THE USE OF A RECORDING RESISTANCE BRIDGE AND BOUYOUCOS PLASTER OF PARIS BLOCKS IN MEASURING INFILTRATION, PERCOLATION AND TRANSMISSION RATES OF RAIN WATER THROUGH SOILS UNDER GRASS, ALFALFA AND OATS

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INTRODUCTION

The growing interest in proper land use has increased the interest in water entering and moving within the soil under different management practices. Why different types of cover on the same soil and land types respond as they do to rainfall can only be answered through experimentation. With such data available land use programs could be worked out with more assurence of success than has been so far possible.

The purpose of this investigation was to study infiltration, percolation and transmission rates of soils under grass, alfalfa and oats under natural conditions. A recording resistance bridge on Bouyoucos's plaster of paris blocks was used to study moisture changes at different depths within the soil profile. It was believed that such moisture data would be of value in determining the rates being studied in this paper.

Definition of Terms

Infiltration is the absorption or passage of water into the soil mass from the atmosphere. The infiltration rate can be expressed as the inches of water moving into the soil mass per hour. Infiltration capacity is the maximum rate at which the soil mass will absorb water through the surface at any instant. This is expressed as inches of water per hour.

Percolation is the water passing a given level within the soil profile. The percolation rate is the amount of water in inches per hour passing a given level. Percolation rates are determined by the infiltration rates minus the available storage in the soil above that level. Infiltration capacity may equal the percolation rate if all the non-capillary pore spaces are filled down to the level of percolation being studied.

Transmission is the downward movement of the water within the soil profile. The transmission rate is the distance in inches per hour (velocity) that water will move downward in any portion of the soil profile.

REVIEW OF LITERATURE

Infiltration Rates

Rates of infiltration have been measured in various ways. The lysimeter is one way that has been used to measure infiltration directly. Two methods have been developed in an effort to obtain infiltration rates for soils under natural conditions.

One method uses watersheds or plots and compares rates of rainfall with rates of runoff. The second which is the least expensive and can be used in all soil types is the "infiltrometer". This usually consists of a cylinder with both ends open. The cylinder is forced vertically into the ground and a head of water is placed at the top end and the infiltration rate is measured directly in inches per hour.

Wilm (17) made a study of "infiltrometers" in use and concludes that infiltration rates are characteristically variable. The largest part of this variation occurs between sites and a smaller amount of variation is due to errors of instruments and techniques. As to the instruments themselves, any of the "infiltrometers" can be expected to give only relative estimates of true infiltration.

Musgrave and Free (10) write that soil type is the dominant factor in the rate of infiltration. The initial infiltration rate for soils of the same type is controlled partly by the non-capillary porosity of the top soil. They found that cultivation of the surface greatly increased the water intake of the soils. In three cases studied the infiltration rates for 15 minutes on soils naturally packed, cultivated 4 inches deep and 6 inches deep, were 0.85 inches, 1.77 inches and 1.87 inches respectively. They also found that soil moisture content has a modifying effect on the initial infiltration. It was found that close vegetation such as bluegrass and alfalfa doesn't seem to increase infiltration rates.

Neal (11) working in the laboratory concluded that infiltration was not affected by either the slope or the rainfall intensity but varied inversely with the initial soil moisture content. Borst (2) also found a strong negative relationship between soil moisture and infiltration.

Percolation and Transmission Rates

Infiltration studies under natural conditions have very seldom been studied in connection with percolation and transmission of the soil profile. The method mainly used to study percolation and transmission rates in soils is to take core samples into the laboratory and add water to the surface. The water that percolates through the core is collected. The time it takes for the water to pass through the core is used to calculate transmission rates. The amount of water in inches per hour that will pass through the core is used to calculate percolation rates. This method can not give the complete record of what happened in the soil at the time of rainfall.

Studies were made by Schiff and Dreibelbis

(12, 13) on infiltration, percolation and transmission rates under natural conditions. Four small watersheds were selected with different management practices. A complete check was kept on time and amounts of rainfall and runoff. Soil moisture was determined using plaster of paris blocks, field sampling and a recording tensiometer. They concluded that runoff rarely occurs if the available storage space in the topsoil is not exhausted by the total infiltration. They found that the Keene silt loam with a low transmission rate could be improved, by proper management practices, to approach the transmission rates of Muskingum silt loam which had a much higher transmission rate. The differences in runoff between the watersheds were due mainly to differences in transmission rates of the subsoils. The subsoil is the bottleneck which must be opened by deep-rooted crops or mechanical means before a decrease in runoff can be obtained.

Schiff and Dreibelbis found that the rates and amounts of runoff occur only when the topsoil storage space is exhausted and rainfall exceeds the percolation at the bottom of the topsoil. Percolation rates are limited by the transmission rates in the subsoil. Some of the percolation rates found have varied from a maximum of 0.60 to a minimum of 0.15 inches per hour for Muskingum silt loam and 0.46 to 0.04 inches per hour for Keene silt loam.

EXPERIMENTAL AREAS AND EQUIPMENT

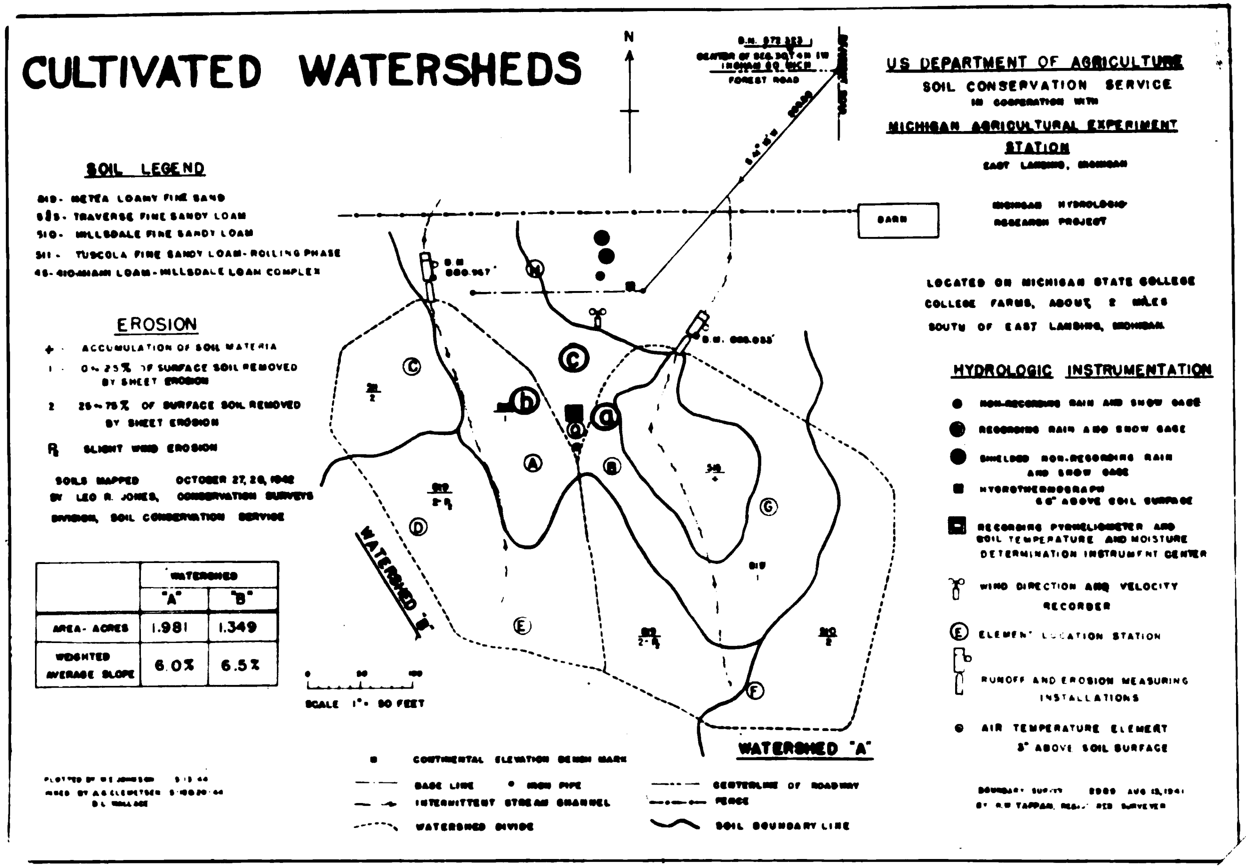
Description of Areas

This study was conducted at the Michigan Hydrologic Research Project located on the Michigan State College Farms about two miles south of East Lansing. The project was established in 1940 as a cooperative study between the United States Soil Conservation Service and the Michigan Agricultural Experiment Station.

The purpose (16) was to study the effect of land use on the hydrology of farm lands. The objectives were to find how varying types of land use contribute to runoff, erosion, and flood flow and how varying types of land use affected the movement of water through the soil profile during the year.

For the project study two areas of land known as watersheds (A and B) were selected (Figure 1). They are characteristic, both in soil and land types, of a large portion of Michigan's farm lands (Figure 2 and 3).

Figure 1. A general view of the cultivated watersheds "A" and "B" and the installations for the collecting of hydrologic data.



