RESEARCH BULLETIN 1025 MARCH 1970

Hydraulic Conductivity Profiles of Toledo and Miami Soils as Measured by Field Monoliths

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Agricultural Research Service
U. S. Department of Agriculture

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ACKNOWLEDGMENT

The authors express appreciation to Dr. Larry Wilding for assistance in selecting and describing the soils utilized in this study.

AGDEX 507

3-70-2.5M

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INTRODUCTION

The saturated hydraulic conductivity of soils is widely recognized as an important factor in infiltration, drainage, and deep seepage. On the other hand, conductivities have been measured on only a few field sites. There are two principal reasons for this delay. One is that present methods for measuring soil hydraulic conductivity are time-consuming, frequently unadaptable, and often give erroneous results. The other reason is that conductivity is not a constant parameter but varies with prevailing and antecedent moisture conditions, compaction, and cultural practices.

This report is a study of hydraulic conductivity evaluations on two Ohio soils under field conditions. One is a moderately well drained Miami silt loam and the other is a very poorly drained Toledo silty clay.[3] The method reported here incorporates some features which improve the accuracy of conductivity measurements but it is more time-consuming than presently recommended methods.

Several methods are available for evaluating the saturated conductivity of soils in the presence of a water table. The two most widely adopted are the auger hole and piezometer tube methods (3, 5). In soils without a water table, inflow into a dry auger hole has been utilized by the Bureau of Reclamation (6, 9). A double-tube method has been used in soils of the arid regions (2). Conductivities have also been estimated by using soil cores taken from field sites, although the physical alteration of the soil during sampling can sometimes lead to large errors (1). The limitations of a relatively small sample size used in all of the above methods have been discussed by Kirkham (5).

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[1]Report of a study conducted by the Department of Agronomy, Ohio Agricultural Research and Development Center, in cooperation with the Corn Belt Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Dept. of Agriculture.

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[3]Nomenclature as reported in Soil Survey Manual, U. S. Deptment of Agriculture Handbook No. 18, 1951.

The purpose of this study was to evaluate saturated soil conductivities by measuring flow in a relatively large and well-defined cross-sectional area of undisturbed soil. Basically, the method involved excavating around a 5-foot-square block of soil to a depth of 5 to 6 feet. Perforated tubes were placed horizontally at different depths in the block and then connected to the ground surface by solid wall tubing. These tubes served as piezometers. The sides of the soil block (or monolith) were then surrounded by an impervious clay to prevent lateral movement of water. Provisions were also made for maintaining a constant level of ponded water. From infiltration rates and piezometer measurements, the conductivity of various soil layers was calculated by Darcy's equation.

METHODS AND MATERIALS

After identification of the soil series, a relatively level site was chosen for the construction of each monolith. It was then irrigated to prevent cave-in during excavation. A backhoe was used to dig a trench around a 5- by 5-foot area to a depth of approximately 6 feet (Fig. 1). During excavation, the exposed soil faces were supported with boards as a precaution against damage to the corners. The soil monolith included the A, B, and C horizons of both the Toledo and Miami soils.

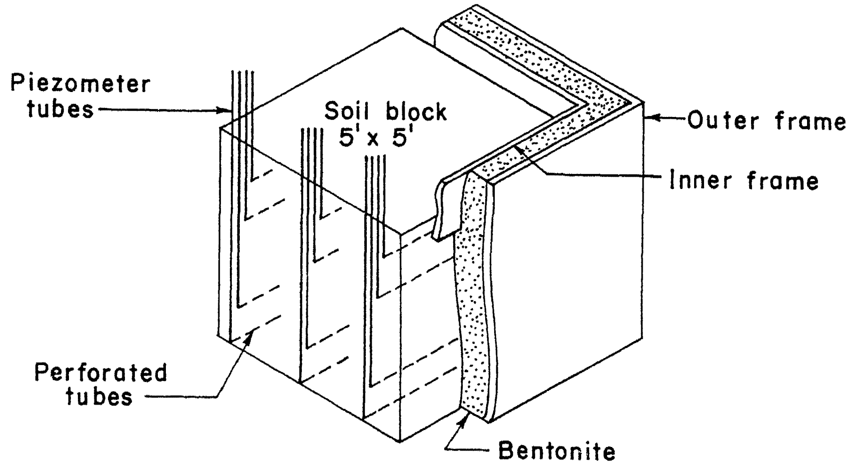

FIG. 1.—Schematic of field monoliths used in measuring soil hydraulic conductivity. Water is ponded within the inner frame and either percolates freely into the underlying soil or is pumped from the lower piezometer tubes. Infiltration rates and piezometer water levels are used to calculate the hydraulic conductivity of different layers.

