INVESTIGATION OF THE INFILTRATION RATES OF LOESSAL SOILS IN NORTHWEST MISSISSIPPI

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INTRODUCTION

The percolation rate of fluids into soils is a phenomenon important to many disciplines such as agriculture, geohydrology, environmental engineering, etc. Percolation rates relate how much of a fluid enters the subsurface time-wise and how rapidly it propagates vertically and laterally. Loess and loessal soils are the primary surface deposits in western Mississippi on the bluffs and uplands adjacent to the Mississippi River floodplain. As a result of the recent economic growth in the northwestern counties of Mississippi, the presence of the loessal soils poses a threat for groundwater pollution due to surface contaminants (i.e. spills, pesticides, etc.) percolating relatively rapidly into and through these porous soils. The majority of Mississippi residences receive their potable water from groundwater that may flow at some depth below loess soils. This investigation evaluated the infiltration rate of loess and loessal soils and assessed the testing methods that are commonly used in the evaluation of infiltration rates.

Loessal soils are less dense and coarser grained than other fine-grained soils. Previous investigations have documented that loess and loessal soils have relatively high permeabilities especially vertically due to the fabric of the wind blown and deposited soils. Infiltration rates into loess should vary as the mineralogy and grain size distribution changes from classic coarse grain silt at the bluffs overlooking the Mississippi floodplain to a fine grained, silt-clay admixture as these mantling deposits are traced eastward over the uplands.

To assess variation in percolation rates due to changes in the character of loess, a study was initiated in northwestern Mississippi to conduct in situ tests north and south along the loess bluffs and eastward from the bluffs. Five test sites throughout Panola County, Mississippi, were investigated for their infiltration rates, along with the soil properties of the loess in January and February of 1997. At each of the test sites, the Open Double Ring Infiltrometer (ODRI), the Two-Stage Borehole permeameter (TSB), and the Soil Science Percolation tests were conducted to evaluate the infiltration rate of loess and loessal soils. The percolation rates were assessed at six and twelve inches below the surface at each of the test sites by the three above mentioned testing methods. When the testing apparatuses were installed, a representative soil sample was taken and preserved for soil laboratory analysis. The soil laboratory analysis consisted of grain size analysis, X-ray diffraction, and the Atterberg Limits.

TEST SITES

In the state of Mississippi, the delineation of the extent of loessal soils has been identified through soil associations. The loess bearing soil associations in Mississippi are the Memphis Silt Loam, the Loring Silt Loam, and the Grenada Silt Loam (Caplenor et al. 1968). Each of the test sites was primarily selected by the extent of the loessal soils. The second consideration in choosing the sites was their north south and east west distribution to allow for spatial analysis within the infiltration rates and soil properties. The last consideration in choosing the research sites was the access to the land.

The Spring Hill Church (SHC) and the West Spring Hill Church (WSHC) sites are located Southwest of Batesville, Mississippi, and are part of the Boyles Estate. The Keith Jenkins (KJ) site is located to the northwest of Batesville, Mississippi, while the Keith Jenkins #2 (KJ#2) site is located to the southwest of Como, Mississippi, and both are owned by Mr. Keith Jenkins of Batesville Mississippi. Southeast of Batesville, is the final field site which is the Goodwin Creek (GC) site. The Goodwin Creek site is currently part of a research effort of the National Sedimentation Laboratory (NSL) located in Oxford, Mississippi.

All of the research sites are known to contain loess derived sediment. The Goodwin Creek site was the only site that a specific depth of the loess deposits was known. At this site, the tested medium was approximated to be four feet thick by Dr. Steve Dearby with the NSL. Dr. Dearby also indicated that he believed that the underlying unit caused perched water to occur.

