SOME RELATIONSHIPS BETWEEN PERMEABILITY OF ST. CLAIR, MIAMI, HILLSDALE, AND COLOMA SOILS AND THE WATER AND SOIL LOSSES, UNDER DIFFERENT CROPPING AND TILLAGE PRACTICES

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Antonio Rezende

1951

This is to certify that the

thesis entitled

Some Relationships Between Permeability of
St. Clair, Miami, Hillsdale, and Coloma Soils and
the Water and Soil Losses under Different Cropping
and Tillage Practices

presented by

Antonio Rezende

has been accepted towards fulfillment
of the requirements for

Master of Science **degree in** Soil Science

L. M. Turk
Major professor

Date April 10, 1951

O-169

SOME RELATIONSHIPS BETWEEN PERMEABILITY OF ST. CLAIR, MIAMI, HILLSDALE, AND COLOMA SOILS AND THE WATER AND SOIL LOSSES, UNDER DIFFERENT CROPPING AND TILLAGE PRACTICES

By

ANTONIO REZENDE

A THESIS

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Soil Science

1951

THESIS

6/29/51
Gift

ACKNOWLEDGMENTS

The author expresses special thanks to Dr. E. P. Whiteside, who gave helpful guidance in the research work.

Thanks are extended to Dr. A. E. Erickson for assistance and counsel in the laboratory studies and to Mr. C. A. Engberg and Mr. J. E. McKittrick for their assistance in obtaining and interpreting records of the Soil Conservation Service.

For the way the Soil Science Department is conducted, providing ample opportunity to the students to learn as much as they can, the author is grateful to Dr. Lløyd M. Turk, Head of the Soil Science Department of Michigan State College.

TABLE OF CONTENTS

INTRODUCTION

Soil erosion is a function of climate; topography; the kind, vigor and density of the vegetation; and the nature of the soil and its condition.

These factors affecting soil erosion may be expressed in the equation: $E = f(C, T, V, S)$.

It is difficult to evaluate each of these factors exactly, because they are closely interrelated. When two or more types of soils are studied in order to estimate the influence of soil type on the degree of erosiveness, the intensity, the amount, and the distribution of rainfall may not be similar, for two or more areas where the experiments are located. Even the organic matter content, the previous vegetation, and the management of these soil types (type, time, and frequency of tillages received) are sub-factors that make it difficult to evaluate the conditions of the soil types, when they are compared so far as erosion is concerned.

There is no doubt that man has a very important influence on erosion, because all the other factors may have less effect on soil erosion if the land is wisely managed. Under certain conditions, climate may be modified by irrigation that may affect soil cover, and in turn may reduce runoff. The planting, and the cultivation time may lessen the effect of climate on erosion.

Topography cannot be changed as the farmer would like, but a wise distribution of land use, through the choice of crops and the possibilities of efficient use of erosion control practices, can reduce water and soil losses.

These variables result in higher or lower infiltration, and more compact or looser soils. If other factors are equal, a higher soil infiltration capacity will result in less soil erosion than lower infiltration capacity. All factors being equal, a looser soil will be more eroded than a more compact one.

It is erroneous to apply the same mechanical measures for surface runoff and erosion control to both permeable and impermeable soils. The rate of infiltration of a soil and the conditions that affect it are important in evaluating the amount of water impounded before designing erosion control measures such as terracing, contour cropping, and strip cropping.

The use of as many grass and legume crops as possible is needed to improve the soil's fertility and its permeability or water holding capacity. The better effect of grass and legume meadows, compared to row crops, on the soil is immediate and lasting due to the greater water impoundage capacity, resulting from the improved physical properties.

Based on both the infiltration and the impoundage of water, the land use planner is able to determine the best space between two terraces or two strips of close growing plants.

For economical reasons, in some climatic zones of the world, the farmers cannot practice crop rotation as advisable. In these areas some of the most erosion conducive crops are the most economical to grow. Because of this fact, the farmers must become aware of the harmful effect of soil erosion and take steps toward diversifying his system of cropping. Unless the farmers can evaluate the damage of soil erosion and the effect of different crops on water and soil losses, they will not realize that a smaller income in one year may result in a larger income in the near future, due to a crop rotation system.

In this investigation, the author studied some relationships between permeability of Saint Clair, Miami, Hillsdale, and Coloma soils and the water and soil losses, under different cropping and tillage practices.

Because of the complexity of the matter, there were not sufficient experimental records to support a better discussion of the author's research work. However some conclusions were drawn and the research work will be useful as a background for further investigations on the same matter in the author's research on Brazilian soils.

REVIEW OF LITERATURE

The Climatic Factor of Erosion

It has been shown (5, 17) that the amount and the distribution of annual precipitation greatly influence water and soil losses. A regular distribution of precipitation may cause little or no runoff, while concentration of precipitation in a short period of time generally results in large water and soil losses.

A thick cover of snow over a frozen soil, when the thawing temperature comes may result in large water and soil losses. The losses will be greater if the thawing temperatures are accompanied by heavy rain.

The seasonal temperature affecting the growth of plants, the organic matter content of the soil, and the soil freezing in cold areas play an important role in soil erosion.

Soils in the Southeastern part of the United States are subject to greater soil and water losses annually because the ground is seldom frozen, nearly all precipitation falls as rain, the rains are more intense than in the Northern part (5, 17).

The Topographic Factor

The degree of slope has been shown as very important in soil loss, but has little effect on percentage of runoff (3).

The effect of the percentage of slope (S) on erosion (E) was shown by Borst *et al.* (6) to vary with the soil type and its moisture content: In dry Wooster silt loam, for four and one-half inches of rainfall per hour, the erosion was equal to $3.73S^{1.48}$. When wet, $E = 4.53S^{1.58}$. For Muskingum silt loam, when dry, $E = 4.84S^{1.30}$ and, when wet, $E = 8.23S^{1.22}$.

Investigation has shown that erosion varies uniformly with slope up to 12% slope. Above 12%, the rate of erosion increases very rapidly (6). Under some conditions, greater slope has been found to increase rather uniformly the amount of runoff. The percentage of slope has its influence on erosion affected by the rainfall intensity, as shown by Borst *et al.* (6). The character of the soil affects more its erodibility than does the slope (18). On longer slopes, the soil loss is greater than on shorter ones, but the percentage of runoff is less for longer slope, as shown by Musgrave and Norton (28).

Vegetation

The type and amount of vegetation is probably the most important single factor influencing runoff and erosion (6). Soil losses have been negligible and runoff has been materially reduced with good pasture sods and meadow crops, regardless of steepness and length of slope (5, 6).

Studies have shown (11, 28) that the presence of vegetation itself is not a dominant factor in increasing the infiltration capacity, per se. The effect of vegetation in reducing runoff is more one of decreasing the movement of surface water, and allowing more time for infiltration. Musgrave (27) suggested the relationship: Rainfall - infiltration = runoff + retention.

It is generally agreed (15, 19, 29) that the dense mat of roots produced by grass sod promotes granulation and good soil structure, while cultivation usually brings about the opposite effect.

Yoder (35) observed that cover crops act by filtering out or holding in place large quantities of coarser separates, or large water stable aggregates. The effectiveness of cover crops in reducing sheet erosion is also due to a reduction in mechanical dispersion by beating rain, reduction of the amount, velocity, and the transporting power of the runoff.

The conclusion of Yoder in relation to strip cropping as a measure of control of erosion is that this practice must be used to support terracing rather than to replace it. Soil is sheet eroded in the non-protective strip and deposited in the close growing strips, but part of the water runs on downslope.

The longer the time a soil remains covered by a dense vegetation which possesses abundance of roots, more protected will be the soil against water and soil losses, because the roots act as soil binders themselves and when decomposed they will leave passageways for water infiltration; and the decaying organic matter will be a soil binding material as organic colloids (5).

Baver (3) classifies the major effects of vegetation on soil erosion into five categories:

(1) interception of rainfall by the vegetative canopy;

(2) the decreasing of the velocity of runoff and the cutting action of water;

(3) the root effects in increasing granulation and porosity;

(4) biological activities associated with vegetative growth and their influence on soil porosity;

(5) the transpiration of water leading to the drying out of the soil.

The Soil Factor of Erosion

So far as susceptibility to erosion is concerned, it seems that the most important single quality inherent in a soil is its dispersion ratio or the readiness with which individual particles go into suspension in water (1).

Middleton (25) conducted a series of determinations on physical and chemical properties of soils to find their effects on soil erosion. He found as more important properties the dispersion ratio, the ratio of colloid to moisture equivalent, and the erosion ratio.

Bouyoucos (7), studied the effect of the clay ratio (the sum of sand and silt percentages divided by the percentage of clay) on erosion rates of several soil types. He concluded that the clay ratio is a good indication of soil erodibility. Usually the greater the clay ratio, the greater the erosion ratio, which is

$$\frac{\text{dispersion ratio}}{\text{ratio of colloid to moisture equivalent}},$$

and more erosive the soil.

Lutz (22) found that Davidson clay soil has a higher degree of flocculation of the colloidal fraction into large and stable aggregates, while Iredell sandy clay loam is more erodible due to its ease of dispersion and low state of aggregation.

It has been shown (17) that erodibility of a soil is greatly influenced by the stability of aggregates and this stability is affected by the binding force of the colloid it contains.

Many investigators (3, 5, 14) have shown the influence of soil permeability (the velocity of water flow through the pore spaces) on its infiltration capacity, which is the downward flow into the surface soil.

The gravitational water movement is many times hindered by impermeable subsoil layers, which trap air as well as water, but this movement is facilitated by the penetration of worms and the activity of other animals, and by the decay of roots, all of which leave passageways (3, 19).

The permeability due to gravitational forces in natural soils has been shown to be a function of the size, the amount and the continuity of the non-capillary pores, which are determined mainly by soil texture, structure, shrinkage or swelling, and biological channels (3).

The percolation and aeration in soils are more dependent upon the size rather than the amount of pore space, and not all soils, even those of same mechanical composition, have the same sized pores (20).

Slater and Byers (31) observed that the field passageways, such as root channels or structural cleavages, are more important than the character or volume of the pore spaces in determining the percolation rate.

It has been suggested (2, 10, 13, 30) that the differences in permeability of soils can be better understood on the basis of the relative amounts of capillary and non-capillary pores in the horizons of the profile. The large size of the non-capillary pores is most effective in the movement of water into and out of the soils.

Bouyoucos (8) determined the rate of infiltration into Nappanee silt loam A, Brookston silt loam A, Miami silt loam and Quartz sand, with 38, 25.5, 22 and 0 per cent of colloids, respectively. The time in minutes for 400 cc of water to pass through soil after initial percolation was 16.09, 18.61, 19.27 and 1.48 respectively.

