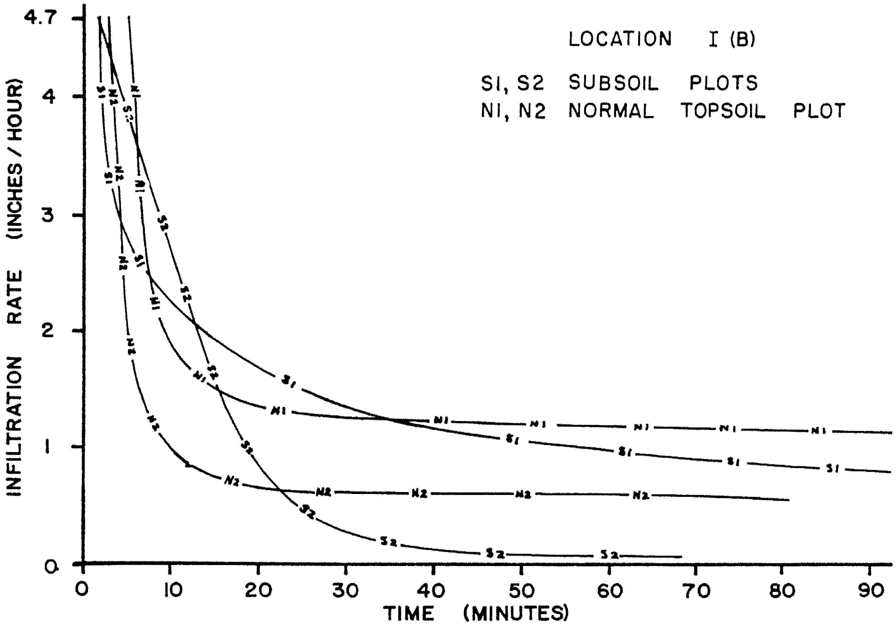

Fig. 10—Mexico soil, bare, under low antecedent moisture.

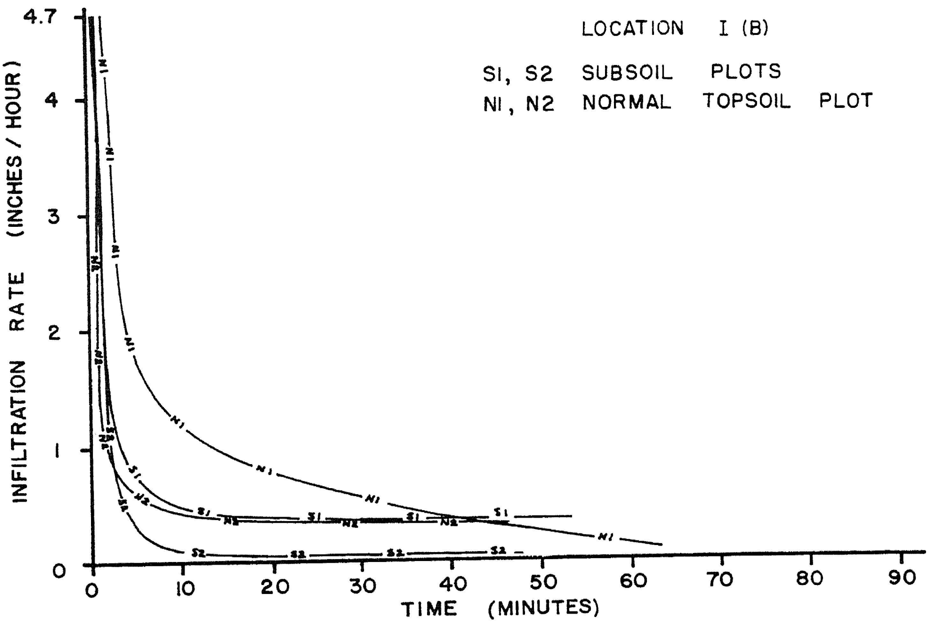

Fig. 11—Mexico soil, bare, under high antecedent moisture.

Location I—Site C

This site is also on a Mexico silt loam. Figures 12, 13, and 14 show the infiltration curves for the two sets of data from the plots at site C.

Figure 12 shows the results of set 1. Tests of the high and low antecedent moisture are on the same figure and give a comparison of the infiltration rates at these two conditions. The bulk density of the medium topsoil plot is lower, which indicates more pore space and, quite likely, is responsible for the higher final values of the infiltration rate.

Figure 13 shows the dry antecedent conditions for set 2. A lower infiltration rate is reached sooner for the subsoil plot that for either the medium or normal plots, likely as a result of the higher bulk densities. The final infiltration rates however, do not vary greatly for the three tests. The degree of aggregation of the surface soil for all three plots is similar. The aggregates of the subsoil plot are slightly more stable, which is probably the reason that the infiltration rate curve is flatter for subsoil plots after the low value is reached.

The less stable aggregates of the normal and medium topsoil plots continue to break apart into finer particles and reduce the intake rate. This accounts for the continually decreasing intake rates of the medium and normal plots.

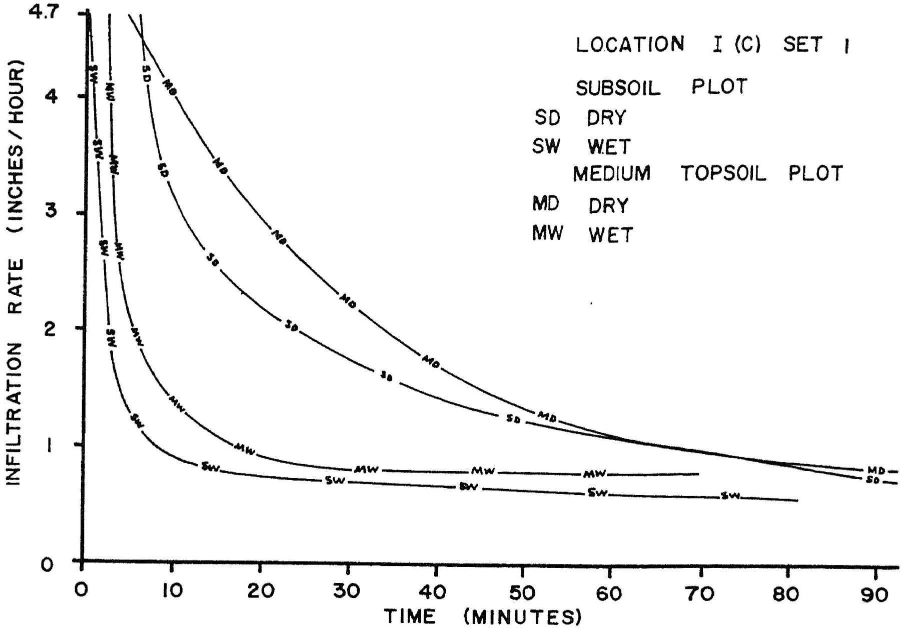

Fig. 12—Mexico soil, bare, under low and high antecedent moisture.