In addition to the above-mentioned sites there are two other sites that have had data collected on them. They are the Nelson Farm and the Short Farm. Both of these sites have ODRI data, while the Nelson Farm also has TSB and Soil Science Percolation test data. The ODRI data was collected by Mr. Craig Chapman in the spring of 1996. The Nelson

Farm TSB and Soil Science Percolation data was collected in the summer of 1996 by Mr. Charles Williams, Mr. Bart Robinson, and the author. The extent of the loessal soil in Tate and Panola Counties, along with the location of each of the test sites, can be seen in Figure 1.

THEORY OF TESTING METHODS

In this investigation, three different percolation testing methods were used. The testing methods are the Soil Science Percolation Test, the Open Double Ring Infiltrometer, and the Two Stage Borehole Infiltrometers. All three of these methods operate on the same principle, free flow produced by a self-imposed head, and each testing method is governed by Darcy's law with a constant value for the hydraulic conductivity.

Darcy's Law is commonly written as:

$$Q = -kiA \qquad (1)$$

Where:

- Q= Flow (L^3/T)
- k= Hydraulic coefficient (L/T)
- i= Hydraulic Gradient (L/L)
- A= Cross Sectional Area Perpendicular to Flow (L^2)

Open Double Ring Infiltrometer

The ODRI consists of two metal rings made of 0.075 inch galvanized steel and is 16.75 inches in height. The outer ring and inner rings are 24 and 12 inches in diameter respectively, (Figure 2). The ODRI is recommended for testing materials with a vertical hydraulic conductivity larger than 10^{-6} cm/sec (Boutwell et al. 1995). This testing method utilizes a one-dimensional flow from the surface that is in the vertical direction. This is accomplished by the outer ring controlling the lateral spreading of the inner ring's water, which is where the readings are taken. The Green - Ampt model for flow in unsaturated soils is the base for the data reduction. The following are assumptions that must be made for the Green-Ampt model to be applicable:

1. The infiltrating water is consumed in filling the air void space of the soil between the source and wetting front.
2. All hydraulic head loss occurs between the infiltration surface and the wetting front.
3. Soil suction only acts at the wetting front if present (Boutwell et al. 1995).

These assumptions allow for the following equations to be applied:

$$I = k_v\ (1+H'Z_w) \qquad (2)$$

$$Z_w = \int^t (I/n_a)\ dt \qquad (3)$$

$$k_{vi} = n_a H'(Z_w/H') - \mathrm{Ln}\ (1+Z_w/H) \qquad (4)$$

$$H' = H + H_s \qquad (5)$$

Where:

- I= Infiltration rate (L/T)
- k_v = Vertical Hydraulic Conductivity
- Z_w = Penetration of 100% saturation front into sample (L)
- t= Time (T)
- n_a = Air Porosity of Soil (L^3/L^3) assumed to be constant in Eq. (2)
- H = Head of water above an infiltration surface (L)
- H_s = Head due to Soil Suction (L)

In testing infiltration rates, the ODRI has a disadvantage that vertical flow assumption is only valid during short test runs (Boutwell et al. 1995).

Two Stage-Borehole Permeameter

The TSBs used in this investigation were composed of a four-inch schedule 40 PVC casing and a six-inch clear PVC standpipe (Figure 2). The TSBs are a modification of the original design by Soil Testing Engineers, Inc. in Baton Rouge, Louisiana. The original TSBs are of the same setup except they consist of a one inch standpipe which is useful in the investigation of a medium that has an infiltration rate on the order of 10^{-7} cm/sec or less. This testing method applies a free-flow three-dimensional flow field as apposed to the one-dimensional flow that the ODRI applies. The head applied during this testing procedure is usually three to four times that of the ODRI and minimizes the relative effect of soil suction (Boutwell et al. 1995). Stage 1 and 2 of the testing procedure allows for the vertical and horizontal infiltration rate to be evaluated, respectively. Stage 1 of the testing procedure utilizes case "C" of Hvorslev-Image equation and allows for the vertical infiltration rate to be evaluated. Case "C" of Hvorslev-Image equation is written as:

$$k_v = (\Pi d^2/11mD_1)\ [(1+a(D_1/4mb_1)]\ \mathrm{Ln}\ (H_1/H_2)/(t_1-t_2) \qquad (6)$$