Bouyoucos (8) observed that the dominant influence of coarse structure upon rapid percolation and good drainage can be entirely overcome by a very small amount of dispersed colloids, or other fine material, placed in certain positions.

Bauer (2) studying the percolation in various soils established the relation: Permeability (rate of percolation) = $f\left[\frac{\text{amount of large pores}}{\text{force necessary to displace water from the pores}}\right]$. This means that permeability varies directly with the content of large pores and indirectly with the force or tension required to drain these pores.

Non-capillary porosity is defined (2, 3) in terms of the size of pores that do not hold water tightly by capillary forces. Consequently, the tension under which a soil is drained may affect the non-capillary porosity (3), as in the following examples:

Soil	pF at flex point	Non-capillary porosity %	Percolation rate cc/10 minutes
Quartz sand (40-60) mesh	1.50	22.0	675
Quartz sand (20-40) mesh	1.25	22.0	1,216

For the same pF, 1.55, at the flex point, Genesee silt loam-1 gave non-capillary porosity of 14.7% and Iredell sandy loam-B gave 9.2%. The percolation rate in cc per 10 minutes was respectively 205 and 36. The rate of flow of liquids varies as the fourth power of the sizes of opening (12).

Lee (21) observed that porosity of earth materials in the absence of substantial amounts of clay depends principally upon the diversity of sizes of particles and may vary from 17 per cent to 45 per cent or more, while in clay or clayey material porosity depends largely upon the degree of consolidation, and may reach

90 per cent in the case of flocculated sedimentation from muddy fresh water streams discharging in salt water.

Baver (4) determined total pore space in core samples of different soils and found no large differences in the total porosity between different textured soils except as influenced by organic matter.

It is believed (10) that flocculation is a prerequisite for aggregation and hence for a good structure that allows easy infiltration.

Bennett (5) pointed out that coarse organic matter incorporated with a soil improves its structure, increases size and amount of non-capillary pores, and consequently the infiltration. He observed that muddy water closes the soil openings when it is not well aggregated.

Thorne and Peterson (32) believe that during the decomposition of organic matter, microbes synthesize a variety of gums, which when dried with the soil act as strong binding agents, holding the particles together in a water stable structure. The gum is decomposed by later microbial activity; hence the importance of adding organic matter to the soil frequently.

As discussed by Joffe (16), effective porosity, so far as soil permeability is concerned, is a function of mineralogical composition, organic matter, moisture, structure, biological activities, and position in profile.

The System of Cropping

Experiments at Ohio Agricultural Experiment Station have shown (29) that different plants and different rotations have different effects on soil aggregation and consequently on soil permeability. Among several rotations of crops, the best, so far as aggregation is concerned, was corn, oats, alfalfa-brome, alfalfa-brome, and next best was a corn, oats, alfalfa rotation. So far as air space porosity (non-capillary porosity) was concerned, through the year, in first place came corn, oats, alfalfa-brome, alfalfa-brome, and in second place corn, oats, alfalfa, alfalfa. Bluegrass continuously, and alfalfa continuously had higher non-capillary porosity than other crops or any rotation.

The rotations including grass and deep rooted legumes, as alfalfa or sweet clover, are more efficient in improving aggregation because the shallow rooted grass improves the aggregation in the surface soil, while a deep rooted legume increases aggregation in deeper layers. Continuous corn resulted in low percentage of aggregation, low air space porosity and low yields. This experiment showed that it is very important in the rotation to maintain a good balance between soil-exposing plants with soil-protecting plants, for the second group adds more organic matter to the soil and gives a higher infiltration capacity to the soil which results in less runoff and less erosion.

Experiments conducted in cooperation with 237 farmers at different locations in Iowa (9), from 1942 through 1944, gave an increase in average yields of 6.2 bushels per acre for corn grown on the contour compared with up and downhill cultivation. The average increase for soybeans in contoured fields was 2.2 bushels per acre.

Van Doren, Gard, and Kidder (33), in experiments at Dixon Spring, Illinois, obtained sixty per cent more soil loss in up and down cultivation compared with contour, for corn and oats. For soybean plots, the soil loss in up and down cultivation was 4.6 times the loss in contour. The increase in yields for contour compared with up and down was 2.4, 2.0, and 2.6 bushels per acre, respectively for corn, oats, and soybeans.

Musgrave (26) observed that a given treatment may be effective in preventing runoff on one soil and ineffective for another soil of similar composition. A treatment giving impoundage of one and one half surface inches of rainfall may prevent erosion in Marshall silt loam, but will not prevent erosion of Shelby silt loam, when a rain of rare duration and intensity occurs. The infiltration of Marshall is 7 to 10 times more rapid than that of Shelby.

It has been demonstrated (5) that the land use may conserve or destroy the fertility of a soil and that a wise distribution of crops and soil conserving practices in accordance with the land capability is a thrifty measure for the farmers individually, and collectively for their country.

Some Properties of the Soils Investigated

According to Veatch (34), St. Clair has medium organic matter content and medium fertility; Miami in general has relatively high fertility; Hillsdale is medium in fertility, and Coloma has medium to low fertility. According to several surveys, Miami has a medium content of organic matter and Hillsdale is in between Miami and Coloma, so far as the content of organic matter is concerned.

Lynd (23) reported a mechanical analysis of Coloma from Southern Michigan, showing only 6.5 per cent of particles less than 0.002 mm, and only 6.5 per cent of particles between 0.002 and 0.05 mm. This soil has a small percentage of water-stable aggregates, according to Lynd (23), and approximately 1.56 per cent of organic matter, and a low supply of available nutrients.

Mick (24) pointed out that the eluviated zones (A2) of St. Clair and Miami are relatively low in fine separates, particularly fine clay, and that the illuviated zones (B2) are relatively high in fine clay. The parent material textures are intermediate between A2 and B2. Mick observed that the fine clays have been produced and dispersed as a result of soil-forming processes, and that they were then transported downward, under favorable conditions of pore size distribution and drainage, to precipitate or flocculate in the B2 horizon.

SOILS INVESTIGATED

The St. Clair, Miami, Hillsdale and Coloma soils were chosen for investigation because they have developed from parent materials widely different in texture, on similar slopes, and there were runoff and erosion data from experimental plots located on these soils. Representative soil profiles were studied at each site in a pit dug for that purpose and each is described below. St. Clair profile, the one formed from the finest textured parent material, is described first and the Coloma soil, formed from the coarsest parent material, is described last. This order is followed in all subsequent discussions and tables.

Profile of St. Clair Silty Clay Loam

Locality:	Central Lapeer Soil Conservation District, Michigan.
Slope:	9%.
Horizon:	A1.
Depth:	0-6".
Properties:	Silty clay loam to clay loam. Grayish brown (10 YR 5/2)* mixed with some gray (10 YR 5/1). Fine granular to fine blocky. Aggregates from 3/8 to 3/4 of an inch in diameter.

---

* The color names and notations are those used in the Munsell Soil Color Charts, distributed by the Munsell Color Company, Inc., Baltimore 2, Maryland. All colors are for moist samples except the Miami profile which was air dry.

Horizon:	B1.
Depth:	6-10".
Properties:	Silty clay loam to silty clay. Dark grayish brown (10 YR 4/2.5 to 5/3) with some brown (10 YR 5/3) 10% and dark yellowish brown (10 YR 4/4) 20%. (Occasional sandy loam pockets at this depth were dark yellowish brown [10 YR 4/4]. This layer is from 6 to 16 inches deep on one side of the pit. Core samples were not taken of this material.) Coarse nuciform structure. Aggregates from 3/4 to 2 inches in diameter.
Horizon:	B2.
Depth:	10-17".
Properties:	Clay. Dark grayish brown (10 YR 4/2). Fine blocky structure.
Horizon:	C.
Depth:	17-23".
Properties:	Clay. Weak red to reddish brown (2.5 YR 4/3) with some lighter weak red (2.5 YR 5/2). Coarse blocky. Aggregates from 1/2 to 1-1/2 inches in diameter. Calcareous.
Horizon:	D1.
Depth:	23-26".
Properties:	Silty clay loam. Brown (10 YR 5/3) with about 30% of yellowish brown (10 YR 5/6). Massive structure (no particular cleavage). Calcareous.
Horizon:	D2.
Depth:	26-29".
Properties:	Sandy loam. Dark yellowish brown (10 YR 4/4). Non-calcareous.
Horizon:	D3.
Depth:	29"-.
Properties:	Clay loam. Reddish brown (5 YR 5/4). Calcareous.

The depth to the top of D Horizon varies from 23 to 32 inches in the pit. Some stones are present in all horizons.

Profile of Miami Sandy Loam (mapped as Miami loam)

Locality: Fenton Soil Conservation District, Michigan.

Slope: 7%.

Horizon: A1.
Depth: 0-6".
Properties: Sandy loam. Dark gray to dark grayish brown (10 YR 4/1.5). Weak platy structure.

Horizon: A2.
Depth: 6-10".
Properties: Sandy loam. Brown to yellowish brown (10 YR 5/3.5). Nuciform structure.

Horizon: B2.
Depth: 10-22".
Properties: Sandy clay loam. Yellow red (5 YR 5/6). Blocky Structure.

Horizon: C1.
Depth: 22-28".
Properties: Sandy clay loam. Dark brown (7.5 YR 4/2). Coarse blocky structure. Calcareous.

Horizon: C2.
Depth: 28"+.
Properties: Sandy clay loam. Grayish brown to brown (10 YR 5/2.5). Coarse blocky structure. Calcareous.

All horizons contain a few stones.

Profile of Hillsdale Sandy Loam

Locality: St. Joseph River Soil Conservation District, Michigan.

Slope: 6%.

Horizon: A1.
Depth: 0-8".
Properties: Sandy loam. Dark brown (10 YR 4/3). Weak fine to median granular structure, with aggregates from 1/16 to 1/4 of an inch in diameter.

Horizon: A2.
Depth: 8-12".
Properties: Fine sandy loam. Yellowish brown (10 YR 5/4), with a few dark reddish brown coatings (5 YR 3/2). Weakly developed coarse granular to fine nuciform structure, with aggregates from 1/4 to 1 inch in diameter.

Horizon: B1.
Depth: 12-19".
Properties: Fine sandy loam. Dark brown (7.5 YR 4/4). Poorly developed nuciform structure, with aggregates from 3/8 to 1-1/2 inches in diameter, and quite a few dark reddish coatings (5 YR 2/2).

Horizon: B2.
Depth: 19-37".
Properties: Sandy clay loam. Dark brown (7.5 YR 4/4) with brown (10 YR 5/3) coatings. Moderately developed nuciform structure, with aggregates from 1/2 to 1-1/2 inches in diameter.