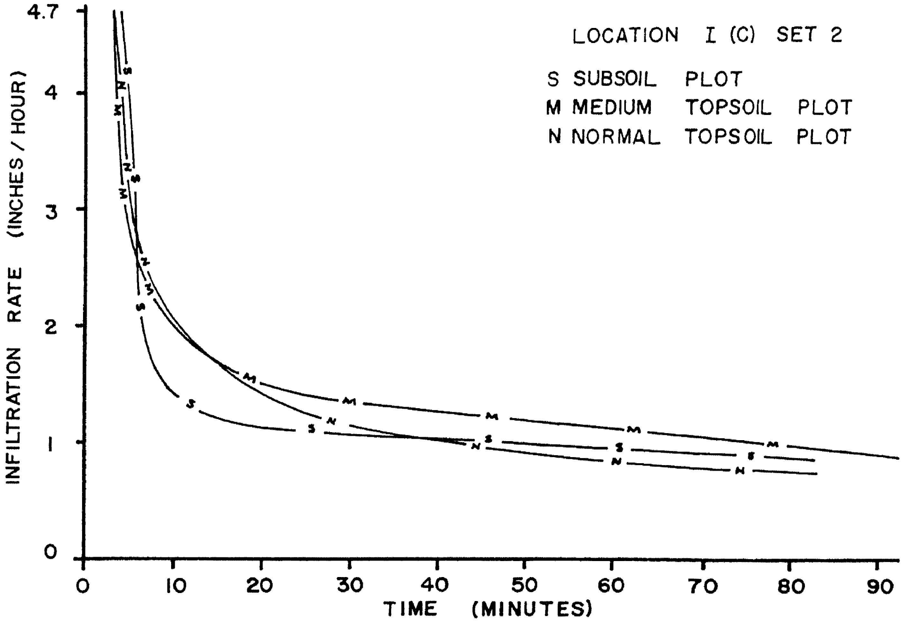

Fig. 13—Mexico soil, bare, under low antecedent moisture.

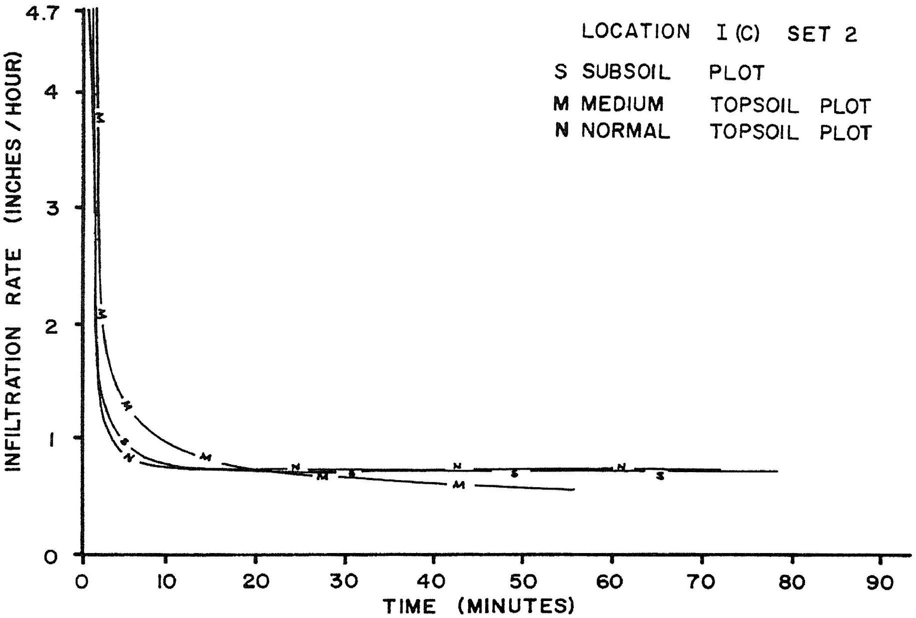

Fig. 14—Mexico soil, bare, under high antecedent moisture.

Figure 14 shows the wet antecedent conditions of the second set. Note that here the intake rates reached after a very few minutes do not continue to decrease at as great a rate as in Figure 13. This is because the less stable aggregates have already been broken down during the previous test.

Location II—Sites X and Y

Two sets of tests were run at this location. The first set was on the non-vegetated soil. The second set was on the vegetated soil.

The results of the test on the low antecedent soil moisture of Set 1 are shown in Figure 15. The high final intake rate of the first subsoil plot (S1) is accounted for by the fact that this area had not been disturbed by man or machine since the freezing and thawing action during the winter and spring. Unfortunately, the bulk density and the degree of aggregation were not measured at the time of the first tests. Observations indicated that the bulk density was lower and degree of aggregation higher when these tests were made than when the second set of tests were made. Sampling for bulk density and degree of aggregation was done after the second set of tests. A rotary tilling and several rains prior to sampling helped to break up the aggregates and compacted the soil, thus resulting in a more compact condition than when the first tests were made.

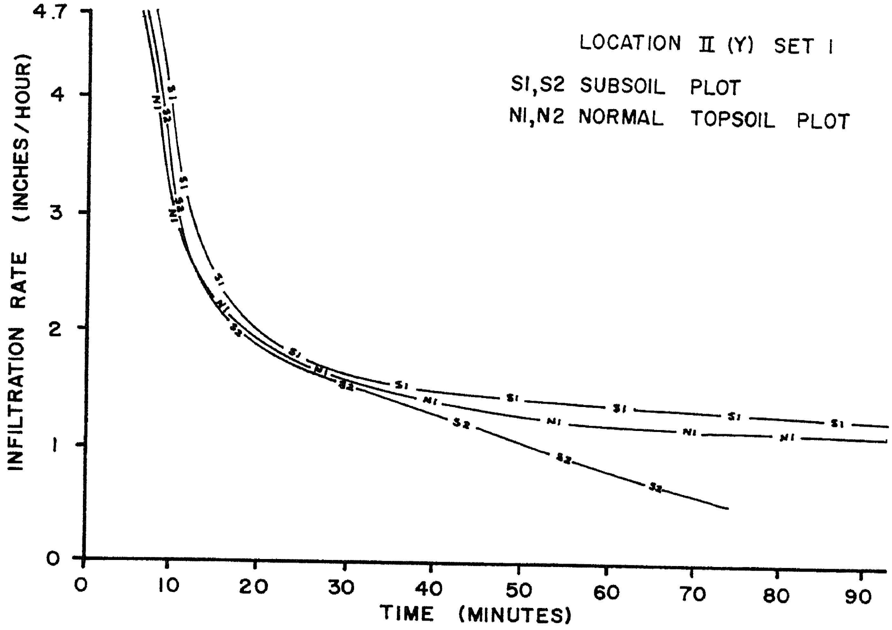

Fig. 15—Mexico soil, bare, under low antecedent moisture.

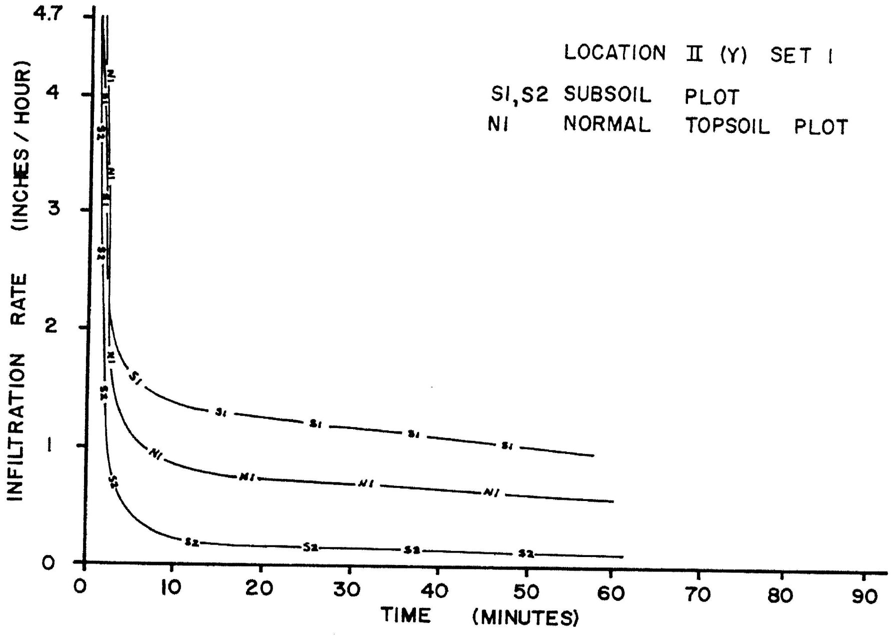

Fig. 16—Mexico soil, bare, under high antecedent moisture.