	WATERSHED "A"	WATERSHED "B"
AREA- ACRES	1.981	1.349
WEIGHTED AVERAGE SLOPE	6.0%	6.5%

Figure 2. A Soil Conservation Survey of watersheds "A" and "B" also the location and identification of the hydrologic instruments used on the project for gathering data.

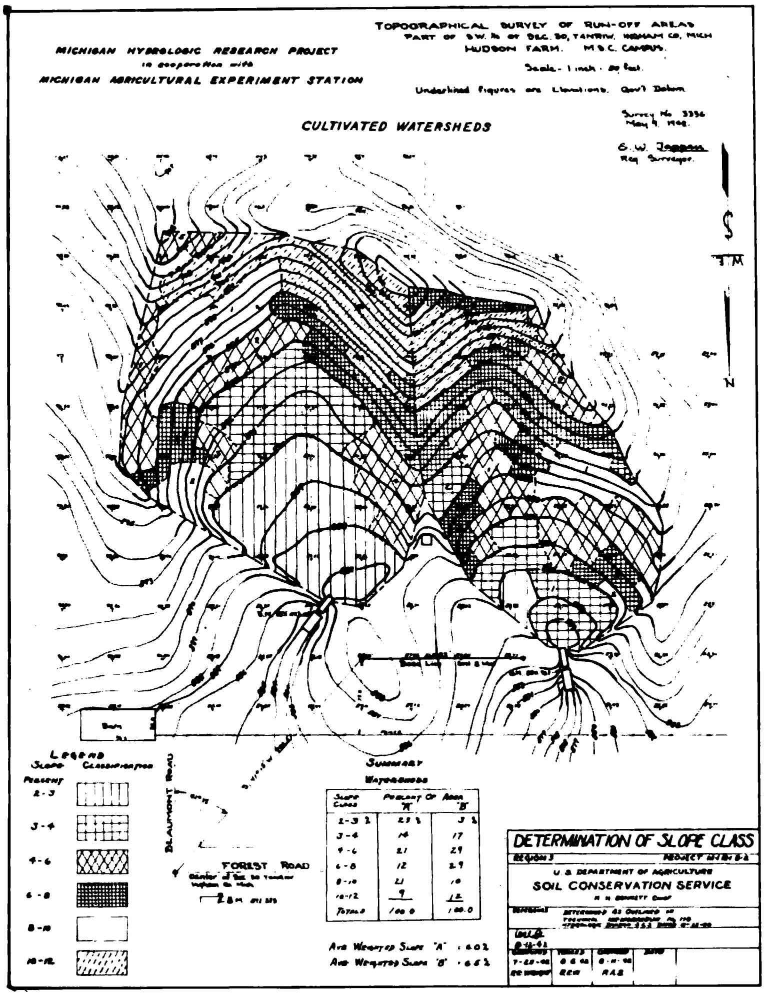


Figure 3. A Soil Conservation Topographical Survey showing the percent and proportion of slope on watershed "A" to the left and watershed "B" to the right.

Watershed "A" has an area equal to 1.98 acres of land with an average weighted* slope of 6.0 per cent. This is oval shaped with a maximum length and width of 420 and 295 feet respectively. The watershed has three distinct soils, Metea loamy fine sand, Traverse and Hillsdale fine sandy loam.

Watershed "B" has an area equal to 1.35 acres of land with an average weighted slope of 6.5 per cent. It is more or less rectangular in shape with a maximum length and width of 400 and 190 feet respectively. There are two soils present in this area, Tuscola fine sandy loam (rolling phase) and Metea loamy fine sand.

The two watersheds have one soil type common to both, the Metea loamy fine sand (Figure 3). This soil takes up better than half of the area in "A" and three-fourths of the area in "B". Both watersheds have soils which are foreign to the other. The Traverse, a soil deposited at the foot of slopes, and the Hillsdale are present in "A" but not in "B". While "B" has the Tuscola soil not found in "A". The soils found in both watersheds are very sandy.

The topography of the two watersheds are similar

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* Calculated by multiplying the percent of area in each slope class by an average of that slope class. The total results are then divided by 100 to get the average weighted slope of the entire area.

with "B" having a slightly higher average weighted slope than "A" (Figure 3). Watershed "A" has 23% of its slopes in a slope class of 2-3% located at the foot of the slope while "B" only has 3% in this slope class. This is the reason why "A" has the Traverse soil while "B" does not. Watershed "A" and "B" vary in the proportion of the slopes in the different slope classes but both watersheds have about equally average weighted slopes.

Management of Watersheds

In the year 1941 the two watersheds were put in a five year rotation of corn, oats and alfalfa brome (three years). This rotation was changed in the year 1946 so as to get comparative data from the two watersheds under different management practices. Watershed "A" from 1946 on has been in the following: 1946, corn; 1947, oats seeded to alfalfa brome; 1948, alfalfa brome; 1949, alfalfa brome. Watershed "B" has been in the following: 1946, alfalfa brome; 1947, corn; 1948, corn; 1949, oats seeded to alfalfa brome. A cover crop of rye is planted in the corn stubble. Fertilizer is drilled in with the oats and manure is plowed under for corn. All tillage practices are across the slopes.

Description of Equipment

After the two watersheds were selected the necessary equipment was installed to obtain the desired data (Figure 2). GarstMa (9) has given a complete description of each instrument and so only the ones pertaining to this study will be discussed.

The amount and time of rainfall was measured with a recording rain and snow gage (of Fergusson design). This gage has a nine-inch capacity, and is operated with a chart-holding clock making one revolution in 12 hours.

The amount and time of runoff was measured with an installation consisting of an approach section leading to a 3-H sheet-metal flume, as designed by the Soil Conservation Service and the National Bureau of Standards, having a capacity of 30 cubic feet per second of flow. The runoff-recorder is of reversing-pen design with a ratio of five inches of chart equal to a 12-inch depth of water in the flume. The recorder-clock operates at the rate of one revolution in 12 hours.

Located in the "V" of the two watersheds is the main instrument house. The lead ends from the soil moisture blocks and the soil temperature thermocouples are located here as well as the Micromax used for this investigation (Figure 4).

Figure 4. A general view of the Micromax installed in the instrument house.

The Micromax

In the year 1949 an instrument was purchased* which would continuously record resistance readings on the plaster of paris blocks (3) and the nylon units (4). This instrument was built by the Leeds and Northrup Company.

The Micromax is an automatically operated Wheatstone bridge and is essentially the same as the manually-operated instruments. It balances a known resistance against the unknown resistance of the block. As the slidewire rotates to balance the bridge it also moves a multiple-point indicator along a logarithmic chart from 250 to 50,000 ohms (Figure 5). Every 57 seconds the Micromax balances the bridge against an unknown plaster of paris block and records the resistance of the block in ohms. After each recording the multiple-point indicator automatically switches to the next soil moisture unit until the entire network of 16 blocks have been recorded. It requires 15 minutes to record the resistance of 16 blocks. This cycle is repeated four times every hour to give a total number of 64 block readings per hour on a month by hour chart. The soil moisture can then be determined from this chart.

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* Purchased by the Experiment Station and Conservation Service.