Horizon: B3.
Depth: 37-48".
Properties: Sandy clay loam. Light brown (7.5 YR 6/4) with dark brown (7.5 YR 3/2) coatings. Weakly developed nuciform structure, with aggregates from 1/2 to 1-1/2 inches in diameter.

Horizon: C.
Depth: 48"+.
Properties: Sand, about 70%, yellowish brown (10 YR 5/4) and about 30% loamy sand, weakly cemented, dark brown (7.5 YR 4/4).

Some stones in all horizons.

Profile of Coloma Loamy Sand

Locality: St. Joseph River Soil Conservation District, Michigan.

Slope: 6%.

Horizon: A1.
Depth: 0-8".
Properties: Loamy sand. Dark grayish brown to dark brown (10 YR 4/2.5 to 5/3). Weak granular structure.

Horizon:	A2.
Depth:	8-18".
Properties:	Loamy sand. Yellowish brown (10 YR 5/4). Weak granular structure.

Horizon:	B1.
Depth:	18-25".
Properties:	Loamy sand. Strong brown (7.5 YR 5/6) with dark reddish brown (5 YR 2/2) coatings. Weak nuciform structure, with aggregates from 1/4 to 1 inch in diameter.

Horizon:	B2.
Depth:	25-38".
Properties:	Loamy sand. Strong brown (7.5 YR 4/6). Weak to very weak nuciform structure.

Horizon:	C.
Depth:	38"+.
Properties:	Sand. Strong brown (7.5 YR 5/6). Single grain structure.

Some stones in all horizons.

SOIL AND WATER LOSSES

Erosion Survey on St. Clair, Miami, Hillsdale and Coloma Soils

The Soil Conservation Service of the U. S. D. A. has made soil surveys on many farms in each of the above mentioned Districts. In those surveys, the soil erosion was classified into five classes as follows: (1) little or none; (2) slight; (3) moderate; (4) severe; and (5) very severe or destroyed land. The slopes were grouped into the following classes:

	Central Lapeer %	Fenton %	St. Joseph %
A	0-2	0-2	0-2
B	2-5	2-6	2-4
C	5-10	6-12	4-8
D	10-15	12-20	8-13
E	15-25	20-30	13-20
F	25-35	30 and over	20-30
G	35 and over		30 and over

Table I shows the acreages of the different erosion classes on B and C slopes of the cropland on the four soils studied in the different districts. The percentage of each erosion class on each slope is also tabulated.

TABLE I

ACREAGES OF EROSION CLASSES IN B AND C SLOPES IN CROPLAND AND TOTAL AREA, OF ST. CLAIR, MIAMI, HILLSDALE AND COLOMA IN CENTRAL LAPEER, FENTON, AND ST. JOSEPH SOIL CONSERVATION DISTRICTS, MICHIGAN**

Land Use	Soil Series	District	Erosion Class	B Slope Acres	B Slope %	C Slope Acres	C Slope %	Total of Class
Cropland	St. Clair	Central Lapeer	1	83.9	75.6	2.0	1.7	302.7
			2	27.0	24.4	98.0	84.3	156.9
			3	-	-	16.2	13.9	111.9
			Total	110.9	19.4*	116.2	20.3*	571.5
Cropland	Miami	Central Lapeer	1	301.0	58.0	11.6	4.1	664.9
			2	217.9	42.0	249.2	87.8	628.5
			3	-	-	23.1	8.1	163.3
			Total	518.9	35.6*	283.9	19.4*	1,456.7
Cropland	Miami	Fenton	1	11,140.0	50.1	125.0	2.0	16,268.0
			2	10,627.0	47.9	4,779.0	77.7	16,971.0
			3	407.0	1.8	1,217.0	19.7	3,631.0
			4	3.0	0.01	37.0	0.6	280.0
			5	-	-	-	-	17.0
			Total	22,177.0	59.6*	6,158.0	16.5*	37,167.0
Cropland	Hillsdale	Central Lapeer	1	208.5	77.5	26.3	16.0	535.1
			2	60.5	22.5	134.3	81.5	339.6
			3	-	-	4.2	2.5	113.3
			5	-	-	-	-	3.9
			Total	269.0	27.1*	164.8	16.6*	991.9
Cropland	Hillsdale	Fenton	1	532.0	36.8	23.0	5.5	774.0
			2	828.0	57.3	323.0	79.7	1,311.0
			3	84.0	5.8	60.0	14.8	218.0
			4	-	-	-	-	3.0
			Total	1,444.0	62.6*	406.0	17.6*	2,306.0
Cropland	Coloma	Fenton	1	181.0	56.5	50.0	45.0	287.0
			2	138.0	43.2	61.0	55.0	339.0
			3	1.0	0.2	-	-	9.0
			Total	320.0	50.3*	111.0	17.4*	635.0
Cropland	Coloma	St. Joseph	1	53.5	23.2	-	-	88.3
			2	126.8	55.1	62.8	58.8	288.2
			3	47.7	20.7	42.6	39.9	105.5
			4	2.2	0.9	1.4	1.3	8.5
			5	-	-	-	-	1.3
			Total	230.2	46.8*	106.8	21.7*	491.8
Orchard	Coloma	St. Joseph	1	57.5	20.8	2.1	2.3	127.0
			2	142.3	51.6	35.0	38.0	336.3
			3	75.5	27.4	54.4	59.1	141.1
			4	0.5	0.18	0.5	0.54	2.3
			5	0.2	0.07	-	-	0.2
			Total	276.0	45.47*	92.0	15.15*	606.9

* Percentage of total area (all slopes) in B or C slope.

** From records of the Soil Conservation Service, U. S. D. A.

It is apparent that erosion has been more active on the C slope than on B slope of all the soils, in all of the districts. In the Lapeer and Fenton districts, the percentage of 1 erosion on B slope relative to the percentage of 1 erosion on C slope decreases from the St. Clair to the Coloma soil, indicating that the effect of greater slope on erosion is greatest on the soils derived from heaviest textured parent materials and least on the soils derived from the coarsest textured tills. However, the erosion has been much greater on the Coloma soil in the St. Joseph River District than on the Coloma soil in the Fenton District.

The Orchards on Coloma soil in the St. Joseph River District are more eroded than the cropland on similar slopes. This difference in land use between these two districts accounts in part for the greater erosion in the St. Joseph River District, but the difference in judgment of the surveyors estimating the amount of erosion in the two areas may also be a factor.

Table I would be more significant if it were known how many years these soils were under cultivation, the cropping system, the crops raised, and other facts that certainly affected the degree of erosion on each slope class. The differences in percentage of slope, in Central Lapeer, Fenton and St. Joseph River Soil Conservation

Districts, for B and C classes, make more difficult the comparisons on the erodibility of these soils.

Data from Erosion Demonstration Plots*

Soil losses

Among the four soils studied, average annual soil losses increased from the St. Clair to the Coloma soil, as is evident from the comparison of Tables II, III and IV. This trend in soil loss on these soils is the reverse of the trend in the proportion of rainfall lost by runoff, discussed in the next section. Apparently, the easier detachment of the soil particles on the coarser textured soils permits the smaller amount of runoff water to cause more erosion on these soils than in the heavier textured soils. Wind is also probably more effective in eroding the sandier soils.

The short duration of the records of the soil losses on three of the four soils, the differences in the slopes, and the wide separation of the plots leave many doubts concerning the value of these figures, in estimating the relative erodibility of these soils. However, they do show that contour cultivation gave less erosion than up and down hill cultivation on each soil. Sod crops gave less erosion than corn on all plots. Oats were less effective than sod crops but usually more effective than corn, in decreasing soil losses.

---

* From records of Soil Conservation Service of U. S. D. A.

TABLE II

SOIL LOSS, IN TONS PER ACRE, ON ST. CLAIR SILT CLAY LOAM, ON A 9% SLOPE 72 FEET LONG, IN THE CENTRAL LAPEER SOIL CONSERVATION DISTRICT, FROM JUNE 15, 1944 TO DECEMBER 31, 1946, UNDER CROPS CULTIVATED UP AND DOWN THE SLOPE OR ON THE CONTOUR

Period	Up and Down			Contour		
	Corn	Oats	Meadow	Corn	Oats	Meadow
6/15 to 12/31 1944	1.20	0.25	0.075	0.25	0.12	0.075
1/1 to 12/31 1945	2.22	1.80	0.150	1.50	0.45	0.200
1/1 to 12/31 1946	4.00	2.42	0.380	1.06	2.42*	0.125
Annual Average	2.921	1.759	0.238	1.106	1.177	0.157

* Unexpected result: Higher loss in oats than corn on contour. This may be accounted for by a poor stand of oats in the contour plot in 1946.

TABLE III

SOIL LOSS, IN TONS PER ACRE, ON MIAMI SANDY LOAM, ON A 7% SLOPE 72 FEET LONG, ON THE BURTON STREET FARM, FENTON SOIL CONSERVATION DISTRICT, MICHIGAN, FROM APRIL 1, 1942 TO APRIL 1, 1949, UNDER CROPS CULTIVATED UP AND DOWN THE SLOPE OR ON THE CONTOUR

Year and Rainfall	Up and Down			Contour		
	Corn	Oats	Meadow	Corn	Oats	Meadow
42-43 28.65	6.55	2.20	0.030	1.95	0.075	0.013
43-44 29.22	3.95	4.62*	0.075	0.70	2.000*	0.075
44-45 18.45	1.75	0.10	0.050	0.10	0.075	0.050
45-46 38.28	6.05	2.15	0.100	1.35	0.050	0.050
46-47 23.40	3.05	1.47	0.150	0.60	0.700	0.100
47-48 33.53	1.40	1.50	0.150	0.10	0.050	0.150
48-49 36.84	7.25	2.350	0.400	3.59	0.500	0.020
Average	4.285	2.057	0.136	1.198	0.492	0.065

* Higher losses than in corn plots because the oats plots had little cover on the soil in May, 1943 (when the corn plots were still in sod, not plowed yet). A rainfall of 2.16 inches fell in one day, and 7.55 inches fell during that month.

TABLE IV

SOIL LOSS, IN TONS PER ACRE, ON HILLSDALE AND COLOMA SOILS, ON 6% SLOPE 72 FEET LONG, UNDER CORN, CULTIVATED UP AND DOWN THE SLOPE OR ON THE CONTOUR, AND SOD, FROM JUNE 1, 1938 TO JANUARY 1, 1941, IN ST. JOSEPH RIVER SOIL CONSERVATION DISTRICT, MICHIGAN

Soil	Total Loss			Annual Loss*		
	Up and Down	Con- tour	Sod	Up and Down	Con- tour	Sod
Hillsdale	55.0	24.0	0.0	21.29	9.29	0.0
Coloma	59.0	43.0	0.05	22.83	16.64	0.019

* Calculated considering thirty-one months, although a greater number of months when erosion is more severe have more weight. As a general practice, meadow and oats plots did not receive cultivation. The meadow was a mixture of red clover and smooth brome grass or timothy.