Where:

- d = Inside Diameter of the Standpipe
- $m = (k_h / k_v)^{1/2}$
- D_1 = Inside Diameter of the casing
- a = -1 for a permeable bottom boundary
- a = 0 for infinite depth to bottom boundary

$a = 1$ for an impermeable bottom boundary
b_1 = Thickness of test medium below base of casing

Stage 2 of the TSB test utilizes case "G" of the Hvorslev equation and allows for the horizontal infiltration rate to be evaluated. Case "G" of Hvorslev-Image equation is written as:

$$k_h = (d^2/16Lfm^2)\ \{2Ln\ (u1)+a\ Ln\ (u)_2+p\ Ln\ (u_3)\}Ln\ (H_1/H_2)/(t_1-t_2) \qquad (7)$$

Where:

L = Length of Stage 2 extension
$f = 1\text{-}0.5623\ Exp\ (-1.566\ L/D)$
$u_1 = \{mL/D_2 + (1+(mL/D_2)^2)^{1/2}$
$u_2 = \{4mb_2/D_2+mL/D_2 + (1+(4mb_2/D_2 +mL/D_2)^2)^{1/2}\}/\{4mb_2/D_2-mL/D_2 + (1+(4mb_2/D_2-mL/D_2)^2)^{1/2}\}$

$u_3 = \{mL/(D_2+2T)+(1+(mL/(D_2+2T)^2)^{1/2}\}$
$p = k_h/k_s$
k_s= Permeability of Smeared Zone
T = Thickness of the smeared Zone (0.6 cm = 0.25 in.)
D_2 = Diameter of Stage 2 extension
b_2 = Distance from center of Stage 2 Cylinder to underlying boundary

The smearing of the infiltration surface is a concern during stage 2 and can produce values that are low for the hydraulic conductivity. This can be avoided by etching the surface with a sharp object during installation.

The Soil Science Percolation Test

The Soil Science Percolation test is composed of digging a four to a twelve-inch diameter hole in the ground. Then a sharp instrument, a knife blade, was used to scratch the bottom of the hole to remove any smear that might have been caused in the excavation. Then the hole is carefully filled with water to ensure that scouring does not occur. Once the hole is filled, the surrounding soil is allowed to saturate and swell. The saturation time is to last at least four hours. Once the saturation time has passed, the percolation holes were carefully filled again and the water was allowed to infiltrate. Over the next several hours, water depth measurements were taken and the infiltration rate is calculated by the following:

$$I = {}_{d1}\text{-}d_2/t_2\text{-}t_1 \qquad (9)$$

Where:

d = the depth of water in the hole
t = time

TESTING PROCEDURE

The testing procedure at each of the sites consisted of three days. Day one of the tests was the placement of the instruments in the ground and the collection and preservation of samples. The second day, each test was initialized and measurements were taken. On the third day, the final measurements were taken and the instruments were removed from the ground. At each of the sites, the instruments were placed at two depths, six and twelve-inches. Along with the infiltration data, a representative soil sample for each of the testing depths was collected. In the soil sampling, the soil of each excavation was examined in the field to ensure representative samples were taken.

Day 1

The ODRIs were installed by placing a four by four-piece of wood across the ring and then driving the ring into the ground with an 8-pound mall. The six-inch instrument was driven from the surface until the rings extended six inches below the surface. In placing the twelve-inch instrument in the ground, the surface was first excavated approximately 8 inches and then driven into the ground as the six-inch instrument was.