An access pit at one face of the monolith was excavated to insert horizontal piezometer pipes at the soil horizon interfaces. Three evenly spaced, 1-inch diameter horizontal holes were augered at selected interfaces. These extended to within 3 inches of the opposite face of the monolith. The holes were subsequently reamed to remove any smeared surfaces.

A perforated ¾-inch plastic pipe was covered with a muslin sleeve and inserted into the holes. One end was connected with an elbow to a solid wall plastic tube which protruded 2 to 3 feet above the ground surface. A plywood box, somewhat larger in cross-sectional area than the monolith, was then lowered into the trench so it extended about 4 inches above the ground surface. The open space between the monolith and the plywood box was filled with about 5 inches of sodium bentonite (a swelling clay) to create a watertight seal around the monolith walls.

The remaining trench space outside the box, including the access pit, was backfilled. Before filling the trenches, soil core samples were taken outside the monolith for mechanical analysis, bulk density, porosity, and hydraulic conductivity determinations.

A 10-inch high, watertight inner frame was slipped over the monolith to a 2-inch depth. This was done to permit water ponding and to keep the bentonite from spreading over the surface of the monolith. The monolith surfaces were either sodded or left in grass if they were constructed in an established sod. The protruding ends of the piezometer were supported by a wooden frame.

Two soil monoliths were constructed on a very poorly drained Toledo silty clay. This is a soil developed in the glacial lakebed near Lake Erie at the North Central Branch, Ohio Agricultural Research and Development Center. The soil and its profile development have been described as a Humic-Gley (Mollic Haplaquept) developed in lacustrine mixed clays and silts (7). Some of the physical properties of this soil type are given in Table 1. The profile has a high clay content and its drainable porosity decreases rapidly with depth. It could be inferred from the greyish to mottled appearance of the profile that drainage is poor over prolonged periods during the winter and spring seasons.

Two soil monoliths were similarly constructed on a moderately well drained Miami silt loam (variant) on The Ohio State University farm, Columbus. This soil was developed in Wisconsin age glaciated till and is classified as a Typic Hapludalf. Table 1 gives some of the physical properties of this soil. The profile has a relatively uniform clay content, except for higher values in the B21 horizon, a somewhat

TABLE 1.—Some Soil Physical Properties of Miami and Toledo Soils at the Chosen Sites.

Soil Type	Horizon	Depth (In.)	Mechanical Analysis %* Sand	Silt	Clay	Bulk Density (g./cc.)	60-cm. Porosity %
Toledo	A_p	0-8	3	46	51	1.22	12
Silty	B1g	8-13	3	43	54	1.39	4
Clay	B21g	13-20	4	41	55	1.43	4
	B22g	20-30	3	38	59	1.45	2
	B23g	30-38	2	40	58	1.48	2
	C11	38-50	5	48	47	1.49	2
	C12	50-64	3	45	52	1.40	2
Miami	A_p	0-10	17	66	17	1.42	8
Silt	B1	10-14	9	62	29	1.50	7
Loam	B21	14-19	9	58	33	1.49	7
	B22	19-25	15	55	30	1.52	6
	B23	25-30	27	46	27	1.58	6
	B31	30-41	26	46	28	1.53	6
	B32	41-48	28	45	27	—	5
	C1	48-57	29	44	27	1.60	5

*Sand represents particle diameters between 2—.05 mm; silt, .05—.002; and clay, less than .002 mm.

denser layer in the C1 horizon, and a relatively high and uniform drainable porosity.

For both soils, the four chosen depths for the perforated plastic pipes were the lower A_P horizon, the boundary between the B21 and B22 horizons, the transitional B-C horizon, and the upper C horizon. The monoliths were installed in 1963 and experimental data were accumulated during the summer months in 1964 and 1965.