Results of tests on this plot in the more compact condition are shown in Figures 17 and 18. Note that the first subsoil plot (S1) in Figures 15 and 16 is the same plot as the subsoil in Figures 17 and 18. The subsoil plot from the second set shows a final intake rate of about one-half that of the first set. This shows the great influence of the degree of aggregation and the bulk density on the intake rate.

The second subsoil plot (S2) of Figures 15 and 16 is on a different clay type than the first subsoil plot (S1). Thus, the difference in the infiltration rate is a result of this difference between clay types.

Figure 16 shows the results of tests on high antecedent moisture of Set 1. Note here the high final intake rate on the first subsoil plot, for the same reasons as explained earlier in discussions about Figure 15. When the aggregates were broken down and the bulk density increased for the first subsoil plot (S1) as was the case in Set 2, Figure 18, the resultant final intake rate was much lower. Under actual farming conditions, which would break apart aggregates and increase bulk density, we would expect a lower final intake rate for the subsoil for high antecedent moisture on this Mexico silt loam.

In Figure 17 we see that for low antecedent moisture the initial intake rate is much higher for the bare subsoil than the vegetated soils. This high initial rate drops off rapidly, and the final intake rate is slightly lower on the bare soil than on either of the vegetated plots. Notice the decreasing intake rate of the normal vegetated plot while the vegetated subsoil decreases more rapidly and then maintains a rather constant intake rate. The degree of aggregation of the vegetated subsoil plot is much higher than that of the vegetated normal. The higher bulk density of the vegetated subsoil, particularly at lower horizons, is likely the cause of the lower intake rates.

High antecedent moisture, shown in Figure 18, reveals that antecedent moisture affects the infiltration rates at the beginning of the tests more than the final values. Figures 17 and 18 show the reduction in the final rate to be of approximately the same percentage on both vegetated plots. However, the final infiltration rate on the bare subsoil has been reduced much more.

Location III

The soil type at this location is a Weldon silt loam. Figure 19 shows the results of the infiltration tests made at the low and high antecedent moisture at this site.

The gradual decreasing infiltration rate of the dry test on the subsoil over a longer time is a result of stability of the aggregates. With their higher stability, the aggregates of the subsoil do not break apart as rapidly and, consequently, the infiltration rate does not fall as fast.

The final values of the infiltration rate under both high and low antecedent moisture for the normal plot are more than twice the final values for the subsoil plot. Note that for this soil type the infiltration rate is not affected by the antecedent moisture conditions nearly as much as a non-vegetated soil (Figure 12).

Location IV—Sites E and F

A Seymour silt loam is the soil type at this location. Figure 20 shows the dry antecedent conditions while Figure 21 shows the wet antecedent conditions for these sites. Comparison of the two graphs shows that for the Seymour soil, under these conditions, the antecedent moisture conditions have relatively little effect on the final infiltration rate. High soil moisture does, however, cause runoff to begin sooner and to reach the low final infiltration rate sooner than dry conditions.

Under both wet and dry conditions the final infiltration rate for the second normal plot (N2) is almost twice that of the second subsoil plot (S2). This is likely caused by the lower bulk density and slightly higher degree of aggregation of the normal soil. The low final infiltration rate on the first normal plot (N1) under dry conditions is probably due to the fact that a run was made for about three minutes the previous day on the same plot when a breadown occurred. This short run was not enough to affect the soil moisture but was enough to destroy the structure of the surface and cause the compact layer at the surface to form, thus reducing the infiltration rate.

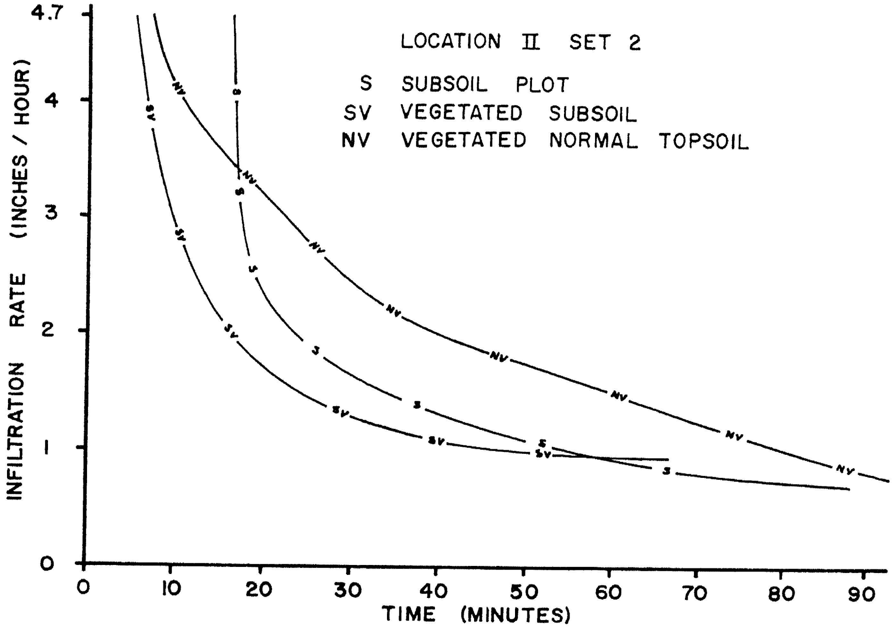

Fig. 17—Mexico soil in grass under low antecedent moisture.

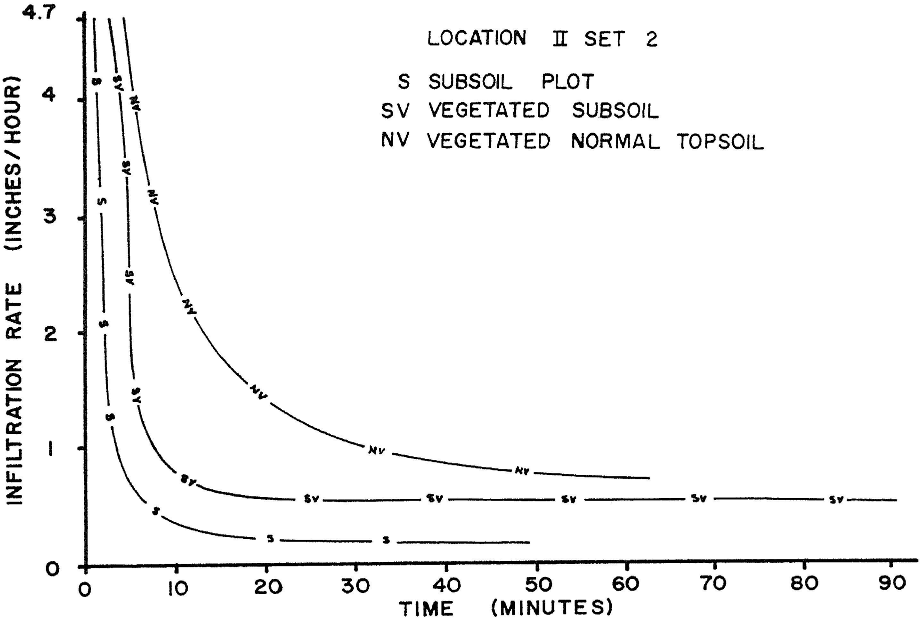

Fig. 18—Mexico soil in grass under high antecedent moisture.