Water losses

Tables V, VI, VII and VIII give the water lost by runoff from the St. Clair, Miami, Hillsdale and Coloma soil plots, during short periods. More representative data were not available.

While these data are too scant and incomplete to warrant concise conclusions they indicate that the proportion of the rainfall lost as runoff from these soils when cropped to corn decreases from the Miami soil developed from moderately fine textured parent material to the

TABLE V

WATER LOST IN RUNOFF, AS PERCENTAGE OF RAINFALL, ON ST. CLAIR SILT CLAY LOAM, IN THE LAPEER SOIL CONSERVATION DISTRICT

Period	Up and Down			Contour		
	Corn	Oats	Meadow	Corn	Oats	Meadow
7/31 to 8/14 1945	10.8	5.9	2.7	5.4	2.7	5.4*
6/17 to 6/18 1946**	87.0	73.0	12.0	61.0	52.0	0.0

* Unexpected and unexplained result.
** 4.05 inches of rainfall.

TABLE VI

RUNOFF AS PERCENTAGE OF RAINFALL AND SOIL LOSS IN TONS PER ACRE, FROM MIAMI SANDY LOAM, ON A 7% SLOPE 72 FEET LONG, UNDER DIFFERENT CULTIVATION PRACTICES AND CROPS, IN THE FENTON SOIL CONSERVATION DISTRICT, MICHIGAN

	Up and Down			Contour	
	Corn	Oats	Meadow	Oats	Meadow
Runoff (I)	40.30	-	28.30	34.50	16.50
Soil Loss	12.80	-	0.05	3.40	0.04
Runoff (II)	53.08	38.10	-	35.60	15.20
Soil Loss	22.16	4.34	-	2.70	0.02

(I) From 4/2/39 to 3/29/40. Rainfall: 21.19".
(II) From 4/3/40 to 4/18/41. Rainfall: 23.04".
Corn was not cropped in contour at that time.

TABLE VII

RUNOFF IN PERCENTAGE OF RAINFALL FROM ST. JOSEPH RIVER SOIL CONSERVATION DISTRICT, MICHIGAN, ON 6% SLOPE OF HILLSDALE AND COLOMA SOILS, CROPPED TO CORN UP AND DOWN OR IN CONTOUR, AND SOD, FROM JUNE 1, 1938 TO JANUARY 1, 1941 (RAINFALL AND RUNOFF FOR FEBRUARY, MARCH, APRIL AND MAY, 1939, NOT MEASURED)

Soil	Total Rain-Fall	Up and Down	Contour	Sod
Hillsdale	66.19"	20.0	10.0	1.0
Coloma	65.99"	10.7	7.0	1.4

TABLE VIII

PERCENTAGE OF THE TOTAL RUNOFF AND TOTAL SOIL LOSS THAT OCCURRED IN JUNE, JULY, AUGUST AND SEPTEMBER OF 1938 AND 1939, FOR CONTOUR CULTIVATION PLOTS ON HILLSDALE AND COLOMA SOILS

Soil	June	July	August	September	Total
Hillsdale					
Runoff	42	13	23	7	86
Soil Loss	57	1	16	2	86
Coloma					
Runoff	42	2	50	1	93
Soil Loss	61	1	37	1	98

Coloma soil developed from coarse textured parent material. This trend is the same whether the corn was cultivated on the contour or up and down the slope. A similar trend is apparent on the sod and meadow plots with the exception of the sod on the Coloma soil, Table VII, which shows a little greater water loss than on the Hillsdale. Perhaps here the lower fertility and lower moisture holding capacity have resulted in a less vigorous growth of the sod cover than on the soils derived from heavier textured parent materials. The data on the runoff from the St. Clair soil are too sketchy to permit even tentative conclusions as to the runoff relative to the other soils. However, the projection of the above mentioned trends on water loss from the soils relative to the texture of the parent materials would lead one to expect the loss of greater proportions of the rainfall from the St. Clair soil than on the other soils under similar conditions, since it is derived from finer textured parent material.

The data on the effectiveness of the up and down hill or contour cultivation and different crops in controlling the water losses from these soils, Tables V, VI, VII, and VIII are undoubtedly much more reliable than the above relationships between the different soils. The plots on a given soil are grouped in a small area where the rainfall amounts and intensities would be more uniform and the data were obtained on all plots during the same period of time. Plots in corn cultivated up and down the slope lost larger proportions of the rainfall by runoff than plots in oats, or sod and meadow. Contour cultivation decreased the proportion of rainfall lost by runoff on the plots in both corn and oats. Sod or meadow crops were more effective than the corn or oats in decreasing the proportion of the rainfall lost by runoff.

Distribution of rainfall and relation to soil and water losses

Tables IX and X show the distribution of rainfall, its intensity, and the runoff and soil losses on Miami sandy loam, at Burton Street Farm, from April, 1939, to April, 1940, and from April 3, 1940, to April 18, 1941, respectively.

Table XI shows the monthly distribution of rainfall during two years, at these plots. Table XII gives the results of measurements on Hillsdale and Coloma soils during a rain on June 21, 1939, in the St. Joseph River Soil Conservation District of Michigan.

On the average, the heaviest monthly soil loss occurs in June, due to relatively high amounts and intensities of precipitation, combined with little soil

TABLE IX

DISTRIBUTION OF RUNOFF AND SOIL LOSS, ON MIAMI, ON A 7% SLOPE 72 FEET LONG, UNDER CORN, WITH UP AND DOWN CULTIVATION, FOR APRIL 1, 1939 TO APRIL 1, 1940

Date	Precipitation		Runoff		Soil Loss	
	Inches	Maximum Intensity 5 Minute Period Inches/Hour	Inches	Per Cent	Pounds	Tons Per Acre
April 2-6-7-8	0.17	-	-	-	-	-
11	0.98	0.36	*	*	*	*
15	0.49	-	-	-	-	-
17-18	1.13	0.60	0.25	22.1	-	-
19-20-22	0.46	-	-	-	-	-
May 9-10	1.81	2.40	0.18	9.9	0.29	0.01
16	0.04	-	-	-	-	-
20-21-22	0.24	-	-	-	-	-
27-28	0.20	-	-	-	-	-
June 8	2.34	4.08	1.35	57.7	96.04	4.80
10	0.52	-	-	-	-	-
11	0.88	3.60	0.82	58.6	35.63	1.78
10-16-20	0.24	-	-	-	-	-
22-23	0.79	1.56	0.35	44.3	18.28	0.91
29-30	1.04	3.08	0.50	65.0	49.95	2.50
July 4	0.60	1.20	0.23	38.3	10.46	0.52
August 9	0.62	2.64	0.16	25.8	7.60	0.38
14	0.63	1.92	0.27	42.9	14.74	0.74
September 5	1.00	2.40	0.57	57.0	15.68	0.78
13	0.72	0.48	0.13	18.1	1.40	0.07
October 11	0.61	0.96	0.16	26.2	1.90	0.09
25-31 & November 2-7	0.77	1.20	0.04	5.2	0.68	0.03
January 14	0.94	0.24	0.15	16.0	0.49	0.02
March 29	3.97**	1.20	3.38	85.1	2.62	0.13
Total	21.19		8.54	40.30	255.76	12.76

* 0.40 inches rain fell before it turned to snow, snowing 0.58 inches. The ground had lost all of its frost and was drying out. This condition allowed the rainfall to be absorbed. The slow melting of the following snow also allowed it to be absorbed by the ground.

** The runoff on March 29 came from an accumulation of snow and rain frozen in the ground.

TABLE X

DISTRIBUTION OF RUNOFF AND SOIL LOSS, ON MIAMI, ON A 7% SLOPE 72 FEET LONG, UNDER CORN, WITH UP AND DOWN CULTIVATION, FROM APRIL 3, 1940 TO APRIL 18, 1941

Date	Precipitation		Runoff		Soil Loss	
	Inches	Maximum Intensity 5 Minute Period Inches/Hour	Inches	Per Cent	Pounds	Tons Per Acre
April 3	0.24	low				
8	0.72	1.20				
23	0.39	0.36				
May 8	0.64	1.68				
22	0.52	0.60				
June 6	0.77	1.20				
13	2.54	4.32	1.46	57.5	60.44	3.02
26	1.75	2.16	0.62	35.4	8.99	0.45
28	0.77	1.20	0.02	3.2	0.66	0.03*
July 17	0.32	1.28	0.06	18.7	2.03	0.10
25	0.36	1.32	-	-	-	-
August 8	0.93	0.96	0.20	21.5	5.20	0.26
14	2.03	7.20	1.26	77.1	227.71	11.38
26	3.05	0.96	1.58	48.5	58.76	3.94
October 18	1.49	2.40	0.45	30.2	10.47	0.52
November 13	0.85	-	0.07	8.2	1.19	0.59
November 14 to January 3	2.32	-	2.52**	108.6	3.77	0.19
January 3 to April 18, 1941	3.35	-	3.68**	109.8	33.37	1.67
Total	23.04		11.92	51.73	412.59	22.15

* Results out of proportion. Evidently a leak in plot.
** Snow accumulation and thawing.

TABLE XI

MONTHLY DISTRIBUTION OF RAINFALL, IN INCHES, ON BURTON STREET FARM, FENTON SOIL CONSERVATION DISTRICT, FROM APRIL, 1941, TO MARCH, 1943

	1941	1942	1943
January		1.84	1.35
February		0.54	0.95
March		3.50	2.30
April	1.82	1.00	
May	1.60	2.70	
June	3.08	3.77	
July	1.02	3.78	
August	2.65	2.98	
September	1.31	1.32	
October	5.15	3.25	
November	1.92	2.90	
December	1.42	2.35	

Total from April, 1941, to March, 1942: 25.85 inches.
Total from April, 1942, to March, 1943: 28.65 inches.

cover when the plants are small, and cultivation is in progress. In June, the soil is saturated by rains of May, the impact of which reduces the infiltration capacity of the soil. The first rains that come after seedbed preparation, in May, meet a loose soil, and are absorbed in great amounts.