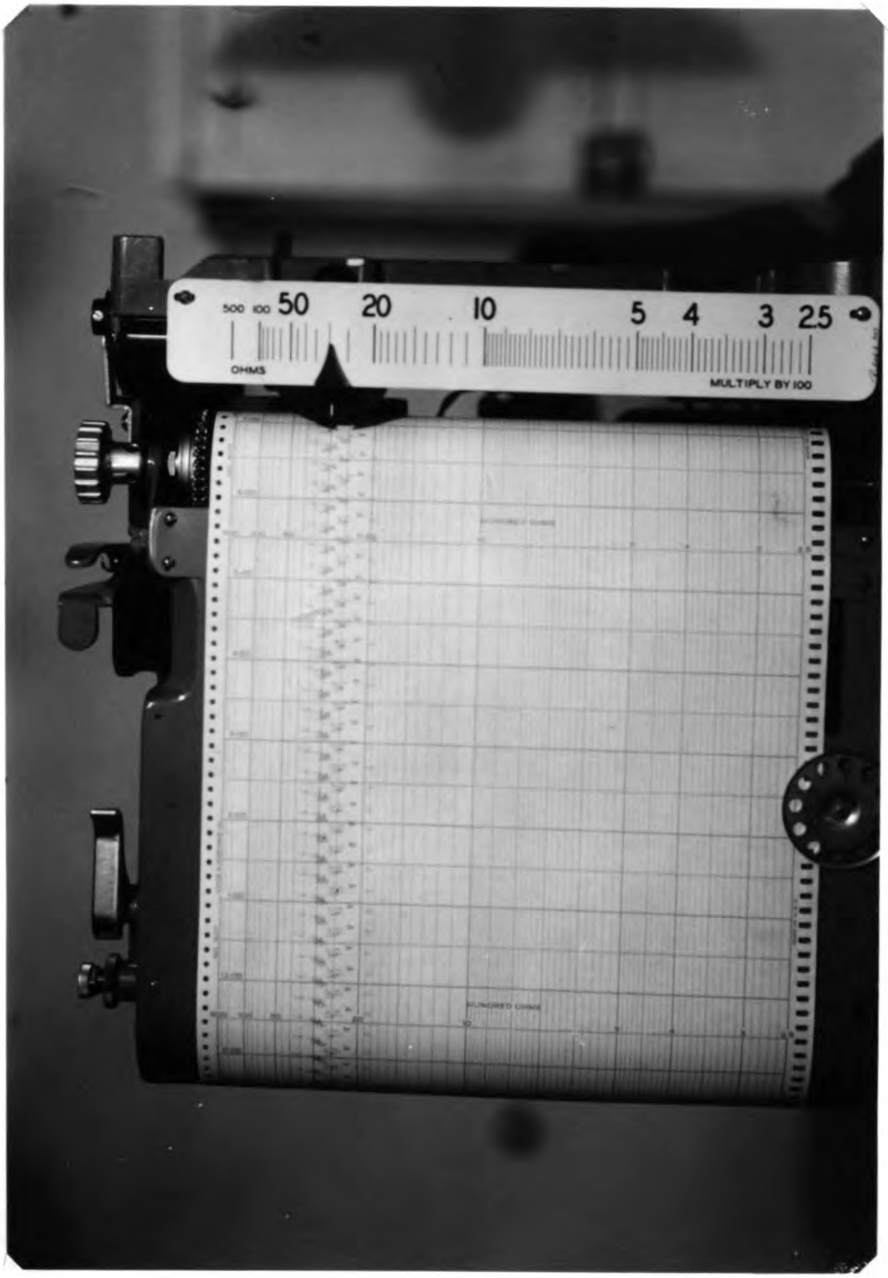

Figure 5. The Micromax with a logarithmic chart.

EXPERIMENTAL PROCEDURE

This study was started in the spring of 1949 and continued through the summer of that year. Watershed "A" was in alfalfa for the second year and Watershed "B" had been plowed and planted to oats. The third area studied was the permanent grass area in front of the instrument house.

One site was selected in each area about 40 feet from the instrument house. At each of these sites (Figure 2, a, b and c) two three-inch holes a foot apart were bored with a soil auger. The soil material removed from each hole was placed in a trough in the order it was removed from the soil profile. At each site one set of plaster of paris blocks and one set of nylon units were buried.

Bouyoucos's (3) second method of placing blocks in the soil was followed. The blocks were placed horizontally at the bottom of the hole and the profile layers returned in the order removed. A sample of soil material from each block location was taken for further study in the laboratory.

All the block leads were buried below the plow layer. The lead ends were located in the instrument house.

The blocks at site "a" and "b" in watershed

"A" and "B" respectively were buried at the following depths 3, 6, 12, 24, 36 and 60 inches. At site "c" in the permanent grass area the blocks were buried at 6, 12, 24 and 36 inches. The total number of blocks were 32, 16 plaster of paris blocks and 16 nylon units. For each plaster of paris block there was a corresponding nylon unit approximately a foot away.

The Micromax could record data on 16 units at one time. The two sets of blocks were installed so comparative data could be obtained as well as measuring the soil moisture below field capacity with the nylon units.

The blocks were buried May 5, 1949 about a month before the Micromax was shipped. This period of time was necessary to "season" the plaster of paris blocks.

The Micromax was installed June 7, 1949. The installation consisted of hanging it on the wall (Figure 4) and connecting the block leads to the micromax's terminals.

The data collected in the field consisted of the following: (1) precipitation (date, time, amount and intensity) (2) runoff (date, time and amount) from Watersheds "A" and "B". (3) soil moisture changes (date, time and amount) at various depths in the soil profile under alfalfa, oats and grass. (4) soil temperature changes (daily) at various depths in the soil profile under alfalfa, oats and grass (5) daily readings were taken on the plaster of paris blocks with the Bouyoucos Soil Moisture Bridge (3), designed for testing the soil moisture blocks.

Description of Soil Types at Block Sites

The predominant soil type in the two watersheds "A" and "B" is Metea loamy fine sand. This soil type was selected for block sites "a" and "b" because it is the only soil present in both watersheds. It makes up a greater part of each watershed and it is located favorably in relation to the instrument house (Figure 2). The soil type in the permanent grass area consists of Coloma sandy loam. The Metea soil type was not available in the grass area so the Coloma soil type was studied in place of it.

According to Veatch (15), Metea loamy fine sand is closely associated with areas of the Coloma, Bellefontaine and Hillsdale. The relief is rolling to hilly highlands with drainage good to excessive. The surface soil from 0 to 9 inches is light yellowish-brown loamy fine sand with enough organic matter to make the mass very slightly coherent. The reaction is medium acid. The subsurface from 9 to 17 inches is gray medium fine sandy material. From 17 to 27 inches the subsoil is a medium fine sandy material containing small amounts of silt and clay. The subsoil from 27 to 52 inches is fine sandy parent material slightly weathered. The rest of the profile is unweathered glacial till of fine sand.

The Coloma sandy loam is located on rolling or hilly upland areas (15). The surface is a brown sandy loam to a depth of 8 to 10 inches. It is acid in reaction. The subsoil is coarse sand down to 3 feet without a retentive clay layer such as is under Metea loamy fine sand.

Procedure in Calibrating Blocks with Soil

The calibration of the block resistance with the moisture of the soil at that resistance is necessary if exact measurements of soil moisture is desired. Exact measurements were desired in this study plus the facts that there were marked differences in the soils at different layers making it necessary to have a curve for each different soil layer.

The procedure followed in calibrating the block with the soil is the same as that used by Bouyoucos (3) with extra precaution. The saturated block was placed in a shallow pan with the soil and then the soil was saturated. Shortly before the block reached the desired resistance the pan, block and soil were placed in a closed container with a saturated atmosphere for a period of 24 to 48 hours. This was done so that the soil moisture on all sides of the block would be the same.

The pan was then taken out of the container. The resistance of the block was taken with the Bouyoucos Bridge. The temperature of the block was determined by a thermometer in the container at all times. A temperature correction was made for the resistance of the block. The per cent moisture of the soil at that resistance was determined on only the one-eighth inch of soil around the block. The procedure followed by Bouyoucos in calibrating the soil with the block did not include the closed container and the thermometer.

RESULTS AND DISCUSSION

Physical Properties of Soils

In order to better understand the soil characteristics, certain physical properties of the soil have to be determined. These determinations were made on samples of soil taken into the laboratory from each block location.

<u>The moisture equivalent</u> from each sample was

determined in duplicate by the method of Briggs and McLane (5) using a force of 1,000 times that of gravity instead of the force of 3,000 used by them (Table 1).

Table 1. The Moisture Equivalent of the Soil at Each Block Location.

	Depth in inches					
Location	3	6	12	24	36	60
Alfalfa						
sod	13.46	13.13	11.82	13.25	9.36	5.29
"a"	13.53	12.43	11.30	12.78	8.56	5.05
Ave.	13.49	12.78	11.56	13.01	8.96	5.17
Oat						
Seeding	11.98	8.52	9.35	11.24	6.40	4.70
"b"	11.80	7.79	8.99	10.95	6.04	5.11
Ave.	11.89	8.15	9.17	11.09	6.22	4.90
Blue Grass						
sod		14.67	9.51	5.06	3.71	
"c"		13.49	9.34	4.36	3.45	
Ave.		14.08	9.42	5.71	3.58	

The values obtained by this method for many fine textured soils equal field capacity. However, according to Browning (7) sandy soils will have a higher value for field capacity than given by the moisture equivalent. Therefore, field capacity values in this study are lower.

From this data it is possible to see the variation not only in profile layers but also in the soil profiles at the different block sites. The moisture equivalent varied the least from 3 to 24 inches in the profile under the alfalfa sod. It also has the highest per cent of moisture except possibly for the 3 and 6 inch depths under the grass sod. This is higher under the grass because of the greater accumulation of organic matter in the surface layer. The 12 inch depth under the alfalfa and grass sod show a decrease in per cent moisture from the 6 inch depth. Why the 6 inch layer of soil under the oat seeding varies so far from the 3 inch layer in the same profile is not known.

The answer could be this, the alfalfa sod and manure were plowed under in 1947 for corn, putting a high concentration of organic matter at the 6" to 7" depth. That year and the next spring of 1948 there was a fairly high amount of water and soil loss. The soil was plowed again in 1948 for corn, turning up the layer of organic matter. In the fall for the third time the soil was plowed for a cover crop of rye, turning under the organic matter. The next spring of 1949 the soil was again plowed for oats turning up the organic matter for the second time and turning under the layer of soil material that had been exposed to erosion for two winters. The soil sample found at the 3 inch depth was taken from the soil layer containing more organic matter while the sample for the

6 inch depth was taken from the soil layer which had been eroded for two winters and did not have the supply of organic matter.

The soil at the 12 inch depths under the oat seeding and grass sod holds about the same per cent moisture while under the alfalfa sod it is 2 to 2.5 per cent higher. This same variation can be seen in the 24 and 36 inch depths for the three profiles. The reason being that the Metea soil type is transitional between a Hillsdale and a Coloma and the soil at site "a" is approaching the Hillsdale while the soil at site "b" is approaching the Coloma and at site "c" it is a Coloma soil. The 24 inch depth shows the silt and clay layer under alfalfa and oats but is entirely lacking under the grass sod. The rest of the depth shows a change from the weathered material to the parent material.