The TSBs were installed by first excavating the ground by the use of a post hole digger to approximately five and eleven inches. Then a flat bottom auger was used to complete the hole to the desired testing depth. At this point, a hoffer tube was pushed into the bottom of the two boreholes where stage two was to be evaluated. The hoffer tube was pushed into the ground approximately 4 inches. This sample was preserved for natural water content to be determined. In the two stage holes, a second flat bottom auger of a four-inch diameter was used to extend the stage two holes an additional 7.5 in. This allowed for horizontal infiltration data to be collected. The soil that was excavated during this extension was the soil that was preserved for laboratory analysis. The bottoms of the holes were etched with a pocket knife to eliminate any smear that might have occurred. Then, a pea-gravel filled stocking was put into the borehole to eliminate scouring during the testing run. The casing was then placed in the hole ensuring to be level. The outer annuluses of the boreholes were then sealed by adding layers of Bentonite clay and water while tamping to allow for a seal to form between the casing and the in situ material. This Bentonite seal was then allowed to hydrate overnight.

The soil science percolation test was set up by digging holes with the post hole digger to various depths. The holes were then identified and the diameter and depth were recorded.

The bottoms of these holes were also etched by a pocket knife to eliminate any smear that might have occurred and then covered with pea-gravel.

Day 2

Upon arriving at the site, each of the TSBs were investigated to ensure that hydration had occurred. The filling order at each test site was not consistent, but the method of filling was. The TSBs were the first testing method to begin at each of the sites. The first TSB was filled to a mid point of the standpipe. The initial water depth and start time was determined and recorded. In the beginning of the tests, measurements were taken at 30 second intervals moving to one, two, five, ten, fifteen, and thirty minute intervals, and then to hours. Once the measurement interval reached 10 minutes, the next TSB test was begun. This was continued until all TSBs were running and exceeding 10 minute intervals between readings. Throughout the testing period, the seals of all PVC joints were examined for leakage along with seepage around the casing. If the water level in the standpipe was getting low, water was added once the measurement was taken. The new head level was recorded.

The ODRIs were started in a similar fashion to the TSBs. The inner ring was initially filled allowing for the overflow to run into the outer ring. In pouring the water into the inner ring, the water was poured against the inner ring to dissipate the energy to minimize the scouring. Readings were taken in a similar fashion as that reported in the TSB methods. Water levels were monitored and water was added and recorded as needed.

The Soil Science Percolation Test was the last test to be initiated at each of the sites. The holes were initially filled and allowed to saturate for a minimum of four hours. Once the saturation portion of the test was conducted, the holes were filled once again and every half hour water depth measurements were taken and recorded. If needed, water was added and recorded.

Once each of the TSBs and ODRIs had been running for at least six hours, the instruments were filled, if needed, and left running overnight. The Soil Science Percolation Tests were usually finished on day 2.

Day 3

Upon returning to the site, each instrument was examined for leakage and a measurement was taken and recorded. The instruments were then removed from the ground and the holes were filled in.

RESULTS

Soil Properties

The soil laboratory results indicate that the loessal soils examined in this investigation consisted mainly of silt size particles. All samples contained greater than 70% of silt size particles. According to the Unified Soil Classification, the soil falls predominantly in the low plasticity silt range. The soil properties found in this investigation are shown in Table 1. The Grain size analysis results can be seen in Table 2. The mineralogy of the samples was composed of predominantly quartz with some muscovite and traces of kaolinite at each of the sites. Traces of montmorillonite were found at the 12" SHC, the 6" WSHC, the 12" WSHC, and the 6" KJ sites.

Infiltration Rates

The infiltration rates were evaluated at the initial and saturated conditions. The infiltration rates that were determined by the above mentioned testing methods during this investigation have been tabulated (Table 3).

Initial. The initial infiltration rate was evaluated by the TSB and the ODRI. The initial TSB infiltration rate results of loessal soils ranged from 0.2 to 0.706 in/hr in the vertical direction, while the horizontal rate varied from 0.007 to 0.915 in./hr. The ODRI consistently gave a greater than or equal vertical infiltration rate than theTSB in the initial infiltration rates. The ODRI initial infiltration rate varied as much as two orders of magnitude from that of the TSB results. The ODRI had a range of initial infiltration rates during this study varying from 15.0 to 0.326 in./hr.