In the second half of May there is heavy soil loss when frequent and intense rains occur. The heaviest soil

TABLE XII

RESULTS FROM RAIN OF JUNE 21, 1939, ON HILLSDALE AND COLOMA SOILS, 6% SLOPE 72 FEET LONG, IN ST. JOSEPH SOIL CONSERVATION DISTRICT, MICHIGAN, UNDER CORN CULTIVATED UP AND DOWN THE SLOPE OR ON THE CONTOUR, AND ON SOD

Soil and Nature of Loss	Rainfall		Land Use and Practice		
	Inches	Intensity in./hr.*	Up and Down	Contour	Sod
Hillsdale	1.76	3.6			
Runoff (%)			54.1	56.2	1.6
Soil (tons/a)			6.5	8.1	0.0
Coloma	2.52	5.1			
Runoff (%)			57.6	47.8	6.0
Soil (tons/a)			24.0	23.0	0.0

* Rainfall intensities for a 20-minute period.

loss in August, Table X, was also associated with a high amount and intensity of rainfall.

In Michigan, the agronomists are recommending corn planting about May 8th. This is the best so far as yield, time of harvesting, and the relation to erosion control are concerned. An early planting time results in less susceptibility of soil to erosion at the end of May and all of June.

The higher loss of water and soil in Hillsdale soil under contour in Table XII is explained in part by the small effect of contouring immediately after planting, but other circumstances must have had an influence in this unexpected result, such as differences in density of weeds and stand of corn. There was a small difference in percentage of water loss from Hillsdale and Coloma, under up and down hill cultivation, cropped to corn.

LABORATORY SOIL STUDIES

Procedure

Five to six core samples were taken of each horizon of the St. Clair, Miami, Hillsdale, and Coloma soils, from pits dug beside the demonstrational plots from which the data on water and soil losses were available. Samples of the Hillsdale and Coloma were taken in the place where the demonstrational plots were located a few years ago. All sampling sites were chosen as representative of the soils on the plots. The sites, except the Hillsdale which was in a cultivated orchard, were covered with grass, but the vegetation was more dense on the St. Clair and Miami soils. The core samples were collected in brass cylinders, 2 inches high, with volumes of 192 cc each, for the laboratory study.

The infiltration was measured using a cylinder of the same dimension as the cylinder holding the sample, above the sample, and joined with a rubber band to hold the water. After putting the samples in a can with the water level near the top of the cylinders, for a period of 24 hours, for complete saturation, the samples were set on a screen and 100 cc of water were poured over the soil sample. As soon as the water disappeared from the sample surface 100 cc more were added. The amount of water in cc that passed through the surface of the sample in 2 hours was measured.

The non-capillary porosity, in percentage of volume, was determined by the difference in weight of the sample when saturated and after being drained on a tension table at 1.6 pF.

The capillary porosity, as percentage by volume, was calculated by taking the difference of weight after taking off of the pF table and after 24 hours in the oven at 110 degrees F.

The volume weight was obtained by dividing the oven dry weight of the soil cores by the volume of the brass cylinder (192 cc).

The specific gravity was determined by the usual pycnometer method.

The total porosity was calculated by the formula: $100 - \left[\frac{\text{volume weight}}{\text{specific gravity}} \times 100\right]$ and by adding non-capillary to capillary porosity.

The percentage of swelling was calculated by measuring the height of the sample over the top of the cylinder, after complete saturation of the sample.

To calculate the shrinkage percentage, the core sample was taken out of the cylinder and put in a can with known volume and which was filled with fine sand and

PLATE 1

PLOTS ON MIAMI SOIL, AT BURTON STREET FARM, FENTON SOIL CONSERVATION DISTRICT, AUGUST, 1950

PLATE 2

SAMPLING ON COLOMA SOIL, ST. JOSEPH RIVER SOIL CONSERVATION DISTRICT

PLATE 3

SAMPLES OF COLOMA SOIL, ST. JOSEPH RIVER SOIL CONSERVATION DISTRICT

PLATE 4

FROM LEFT TO RIGHT: PLAINFIELD, HILLSDALE, MIAMI, AND ST. CLAIR MONOLITHS
PLAINFIELD IS VERY SIMILAR TO COLOMA

shaken in the same way for every sample. The sand displaced was measured in a graduated cylinder. From the difference between 192 cc and the volume of the oven-dry sample the volume percentage of shrinkage was calculated.

Experimental Results

Tables A, B, C, and D, in the Appendix, give the infiltration in millimeters per hour, non-capillary, capillary and total porosity in percentage of volume, volume weight, specific gravity, swelling and shrinkage as percentage of volume found in the samples of the four soils studied. The presence of some stones close to the walls of the cylinder was responsible for some variations in the data. Table XIII summarizes the mean values of each of these properties for each of these soils studied. Table XIV shows the total changes in volume by swelling and shrinkage with changes in the moisture content, expressed as percentage of the oven-dry volumes. Table XV gives the mean values of non-capillary, capillary and total porosity, considering the volume of core sample after swelling.

TABLE XIII

SUMMARY OF THE MEAN VALUES OF INFILTRATION RATE, POROSITY, VOLUME WEIGHT, SPECIFIC GRAVITY, SWELLING AND SHRINKAGE OF THE HORIZONS OF ST. CLAIR, MIAMI, HILLSDALE AND COLOMA SOILS

Soils	Properties	Horizons							
		A1	A2	B1	B2	C1	C2	D2	D3
St. Clair	Infiltration	246.0		40.0	63.1	114.9		9.1	7.1
Miami	mm/h	124.0	20.3		43.1	28.1	10.3		
Hillsdale		47.0	23.5	27.5	70.0	326.5			
Coloma		283.6	216.9	309.1	393.9	449.3			
St. Clair	Non-	12.3		8.9	8.5	7.4		7.0	7.9
Miami	Capillary	13.7	10.8		12.6	11.9	9.7		
Hillsdale	Pores	19.0	15.6	13.9	10.9	14.6			
Coloma	Volume %	11.5	12.2	15.5	15.7	12.8			
St. Clair	Capillary	29.6		35.1	37.7	38.4		33.7	29.4
Miami	Pores	30.2	28.2		34.0	34.5	30.6		
Hillsdale	Volume %	19.0	23.3	23.7	27.0	17.3			
Coloma		31.3	28.1	24.4	24.0	25.3			
St. Clair	Total**	41.9		44.0	46.2	45.8		40.7	37.3
Miami	Pores	43.9	39.0		46.6	46.3	40.3		
Hillsdale	Volume %	38.0	38.9	37.6	37.9	31.9			
Coloma		42.8	40.3	39.9	39.7	38.1			
St. Clair	Volume	1.50		1.53	1.46	1.52		1.61	1.79
Miami	Weight	1.50	1.76		1.58	1.56	1.76		
Hillsdale		1.64	1.69	1.67	1.62	1.58			
Coloma		1.45	1.51	1.50	1.50	1.52			
St. Clair	Specific	2.65		2.66	2.71	2.68		2.70	2.72
Miami	Gravity	2.64	2.65		2.71	2.70	2.70		
Hillsdale		2.65	2.68	2.68	2.70	2.67			
Coloma		2.60	2.61	2.62	2.65	2.68			
St. Clair	Swelling	3.98		2.98	2.78	2.18		3.97	3.65
Miami	Volume %	2.47	4.30		3.71	3.19	3.77		
Hillsdale		-	2.31	2.77	1.19	-			
Coloma		-	-	-	-	-			
St. Clair	Shrinkage	11.2		7.4	13.7	14.9		4.8	4.7
Miami	Volume %	16.1	5.3		11.9	9.3	1.3		
Hillsdale		3.1	3.6	5.6	6.3	-			
Coloma		7.1	5.0	2.8	2.4	1.0			

** Sum of non-capillary and capillary porosity.

TABLE XIV

TOTAL CHANGE IN SOIL VOLUME FROM OVEN-DRY TO SATURATED, ON OVEN DRY BASIS, FROM THE MEAN VALUES OF SHRINKAGE AND SWELLING PERCENTAGES*

Soils	Horizons							
	A1	A2	B1	B2	C1	C2	D2	D3
St. Clair	17.0		11.0	20.0	20.0		9.6	9.0
Miami	22.0	10.6		18.4	14.2	5.2		
Hillsdale	3.1	6.2	8.1	8.1	0.0			
Coloma	7.6	5.2	2.8	2.4	1.0			

*Calculated by the formula:

$$\frac{\text{shrinkage + swelling}}{\text{100 - shrinkage}} \times 100.$$

All numbers represent percentage.

Discussion

According to the mean values of Table XIII, the A2 horizon is the least permeable in the solum. The permeability of this horizon increases in the following order: Miami, Hillsdale, and Coloma soils. The low infiltration rate of A2 in relation to the other horizons in the solum of Miami, Hillsdale and Coloma is attributed to the compactness of this horizon, as it is shown by the low porosity in all three soils and by its higher volume weight in relation to other horizons of the solum. This higher volume weight of A2 compared with other horizons of the solum was observed also in Miami under forest

TABLE XV

MEAN VALUES OF NON-CAPILLARY, CAPILLARY AND TOTAL POROSITY, CONSIDERING THE VOLUME OF CORE SAMPLE AFTER SWELLING. THE FIRST GROUP OF NUMBERS REFERS TO NON-CAPILLARY, THE SECOND TO CAPILLARY, AND THE LAST TO TOTAL POROSITY*

Soils	Horizons							
	A1	A2	B1	B2	C1	C2	D2	D3
St. Clair	17.3		10.0	10.7	6.8		10.6	8.1
Miami	14.9	8.2		11.4	10.8	7.5		
Hillsdale	19.3	16.8	16.2	13.8	23.3			
Coloma	12.8	14.1	18.3	19.2	18.0			
St. Clair	28.3		34.0	36.6	37.6		32.4	28.3
Miami	29.4	27.0		32.6	33.2	29.5		
Hillsdale	19.0	22.7	23.0	26.7	17.3			
Coloma	31.3	28.1	24.4	24.0	25.3			
St. Clair	45.6		44.0	47.3	44.4		43.0	36.4
Miami	44.3	35.2		44.0	44.0	37.0		
Hillsdale	38.3	39.5	39.2	40.5	40.6			
Coloma	44.1	42.2	42.7	43.2	43.3			

* Total porosity, on saturated basis =

$$\frac{\text{total pores \%} + \text{swelling volume \%}}{100\% + \text{swelling volume \%}}$$

$$\text{Total pores} = 100 - \left[\frac{\text{volume weight}}{\text{specific gravity}}\right] \times 100$$

Non-capillary porosity = Total porosity - capillary porosity. Capillary porosity based on 192 cc plus swelling volume.

vegetation, by students in the course of Micropedology (S. Science 417, Fall, 1950).

Bouyoucos (8) observed that a very small amount of dispersed colloids or other fine material, placed in certain positions, can overcome the dominant influence of coarse granular structure upon rapid percolation.