To eliminate as much entrapped air as possible before evaluating the hydraulic conductivity, the profiles were wetted to a 6-foot depth by trickling water on the surface of the monolith for several days before an experimental run. The rate of water addition was not sufficiently large to cause ponding. Just prior to an infiltration run, water was added to the lowest piezometer level (60-inch depth) until water rose in the piezometers at the next higher level. Water was then added to piezometers at the latter level and the same procedure was followed for this and other levels until water ponded on the ground surface. A constant level of ponded water was then maintained on the surface.

Quick ponding instead of the above-mentioned procedure invariably resulted in large amounts of entrapped air, especially in the upper soil horizons, and in lower infiltration rates. In the Miami soil, deep seepage was sufficient to yield measurable infiltration rates and hydraulic gradients. But the Toledo soil monolith contained layers of very low conductivity and it was necessary to pump out the lowest piezometers to provide measurable differences in hydraulic head at the various piezometer levels.

To evaluate the hydraulic conductivity of a particular layer, Darcy's equation for one-dimensional flow was assumed to apply to a homogeneous soil:

$$v = Q/AT = K\ (\phi_1 - \phi_2)\ /L \qquad (1)$$

where:

ϕ = Elevation of water in the piezometer tube as measured from a horizontal datum plane. Sometimes called "piezometric head" or more simply "head".

ϕ_1, ϕ_2 = Head measured in tubes inserted at upper and lower faces of a soil layer, respectively.

L = Thickness of the layer. The units for ϕ and L must be the same.

Q = Volume of water percolating through the entire monolith of cross-sectional area A in the time interval T during steady state flow. The units for Q and A are cubic inches and square inches, respectively.

A = Cross-sectional area of layers (or monolith) in inches.

T = Time.

v = The flow velocity as defined by Q, A, and T.

At various times, the head (ϕ) was measured in all piezometers along with the steady-state volume of water (Q) entering the monolith. Water levels in the piezometers were measured with a calibrated flexible blow tube.

The equation of Vimoke and Taylor (8) was used to correct for convergence of streamlines to the perforated tubes when K was evaluated for a layer directly above the pumped piezometers. In the case where the A_P horizon had a relatively high permeability, the hydraulic head loss was too small to be measured accurately. The hydraulic conductivity of such a layer was evaluated by applying the following formula which was developed for heat flow through a series of slabs with different thermal conductivities (10):

$$Q/AT = \phi_T \ / \sum_{i=1}^{n} (L_i/K_i) \qquad (2)$$

where:

ϕ_T = Total hydraulic head loss from surface of monolith to the lowest piezometer level. (In case of pumping, to the level of pumped piezometers.)

L_i = Thickness of layer i.

K_i = Hydraulic conductivity of layer i.

The pressure at the pumped piezometers was assumed to be zero (gauge), since an open contact with the atmosphere was maintained through the piezometer tubes during pumping. This appeared to be a sound assumption because a large volume of air was always mixed with the outflow.

RESULTS AND DISCUSSION

The soil hydraulic conductivities (K) reported are those which remained fairly constant over a period of a day. Since K is very sensitive to entrapped soil air and to clogging of pore channels, infiltration periods of 2 or 3 days were necessary to obtain steady-state conditions.

Early in the study it became apparent that rapid ponding of the soil resulted in low infiltration rates (I) and in low K values for most of the soil horizons. This was particularly true for the Miami soil. An example of this phenomenon is given in Table 2. These data show a two- or three-fold decrease in I when the monoliths were ponded rapidly. The K values for different soil layers are more variable than I. In general they show an increase when the soil is slowly wetted from below. Apparently the reductions in I and K following rapid ponding are due almost solely to entrapped air. After wetting by rapid ponding, numerous air bubbles could be dislodged by pressing lightly on the submerged soil surface.

The reductions in I and K are more pronounced in the Miami soil, apparently because greater amounts of air are entrapped. This soil is on a well-drained site and consequently contains larger percentages of air-filled voids (Table 1). Even with initial wetting from below, the

TABLE 2.—Hydraulic Conductivity and Infiltration Rates as Influenced by Rapidity of Ponding.* All Values Are the Average of Three Consecutive Hourly Ones.