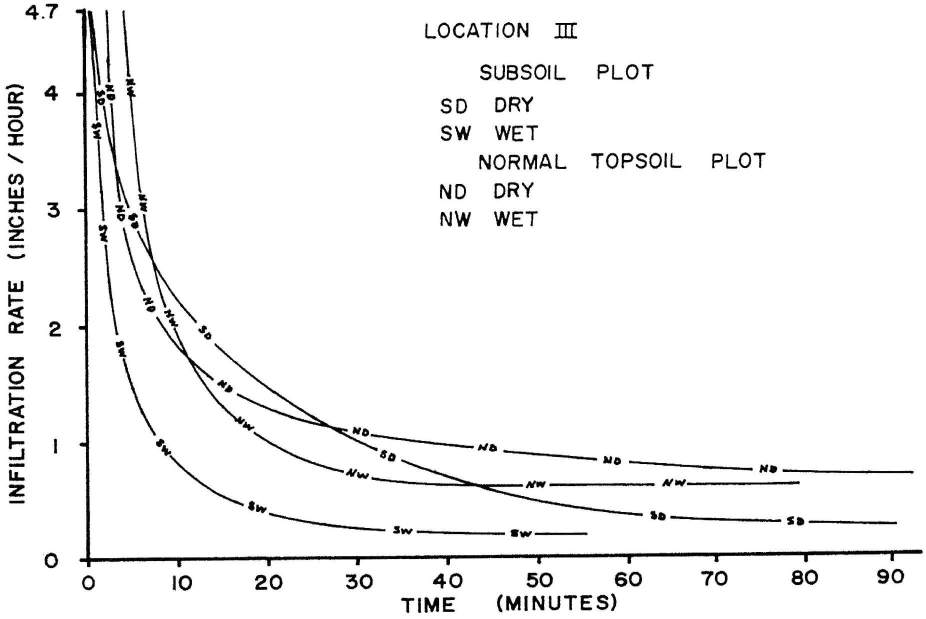

Fig. 19—Weldon soil in pasture under high and low antecedent moisture.

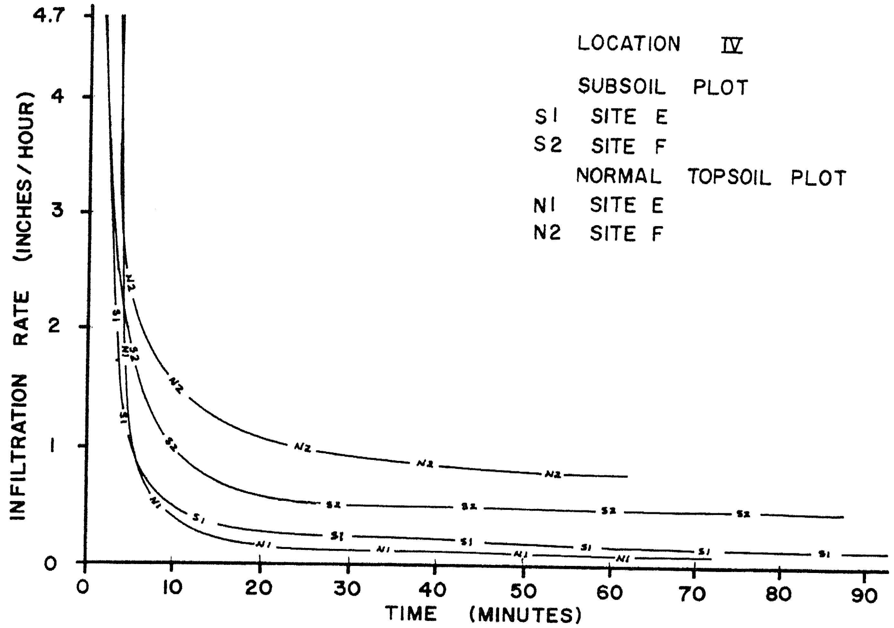

Fig. 20—Seymour soil, bare, under low antecedent moisture.

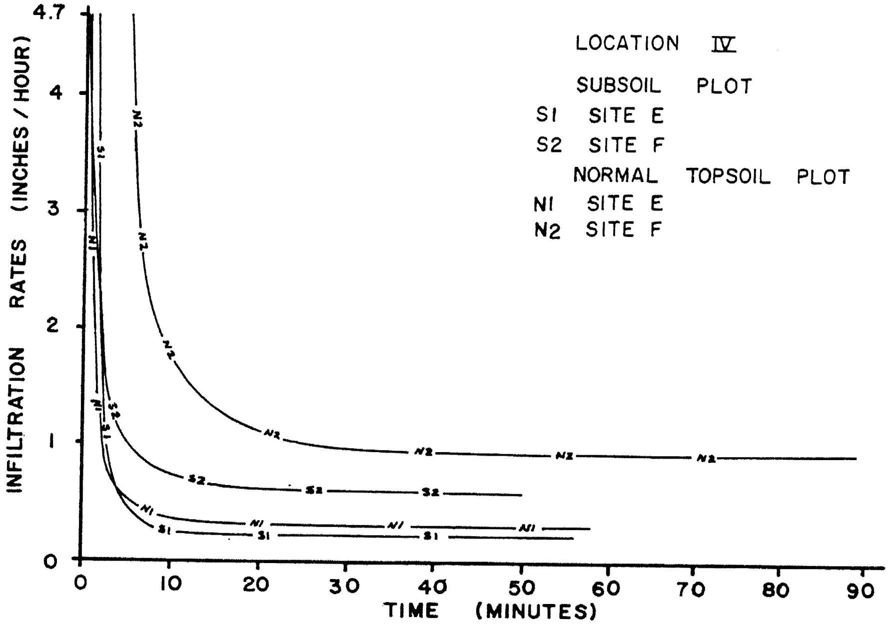

Fig. 21—Seymour soil, bare, under high antecedent moisture.

Location V—Site X and Site Y

The soil type at this location is a Menfro silt loam. Figure 22 shows the high and low antecedent moisture on vegetated soil (Site X) at this site. The antecedent moisture had little effect on the infiltration rates. The final infilration rate for the subsoil plot was approximately one-third of that from the normal plot. This can be due in part to the higher degree of aggregation; however, this is not sufficient to explain a difference of this magnitude. This, then, is a good example of the effect of soil erosion on the infiltration rates of soils.

Figure 23 shows the infiltration curve for bare soil (Site Y) under wet and dry antecedent conditions. The wet antecedent conditions reduce the final infiltration rate to less than one-half the dry antecedent conditions. This is true for both plots. The difference between the infiltration rates for the normal and subsoil plots is negligible. This figure shows that antecedent soil moisture has a relatively large effect on the infiltration rates.