<u>The wilting percentages</u> were calculated to further study the differences between the soils at each block location. The wilting percentages were calculated in duplicate by the method of Briggs and Shantz (6). The hygroscopic coefficient is determined and this value is divided by a constant of 0.68. The data in Table 2 was obtained from the samples taken at each of the plaster of paris block locations. The calculated values for wilting percentages on sandy

Table 2. The Wilting Percentage* of the Soils at Each Block Location.

	Depth in inches					
Location	3	6	12	24	36	60
Alfalfa						
sod	1.38	1.33	0.94	1.49	0.86	0.57
"a"	1.33	1.36	0.96	1.23	0.72	0.60
Ave.	1.35	1.34	0.95	1.36	0.79	0.58
Oat						
seeding	1.07	0.77	0.97	1.22	0.66	0.46
"b"	1.05	0.65	0.93	1.13	0.58	0.54
Ave.	1.06	0.71	0.95	1.18	0.52	0.50
Blue Grass						
sod		1.25	0.72	0.43	0.42	
"c"		1.26	0.74	0.45	0.40	
Ave.		1.26	0.73	0.44	0.41	

* Calculated $\frac{HC}{.68} = $ W. P.

soils are low as was the case in field capacity.

The same relationship exists in this as in the moisture equivalent. The soil under alfalfa sod has the higher wilting point due to the higher per cent of colloidal material present. The 6 inch depth under the oat seeding is low based on the same reasoning as for the moisture equivalent. The 24 inch depths under alfalfa and oats are high due to the accumulation of colloidal material. The lack of colloidal material causes very low wilting points under the grass sod except for the plow layer.

The mechanical analyses made in 1941 (9) on samples taken at sites "A" and "B" (Figure 2) are included to show the variation in the Metea loamy fine sand (Table 3).

Table 3. A Mechanical Analysis of the Profile Under Alfalfa Sod and Oat Seeding Taken in 1941.

Soil Separates*	Profile Depth in Inches					
	3	6	12	24	36	60
Alfalfa Sod						
Sand	62.34	-	56.66	53.02	73.66	52.84
Silt	28.86	-	33.86	31.18	23.54	41.18
Clay	8.80	-	9.48	15.80	2.80	5.98
Oat Seeding						
Sand	66.38	63.74	68.84	73.56	72.84	71.56
Silt	24.50	26.14	20.36	19.00	20.86	21.50
Clay	9.12	10.12	10.80	7.44	6.30	6.94

* Determined by hydrometer method.

The alfalfa sod has the lower percentage of sand down to the 24 inch depth. The 24 inch depth shows the wide variation in the two profiles, with 20 per cent more silt and clay in the profile under the alfalfa sod.

During the period of this investigation core samples were taken with a Bradfield soil-sampling tube around each block site. These samples were taken into the laboratory and porosity determinations were made (Table 4).

Table 4. The Porosity of Surface Soils at the Block Sites.

Location	Total porosity per cent by volume	Capillary porosity per cent by volume*	Non-capillary porosity per cent by volume
Alfalfa			
sod	53.68	37.68	15.99
"a"	54.47	37.78	16.68
	53.31	38.78	14.52
	53.26	36.73	16.52
	53.20	37.26	15.94
Ave.	53.58	37.64	15.93
Oat			
seeding	52.52	43.63	8.89
"b"	54.78	44.99	9.78
	53.10	44.84	8.26
	53.15	44.47	8.68
	-	-	-
Ave.	53.38	44.48	8.90
Blue Grass			
sod	55.41	40.05	15.36
"c"	56.20	39.10	17.10
	55.26	39.36	15.89
	57.31	39.47	17.84
	56.78	38.41	18.36
Ave.	56.19	39.27	16.91

* Determined at pF 1.6.

The total porosity for the three sites was about the same with the grass sod having 3 per cent more total porosity than either the alfalfa or the oats. The alfalfa and grass sod were about equal in the per cent capillary and non-capillary pore space. However, the oat seeding shows a marked variation from the other two sites in capillary and non-capillary porosity. Although the total pore space was the same for all three sites the capillary pore space under oats was from 5 to 7 per cent higher than the other two sites. The non-capillary porosity which partially controls the initial infiltration rates of soils was considerably lower. This wide variation in non-capillary pore space seems to be a surface feature caused by rain packing the partially unprotected surface soil under oats. This is further substantiated in that the non-capillary porosity (Table 5) of the 3 inch depth, which didn't include the surface soil, is much higher than was found for the surface soils on the same watershed.

According to Baver (1) the ideal soil should have the pore space about equally divided between non-capillary and capillary pore spaces. Such soils would have sufficient areation, permeability and water-holding properties.

Table 5. The Porosity Characteristics at Different Depths in the Metea Soil Profile Under Oats.

Profile depth in inches	Porosity	Replicates 1*	2	3	4	Ave.
3	Total	50.63	51.89	51.41	50.05	51.00
	Capillary	40.21	38.94	37.94	36.63	38.43
	Non-capillary	10.42	12.94	13.47	13.42	12.56
6	Total	51.73	49.26	52.52	-	51.17
	Capillary	37.94	37.99	36.63	-	37.52
	Non-capillary	13.78	11.26	15.89	-	13.64
12	Total	46.57	47.99	47.15	48.41	47.53
	Capillary	35.47	36.78	32.52	31.78	34.14
	Non-capillary	11.10	11.21	14.63	16.63	13.34
18	Total	47.36	45.68	38.47	-	43.84
	Capillary	37.36	36.73	27.73	-	33.94
	Non-capillary	9.99	8.94	10.73	-	9.89
24	Total	46.36	-	40.26	39.84	42.19
	Capillary	38.20	-	27.57	27.94	31.24
	Non-capillary	8.15	-	12.68	11.89	10.91
30	Total	48.94	50.26	51.36	49.68	50.06
	Capillary	39.36	39.20	38.68	35.31	38.14
	Non-capillary	9.57	11.05	12.68	14.36	11.92
36	Total	49.52	49.57	51.36	51.52	50.49
	Capillary	36.41	38.36	37.89	37.31	37.49
	Non-capillary	13.10	11.21	13.47	14.21	12.99
48	Total	-	48.57	43.41	52.05	48.01
	Capillary	-	33.99	30.15	39.31	34.48
	Non-capillary	-	14.57	13.26	12.73	13.52
60	Total	48.47	49.15	51.31	50.26	49.80
	Capillary	39.78	40.10	38.52	37.63	39.01
	Non-capillary	8.68	9.05	12.78	12.56	10.77

* The first two samples of each depth taken six feet away from the second two samples.

During the fall of 1949 core samples were taken at various depths in the profile. These were taken for two purposes: (1) to determine porosity characteristics in the soil profile and (2) to obtain volume weight values of the various horizons in the profile.

The procedure for obtaining these core samples was to dig a hole two by six feet and five feet deep in watershed "B". The location of the hole was 30 feet south of site "b". Two core samples were taken at each end of the hole for the following depths: 3, 6, 12, 18, 24, 30, 36, 48 and 60 inches. These were taken into the laboratory and the porosity characteristics determined (Table 5).

There is only a slight variation in the total porosity at the various depths except at 18 and 24 inches. This is due partly to the fact that at one end of the hole there was a very tight compact layer of coarse clay material at both 18 and 24 inches. In general, the variation in the capillary and non-capillary pores was not significant except at the 18 and 24 inch depths.

Method Used to Calculate Soil Moisture

Soil moisture can be expressed in two ways: (1) on a percentage by weight basis, (2) on a volume basis. Both have certain advantages over the other.

The moisture expressed on a dry weight basis is usually determined by taking a sample of soil from the field and drying it in an oven at 105° to 110° C. The percentage of water held by the soil on a dry basis is the moisture content. This method is very simple and useful in many respects. However, it is possible for two soils to have the same moisture content on a percentage by weight basis but not on a volume basis.

The second method of expressing soil moisture on a volume basis also requires volume weight data. The advantage is that the degree of saturation of pore space with moisture can be more readily seen. Soil moisture on a volume basis is usually expressed in inches of water per unit depth of soil. On this basis it is easy to see how the water is distributed through the profile.

The volume weights for the different depths of the Metea profile are given in Table 6. The 12, 18 and 24 inch depths have the high volume weights. The 24 inch depth has the highest at 1.65 while the 48 inch depth has the lowest volume weight. If the per cent moisture, on a dry weight basis, was the same throughout the soil profile there would be a marked variation between the 24 inch depth and the 48 inch depth as to volume of water held.

Table 6. The Volume Weight of the Metea Profile at Different Depths Under Oats.

Depth in inches	Replicates				
	1	2	3	4	Ave.
3	1.37	1.33	1.35	1.38	1.36
6	1.37	1.40	1.38	-	1.38
12	1.51	1.47	1.55	1.45	1.49
18	1.41	1.50	1.71	-	1.54
24	1.55	-	1.76	1.64	1.65
30	1.33	1.36	1.46	1.51	1.42
36	1.35	1.36	1.42	1.44	1.39
48	-	1.30	1.45	1.30	1.35
60	1.45	1.46	1.31	1.22	1.36

The movement of water through a soil must take place through the soil pore space. This is brought about by the action of gravity or capillary pull. Theoretically the rain water moves downward in the soil profile as each layer reaches a moisture content above field capacity. As the moisture equivalent gives a fairly reliable measurement of the field capacity, it has been used to calculate the inches of water held by the various soil layers against the force of gravity (Table 7). This could be classed as the permanent storage space of the soil while the non-capillary pore space could be classed as the temporary storage space of the soil.