Soil	Initial Wetting	Infiltration Rate	Conductivity of Soil Layers			
			0-8″	8-20″	20-40″	40-60″
				(In./Hr.)		
Miami Silt Loam	Rapid	.29	.21	.38	.27	.45
	Slow	.82	1.38	.58	1.16	1.07
Toledo Silty Clay	Rapid	.03	.57	.34	.03	.02
	Slow	.06	.45	.39	.04	.04

*"Rapid ponding" was brought about in 10 to 15 minutes by supplying water from a 55-gallon barrel. "Slow" ponding resulted from slowly wetting upward from the lower piezometer tubes for an hour or more.

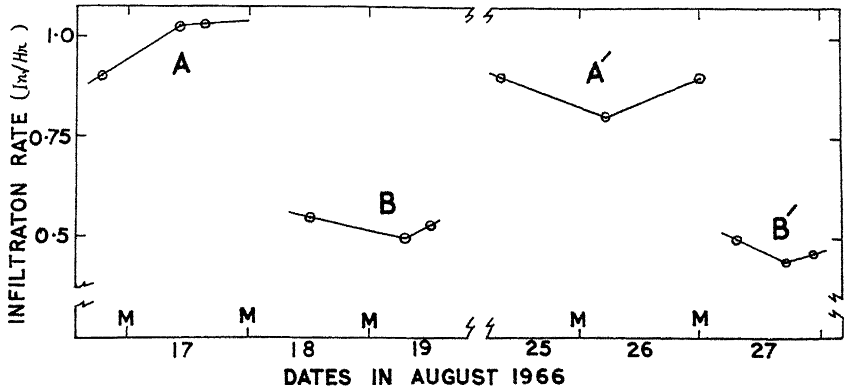

FIG. 2.—Infiltration rates for Miami silt loam as affected by the time interval between successive pondings. Prior to infiltration periods given by lines A and A′, 144 hours had elapsed. Only 10 hours had elapsed prior to infiltration periods B and B′. In all cases, rapid ponding was brought about within 10 to 15 minutes by supplying water from a 55-gallon barrel.

I and K values showed greater deviation from one date to another in the Miami soil than in the Toledo soil.

The time interval for drainage between successive pondings also significantly affected the infiltration rate when rapid ponding was practiced. This is illustrated in Figure 2 for the Miami soil. The I values are reported for four successive infiltration periods, with a variable drainage interval between periods. At the beginning of this particular study, the soil had not been ponded for more than a week. During the first infiltration (line A in Fig. 2), the water supply was inadequate and the ponded water inadvertently drained during the night. Upon reponding 10 hours later, much lower rates were obtained (line B). To see if lines A and B could be reproduced, the soil was ponded 6 days later to yield line A′. The soil was again permitted to drain and then reponded 10 hours later to yield line B′.

Reponding water after only 10 hours of drainage reduced the rate by one-half. Apparently this reduction is also caused by entrapped air. While the mechanism of air entrapment is not clearly understood, the practical implications are more evident. It is apparent that reponding soils after a relatively short drainage period will affect such processes as infiltration, drainage, and deep seepage.

The hydraulic conductivities of different soil horizons in the Miami and Toledo soils are shown in Figures 3 and 4. All values shown in these figures were obtained by slowly wetting the monoliths from below as described earlier. The average K value is plotted as a single point at the average depth of each horizon and is the mean of three separate infiltration runs on each of the two monoliths at each site.

Differences in conductivity rates for a particular horizon were much smaller between the two monoliths than between different infiltration runs in any one of the monoliths. Hence, conductivity values are not