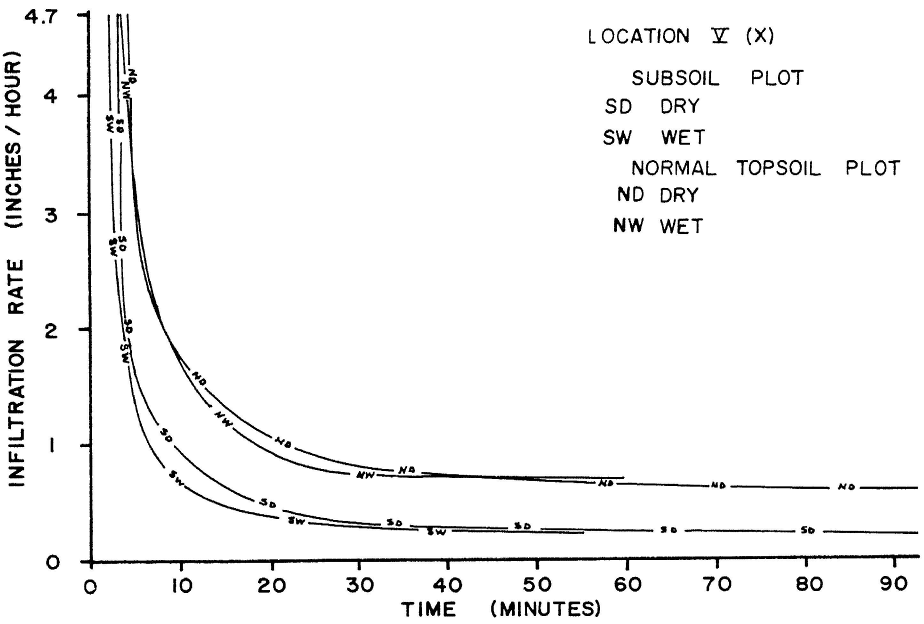

Fig. 22—Menfro soil in alfalfa under low and high antecedent moisture.

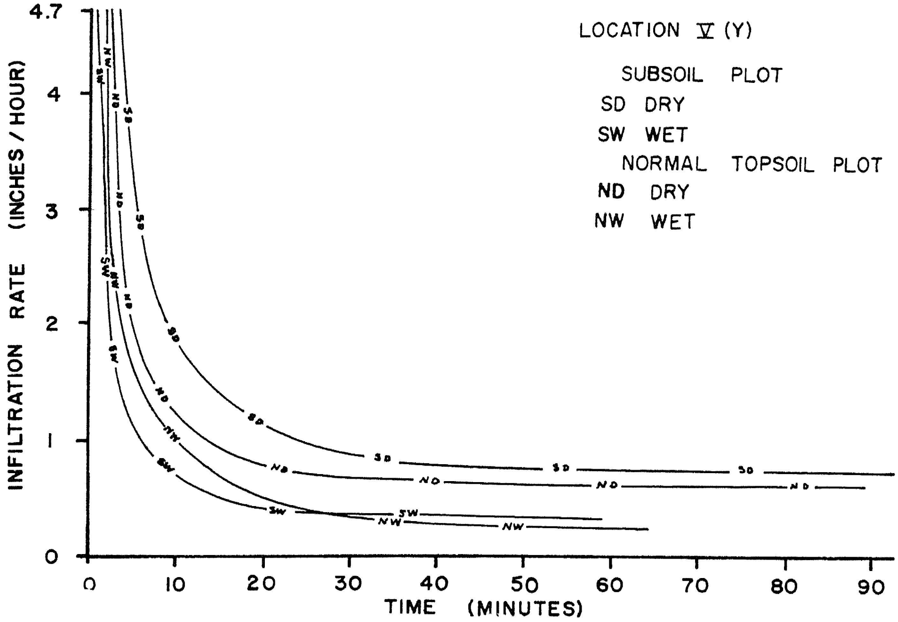

Fig. 23—Menfro soil, bare, under low and high antecedent moisture.

Discussion of Results

The infiltration curves obtained follow very closely the form expected from the infiltration equation developed by Horton. (10) (12) This equation,

$$f = f_c + (f_o - f_c)e^{-kt}, \quad (1)$$

gives a fairly accurate mathematical expression which can be used to describe an infiltration rate curve. The constant, k, is dependent primarily on soil type, antecedent moisture, and crop cover (8, 9). The value of this constant determines the time required to reach the relatively constant final rate.

The area under the infiltration curve represents the total volume of water taken into the soil. This, then, may be obtained by taking the integral of the infiltration equation.

Thus, total infiltration (I) at some time (T)

$$tI = \int_O^T f dt$$

$$= \int_O^T f_c dt + \int_O^T (f_o - f_c)e^{-kt} dt$$

which, when integrated, gives

$$tI = f_c t \Big|_{O}^{T} - (f_o - f_c)\,\frac{e^{-kt}}{k}\Big|_{O}^{T} \tag{2}$$

Equation 2 may be evaluated at any time (t) to give the total infiltration up to that time.

From the infiltration rate curves it is evident that no single factor has the same effect on the infiltration rates under all conditions. A number of factors affect infiltration, but the degree of that effect is dependent on other conditions present. Factors which have the greatest influence are bulk density, antecedent soil moisture, degree of aggregation, crop cover and condition, soil type, and degree of erosion.

The degree of erosion has a direct influence on clay content of the surface soil, organic matter, and soil fertility. These factors influence, indirectly, the degree of aggregation, aggregate stability, percent porosity, bulk density and crop cover. Because of the number of factors that are affected by the degree of erosion and because these same factors are affected by other conditions, it is almost impossible to put a quantitative value on the effect of the degree of erosion on the infiltration rate.

Results show that, usually, the effect of erosion on the infiltration rate is greatest (up to 60 percent reduction between eroded and noneroded) under cropped conditions. The least effect is shown when there has been recent cultivation. In general, soil erosion certainly does not improve the infiltration rates, except under extremely dry conditions when there is extensive cracking, and, in most cases, it decreases the infiltration rate. Soil erosion affects infiltration rates because of its effect on other factors such as bulk density and degree of aggregation.

The antecedent soil moisture has its greatest effect on infiltration when the soil is bare. This is as expected, since the beating action of the water and sorting of particles to fill the pores is greatest when the soil is bare.

Soil type has some definite effects on water infiltration rates. The crop cover and tillage practices between soil types, however, were such that comparisons between soil types could not be made. In general, there was more difference between the clay pan and non-clay pan soils than among soils within those groups.

The differences between the tests made in the same area were due in part to errors in recording the runoff and in part to the real differences in the infiltration rate at the two locations. These differences may be caused by the compactness of the soil due to tillage operation, by the bulk density which in some cases appeared to change drastically from one side of the test frame to the other, by the difference in crop cover, or by other conditions.

In recording the runoff the errors were small enough over the time involved that the final infiltration rate was affected very little. At any instantaneous time interval, however, the rate was found to differ more.

The results of this study show that under many conditions the degree of erosion affects to a measurable extent the infiltration rate. This effect tends to be greater when the soil is in a compact condition and less when the soil has been tilled.

The overall effect of extreme soil erosion is that on the average it may reduce the infiltration rate considerably (up to 60 percent). This, then, would make less water available for crop growth. For average years, with plenty of water available, the net difference between yields on fields in eroded and non-eroded conditions likely would not be great. For adverse years of low moisture, the net difference in yields would likely be much greater.

The result of applying conservation practices to reduce erosion will result in more soil moisture available for crop growth, lower peak flows from watersheds, less flood damage, and less total runoff.

It was found that the effect of soil erosion on the infiltration rate was particularly dependent on surface characteristics of the soil. The greatest reduction in the infiltration rates as a result of erosion was found on the Menfro silt loam (Figure 22) when the soil was vegetated and the surface dense. This same soil, on the other hand, showed very little effect of erosion when in the cultivated, bare, condition (Figure 23). Note in Figure 23 that the effect of the antecedent moisture on the infiltration rate was least when the soil was vegetated and dense and greatest when the soil was cultivated.

Under no condition, except when the soil is very dry and extensively cracked on the eroded area because of higher clay content, can we expect an increase in the infiltration rate on the eroded soil. The net result is that if erosion is significantly reduced the average infiltration rate will be correspondingly increased.