The inches of water held by the plow layer is

Table 7. The Water Held at Field Capacity in the Soil Profile.

Depth in inches	Inches of water for each soil layer		
	Alfalfa	Oats	Grass
0- 3	0.55	0.48	0.57
3- 6	0.53	0.41	0.57
6-12	1.05	0.75	0.99
12-18	1.05	0.83	0.84
18-24	1.14	0.93	0.72
24-30	1.03	0.80	0.44
30-36	0.76	0.51	0.30
36-42	0.75	0.52	0.30
42-48	0.73	0.50	0.29
48-54	0.73	0.50	0.29
54-60	0.42	0.40	0.29
Total	8.74	6.63	5.60

high due to the accumulation of organic matter even though the volume weight is low. The 18 and 24 inch layers in the alfalfa and oats profiles are high due to the accumulation of colloidal material plus the fact that there is a high volume weight.

The soil under the alfalfa has the most total storage of the three profiles. The soil under oats is next in total storage but down to the 18 inch depth it has the least. The storage space of the top soil is most important in controlling runoff as well as supplying moisture to plants.

The inches of water held by the soil profile at the wilting percentage was calculated (Table 8).

Table 8. The Water Held at the Wilting Percentage in the Soil Profile.

Depth in inches	Inches of water for each soil layer		
	Alfalfa	Oats	Grass
0- 3	0.05	0.04	0.05
3- 6	0.05	0.04	0.05
6-12	0.10	0.07	0.08
12-18	0.09	0.09	0.07
18-24	0.11	0.09	0.05
24-30	0.10	0.08	0.04
30-36	0.07	0.04	0.04
36-42	0.07	0.04	0.04
42-48	0.05	0.04	0.04
48-54	0.05	0.04	0.04
54-60	0.05	0.04	0.04
Total	0.79	0.61	0.54

Although these values are lower than the actual wilting percentages obtained by other methods they can be used to show certain relations.

The total inches of water available to plants in the soil profile under alfalfa is approximately 8 inches. The total 8 inches is more available to a cover such as alfalfa than it is to almost any other type of cover. The soil profile under oats has approximately 6 inches of available water but can only use about 2 inches because of its shallow rooting system.

The profile under grass has 5 inches of available

water and of this more than 2.5 to 3.0 inches can be used by the plants. The profiles under the three types of cover are entirely different as to the amount of water available to plants and the location of this water. The one under alfalfa is the best of the three studied, while the one under grass would be as good, if not better, than the one under oats for plant growth.

The Micromax Data

Schiff and Dreibelbis (8) have used the recording tensiometer to study moisture changes within soils from saturation to field capacity. To the author's knowledge this is the first and only published data where a recording instrument was used to study soil moisture changes.

It was believed that by using both the plaster and nylon blocks a continuous record could be had of all moisture changes within the soil from saturation to almost the wilting point. This proved to be true only in part.

The Micromax's readings of ohms resistance on the block as compared to the Bouyoucos Bridge were abnormally high. The reason for this higher reading by the Micromax has not been found. When any standard resistance was connected to the Micromax or the bridge, identical readings were obtained by both instruments which was the same as the standard resistance. This is not true of either the nylon or plaster blocks. The Micromax always gives a higher reading than the bridge. The idea at first was that the length of the leads caused this variation. In order to test this, blocks were buried in soil in containers with long leads and short leads and the same results were obtained.

The high readings of the Micromax plus the fact that the nylon blocks in the sandy soil gave readings considerably higher than the plaster block caused all readings taken by the Micromax on the nylon units to be between 30,000 to 50,000 ohms even when the soil was at field capacity. The further use of the nylon units was discontinued which eliminated the study of moisture changes below field capacity.

The Micromax gave favorable readings on the plaster of paris block and showed the changes in soil moisture satisfactorily. All data on soil moisture changes used in this study were taken by the Micromax on the plaster of paris blocks.

At the same time the data on soil moisture changes was being taken readings were being made daily on the same blocks with the Bouyoucos Bridge. The double readings on the same block were used to set up a correction curve (Figure 6). All resistance readings taken by the Micromax and used in this study

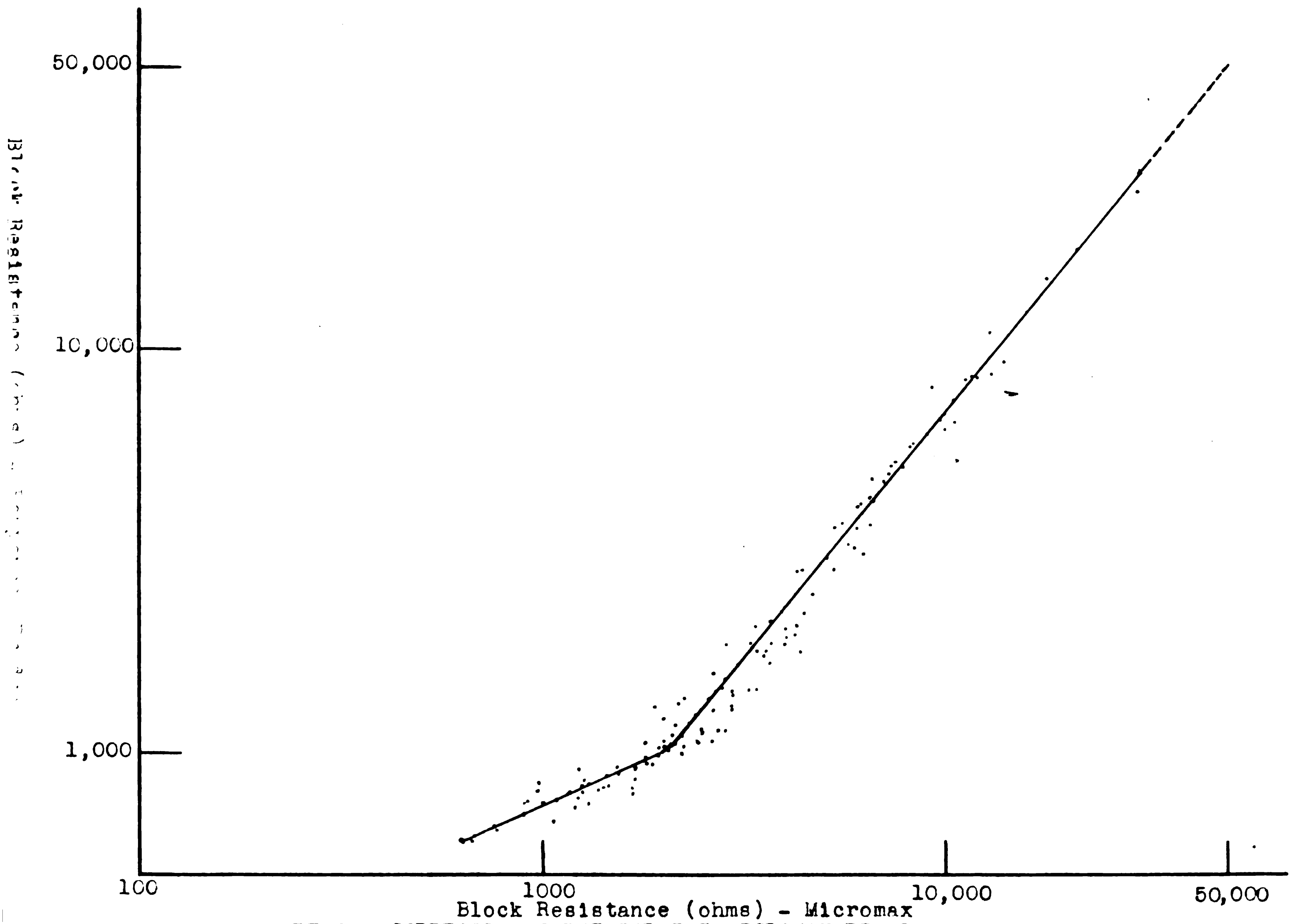

FIGURE 6. CORRECTION CURVE FOR THE MICROMAX READINGS TAKEN ON THE PLASTER OF PARIS BLOCKS

were corrected to the reading of the Bouyoucos Bridge with the aid of this curve.

A second correction was made on the data for temperature. All resistance readings were corrected to 60° F. with the aid of the calibration curves described and made by White (16) for use on the project. The temperature of the soil at various depths in the profile were taken daily. All readings taken by the Micromax for a day were corrected to 60° F. using the temperature of each soil depth for that day.

After these two corrections were made the resistances were converted to soil moisture, per cent by weight. The curves in Figure 7 were used for this conversion. The curves were calibrated on soils taken from the Metea profile under oats. The depths used were 3, 12, 24 and 36 inches.

The fourth and final conversion of the original resistance data taken with the Micromax, was per cent moisture by weight to inches of water per inch of soil. This was done by multiplying the volume weight of each depth by the per cent moisture by weight.