Saturated. The saturated infiltration rates were evaluated by all three testing methods. The Soil Science Percolation Test results were at least one order of magnitude larger than either of the other two testing methods at each of the sites. The Soil Science Percolation Test indicated a range of infiltration rates of 6.63 to 0.714 in/hr. The saturated infiltration rate ob- tained by the TSB in this investigation ranged from 0.004 to 0.089 in/hr in the vertical direction; the horizontal ranged from 0.002 to 0.741 in/hr. Vertical infiltration rates obtained by the ODRI ranged from a maximum of 0.691 in./hr to a minimum of 0.015 in./hr.

All of the infiltration values obtained during this investigation fall within the range of magnitudes of hydraulic conductivity and permeability values of loess deposits given by Freeze and Cherry (1979).

DISCUSSION

The results of the previous studies done by Chapman (1996) and Rohs et al. (1996) support the range of values that have been indicated in this study. See Table 4.

A lateral variation in the grain size in this eolian deposits from north to south along the Mississippi River and eastward from the river was expected.. The percentage of fine particles increased slightly southward, but no clear trend could be noticed eastward from this study. The other soil properties investigated had no trend that was noticed. With depth, the soil showed more silt properties which were to be expected due to the natural process of weathering.

It is commonly accepted that coarse soils, natural water content, and uncompacted soils encourage high infiltration rates. It is also commonly accepted that depth depth of ponded water influences the infiltration rate of satu rated soils. During this investigation, the changes in soil properties from site to site were very small, the infiltration rate found by each of the testing methods were highly variable, and no direct relationship could be drawn between the soil properties and the infiltration rate. Different testing methods did allow for testing of percolation rates under different hydraulic head values. The amount of hydraulic head applied to the soils by ponded water appears to be negligible at the saturated state.

Elrick and Reynolds (1986) reported that the percolation rate obtained through the use of the Soil Science Percolation Test depended on several test parameters and not solely the medium which was being tested. The test parameters that influenced the percolation rates were stated to be the radius of the test hole, the depth of water in the test hole, the depth of the water surface in the test hole below the soil surface, and the depth of the water table and impermeable layers, if present, below the bottom of the test hole. As a result of this, it is not believed that the Soil Science Percolation Test results are as valid as the TSB or ODRI testing methods.

The TSB and ODRI results both varied by an order of magnitude during this investigation. Neither test method was consistently higher or lower than the other. The ODRI test can be conducted the same day as installed at the sight. It is recommended that the TSB be allowed to saturate for at least 12 hours if not overnight. As more depth is needed for investigation, the ODRI becomes more difficult to install.

As a result of this investigation the time and depth of investigation are the two most important factors in the determining the most effective testing procedure.

REFERENCES

Boutwell, G. P. The STEI Two Stage Borehole Field Permeability Test, March 12, 1992.

Boutwell, G. P., K. L. McManis, and N. S. Mysore. Field measurment of infiltration rate, June 30, 1995.

Caplenor, C.D., R.E. Bell, J. Brook, D. Caldwell, C. Hughes, A. Regan, A. Scott, S. Ware, M. Wells. Forests of West Mississippi as affected by loess. Mississippi Geological Survey. Mississippi Geological Economic, and Topographical Survey Bulletin, 111.

Chapman, C. Infiltration in loessal soils in Northern Mississippi. Masters Project, University of Mississippi, April 16, 1996. Unpublished Report.

Dearby, S. 1997. Personal Communication.

Elrick, D. E., and Reynolds, W. D., Analysis of the Percolation Tests Based on Three Dimensional Saturated-Unsaturated Flow from a Cylindrical Test Hole, Soil Science, v.142, # 5.308-321. Nov. 1986.

Freeze, R. A. and John. A. Cherry. 1979. Groundwater. Englewood Cliffs, NJ: Prentice Hall, Inc.

Rohs, T. S., B. Robinson, and C. Williams. Infiltration Test of the Nelson Farm. University of Mississippi. July 29, 1996, Unpublished Report.