If conservation measures are applied and erosion is greatly reduced, under most conditions, additional soil moisture will be available for crop growth, and there will be lower peak flows from watersheds and less total runoff. These, in turn, result in better farms and higher incomes, less possibility of floods, reduced need for expensive flood prevention structures, and reduction in problems of down-stream sedimentation. All of this is brought about because prevention of soil erosion brings higher infiltration rates. In addition, the conservation measures retard the flow of water and allow more time for the water to be taken into the soil.

CONCLUSIONS

Results of this study, like previous experiments, show that the effect of any one factor on the infiltration rate is dependent on many other factors. To make valid conclusions, then, we either need to keep other factors constant or know the effect they have on the results. In this experiment the quantity of the data is somewhat limited and, consequently, the effect of some factors cannot be determined.

The effect of soil erosion on the infiltration rate is particularly dependent on surface characteristics of the soil. These surface characteristics are determined by crop cover, bulk density, and degree of aggregation. The reduction of infiltration rates as a result of erosion is greatest, up to 60 percent (see Figure 22), when the soil is vegetated and the surface is dense. Under no conditions, except when the soil is very dry and cracking results on the eroded soil because of higher clay content, can we expect an increase in the infiltration rate. The net result, then, is that if erosion is greatly reduced the infiltration rate will be increased.

The results of this experiment showed that the effect of antecedent moisture on the infiltration rate is also dependent on other factors. Factors which have the largest influence are crop cover, degree of aggregation, and bulk density. Results of the experiment showed that the effect of antecedent moisture on the infiltration rates was greateset when the soil was bare and well tilled. Results showed that the infiltration rate was usually controlled by the soil surface. However, in clay pan soils, when the volume above the clay layer has been filled, the infiltration rate is then the rate at which the water can percolate the clay layer.

Results of this study in some cases seem to contradict results of previous researchers in that they have reported antecedent moisture as a major factor in influencing the infiltration rate. Figures 20, 21, and 22 show the final infiltration rate to be affected only to a minor extent by the antecedent moisture.

Bulk density and the degree of aggregation can have a large effect on the infiltration rate. These factors change throughout the year with tillage practices, freezing and thrawing of the soil, and soil moisture. Consequently, the infiltration rates change accordingly.

The potential value of data on infiltration rates has been greatly expanded by the development and application of the computer. The possibilities of watershed analysis and predictions of maximum discharge and total stream flow by generalized hydrologic models adapted to computer solution hold much promise for the future. One of the primary inputs needed in this computer solution is the infiltration rate of the many different soils and soil characteristics represented on our many watersheds. The infiltrometer which has been developed is a quick, convenient, and reliable device whereby this information can be obtained.

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APPENDIX

TABLE I--ANTECEDENT SOIL MOISTURE AT TIME OF TEST
(PER CENT BY VOLUME)

Location	Plot	Test	Depth (inches)			
			0-6	6-12	12-18	18-24
I Site A, Set 1	S	Dry	17.21	26.41	27.97	29.00
		Wet	39.30	37.65	34.24	27.84
	N1	Dry	22.06	21.43	31.91	47.26
		Wet	38.42	38.00	40.29	38.11
	N2	Dry	13.43	26.69	33.81	36.08
		Wet	35.27	30.50	40.44	43.20
	D1	Dry	18.53	21.96	28.79	34.93
		Wet	27.61	26.05	36.01	42.63
	D2	Dry	16.63	17.33	23.76	36.44
		Wet	31.18	18.80	27.36	37.44
I Site A, Set 2	S	Dry	38.88	39.84	36.95	35.70
		Wet	40.90	40.51	33.81	33.04
	N1	Dry	27.01	29.59	35.80	33.70
		Wet	36.33	35.79	37.64	36.08
	N2	Dry	35.30	35.39	40.51	45.05
		Wet	38.77	37.11	40.21	47.75
	D1	Dry	25.07	23.90	26.03	31.36
		Wet	33.24	32.80	31.58	39.38
	D2	Dry	23.83	21.96	21.94	36.41
		Wet	33.41	23.94	19.96	34.90
I Site A, Set 3	S1	Dry	24.71	38.38	47.25	43.06
		Wet	39.80	45.39	47.58	43.04
	S2	Dry	26.37	43.43	47.81	45.26
		Wet	40.56	49.31	50.86	45.70
	N1	Dry	15.02	28.20	37.11	37.85
		Wet	31.89	33.20	39.76	38.86
	N2	Dry	17.43	31.53	44.34	52.62
		Wet	37.52	39.74	47.08	48.29
	D1	Dry	13.35	18.22	24.58	35.66
		Wet	31.46	29.45	23.44	36.96
	D2	Dry	13.96	20.84	26.36	29.82
		Wet	29.53	24.49	27.42	33.79
I Site B, Set 1	S1	Dry	34.84	39.25	35.87	34.16
		Wet	43.32	45.88	37.76	32.39
	S2	Dry	26.61	23.82	24.60	27.19
		Wet	37.91	33.41	29.51	27.91
	N1	Dry	28.93	25.91	36.47	34.01
		Wet	36.96	34.98	39.34	35.67
	N2	Dry	26.65	19.66	26.58	31.29
		Wet	38.00	26.21	26.87	30.07
I Site C, Set 1	S	Dry	22.95	35.30	33.61	35.06
		Wet	39.61	42.94	38.29	36.87
	M	Dry	18.40	29.82	37.31	34.57
		Wet	34.83	37.12	42.78	36.19

(continued)

TABLE I (continued)

Location	Plot	Test	Depth (inches)			
			0-6	6-12	12-18	18-24
I Site C, Set 2	S	Dry	27.40	35.32	36.69	37.63
		Wet	43.00	43.29	38.71	38.37
	M	Dry	23.18	40.61	38.20	36.26
		Wet	37.99	40.71	43.59	38.03
	N	Dry	22.44	29.57	38.82	35.85
		Wet	37.28	37.43	43.69	41.29
II Site Y, Set 1	S1	Dry	26.02	31.34	42.43	35.83
		Wet	40.13	40.67	40.69	41.98
	S2	Dry	15.57	32.71	28.74	32.64
		Wet	36.75	32.25	37.24	33.24
	N	Dry	20.44	25.85	24.68	34.11
		Wet	41.24	42.62	36.33	42.82
II Site X, Set 2	S	Dry	29.14	27.18	35.42	39.69
		Wet	39.36	43.05	40.91	41.73
	SV	Dry	22.30	35.98	35.14	37.31
		Wet	38.35	38.37	35.53	36.15
	NV	Dry	26.04	32.03	35.76	32.71
		Wet	37.17	36.73	40.81	37.37
III	S	Dry	16.65	30.29	29.69	32.26
		Wet	30.04	33.78	31.29	29.51
	N	Dry	18.69	21.36	32.53	27.83
		Wet	32.39	27.71	33.92	30.02
IV Site E	S1	Dry	15.58	16.04	25.12	29.05
		Wet	29.53	29.67	27.77	28.99
	N1	Dry	22.10	20.14	21.32	27.88
		Wet	27.34	19.78	20.58	27.57
IV Site F	S2	Dry	14.97	20.43	22.63	27.22
		Wet	25.96	18.15	24.25	27.13
	N2	Dry	19.29	17.11	17.36	30.98
		Wet	36.17	20.98	18.01	31.34
V Site Y	S	Dry	35.51	40.91	40.84	41.73
		Wet	36.31	43.44	41.97	43.14
	N	Dry	23.34	25.46	32.84	37.34
		Wet	31.69	33.26	34.58	35.71
V Site X	S	Dry	24.59	20.83	24.95	22.78
		Wet	28.89	21.47	24.98	27.45
	N	Dry	24.56	18.51	17.91	19.93
		Wet	33.42	29.99	23.41	19.98