Data were collected for the summer and fall of 1949. From these data three storms, beginning on June 13, June 29 and July 7, were selected and analyzed. During the rest of the summer and fall the soil became

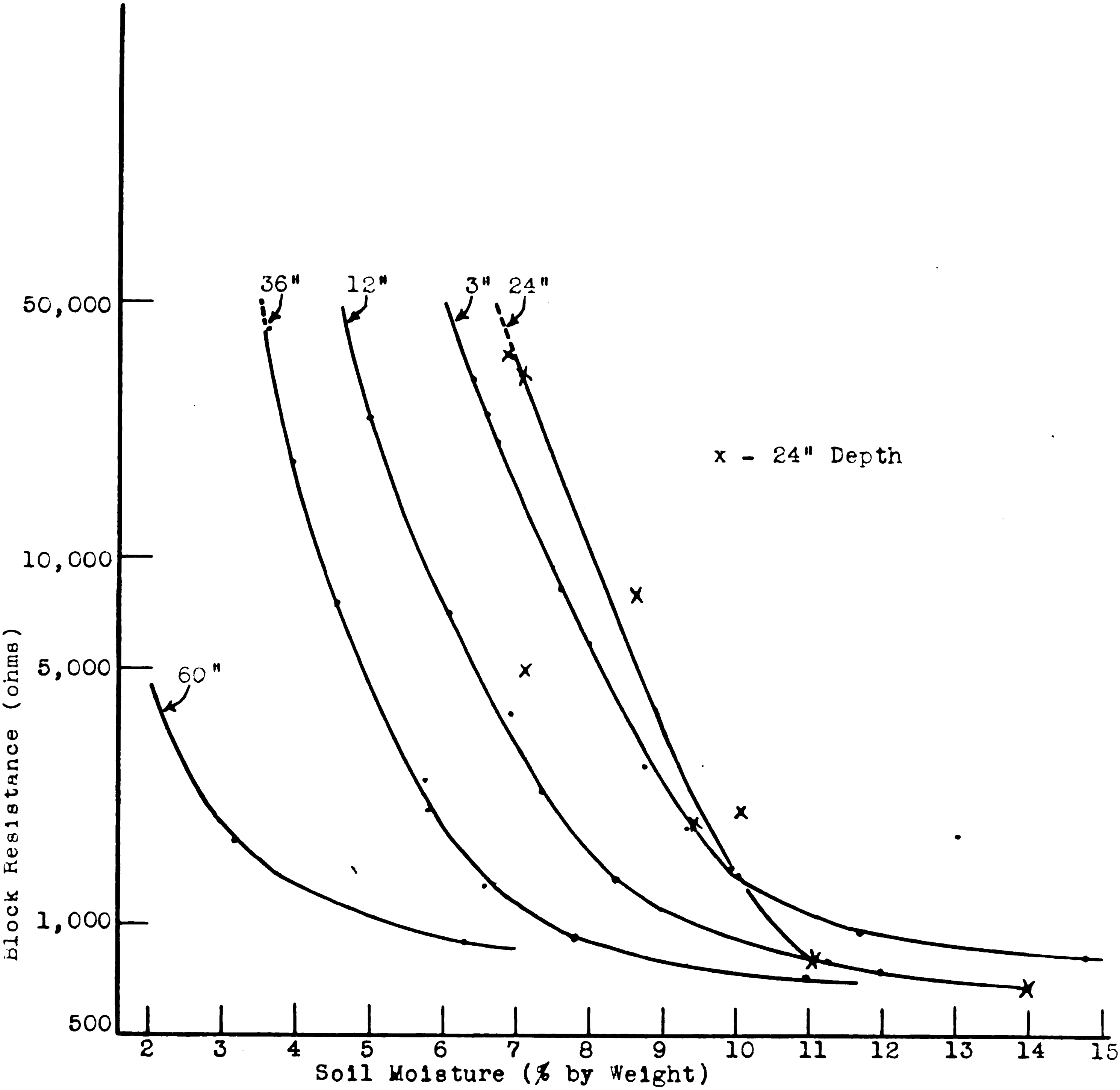

FIGURE 7

BLOCK RESISTANCE - SOIL MOISTURE CURVES
AT DIFFERENT DEPTHS IN THE SOIL PROFILE

very dry and the rainfall came in such small amounts that changes in soil moisture were too small to analyze. The soil was at field capacity for the storm of July 7, therefore, the blocks did not record moisture changes so further study could not be made on this storm. The other two storms were used to study infiltration, percolation and transmission rates of soils under different types of cover.

Infiltration Rate and Capacity

Total infiltration for any period of rainfall is the amount of water absorbed by the soil mass. This is equal to the inches of rainfall minus the inches of runoff and inches of interception storage (rain water held by the plants on it's leaves and stems). The infiltraion rate is a function of the inches of rainfall per hour. When the infiltration becomes a function of the soil it is called infiltration capacity.

The storm on June 29, 1949 was the only storm during the period of this investigation which had high enough intensity and inches of rainfall to produce runoff on both watersheds "A" and "B". Soils in both watersheds were at or a little below field capacity. The rain before this was on the 25th of June with 0.46 inches of rainfall. The first period of rain lasted for 11 minutes with 0.23 inches of rainfall. This was counted as interception storage, water collected on the surface of plants, although a trace of runoff was indicated on the chart for Watershed "B".

The data in Table 9 is for Watershed "A".

Table 9. Analyses of Data for the Storm of June 29, 1949.

Precipitation*			Alfalfa							
Time		Amt	in-ten-sity	Runoff From		To		Amt	Total infil-tra-tion	Infil-tra-tion rate	Infil-tration capa-city
h	m	in	in/hr	h	m	h	m		in	in/hr	in/hr
14	00	.00						0	0.00		
14	11	.23**	1.28					0	0.00		
14	18	.00	0.00					0	0.00		
14	24	.12	1.20					0	0.12	1.20	
14	30	.03	0.30					0	0.15	0.30	
14	40	.03	0.18					0	0.18	0.18	
14	45	.28	3.36	14	42	14	45	T	0.46	3.36	3.36
14	52	.35	3.00	14	45	14	52	T	0.81	3.00	3.00
14	58	.25	2.50	14	52	14	58	T	1.06	2.50	2.50
15	12	.15	0.65	14	58	15	12	T	1.21	0.65	0.65
15	26	.11	0.47					0	1.32	0.47	
17	12	.35	0.21					0	1.67	0.21	

* Previous precipitation 4 days
** Interception storage

The total rainfall for this period was 1.90 inches, of this, 1.67 inches infiltrated into the soil. The only loss was 0.23 inches lost by being evaporated from the plant surfaces and less than 0.01 inch for runoff. The infiltration capacity started out at 3.36 inches per hour for a period of 5 minutes. By this time the surface soil was saturated and the capacity was lowered to 3.00 inches per hour. This capacity lasted for 7 minutes. As the pore spaces filled up in the top soil the infiltration became less until it reached a capacity of 0.65 inches. This capacity may be low due to the time lag between rainfall causing runoff and the recording of this runoff. The higher infiltration capacity was possible only as long as the soil had temperary storage space in the non-capillary pores of the top soil. After these were filled the infiltration capacity was controlled by the rate at which the water will move through the subsoil.

The data in Table 10 is for the same period of rainfall only for Watershed "B" which is planted to oats. From the total rainfall of 1.90 inches only 1.35 inches infiltrated into the soil. The loss was 0.23 inches for interception storage and 0.32 inches of runoff. This was a total loss of 0.55 inches of water. The trace of runoff (.0001 inches) from 1400 to 1430 o'clock was disregarded as a measurement of infiltration capacity because of the high capacity at 1440. The infiltration capacity on Watershed "B" was the same as Watershed "A" for the first 5 minutes.

However, it decreases more rapidly and reached a low rate of 0.32 inches per hour.

Table 10. Analyses of Data for the Storm of June 29, 1949.

Precipitation*			Oats						
			Runoff						
Time	Amt	in-ten-sity	From	To	Amt	Total infil-tra-tion	Infil-tra-tion rate	Infil-tration capa-city
h m	in	in/hr	h m	h m		in	in/hr	in/hr
14 00	.00	0.00			0	0.00		
14 11	.23**	1.28	14 09	14 11	T	0.00		
14 18	.00	0.00	14 11	14 16	T	0.00		
14 24	.12	1.20	14 22	14 24	T	0.12	1.20	
14 30	.03	0.30	14 24	14 28	T	0.15	0.30	
14 40	.03	0.18			0	0.18	0.18	
14 45	.28	3.36	14 42	14 45	T	0.46	3.36	3.36
14 52	.35	3.00	14 45	14 42	.09	0.72	2.23	2.23
14 58	.25	2.50	14 52	14 48	.12	0.86	1.30	1.30
15 12	.15	0.65						
15 26	.11	0.47	14 48	15 26	.11	1.01	0.32	0.32
17 12	.35	0.21			0	1.35	0.21	

* Previous precipitation 4 days
** Interception storage

Watershed "B" lost 0.32 inches more water than did Watershed "A". It lost through runoff 17 per cent of the 1.90 inches of rainfall. The reason for this loss is partly shown in Table 4 in the proportion of non-capillary pore space under the oats as compared to alfalfa which has almost twice as high a per cent of non-capillary pore space. The alfalfa profile had more room to store the water than did the oats. The fact that Watershed "B" has a higher average weighted slope than Watershed "A" would not necessarily have any affect on the infiltration capacity of the soil.

Infiltration could not be studied on the grass areas because there is no installation for measuring runoff.