The second least permeable horizon in the solum of St. Clair or Hillsdale is the B1. In the B2 horizons, the permeability increases in the following order: Miami, St. Clair, Hillsdale and Coloma. The B2 horizons are more clayey than the A2 or B1 horizons. This accounts for the greater swelling of the B2 horizons in the St. Clair, Miami, and Hillsdale profiles. However, in the Coloma profile this is not true. The blocky structure in the B2 horizons seems to be responsible for their greater infiltration rates than that of A2 or B1 horizons of St. Clair, Miami, and Hillsdale. The large changes in volume with moisture content, Table XIV, probably aid in the formation of this blocky structure.

In the A1 horizons, the infiltration rate increased in the order: Hillsdale, Miami, St. Clair and Coloma. In the C1 horizons, the order is: Miami, St. Clair, Hillsdale and Coloma. The infiltration rate of the least permeable horizon in each profile increases in the order: St. Clair, Miami, Hillsdale and Coloma. Apparently, the relative infiltration rates of these soils will vary with the depth to which they are wetted or eroded.

The low infiltration into Hillsdale A1 is probably due to a peculiar arrangement of the particles, packed together in such a way as to reduce the infiltration rate. The lower infiltration rate on Miami in relation to St. Clair is likely to be due to the differences in natural cleavages, that is, the openings between aggregates are more favorable to infiltration on St. Clair. The A1 horizon in Miami has weak platy structure, which seems to be an index of low infiltration rate.

There is no apparent relationship between total porosity, capillary porosity, or non-capillary porosity and infiltration rate, in Table XIII. As some investigators have suggested (2, 10, 13, 20, 30), the size of the non-capillary pores is more important than the amount. In part this lack of correlation between porosity and infiltration rate is due to errors in the estimation of the former in Table XIII. These errors are of three kinds: (1) Entrapped air in the cores; (2) loss of water from the largest non-capillary pores in transferring the cores to the balance; and (3) increases in volumes of the cores on saturation with water. In Table XV the data have been recalculated to avoid these difficulties. A comparison of the values in these two tables shows that: (1) the capillary porosity is overestimated on samples that swelled on wetting; (2) the non-capillary porosity is underestimated in most cases; and (3) the total porosity was usually underestimated by the usual procedures used in Table XIII.

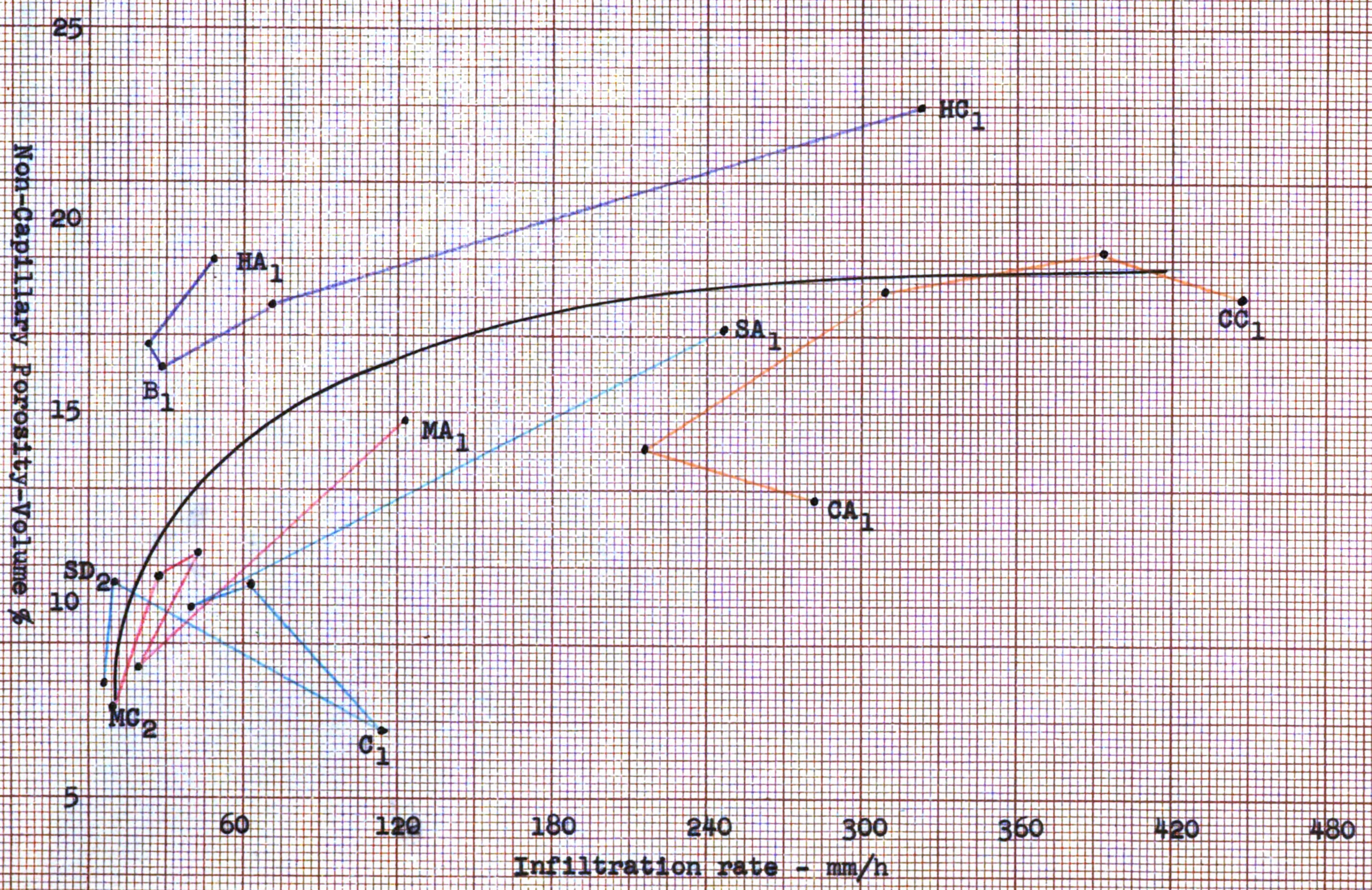
While there was no apparent influence of swelling or shrinkage, *per se*, on infiltration rate for the coarser textured Hillsdale and Coloma, a higher total change in volume of the St. Clair and Miami horizons was associated with higher infiltration rate, with few exceptions.

The small differences in total porosity of these soils, Table XV, are in accordance with results of Baver (4). He determined pore space of different soils and found no large differences in total porosity between different textured soils except as influenced by organic matter.

As shown in Graph 1, there is no close correlation between percentage of non-capillary porosity and infiltration rate, but the trend of the curve that expresses the relationship between these two properties indicates some correlation between them.

GRAPH 1

RELATIONSHIP BETWEEN PERCENTAGE OF NON-CAPILLARY POROSITY AND INFILTRATION RATE



S, St. Clair H, Hillsdale
M, Miami C, Coloma

SUMMARY

In this investigation, involving runoff and erosion data from field plots and laboratory studies of core samples from four soil profiles, the objective was to study some relationships between permeability and water and soil losses from these soils under different cropping systems and tillage practices. St. Clair, Miami, Hillsdale and Coloma soils on slopes of 9, 7, 6, and 6%, respectively, were selected for these studies.

Records of water and soil losses on St. Clair and Miami cropped to corn, oats, and meadow, when cultivated both up and down the slope, and on the contour were available. Soil and water losses on Hillsdale and Coloma, cropped to continuous corn cultivated up and down the slope and on the contour, or in continuous sod had also been measured by the Soil Conservation Service of the U. S. D. A. Estimates of the amount of erosion on B and C slopes of these soils had also been tabulated for areas near where the above data and soil samples were obtained.

Core samples from all horizons of these four soils were studied. The infiltration rate, non-capillary, capillary and total porosity; volume weight, specific gravity, swelling and shrinkage of each sample were measured.

As a result of these studies, the following statements can be made:

1. Erosion has been more active on the C slopes than on B slopes of all these soils.

2. Contouring reduced to a great extent the soil loss compared to up and down cultivation. Soil losses were reduced more than 50% on St. Clair, Miami and Hillsdale, and less on Coloma.

3. Contouring reduced the water losses. In general the loss on contoured plots was more than 50% of the loss under up and down cultivation.

4. Corn was the most soil erosion exposing crop, followed by oats. On Miami the soil loss from oats plots was less than 50% of the soil loss on plots cropped to corn. Plots under sod or meadow had insignificant soil loss and a small percentage of water loss.

5. The water lost by runoff was greater from Miami than from Hillsdale and least from Coloma soil. This is in the order of increasing permeability of the least permeable horizon in each profile.

6. Two factors were evident as very important in soil loss: the clay ratio, influencing the ease of dispersion of the soil, and infiltration rate, governing the amount of runoff.

    A. A very high clay ratio can overcome a favorable infiltration rate, as happens on Coloma soil. Coloma has a higher infiltration rate than Hillsdale but is more susceptible to erosion due to a higher clay ratio.

    B. A smaller percentage of clay in Hillsdale, compared to Miami and St. Clair, was responsible for a lower rate of infiltration into Hillsdale A1 due to less aggregation of the latter and a special arrangement of the Hillsdale soil particles.

    C. St. Clair silt clay loam is less erodible than Miami sandy loam due to a lower clay ratio and a higher infiltration rate.

7. On these four soils, there is a general relationship between non-capillary porosity and infiltration rate. High non-capillary porosity is associated with high infiltration rate, but this relationship is not consistent for all horizons of these soils.

8. The A2 horizon of Miami, Hillsdale and Coloma was the least permeable, had the highest volume weight and the lowest total porosity, in the solum. Except for Hillsdale, where the total porosity of the B1 was slightly smaller. These properties indicate a special arrangement of the soil separates in A2, which reduces the infiltration rate. No A2 horizon was present in the St. Clair and there the B1 was the least permeable horizon, had the highest volume weight and the lowest total porosity in the solum.

9. If the swelling volume of saturated core samples is not considered in the calculation of pore space, there is usually an overestimation of capillary porosity and an underestimation of non-capillary and total porosity.

BIBLIOGRAPHY

1. Ayres, Q. C., Soil Erosion and its Control, McGraw-
   1936 Hill Book Company, New York.

2. Baver, L. D., "Soil Permeability in Relation to Non-
   1938 capillary Porosity." Soil Sci. Soc. Am. Proc. 3:52-56.

3. Baver, L. D., Soil Physics, John Wiley and Sons,
   1948 Inc., New York.

4. Baver, L. D., "Report of the Committee on Physics
   1935 of Soil-moisture." Am. Geophy. Union Trans. 16:427.

5. Bennett, H. H., Soil Conservation, McGraw-Hill Book
   1939 Company, New York.

6. Borst, H. L., A. G. McCall, and F. G. Bell, "Investi-
   1945 gation in Erosion Control and the Reclamation of Eroded Land at the Northwest Appalachian Conservation Experiment Station, Zanesville, Ohio, 1934-42." Technical Bul. No. 888, U. S. D. A. in cooperation with the Ohio Ag. Exp. Sta.