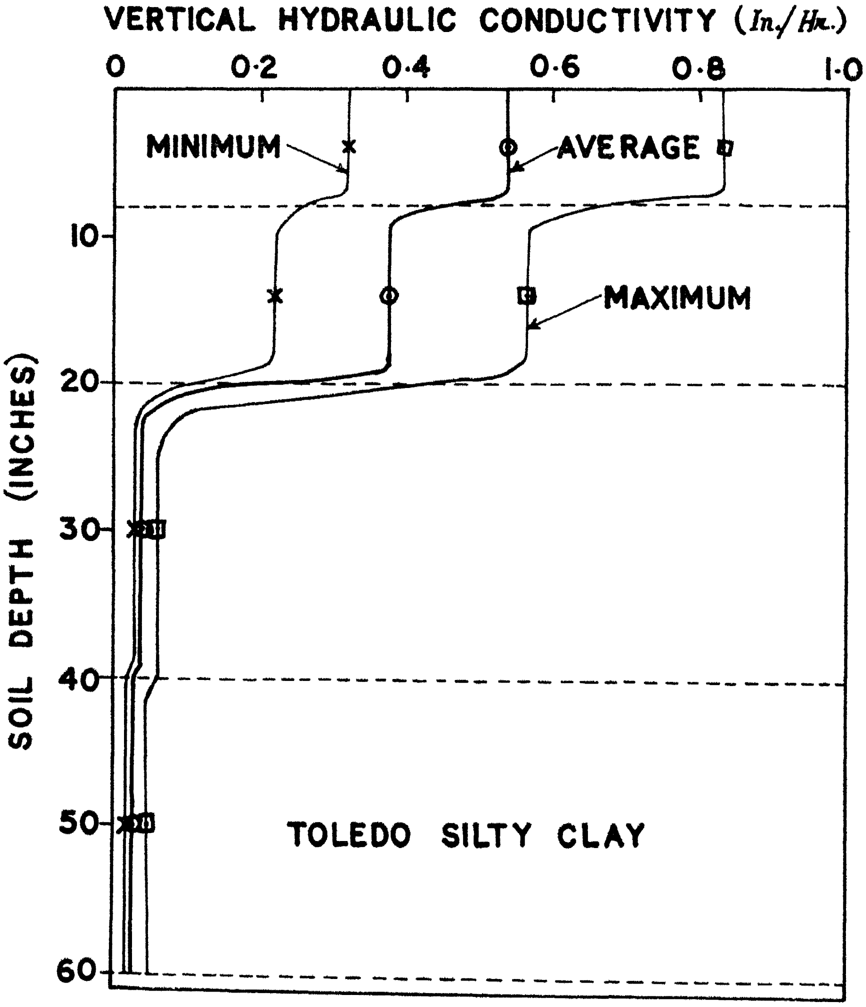

FIG. 3.—The vertical hydraulic conductivity profile of Toledo silty clay as evaluated by ponded flow in field monoliths. The experimental points for the center line represent the average of six values. The horizontal dashed lines indicate depths at which piezometers were installed.

shown separately for the two monoliths but are averaged as if they represented different infiltration runs for a single monolith.

The Toledo soil has much lower conductivities than the Miami. (Note difference in conductivity scales for the two soils.) In addition, the conductivity in the Toledo soil decreases appreciably with depth, being only 0.04 inch per hour at the 20-inch depth. On the other hand, K values for the Miami soil decrease little with depth, remaining about 1.2 to 1.3 inches per hour.

For the Toledo soil, the lower piezometer tubes were pumped during the infiltration runs to bring about a sufficiently high hydraulic