Transmission Rates

The permeability of a soil controls the rate at which water will move through it. Most permeability studies are concerned with percolation rates of soil-water. Schiff and Dreibelbis (14) have been interested in not only the percolation rate but also in transmission rates as a method to study moisture movements in the soil. Their method to determine these rates was a laboratory procedure using core samples.

With the Micromax giving a reading every 15 minutes on the same block, it was believed possible to measure transmission rates in the soil from the time it would take moisture to move from one block to the next. This would be possible to do whenever the water was not a limiting factor such as in the storm of June 29, 1949. The data for the transmission rates of soil under the three types of cover are presented in Table 11.

Table 11. Transmission Rates Within the Soil Profile Under the Three Types of Cover For the Storm of June 29, 1949.

Type of cover	Time	Accumulated infiltration	Depth soil moisture reached	Transmission rate for each increment	Transmission rate total depth
	h m	in	in	in/hr	in/hr
Alfalfa	14 00	0.00	0	0.0	
	14 18	0.00*	0	0.0	
	14 36	0.30	3	10.0	
	14 41	0.38	6	36.0	15.7
	15 11	1.38	12	12.0	13.7
Oats	14 00	0.00	0	0.0	
	14 18	0.00*	0	0.0	
	14 44	0.55	3	6.9	
	15 16	0.76	6	5.6	6.2
	17 20	1.50	12	2.9	4.0
Grass	14 00	0.00	0	0.0	
	14 18	0.00*	0	0.0	
	14 50	0.86	6	11.2	
	15 22	1.37	12	11.2	11.2

* Allowed for interception storage .23 inches of precipitation.

The high reading of 36.0 inches per hour, as compared to the other readings of 10.0 and 11.0 inches per hour, would seem to be in error. This is possible in that each time a reading is made a period of 15 minutes lapses before another reading is made on that block. So if the change in soil moisture were to reach the block the instant after a reading was made on that block there would be an error of 15 minutes. This could be corrected by connecting the same block to more than one station. In this way a reading could be made every 57 seconds if only one block was used.

The profile under grass had the same transmission rate for the surface soil as for the subsurface soil. The profile under alfalfa had the highest transmission rate. It was three and four times as high as the profile under oats. The lowest transmission rate was from the 6 to the 12 inch depth in the profile under oats. The low transmission rate of 2.9 for this study is not unusual for subsoils. Schiff and Dreibelbis (13) data show transmission rates for subsoils (7" to 14") as low as 0.25 inches per hour.

On Watershed "A" runoff started one minute after the water reached the 6 inch depth. On Watershed "B" runoff started two minutes before the water reached the three inch depth.

The runoff which occured on Watershed "B" was in part due to the low percentage of non-capillary pore space and also to the low transmission rates for both the topsoil and the subsoil.

Percolation Rates

Percolation rates of soils therorically can be studied only when soils are between field capacity and saturation. The percolation results of this study are contained in Table 12.

Table 12. Percolation Rates at Different Levels in the Soil Profile Under Alfalfa and Oats.

Time	Precip-itation	Percolation rates inches per hour					
		Alfalfa			Oats		
h m	in	3 in	6 in	12 in	3 in	6 in	12 in
June 13, 1949							
8 00	.04*						
17 00	.17						
21 00							
22 00	.16				.002		
23 00					.009		
24 00					.017		
June 14, 1949							
1 00					.008		
2 00		.001			.007		
3 00		.001			.004		
4 00	.22	.002			.004		
5 00	.03	.002			.034		
6 00		.011			***		
7 00		.013					
8 00		.005					
9 00		.005					
10 00		.006				.002	
11 00		.004				.001	
12 00		.007				.002	
13 00		.008				.004	
14 00	.26**	.007				.003	
15 00	.31**	.015				.003	
16 00		***	.002			.021	
17 00			.031			.033	

* Previous rainfall June 3, 1949
** Runoff on oats (T)
*** Soil too wet for plaster blocks

Table 12 (continued). Percolation Rates at Different Levels in the Soil Profile Under Alfalfa and Oats.

Time	Precip-itation	Percolation rates inches per hour					
		Alfalfa			Oats		
h m	in	3 in	6 in	12 in	3 in	6 in	12 in
18 00			.043			.020	
19 00			.032			.015	.001
20 00			***			***	.001
21 00							.001
22 00							.001
23 00							.001
24 00							.001
June 15, 1949							
1 00							.001
2 00							.001
3 00							.001
4 00	.04						.001
5 00							.001
6 00	.04						.001
7 00	.06						.001
8 00	.31**						.002
9 00	.46**						.001
10 00				.001			.002
11 00				.001			.001
12 00				.001			.014
13 00				.014			.017
14 00				.024			.020
15 00				.024			.006
16 00				.014			***
17 00				.014			
18 00				***			

** Runoff on oats (T and .04)

The data for these results were taken with the plaster of paris blocks and so can only show a part of the percolation which took place in the soil profile for the storm on June 13, 14 and 15, 1949. This was the only period during the summer and fall in which part of the soil profile was below field capacity and then re-wet to field capacity.

On May 13, 1949 at 8:00 A.M. the first rain of .04 inches occurred. This was intercepted by the plant. The next rain of .17 inches reached the 3 inch depth in the profile under oats. The next rain of .16 inches just reached the 3 inch depth under alfalfa. The profile under the alfalfa required the greater amount of water to change the soil back to field capacity. Runoff occurred at two different times on the oats. Both times were after the water had reached the six inch level. The first runoff on June 14 was caused by a downpour with an intensity of 1.80 inches per hour. The transmission rates of the soil between 3 and 6 inches was not high enough to move the water from the surface layer. The second rain that caused runoff June 15 on the oats had an intensity of 1.20 inches per hour. This runoff was caused by the still lower transmission rate from 6 to 12 inches.

The rains on June 13, 14, 15 percolated water passed the 12 inch depth but never reached the 24 inch depth. Other rains later on reached the 24 inch depth. The per cent of rain water that percolates through the soil profile down to the 24 inch depth is very small during the summer months.

The rate at which water will percolate through a soil depends on the kind of soil, its state of packing and the moisture content (1). The percolation will increase as the moisture content increases and decrease with the size of the soil pore. This will be at a maximum when the soil is saturated and decrease to a minimum at field capacity.

The three inch depth under oats (Table 12) started to change in moisture content before the alfalfa because the soil under oats was more firmly packed due to tillage operations in preparing a seed bed also the soil had a lower moisture equivalent, with a higher moisture content at the time of rainfall. The percolation was slow at the 3 inch depth for both profiles because the soil moisture was nearer field capacity than saturation. The percolation rate at the 6 inch depth was higher because the soil moisture was nearer saturation than field capacity due to the high amount of rainfall at 14:00 and 15:00 hours on June 14. The percolation rate at the 12 inch depth under oats was slow because the soil between 6 and 12 inches was near field capacity. However, after the high rainfall at 8:00 and 9:00 on June 15, the soil moisture increased and so did the percolation rates at the 12 inch depths under both the alfalfa and oat covers. The percolation rates were a function of the rainfall in the alfalfa area. However, for two periods of rainfall in the oats area the percolation rates were a function of the transmission rates of the soil.

A general discussion of this storm combined with other data gathered would be of value in bringing together some of the points discussed in various parts of the paper.

The data from Tables 13 and 14 were plotted graphically in Figure 8 along with the moisture content of the soil before the storm on June 13, 1949. This

Table 13. The Water Held Per Unit Depth at Field Capacity.

Inch layer at	Inches of water per inch layer of soil at each depth.		
	Alfalfa	Oats	Grass
3	.184	.162	.192
6	.176	.113	.194
12	.172	.137	.140
18	.178	.141	.140
24	.215	.183	.094
30	.127	.083	.051
36	.125	.087	.050
48	.121	.084	.048
60	.070	.066	.049

Table 14. The Water Held Per Unit Depth at Wilting Percentage.

Inch layer at	Inches of water per inch layer of soil each depth.		
	Alfalfa	Oats	Grass
3	.018	.014	.017
6	.018	.010	.017
12	.014	.014	.011
18	.015	.015	.011
24	.022	.019	.006
30	.011	.007	.006
36	.011	.007	.006
48	.008	.007	.006
60	.008	.007	.006

figure gives a profile characterization of the wilting percentage, field capacity, and distribution of the soil moisture within the soil profile.

The moisture relations of the three profiles under the three types of cover have marked variations (Figure 8). From the standpoint of available water to plants the profile under alfalfa is by far the most desired. It has more inches of available water throughout the profile giving deep rooted plants such as alfalfa more water in times of drought.