TABLE II--BULK DENSITIES AND PER CENT MOISTURE (BY VOLUME) OF VARIOUS HORIZONS OF TEST PLOTS

Location	Plot	Depth (inches)			
		0-6	6-12	12-18	18-24
I Site A	Subsoil	1.267	1.344	1.565	1.603
		20.82	25.56	26.29	26.29
	Normal	1.373	1.331	1.358	1.450
		18.62	24.46	35.77	36.34
	Double	1.284	1.336	1.360	1.373
		18.08	19.71	26.10	39.06
I Site B	Subsoil 1	1.371	1.470	1.506	1.530
		33.41	40.54	33.22	30.86
	Subsoil 2	1.448	1.583	1.629	1.669
		32.68	32.32	28.69	27.02
	Normal	1.442	1.406	1.318	1.402
		29.03	27.57	34.86	33.05
I Site C	Subsoil	1.346	1.375	1.453	1.510
		24.65	37.98	36.50	38.22
	Medium	1.236	1.280	1.419	1.435
		16.61	27.93	35.60	31.76
	Normal	1.285	1.285	1.374	1.473
		15.51	20.26	35.04	31.39
II Site X	Subsoil	1.338	1.504	1.552	1.587
		31.22	31.76	33.04	34.52
	Normal	1.293	1.384	1.419	1.234
		31.41	33.78	37.43	36.69
II Site Y	Subsoil	1.231	1.389	1.468	1.636
		28.67	31.57	30.49	35.42
	Normal	1.362	1.479	1.384	1.459
		29.02	31.40	34.32	37.07
III	Subsoil	1.382	1.411	1.397	1.453
		21.37	25.92	24.84	29.39
	Normal	1.492	1.380	1.464	1.548
		12.23	23.18	28.30	24.64
IV Site E	Subsoil	1.307	1.451	1.486	1.506
		17.88	17.15	20.08	24.82
	Normal	1.322	1.415	1.347	1.378
		15.69	17.52	19.88	25.73
IV Site F	Subsoil	1.442	1.389	1.419	1.524
		21.36	18.97	26.29	26.82
	Normal	1.335	1.413	1.397	1.435
		27.38	22.45	23.01	31.02

TABLE II (Continued)

Location	Plot	Depth (inches) 0-6	6-12	12-18	18-24
V Site X	Subsoil	1.406	1.373	1.484	1.541
		30.48	30.67	31.21	26.83
	Normal	1.388	1.490	1.527	1.537
		20.82	19.36	20.48	16.29
V Site Y	Subsoil	1.289	1.503	1.466	1.481
		25.37	27.20	32.49	36.33
	Normal	1.294	1.395	1.377	1.430
		19.89	24.09	30.13	35.79

TABLE III--RESULTS OF SOIL TESTS

Location	Plot	P_20_5 lbs/A	K lbs/A	Mg lbs/A	Ca lbs/A	pH	
						pH_w	pH_s
I Site A	Subsoil	172	415	900	5000	4.5	4.3
	Normal	137	175	400	4100	4.6	4.3
	Double	137	255	430	4300	4.9	4.7
I Site B	Subsoil 1	192	550	1020	5600	4.5	4.3
	Subsoil 2	70	420	1020	4500	4.1	4.0
	Normal	320	300	520	5600	5.5	5.2
I Site C	Subsoil	32	270	860	5000	4.6	4.2
	Medium	99	140	380	4600	5.4	5.1
	Normal	204	160	360	4800	5.0	4.8
II Site X	Subsoil	57	380	920	4400	4.2	4.1
	Normal	338	240	380	5200	6.0	5.8
II Site Y	Subsoil	54	330	920	2600	4.5	4.2
	Normal	160	320	600	4700	5.0	4.8
III	Subsoil	185	500	1020	5850	5.3	4.9
	Normal	306	600	340	4100	6.0	5.7
IV Site E	Subsoil	288	580	400	4400	5.3	5.1
IV Site E	Normal	256	600+	380	6800	5.7	5.7
IV Site F	Subsoil	182	225	420	4100	4.5	4.4
	Normal	530	195	430	6400	5.0	4.8
V Site X	Subsoil	338	270	600	4800	5.5	5.2
V Site X	Normal	454	320	220	6100	5.9	5.6
V Site Y	Subsoil	442	600	820	6100	5.8	5.6
	Normal	300	460	310	4600	5.4	5.2

TABLE IV--ORGANIC MATTER

Location	Plot	Depth	Organic Matter (Per Cent)	Location	Plot	Depth	Organic Matter (Per Cent)
I Site A	Subsoil	0-6	2.4	I Site B	Subsoil 2	0-6	1.7
		6-12	1.9			6-12	.9
		12-18	1.4			12-18	.8
		18-24	.9			18-24	.6
	Normal	0-6	2.2		Normal	0-6	1.9
		6-12	1.8			6-12	1.7
		12-18	1.8			12-18	1.7
		18-24	1.6			18-24	1.1
	Double	0-6	2.8	I Site C	Subsoil	0-6	1.8
		6-12	2.1			6-12	1.5
		12-18	1.5			12-18	1.0
		18-24	1.4			18-24	0.7
I Site B	Subsoil 1	0-6	1.9		Medium	0-6	2.5
		6-12	1.1			6-12	1.8
		12-18	.9			12-18	1.6
		18-24	.6			18-24	1.1
I Site C	Normal	0-6	3.0	II Site Y	Normal	0-6	1.9
		6-12	2.0			6-12	2.2
		12-18	2.0			12-18	1.7
		18-24	1.3			18-24	1.3
II Site X	Subsoil	0-6	1.8	III	Subsoil	0-6	1.9
		6-12	1.2			6-12	1.0
		12-18	.9			12-18	.6
		18-24	.7			18-24	1.7

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TABLE IV (continued)

Location	Plot	Depth	Organic Matter (Per Cent)	Location	Plot	Depth	Organic Matter (Per Cent)
	Normal	0-6	2.2		Normal	0-6	1.5
		6-12	2.1			6-12	1.7
		12-18	2.5			12-18	1.5
		18-24	2.6			18-24	.8
II Site Y	Subsoil	0-6	1.1	IV Site E	Subsoil	0-6	2.2
		6-12	1.0			6-12	1.4
		12-18	.9			12-18	.9
		18-24	.8			18-24	.9
IV Site E	Normal	0-6	3.2	V Site X	Normal	0-6	2.2
		6-12	2.7			6-12	1.1
		12-18	1.9			12-18	1.1
		18-24	1.8			18-24	1.3
IV Site F	Subsoil	0-6	2.9	V Site Y	Subsoil	0-6	2.2
		6-12	1.6			6-12	1.4
		12-18	1.6			12-18	.8
		18-24	.9			18-24	.6
	Normal	0-6	3.9		Normal	0-6	2.2
		6-12	2.9			6-12	1.9
		12-18	1.8			12-18	1.5
		18-24	1.6			18-24	1.2
V Site X	Subsoil	0-6	2.5				
		6-12	1.6				
		12-18	.9				
		18-24	.8				