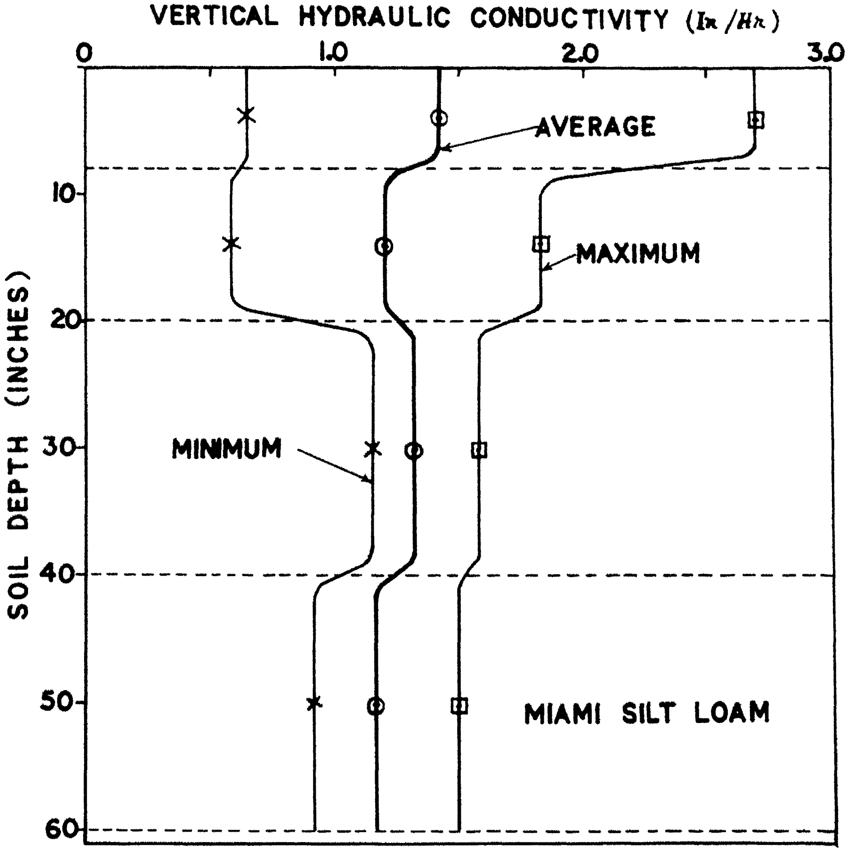

FIG. 4.—The vertical hydraulic conductivity profile of Miami silt loam as evaluated by ponded flow in the field monolith. The experimental points for the center line represent the average of six values. The horizontal dashed lines indicate depths at which piezometers were installed.

gradient (about 1.0) to obtain a measurable infiltration rate. Pumping caused infiltration rates for the Toledo soil to be essentially equal to the conductivity at the 20- to 60-inch depth. Without pumping, the infiltration rate was less than evaporation from the ponded surface and the water level in all piezometers stood at the same elevation as the ponded surface. This was due to low soil conductivities below the monolith as well as within the lower portion of the monolith.

Because the Miami soil was at a well-drained site, no pumping was necessary to obtain a measurable infiltration rate. The infiltration rate for the Miami soil was approximately one-half the conductivities in the upper 60 inches. The infiltration rate was lower than the hydraulic conductivities because one or more soil layers below 60 inches had low conductivity. For example, during infiltration runs the water level was at 20 to 30 inches in the 60-inch depth piezometers. Thus, the average hydraulic gradient inside the monoliths was about 0.5. Hydraulic conductivities are always reported for unit gradient; hence, the higher values for K than for I at this site.

It is difficult to explain the large range in K values obtained for a particular horizon. As described previously, precautions were taken to exclude as much soil air as possible. Other investigators have also reported large variations in field conductivities between different locations in a particular soil horizon. These variations may be as large as 1000% (4).

The major cause for such variations in this study appears to be entrapped air, although intermittent plugging and unplugging of pore channels by suspended materials may play a secondary role. The plow layer and the subsurface layers to 20 inches had the most variable K values. These layers included the Toledo B1g and B21g and the Miami B1 and B21 horizons. The large variability was probably due to large volumes of entrapped air in these layers. Therefore, the prevailing conductivity of these layers should be looked upon as having a range of values rather than being a fixed quantity. The K values were less variable for the lower layers, apparently because natural disturbances in the water-conducting pore space are smaller and because there was less soil air to entrap following ponding.

The K values of the A_P horizon decreased with time in the course of an experimental run. The average decrease over an infiltration period of 2 days was about 25 to 50%. This appeared to be caused by the formation of gases and subsequent plugging of pore channels with air bubbles in the top soil layer. The temperature of the well water used in these measurements was several degrees lower than the soil temperature. Air bubbles could have been formed from dissolution of gases

TABLE 3.—Miami Silt Loam Hydraulic Conductivities in Inches per Hour as Evaluated by Monoliths, by 3-Inch Diameter Soil Cores and by Outflow from Previous Dry Auger Holes. The Soil Conservation Service Assigned Permeability Class Is Given in the Last Column.

Soil Depth (In.)	Monolith Method	3-Inch Soil Cores	Auger Hole Outflow	SCS—Permeability Class
0-8	1.40	3.83	—	"Moderate"
8-20	1.25	4.42	—	(0.20 to
20-40	1.30	1.80	0.06	0.63 in. per hour)
40-60	0.95	0.14	—	

when the water temperature increased. Touching the ponded soil surface after a lapse of time resulted in air bubbles rising to the surface.