7. Bouyoucos, G. J., "The Clay Ratio as a Criterion of
   1935 Susceptibility of Soil to Erosion." Am. Soc. Agron. Jour. 27:738-741.

8. Bouyoucos, G. J., "A New Method of Measuring the
   1930 Comparative Rate of Percolation of Water in Different Soils." Am. Soc. Agron. Jour. 22:428-445.

9. Browning, G. M., R. A. Norton, and A. G. McCall,
   1948 "Investigation in Erosion Control and the Reclamation of Eroded Land at the Missouri Valley Loess Conservation Exp. Sta., Clarinda, Iowa, 1931-42." Tech. Bul. No. 959, U. S. D. A. in cooperation with the Iowa Agr. Exp. Sta.

10. Daubenmire, R. F., Plants and Environment, John
    1950 Wiley and Sons, Inc., New York.

11. Ellison, W. D., "Soil Erosion." Soil Sci. Soc. Am. 1947 Proc. 12:479-484.

12. Gustafson, A. F., Soils and Soil Management, McGraw- 1941 Hill Book Company, New York.

13. Gustafson, A. F., Using and Managing Soils, McGraw- 1948 Hill Book Company, New York.

14. Israelsen, O. W., Irrigation Principles and Practices, 1950 John Wiley & Sons, Inc., New York.

15. Jenny, H., Factors of Soil Formation, McGraw-Hill 1941 Book Company, New York.

16. Joffe, J. S., The A B C of Soils, Pedology Publica- 1949 tions, New Brunswick, N. J.

17. Jones, L. G., and L. M. Thompson, Soil Erosion and 1941 its Control, A. & M. College, Texas.

18. Kellogg, C. E., The Soils that Support Us, The Mac- 1949 millan Company, New York.

19. Kramer, P. J., Plant and Soil Water Relationships, 1949 McGraw-Hill Book Company, New York.

20. Leamer, R. W., and J. F. Lutz, "Determination of 1940 Pore-size Distribution in Soils." Soil Sci. 49:347-360.

21. Lee, C. E., "Report of the Committee on Physics of 1935 Soil Moisture." Am. Geophy. Union Trans. 16:429.

22. Lutz, J. F., "The Relation of Soil Erosion to Cer- 1935 tain Inherent Soil Properties." Soil Sci. 40:439-457.

23. Lynd, J. Q., "Injurious Effects of Overliming an 1947 Acid Soil." M. S. Thesis, Michigan State College.

24. Mick, A. H., "The Pedology of Several Profiles De- 1949 veloped from the Calcareous Drift of Eastern Michigan." Agri. Expt. Sta. Tech. Bul. 212.

25. Middleton, H. E., "The Properties of Soils Which 1930 Influence Erosion." U. S. D. A. Tech. Bul. No. 178.

26. Musgrave, G. W., "The Infiltration Capacity of Soils
1935 in Relation to the Control of Surface Runoff and Erosion." Am. Soc. Agron. Jour. 27:336-345.

27. Musgrave, G. W., "Some Relationships Between Slope-
1935 length, Surface-runoff, and the Silt-load of Surface-runoff." Am. Geophy. Union Trans. 16:472-478.

28. Musgrave, G. W., and R. A. Norton, "Soil and Water
1937 Conservation Investigations." U. S. D. A. Tech. Bulletin No. 558 in coop. with the Iowa Ag. Exp. Sta.

29. Page, J. B., and C. J. Willard, "Cropping Systems
1946 and Soil Properties." Soil Sci. Soc. Am. Proc. 11:81-88.

30. Schiff, L., and F. R. Dreibelbis, "Infiltration,
1948 Soil Moisture, and Land Use Relationships with Reference to Surface Runoff." S. C. Service, U. S. D. A. Research Summaries, Part VII.

31. Slater, C. S., and H. G. Byers, "A Laboratory Study
1931 of the Field Percolation Rates of Soils." U. S. D. A. Tech. Bulletin No. 232.

32. Thorne, D. W., and H. B. Paterson, Irrigated Soils,
1949 The Blakiston Company, Philadelphia and Toronto.

33. Van Doren, C. A., L. E. Gard, and E. H. Kidder,
1948 "Summary of Results - Soil and Water Conservation Experiments, Dixon Springs, Ill." S. C. Service, U. S. D. A. Research Summaries, Part VII.

34. Veatch, J. O., "Agricultural Land Classification and
1941 Land Types of Michigan." Michigan Spec. Bul. 231.

35. Yoder, R. E., "A direct Method of Aggregate Analyses
1936 of Soils and a Study of the Physical Nature of Erosion Losses." Amer. Soc. Agron. Jour. 28:337-351.

APPENDIX

TABLE A

INFILTRATION RATE, POROSITY, VOLUME WEIGHT, SPECIFIC GRAVITY, SWELLING AND SHRINKAGE OF ST. CLAIR

Sample	Horizon	Depth in Inches	Infiltration mm/h	Non-Capillary Pores Volume %	Capillary Pores Volume %	Total Pores %	Volume Weight	Specific Gravity	Swelling % Volume	Shrinkage % Volume
1	A1	2-4	196.0	10.9	21.6	41.0	1.56	2.65	1.98	13.0
2	"	"	487.0	15.7	30.6	48.0	1.39	"	3.96	13.0
3	"	"	250.0	8.6	33.2	39.0	1.62	"	6.00	5.2
4	"	"	254.0	11.4	31.8	46.0	1.44	"	3.96	13.0
5	"	"	118.0	17.3	28.4	45.0	1.46	"	6.00	11.7
6	"	"	171.0	9.9	32.0	42.0	1.53	"	1.98	12.5
Average			246.0	12.3	29.6	43.5	1.50		3.98	11.2
7	B1	7-9	7.9	8.0	38.3	38.0	1.66	2.66	5.00	6.8
8	"	"	98.5	10.6	27.6	41.0	1.56	"	1.98	7.5
9	"	"	10.0	8.2	27.6	40.0	1.61	"	1.98	8.0
10	"	"	46.8	9.4	41.5	47.0	1.41	"	1.98	6.8
11	"	"	36.8	8.4	40.5	46.0	1.44	"	3.96	8.0
Average			40.0	8.9	35.1	42.4	1.53		2.98	7.4
12	B2	12-14	47.0	7.1	39.9	46.5	1.45	2.71	1.98	9.9
13	"	"	60.0	7.1	41.0	47.0	1.43	"	1.98	13.3
14	"	"	94.8	7.9	41.3	47.5	1.42	"	1.98	15.6
15	"	"	36.8	10.2	39.0	46.0	1.46	"	6.00	16.6
16	"	"	77.0	10.1	27.1	42.5	1.56	"	1.98	13.0
Average			63.1	8.5	37.7	45.9	1.46		2.78	13.7
17	C	19-21	103.0	6.6	37.2	42.5	1.54	2.68	1.98	15.6
18	"	"	145.0	8.7	41.7	45.5	1.46	"	1.98	18.2
19	"	"	39.5	8.1	40.0	44.5	1.49	"	0.99	16.1
20	"	"	105.0	5.6	35.4	41.5	1.57	"	1.98	11.5
21	"	"	182.0	7.9	37.5	42.0	1.56	"	3.96	13.3
Average			114.9	7.4	38.4	43.2	1.52		2.18	14.9
22	D2	26-28	5.2	8.1	33.4	41.0	1.60	2.70	5.00	5.5
23	"	"	11.1	7.0	33.8	40.0	1.62	"	3.96	4.2
24	"	"	11.1	6.0	33.8	40.0	1.62	"	2.96	4.7
Average			9.1	7.0	33.7	40.3	1.61		3.97	4.8
25	D3	32-34	7.6	7.0	35.2	38.0	1.69	2.72	6.00	3.6
26	"	"	10.0	8.2	26.0	31.5	1.86	"	0.99	4.7
27	"	"	3.9	8.4	27.0	33.0	1.82	"	3.96	5.7
Average			7.1	7.9	29.4	34.1	1.79		3.65	4.7

TABLE B

INFILTRATION RATE, POROSITY, VOLUME WEIGHT, SPECIFIC GRAVITY, SWELLING AND SHRINKAGE OF MIAMI

Sample	Horizon	Depth in Inches	Infiltration mm/h	Non-Capillary Pores Volume %	Capillary Pores Volume %	Total Pores %	Volume Weight	Specific Gravity	Swelling % Volume	Shrinkage % Volume
1	A1	½-2½	111.5	14.8	30.2	44.0	1.48	2.64	0.00	19.3
2	"	"	130.7	15.3	31.9	46.5	1.41	"	1.98	20.3
3	"	"	124.5	14.2	33.0	49.5	1.33	"	1.98	23.7
4	"	"	100.5	14.2	32.0	45.0	1.45	"	1.98	25.0
5	"	"	196.0	14.5	31.2	48.5	1.36	"	3.96	20.9
6	"	"	210.0	18.7	32.0	50.5	1.31	"	3.96	22.4
Average			145.5	15.3	31.7	47.3	1.39		2.31	21.9
7	"	3½-5½	60.0	12.3	28.0	36.5	1.68	"	3.96	12.0
8	"	"	84.7	13.5	28.9	38.5	1.63	"	3.96	9.4
9	"	"	61.2	10.7	29.4	37.5	1.65	"	3.96	7.8
10	"	"	57.5	13.4	28.2	39.0	1.61	"	3.96	9.4
11	"	"	57.0	12.9	28.5	40.0	1.59	"	0.00	12.0
12	"	"	54.7	10.6	29.0	40.0	1.58	"	0.00	12.0
Average			62.5	12.2	28.7	38.6	1.62		2.64	10.4
Average	A1	½-5½	124.0	13.7	30.2	42.9	1.50		2.47	16.1
13	A2	7-9	18.8	11.4	27.8	33.0	1.77	2.65	3.96	5.8
14	"	"	21.4	9.8	29.4	30.5	1.84	"	6.00	7.3
15	"	"	28.5	11.5	29.2	35.0	1.72	"	3.96	4.2
16	"	"	11.5	10.9	27.4	32.0	1.80	"	3.96	6.8
17	"	"	15.5	9.9	28.0	33.5	1.76	"	3.96	3.9
18	"	"	26.1	11.3	27.3	36.0	1.69	"	3.96	3.7
Average			20.3	10.8	28.2	33.3	1.76		4.30	5.3
19	B2	11-13	21.7	10.9	32.6	37.5	1.69	2.71	3.96	6.8
20	"	"	73.0	14.2	29.2	40.5	1.61	"	1.98	11.5
21	"	"	22.2	12.0	32.0	38.0	1.68	"	3.96	9.9
22	"	"	42.3	12.7	30.7	39.0	1.65	"	6.00	8.4
23	"	"	18.8	11.0	33.0	36.0	1.73	"	6.00	7.3
Average			35.6	12.2	31.5	38.2	1.67		4.38	8.8
24	"	15-17	30.1	11.6	38.1	40.0	1.60	"	6.00	-
25	"	"	57.5	14.4	31.9	42.0	1.57	"	1.98	15.9
26	"	"	43.1	15.8	32.8	42.0	1.57	"	3.96	9.4
27	"	"	26.1	12.1	35.8	43.0	1.55	"	6.00	-
28	"	"	50.9	13.1	33.6	44.5	1.50	"	1.98	13.6
Average			41.5	13.4	35.2	42.1	1.55		3.98	12.9