TABLE V--RESULTS OF PARTICLE SIZE ANALYSIS AND DEGREE OF AGGREGATION

Location	Plot	Depth	Per Cent Sand	Median Diameter	Comminution Number	Per Cent Clay	Degree of Aggregation	Aggregate Stability
I Site A	Subsoil	0-6	60.3	0.0203	4.28	39.7	89.6	81.2
		6-12	59.3	0.0204	3.87	40.7	95.6	88.2
		12-18	64.6	0.0199	3.90	35.4	89.4	84.0
		18-24	63.6	0.0208	4.18	36.4	88.5	80.1
	Normal	0-6	77.0	0.0203	3.88	23.0	80.3	70.8
		6-12	63.9	0.0214	4.81	36.1	79.3	73.1
		12-18	43.7	0.0221	5.25	56.3	89.3	85.3
		18-24	44.7	0.0217	5.09	55.3	85.8	81.7
	Double	0-6	80.4	0.0196	3.63	19.7	78.7	63.8
		6-12	80.1	0.0201	3.67	19.9	75.8	65.1
		12-18	68.3	0.0203	4.03	31.7	71.6	64.2
		18-24	51.5	0.0202	4.38	48.5	83.1	78.9
I Site B	Subsoil 1	0-6	61.6	0.0209	4.59	38.4	72.4	63.1
		6-12	56.5	0.0222	5.22	43.5	88.3	83.2
		12-18	73.7	0.0204	4.52	26.4	83.9	79.8
		18-24	79.3	0.0202	4.43	20.7	50.7	42.4
I Site B	Subsoil 2	0-6	56.0	0.0192	1.44	44.0	95.2	91.7
		6-12	61.3	0.0188	1.57	38.7	89.3	83.4
		12-18	66.3	0.0107	2.32	33.7	76.1	71.5
		18-24	67.0	0.0185	1.23	33.0	69.0	61.8

(continued on next page)

TABLE V (continued)

Location	Plot	Depth	Per Cent Sand	Median Diameter	Comminution Number	Per Cent Clay	Degree of Aggregation	Aggregate Stability
	Normal	0-6	79.3	0.0201	3.45	20.7	61.3	52.7
		6-12	78.3	0.0207	3.85	21.7	63.5	52.9
		12-18	59.3	0.0218	4.62	40.7	96.9	94.9
		18-24	55.8	0.0224	5.37	44.2	83.8	79.8
I Site C	Subsoil	0-6	69.0	0.0211	4.57	31.0	71.3	66.1
		6-12	51.8	0.0219	5.22	48.2	92.4	89.3
		12-18	63.9	0.0221	5.14	36.1	81.5	78.4
		18-24	69.9	0.0221	4.93	30.1	58.4	53.3
	Medium	0-6	78.3	0.0205	4.64	21.7	70.8	60.5
		6-12	58.8	0.0218	5.21	41.2	84.0	80.0
		12-18	52.5	0.0220	5.32	47.5	92.7	88.6
		18-24	63.9	0.0216	5.21	36.1	89.1	85.1
I Site C	Normal	0-6	80.7	0.0203	4.23	19.3	74.0	63.5
		6-12	70.6	0.0213	4.76	29.4	79.2	70.0
		12-18	51.8	0.0223	1.53	48.2	89.7	88.7
		18-24	62.6	0.0217	5.13	37.4	78.3	73.2
II Site X	Subsoil	0-6	58.6	0.0206	4.95	41.5	75.3	70.2
		6-12	61.1	0.0218	5.30	38.9	87.1	82.1
		12-18	60.6	0.0216	5.29	39.4	79.0	71.9
		18-24	61.3	0.0214	5.10	38.7	63.9	59.8
	Normal	0-6	81.7	0.0202	4.56	18.3	65.8	57.6
		6-12	82.4	0.0199	4.40	17.6	63.0	51.6
		12-18	79.7	0.0204	4.70	20.3	64.4	53.2
		18-24	79.0	0.0208	4.81	21.0	76.7	68.5

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TABLE V (continued)

Location	Plot	Depth	Per Cent Sand	Median Diameter	Comminution Number	Per Cent Clay	Degree of Aggregation	Aggregate Stability
II Site Y	Subsoil	0-6	70.9	0.0202	4.18	29.1	60.9	53.6
		6-12	74.7	0.0201	3.58	25.4	77.3	71.9
		12-18	83.7	0.0196	2.04	16.3	76.9	68.9
		18-24	73.7	0.0206	3.42	26.7	62.0	52.2
II Site Y	Normal	0-6	76.3	0.0203	4.45	32.7	69.8	55.7
		6-12	78.7	0.0200	4.50	21.3	65.0	54.7
		12-18	58.3	0.0207	4.50	41.7	77.6	71.4
		18-24	58.6	0.0208	4.60	41.5	82.5	74.2
III	Subsoil	0-6	60.3	0.0197	3.79	39.7	79.3	66.6
		6-12	54.3	0.0201	4.34	45.7	92.4	88.3
		12-18	57.3	0.0200	3.99	42.7	91.8	85.4
		18-24	61.6	0.0198	4.16	38.4	80.8	74.5
	Normal	0-6	84.7	0.0206	3.82	15.3	74.2	41.3
		6-12	57.8	0.0213	4.88	42.2	66.5	58.3
		12-18	50.8	0.0223	5.48	49.2	90.6	82.6
		18-24	61.9	0.0217	5.10	38.2	79.4	75.3
IV Site E	Subsoil	0-6	85.4	0.0183	1.03	14.6	66.6	55.9
		6-12	81.4	0.0181	0.99	18.7	76.4	69.2
		12-18	71.3	0.0183	1.30	28.7	82.5	78.9
		18-24	62.3	0.0182	1.29	37.7	96.6	97.8

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TABLE V (continued)

Location	Plot	Depth	Per Cent Sand	Median Diameter	Comminution Number	Per Cent Clay	Degree of Aggregation	Aggregate Stability
IV Site E	Normal	0-6	81.7	0.0199	4.03	18.3	69.2	56.6
		6-12	80.4	0.0203	4.22	19.7	72.8	61.4
		12-18	70.3	0.0204	4.01	29.7	61.0	51.6
		18-24	56.5	0.0203	4.44	43.5	62.3	56.1
IV Site F	Subsoil	0-6	81.7	0.0195	2.49	18.3	61.6	50.4
		6-12	75.7	0.0194	2.38	24.3	64.0	58.4
		12-18	61.6	0.0192	2.61	38.4	73.8	68.2
		18-24	62.6	0.0191	2.06	37.4	99.7	96.2
	Normal	0-6	85.1	0.0203	4.26	14.9	61.5	58.4
		6-12	70.9	0.0216	4.81	29.1	69.8	59.5
		12-18	67.6	0.0217	4.94	32.4	69.4	64.3
		18-24	64.6	0.0209	4.72	35.4	86.5	85.5
V Site X	Subsoil	0-6	77.7	0.0199	4.41	22.3	58.9	50.6
		6-12	78.7	0.0195	3.64	21.3	49.2	41.7
		12-18	71.3	0.0197	4.71	28.7	58.3	49.1
		18-24	73.7	0.0195	4.01	26.4	65.3	50.5
V Site X	Normal	0-6	81.4	0.0196	4.22	18.7	70.3	58.9
		6-12	81.4	0.0191	4.12	18.7	67.3	57.0
		12-18	82.4	0.0189	3.93	17.6	55.3	49.1
		18-24	83.7	0.0194	4.46	16.3	102.7	102.7

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TABLE V (continued)

Location	Plot	Depth	Per Cent Sand	Median Diameter	Comminution Number	Per Cent Clay	Degree of Aggregation	Aggregate Stability
V Site Y	Subsoil	0-6	68.3	0.0204	4.67	31.7	50.2	42.0
		6-12	69.9	0.0202	4.62	30.1	52.6	46.4
		12-18	70.3	0.0197	4.27	29.7	45.8	38.5
		18-24	72.6	0.0196	3.99	27.4	43.3	35.9
	Normal	0-6	81.4	0.0195	4.17	18.7	59.3	51.0
		6-12	77.7	0.0200	4.63	22.3	55.2	49.1
		12-18	70.3	0.0207	4.97	29.7	71.1	64.0
		18-24	68.6	0.0210	5.08	31.4	51.7	46.6