If all three profiles had the same moisture content the profile under alfalfa would have about the same initial infiltration. This was found to be true earlier in this paper (Tables 9 and 10). However,

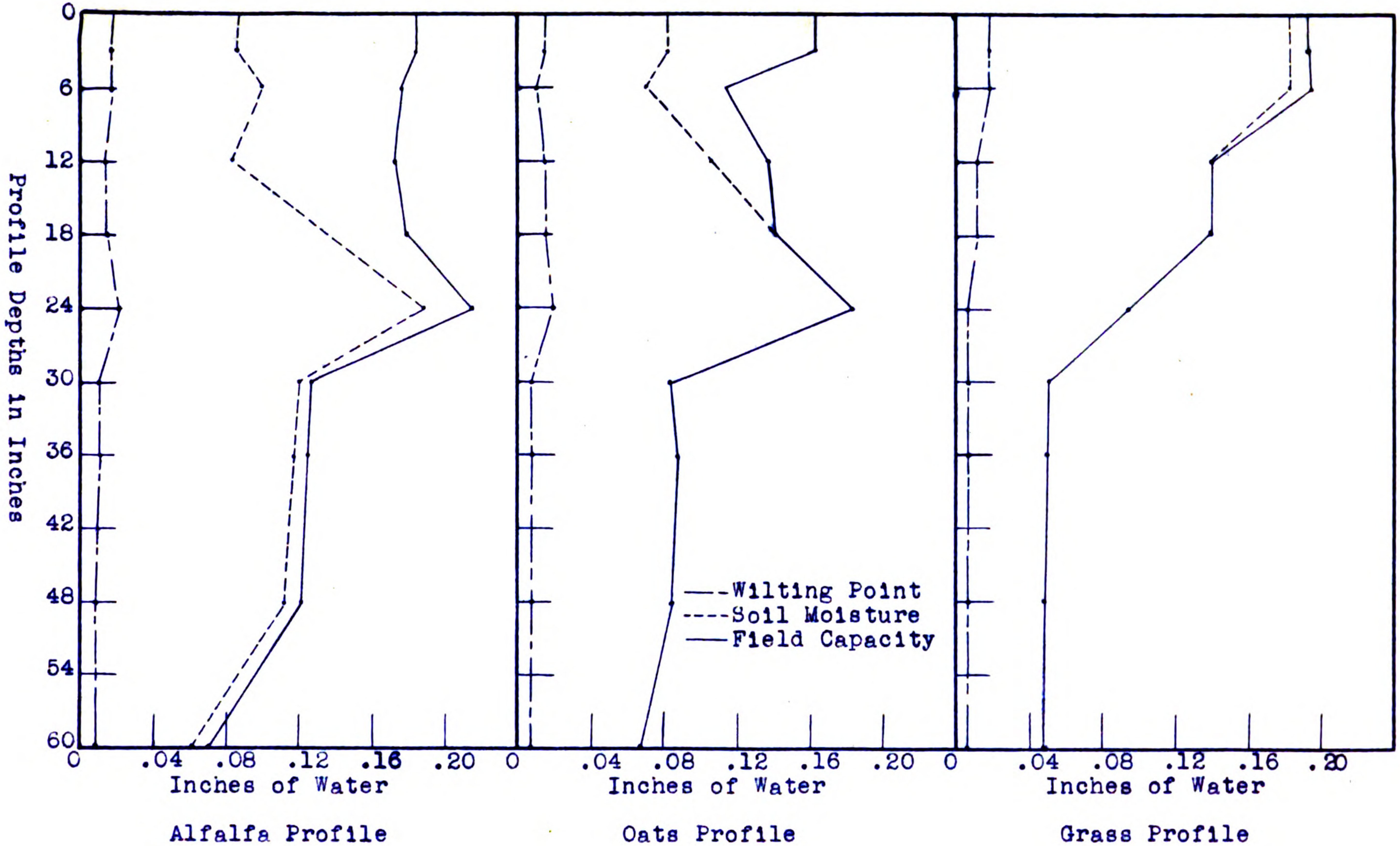

FIGURE 8

THE INCHES OF WATER HELD IN THE SOIL PROFILE BEFORE THE STORM OF JUNE 13, 1949
AS COMPARED TO THE INCHES HELD AT FIELD CAPACITY AND WILTING PERCENTAGE

after the first few minutes of rainfall the infiltration capacity under oats decreased sharply due to the bottleneck at the 6 inch depth. The area under grass, if at the same moisture content, would have remained longer at a high infiltration capacity as did the area under alfalfa.

The soil profile under oats is better for crop production than is that under grass because of the retensive layer at the 18 to 24 inches. However, the grass area under long periods of rainfall would have less water losses due to runoff than either of the other two areas. The water could percolate through the soil mass to subsurface drainage ways faster without a heavy clay layer to pass through in its downward movement.

The moisture content of the soil profiles on June 13, 1949 was markedly different. The alfalfa had already been established and so had considerable growth at the time of this dry period. The oats were half grown while the grass had been clipped short several times during the spring.

The alfalfa had taken up over half of the water in the 0 to 12 inch layer plus varying amounts throughout the profile. The oats had used over half of the water in the 0 to 6 inch layer and had drawn on water down to the 18 inch depth. The grass area had used only small amounts of water from the 0 to 12 inch layer. The clipping had reduced the amounts of water used by grass as compared to grass allowed to grow normally. Daniels(8) also found that continual clipping decreased the amount of moisture used by grass areas.

If all the factors except moisture were constant the initial infiltration for a given period of time would be the lowest on the grass area and the highest on the alfalfa with the oats being almost the same as the alfalfa. In Table 4 it was shown that the surface soil under oats had a very low non-capillary porosity. This would lower the initial infiltration under oats. The alfalfa would have higher infiltration capacity for a longer period of time than either the oats or grass areas. The differences between alfalfa and oats were shown in Tables 9, 10 and 12.

The alfalfa had the least water loss due to runoff because of a more favorable balance of factors which control the water losses from the soil such as a higher infiltration capacity due to a wider range in the moisture content and field capacity and a higher per cent non-capillary porosity. The higher transmission rates of the soil also decreased the water loss.

SUMMARY AND CONCLUSIONS

This investigation was primarily interested in studying the movement of rainwater into and through the soil profiles under three types of cover:alfalfa, oats and grass.

The entire investigation was conducted at the Michigan Hydrologic Research Project. Data were collected on two cultivated watersheds and a permanent blue grass area.

The method used in recording soil moisture changes, on the moisture blocks developed by Bouyoucos, is entirely new. A Micromax that records ohms resistance on 16 different units every 15 minutes was connected to a network of moisture blocks. These blocks, one set of plaster and one set of nylon, were buried at different depths in the soil profile under alfalfa, oats and grass.

The results from this method were not entirely satisfactory. The resistance readings, taken by the Micromax, on the nylon units were out of the Micromax range when the soil was at field capacity. The phase of the experiment using nylon blocks was discontinued. However, the resistance readings taken by the Micromax on the plaster units was of value in studying moisture changes in the soil, even though a correction was necessary to bring the resistance reading in line with the Bouyoucos Bridge. This instrument would be valuable in measuring infiltration, percolation and transmission rates in soils if it could be set up to measure soil moisture from saturation to field capacity.

In calibrating the apparatus with the soil fairly smooth curves were obtained by placing the imbedded block, soil and pan in a moist container for a period of time before determining the soil moisture and the resistance.

The physical properties of the soil under the three types of cover are widely different. The soil under the oat cover varied the most in the surface layer with a very low non-capillary porosity, moisture equivalent and wilting point.

The soils varied considerably in the inches of water held in the profile at the moisture equivalent. The profile under alfalfa was the highest with 8.74 inches while under oats it was 6.63 inches and under grass was the lowest with 5.60 inches. The grass, however, held more in the surface soil than either one of the other profiles.

The differences in infiltration capacity and transmission rates of the soil under each type of cover would indicate the difference in physical properties of the soil. This difference is partially due to the immediate management practices in each area.

The infiltration capacity was determined on areas in alfalfa and oats by the time and amount of rainfall minus the runoff. The alfalfa and oats had the same infiltration capacity for the first five minutes of 3.36 inches per hour. The infiltration capacity in the soil under oats decreased much faster and reached a low of 0.32 inches per hour while the low for the soil under alfalfa was 0.65 inches per hour. The area in oats lost 17 per cent of the rainfall in runoff while the area in alfalfa only lost a trace due to runoff.

The slopes were not the cause of the water loss on the oat area. The main causes were the lack of storage space for the excess water not taken up by the soil and the slowness at which this water moved through the profile.

The temporary storage space of its surface layer was decreased in the area under oats. This was due to tillage practices before the planting of oats and the packing caused by rain on a partially unprotected surface soil. The low moisture equivalent of the 0 to 6 inch layer under oats was caused by the erosion of the finer particles from the soil. This was also a factor in causing more loss from the area under oats.

The transmission rates of the two profiles under oats and alfalfa varied with depth while under grass it was the same from 0 to 12 inches. The profile under alfalfa had the highest rate for the 0 to 12 inches of 13.7 inches per hour while the grass area was next with 11.2 inches per hour. The oats area was the lowest with 4.0 inches per hour. This low transmission rate, as already stated, was one factor that caused far more runoff on oats than alfalfa. The deeper rooting system of the alfalfa plant seems to be the cause of the higher transmission rates.

Percolation rates were studied in the soil profile under oats and alfalfa at 3, 6 and 12 inch levels. The higher percolation rates from field capacity to saturation could not be determined because the plaster block only measured a little below field capacity. The highest rate found was .043 inches per hour under alfalfa at the 6 inch level.

In general, runoff is not caused entirely by high intensities and amounts of rainfall (except on bare ground where sealing takes place). Runoff occurs when the storage in the surface soil is filled and the non-capillary pores are full. That is, if the ground rainfall exceeds the percolation rate. The percolation rate at the top of the subsoil is controlled by the transmission rates of the subsoil. This many times can be increased by deep rooted crops or by mechanical methods.

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