(Continued)

TABLE B (Continued)

Sample	Horizon	Depth in Inches	Infiltration mm/h	Non-Capillary Pores Volume %	Capillary Pores Volume %	Total Pores %	Volume Weight	Specific Gravity	Swelling % Volume	Shrinkage % Volume
29	B2	19-21	30.0	13.7	36.3	44.0	1.52	2.71	1.98	14.6
30	"	"	143.5	12.0	32.6	44.5	1.50	"	1.98	14.6
31	"	"	18.8	13.3	36.8	43.5	1.53	"	3.96	14.6
32	"	"	32.1	9.8	32.7	44.0	1.51	"	0.00	15.1
33	"	"	36.5	12.6	37.8	45.5	1.48	"	6.00	11.5
Average			52.2	12.3	35.2	44.3	1.51		2.78	14.1
Average	B2	11-21	43.1	12.9	34.0	41.9	1.58		3.71	11.9
34	C1	24-26	39.5	10.1	31.6	44.5	1.50	2.70	0.00	7.8
35	"	"	28.0	12.5	36.3	41.0	1.59	"	6.00	9.9
36	"	"	9.9	11.6	38.2	42.5	1.55	"	6.00	9.9
37	"	"	40.2	12.5	30.6	40.5	1.61	"	0.00	12.0
38	"	"	23.0	12.8	35.7	43.5	1.53	"	3.96	6.8
Average			28.1	11.9	34.5	42.4	1.56		3.19	9.3
39	C2	30-32	21.4	11.9	34.4	40.0	1.62	2.70	3.96	8.4
40	"	"	14.3	11.5	37.4	43.5	1.53	"	3.96	7.1
41	"	"	7.5	11.0	33.0	39.0	1.64	"	1.98	9.7
42	"	"	3.3	10.1	33.2	34.0	1.78	"	3.96	6.8
43	"	"	-	8.6	31.0	31.5	1.85	"	6.00	7.6
Average			11.6	10.6	33.8	37.6	1.68		3.97	7.9
44	"	36-38	21.6	10.6	27.8	34.0	1.78	"	3.96	9.4
45	"	"	11.2	9.9	26.9	33.5	1.80	"	6.00	4.7
46	"	"	6.0	8.1	28.2	31.5	1.85	"	1.98	3.7
47	"	"	3.9	8.7	27.7	29.5	1.90	"	3.96	5.8
48	"	"	2.5	6.9	26.5	29.5	1.90	"	1.98	9.9
Average			9.0	8.8	27.4	31.6	1.85		3.58	6.7
Average	C2	30-38	10.3	9.7	30.6	34.6	1.76		3.77	7.3

TABLE C

INFILTRATION RATE, POROSITY, VOLUME WEIGHT, SPECIFIC GRAVITY, SWELLING AND SHRINKAGE OF HILLSDALE

Sample	Horizon	Depth in Inches	Infiltration mm/h	Non-Capillary Pores Volume %	Capillary Pores Volume %	Total Pores %	Volume Weight	Specific Gravity	Swelling % Volume	Shrinkage % Volume
1	A1	3-5	52.2	19.1	20.3	40.1	1.59	1.65	-	4.7
2	"	"	51.0	19.8	18.8	39.0	1.62	"	-	5.2
3	"	"	46.0	18.3	19.4	38.5	1.63	"	-	3.1
4	"	"	53.0	21.0	16.7	37.0	1.67	"	-	1.0
5	"	"	32.8	16.9	19.7	37.0	1.67	"	-	1.5
Average			47.0	19.0	19.0	38.3	1.64		-	3.1
6	A2	9-11	26.1	15.8	22.4	38.7	1.64	2.68	-	4.1
7	"	"	22.0	15.6	25.2	39.0	1.63	"	1.98	4.7
8	"	"	14.9	13.5	23.7	33.6	1.78	"	0.99	4.1
9	"	"	34.7	14.8	22.4	35.7	1.72	"	-	3.6
10	"	"	20.1	18.2	24.7	37.7	1.67	"	3.96	1.5
Average			23.5	15.6	23.3	36.5	1.69		2.31	3.6
11	B1	14-16	16.7	16.9	27.2	37.0	1.69	2.68	3.96	2.1
12	"	"	24.5	14.9	23.8	37.3	1.68	"	-	7.8
13	"	"	37.3	14.2	24.2	38.0	1.66	"	1.58	5.7
14	"	"	25.1	11.7	25.2	38.0	1.66	"	-	6.2
15	"	"	34.0	12.0	23.9	37.3	1.68	"	-	6.2
Average			27.5	13.9	23.7	37.5	1.67		2.77	5.6
16	B2	22-24	20.6	12.3	25.4	39.5	1.63	2.70	-	6.2
17	"	"	102.0	14.7	26.0	40.7	1.60	"	-	3.1
18	"	"	142.0	9.1	28.5	40.0	1.62	"	1.19	6.2
19	"	"	15.7	7.7	28.0	39.0	1.65	"	-	9.9
Average			70.0	10.9	27.0	39.8	1.62		1.19	6.3
20	C	52-54	340.0	16.7	13.0	40.0	1.60	2.67	-	*
21	"	"	340.0	17.7	15.4	40.5	1.59	"	-	*
22	"	"	300.0	15.8	16.5	40.8	1.58	"	-	*
23	"	"	340.0	10.1	21.9	41.5	1.56	"	-	*
24	"	"	312.5	12.8	19.5	40.5	1.59	"	-	*
Average			326.5	14.6	17.3	40.6	1.58			

* Samples cemented on the cylinder walls. No apparent shrinkage.

TABLE D

INFILTRATION RATE, POROSITY, VOLUME WEIGHT, SPECIFIC GRAVITY AND SHRINKAGE OF COLOMA

Sample	Horizon	Depth in Inches	Infiltration mm/h	Non-Capillary Pores Volume %	Capillary Pores Volume %	Total Pores %	Volume Weight	Specific Gravity	Shrinkage % Volume
1	A1	2-4	266.0	12.5	28.9	44.2	1.45	2.60	9.6
2	"	"	285.0	12.2	31.2	45.7	1.41	"	9.1
3	"	"	272.0	11.4	32.1	43.5	1.47	"	5.7
4	"	"	307.5	10.6	32.1	42.0	1.51	"	4.2
5	"	"	287.5	10.7	32.2	45.0	1.43	"	*
Average			283.6	11.5	31.3	44.1	1.45		7.1
6	A2	9-11	243.5	11.3	29.8	42.2	1.51	2.61	*
7	"	"	177.5	10.3	30.2	42.2	1.51	"	*
8	"	"	233.5	9.9	30.5	46.0	1.41	"	4.9
9	"	"	245.0	11.1	30.4	42.8	1.49	"	1.6
10	"	"	178.0	8.7	32.7	41.7	1.52	"	4.7
Average			215.5	10.5	30.7	43.0	1.49		3.73
11	"	14-16	144.0	12.6	24.0	41.0	1.54	"	6.2
12	"	"	202.0	12.4	27.3	41.0	1.54	"	6.2
13	"	"	270.0	12.9	28.6	42.5	1.50	"	5.7
14	"	"	200.0	13.3	25.2	40.5	1.55	"	6.2
15	"	"	276.0	20.0	22.2	42.2	1.51	"	7.8
Average			218.4	14.2	25.5	41.4	1.53		6.4
Average	A2	9-16	216.9	12.2	28.1	42.2	1.51		5.0
16	B1	20-22	233.5	12.8	25.7	41.2	1.54	2.62	3.1
17	"	"	261.5	13.1	26.2	43.5	1.48	"	3.1
18	"	"	293.0	14.5	23.8	41.6	1.53	"	1.6
19	"	"	457.5	18.9	25.5	45.7	1.42	"	2.6
20	"	"	300.0	18.1	20.7	41.6	1.53	"	3.6
Average			309.1	15.5	24.4	42.7	1.50		2.8
21	B2	27-29	324.0	18.8	22.2	43.4	1.50	2.65	5.7
22	"	"	427.0	13.3	25.4	44.1	1.48	"	2.1
23	"	"	397.5	13.4	26.4	42.0	1.54	"	3.1
24	"	"	400.0	14.9	25.2	42.0	1.54	"	2.6
25	"	"	257.5	16.8	22.9	43.8	1.49	"	1.0
Average			361.2	15.4	24.4	43.1	1.51		2.9

(Continued)

TABLE D (Continued)

Sample	Horizon	Depth in Inches	Infiltration mm/h	Non-Capillary Pores Volume %	Capillary Pores Volume %	Total Pores %	Volume Weight	Specific Gravity	Shrinkage % Volume
26	B2	34-36	480.0	19.2	20.2	43.4	1.50	2.65	2.1
27	"	"	422.5	15.1	25.0	43.0	1.51	"	3.1
28	"	"	335.0	13.7	26.9	42.3	1.53	"	2.1
29	"	"	482.5	19.4	21.0	44.1	1.48	"	1.0
30	"	"	413.0	12.4	25.6	44.1	1.48	"	1.0
Average			426.6	16.0	23.7	43.4	1.50		1.9
Average	B2	27-36	393.9	15.7	24.0	43.2	1.50		2.4
31	C	42-44	510.0	14.8	22.4	44.0	1.50	2.68	0.5
32	"	"	457.5	12.9	23.9	44.0	1.50	"	1.6
33	"	"	417.0	11.7	26.2	42.5	1.54	"	1.0
34	"	"	430.5	12.3	27.2	42.2	1.55	"	1.0
35	"	"	431.5	12.3	26.6	44.0	1.50	"	1.0
Average			449.3	12.8	25.5	43.3	1.52		1.0

* Samples cemented on the cylinder walls.