An attempt was made to evaluate the hydraulic conductivity of the Miami soil by percolating water through 3-inch diameter soil cores. The cores were taken from all horizons and only a few fect away from the monoliths. The conductivity values were quite variable, as shown by the range of conductivities for each horizon:

Horizon Depth (Inches	Range of Conductivities (Inches/Hour)
0– 8	0.8 – 12.7
8–20	2.4 – 7.4
20–40	0.6 – 3.0
40–60	.03 – 0.6

The range of conductivities was several times greater than those reported in Figure 4 for the soil monoliths. The mean conductivity for each horizon is given in Table 3. The soil core method gave conductivity values three to four times higher in the 0 to 20-inch depth than the monolith method. Comparable values were obtained by both methods in the 20- to 40-inch soil depths. The soil cores gave much lower values than the monolith for the 40- to 60-inch depths.

The last column in Table 3 reports the permeability class assigned by the Soil Conservation Service.[4] The "moderate" classs includes the conductivity range between 0.20 and 0.63 inch per hour and this particular site is probably more permeable than the regular members of the Miami soil series. The Soil Conservation Service criterion for permeability classes gives greatest emphasis to the most slowly permeable horizon in the solum.

[4]Personal communication with Donald E. McCormack, State Soil Scientist (Ohio), Soil Conservation Service, U. S. Dept. of Agriculture.

Soil conductivities of the upper B horizon at the Miami site were also measured by outflow from previously dry auger holes. The depth of the auger holes was 30 inches. There was no natural water table within 6 feet of the ground surface. Water was ponded 15 inches in the auger hole and the hydraulic conductivity was calculated from the outflow rate by the procedure given by Glover (6). The average value was 0.06 inch per hour (Table 3). This value was only 1/20 of those measured by the monoliths and only 1/10 of the steady-state infiltration rates. Because of this wide discrepancy, no further attempt was made to measure conductivities at other depths by auger holes.

Hoffman and Schwab (4) reported soil conductivities at the Toledo site. Their values were derived from a consideration of tile flow rates and the midplane water table height above the drains. Their values ranged from 0.2 to 1.2 inches per hour for the 0 to 8-inch soil depth, from .02 to .08 inch for the 8- to 20-inch depth, and were less than .02 inch per hour for the 20- to 40-inch depths. As shown in Table 4, their mean conductivity values were 0.68 inch per hour for the 0 to 8-inch horizon and 0.04 inch per hour for the 8- to 20-inch depths. Their conductivities agree quite well with those obtained by monoliths in this study.

In a previous study by Taylor, Goins, and Holowaychuk (7) on the Toledo soil, an *equivalent conductivity* of 0.43 inch per hour was obtained (Table 4.) This value was based on water removal rates by drains and midplane water table elevation and represented the equivalent soil conductivity in the upper 36 inches. It agrees quite closely with the monolith conductivities for the 0 to 8-inch and 8- to 20-inch

TABLE 4.—Soil Hydraulic Conductivity in Inches per Hour of the Toledo Silty Clay as Evaluated by Monoliths in This Study and by Drain Outflow Rates and Midplane Water Table Elevations. The Soil Conservation Service Assigned Permeability Class Is Given in the Last Column.

Soil Depth (In.)	Monolith Method	Drain Outflow: Hoffmann and Schwab (4)	Drain Outflow: Taylor, et al. (7)	SCS Permeability Class
0-8	0.55	0.68	↑	"Slow"
8-20	0.40	0.11	0.43*	(.063 to 0.20 in. per hr.)
20-40	0.04	0.02	↓	
40-60	0.02	—	—	

*Equivalent hydraulic conductivity for upper 36 inches of soil.

soil depths. Since these are the soil depths which have conductivities of appreciable magnitude, tile flow rates are probably dominated by conductivities of these layers.

The Soil Conservation Service's assigned permeability class is shown in the last column of Table 4. Based on the other information in this table, it appears that the assigned permeability class is appropriate.

The effect of swelling pressures exerted by the wetted bentonite was not evaluated in this study. Such effects would tend to reduce the pore diameters and consequently the conductivity. It might be expected that such pressures would be dissipated over 2 or 3 inches of soil adjacent to the walls. In such case, the soil cross-sectional area affected would be roughly 4 square feet or 16 percent of the monolith cross-sectional area.

Excavation around one of the monoliths on the Toledo soil 1 year after installation revealed no visible evidence of soil compaction near the bentonite liner. Similarly, there were no protusions of bentonite into the soil, as one might expect from a plastic material like bentonite when subjected to pressure. If 16 percent of the soil volume was no longer contributing to any water flow due to compaction, the conductivity could also be expected to decrease proportionately. The resulting error is much smaller than that expected from field measurements of conductivity and it cannot be considered a major disadvantage to the monolith method.

A comparison of methods for evaluating field conductivities is difficult because there is no absolute standard and field soils are extremely variable. This study was faced with the same difficulty. It appears, however, that a method for determining conductivity would be more reliable and useful when the following conditions are met:

1. Reproducible conductivity values can be obtained with a small number of samples.
2. The measured conductivity is based on flow through a large and well-defined cross-sectional area. This is aided by unidirectional flow.
3. Positive pressures exist throughout the entire soil region in which K is being measured.
4. The measured values of K are applicable to the intended use.
5. The method is simple and practical.

On the basis of these criteria, the monoliths utilized in this study meet conditions 1, 2, and 3 reasonably well. While the two monoliths at each site gave closely reproducible values, conditions at other sites may require larger cross-sectional areas or more replicates. Condition 4 is only partially met by the monoliths. Conductivities and infiltration rates determined by the monoliths would be directly applicable to infiltration, deep seepage, and other situations where vertical flow predominates. Condition 5 is generally not met by the monoliths because of the relatively large investment in time and labor. It would appear, however, that the use of monoliths might be justified for situations such as the following:

- As a preliminary study for more costly operations which are dependent on flow characteristics in soil. An example would be a drainage installation or an aquifer recharge operation.
- To provide hydraulic conductivity data for a few selected soils in an area. These data would provide benchmark information. Soil morphological data might then be used to estimate the conductivity of other soils.

SUMMARY

The vertical hydraulic conductivities of a Toledo and a Miami soil were determined in undisturbed soil monoliths. These were rectangular pillars of soil with a 5- by 5-foot cross-section area and a depth of 5 feet. The monoliths were in natural contact with the surrounding soil at their base. They were surrounded with a blanket of impervious clay to prevent lateral water movement. Horizontal tubes were placed at various depths to measure the piezometric head and to serve as horizontal drains when necessary to increase infiltration by pumping. From the steady-state infiltration rates of ponded water and the concurrent piezometric head measurement, the vertical conductivities were calculated by the Darcy equation.

Rapid ponding of water on the monoliths resulted in lower infiltration rates and conductivities than slowly wetting them from their base upward. Reponding water on the monoliths after only a few hours of drainage also lowered infiltration rates and hydraulic conductivities. Both phenomena appeared to be related to the amount of air entrapped during ponding.

The hydraulic conductivity profiles of the Toledo and Miami soils are distinctly different. The Toledo soil had much lower conductivities throughout the upper 5 feet than the Miami. In addition, the conductivity of the Toledo soil decreased to only .04 inch per hour at the 20- to 40-inch depths. The conductivities of the Miami soil showed little decrease with depth, remaining at 1.2 to 1.3 inches per hour.

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Research is conducted by 13 departments on more than 6200 acres at Center headquarters in Wooster, nine branches, and The Ohio State University.

Center Headquarters, Wooster, Wayne County: 1953 acres

Eastern Ohio Resource Development Center, Caldwell, Noble County: 2053 acres

Jackson Branch, Jackson, Jackson County: 344 acres

Mahoning County Farm, Canfield: 275 acres

Muck Crops Branch, Willard, Huron County: 15 acres

North Central Branch, Vickery, Erie County: 335 acres

Northwestern Branch, Hoytville, Wood County: 247 acres

Southeastern Branch, Carpenter, Meigs County: 330 acres

Southern Branch, Ripley, Brown County: 275 acres

Western Branch, South Charleston, Clark County: 428 acres