Terazghi, K. and R. B. Peck, 1948. Soil Mechanics in Engineering Practice. New York, NY. John Wiley & Son, Inc.

Table 1. The results of the laboratory soil analysis of this investigation.

Site	Natural Water Content	Plastic Limit	Liquid Limit	Shrinkage Limit	Plasticity Index	Unified Soil Classification
6" SHC	19.59	19.31	25	28.5	5.69	ML-CL
12" SHC	21.57	21.26	29	30.7	7.74	CL
6" WSHC	21.12	22.03	28.6	27.2	6.57	ML-OL
12" WSHC	19.95	23.28	29.85	30.8	6.57	ML-OL
6" KJ	19.94	26.31	27.2	26.4	0.89	ML-OL
12" KJ	22.73	23.95	31.5	27.8	7.55	ML-OL
6" KJ#2	20.61	23.40	31.75	24.6	8.35	ML-OL
12" KJ#2	20.77	24.97	26	27.1	1.03	ML-OL
6" GC	14.45	17.32	18.10	22.8	0.78	ML-OL
12" GC	18.46	18.41	20.5	24.3	2.09	ML-OL

Table 2. Results from the grain size analysis.

Site	% coarse grained	D60 (mm)	D30 (mm)	D10 (mm)	Uniformity Coefficient	Coefficient of Curvature
6" SHC	0.00	0.023	0.006	0.0001	225	16
12" SHC	0.00	0.028	0.006	0.0002	140	6.4
6" WSHC	0.00	0.022	0.006	0.0001	220	17.5
12" WSHC	0.00	0.022	0.009	0.0001	220	36.8
6" KJ	0.00	0.022	0.003	0.0001	220	4.1
12" KJ	0.00	0.022	0.003	0.0001	220	4.1
6" KJ#2	0.00	0.019	0.002	0.0001	190	2.1
12" KJ#2	0.00	0.06	0.008	0.001	60	0.9
6" GC	21.68	0.06	0.017	0.005	12	1.0
12" GC	21.55	0.05	0.016	0.005	10	1.0

Table 3. The infiltration rates that were determined using the TSB, ODRI, and Soil Science Percolation Test.

Site Name	TSB-V (in/hr)		ODRI (in/hr)		TSB-H (in/hr)		Soil Science Percolation (in/hr)
	early	late	early	late	early	late	
6" SHC	failed	failed	3.0	0.133	0.121	0.051	4.125
12" SHC	0.02	0.015	15.0	0.015	0.033	0.047	6.63
6" WSHC	0.68	0.045	1.875	0.105	0.028	0.019	0.714
12" WSHC	0.322	0.039	3.75	0.015	0.234	0.007	1.518
6" KJ	0.611	0.089	2.14	0.04	0.007	0.002	2.47
12" KJ	0.08	0.004	6.06	0.366	0.165	0.741	2.58
6" KJ#2	0.14	0.004	3.46	0.691	0.297	0.019	4.94
12 KJ#2	0.26	0.013	14.25	0.266	0.263	0.123	2.75
6" GC	0.084	0.01	0.326	0.081	0.929	0.024	3.18
12 GC	0.725	0.009	0.938	0.119	0.245	0.046	6.5

Table 4. Infiltration testing results from Chapman (1996) and Rohs et al, (1996).

Location and Depth	Instrumentation	Initial Percolation Rate (in/hr)	Saturated Percolation Rate (in/hr)
Nelson Farm at the Surface	ODRI	1.725	0.828
Nelson Farm at 4 Inches	ODRI	1.287	0.583
Nelson Farm at 12 Inches	ODRI	0.69	0.189
Short Farm at the Surface	ODRI	2.657	0.611
Short Farm at 5 Inches	ODRI	1.5	0.793
Short Farm at 12 Inches	ODRI	2.325	0.456
Nelson Farm at 18 Inches	TSB-V	NA	0.352
Nelson Farm at 18 Inches	TSB-H	NA	16.92

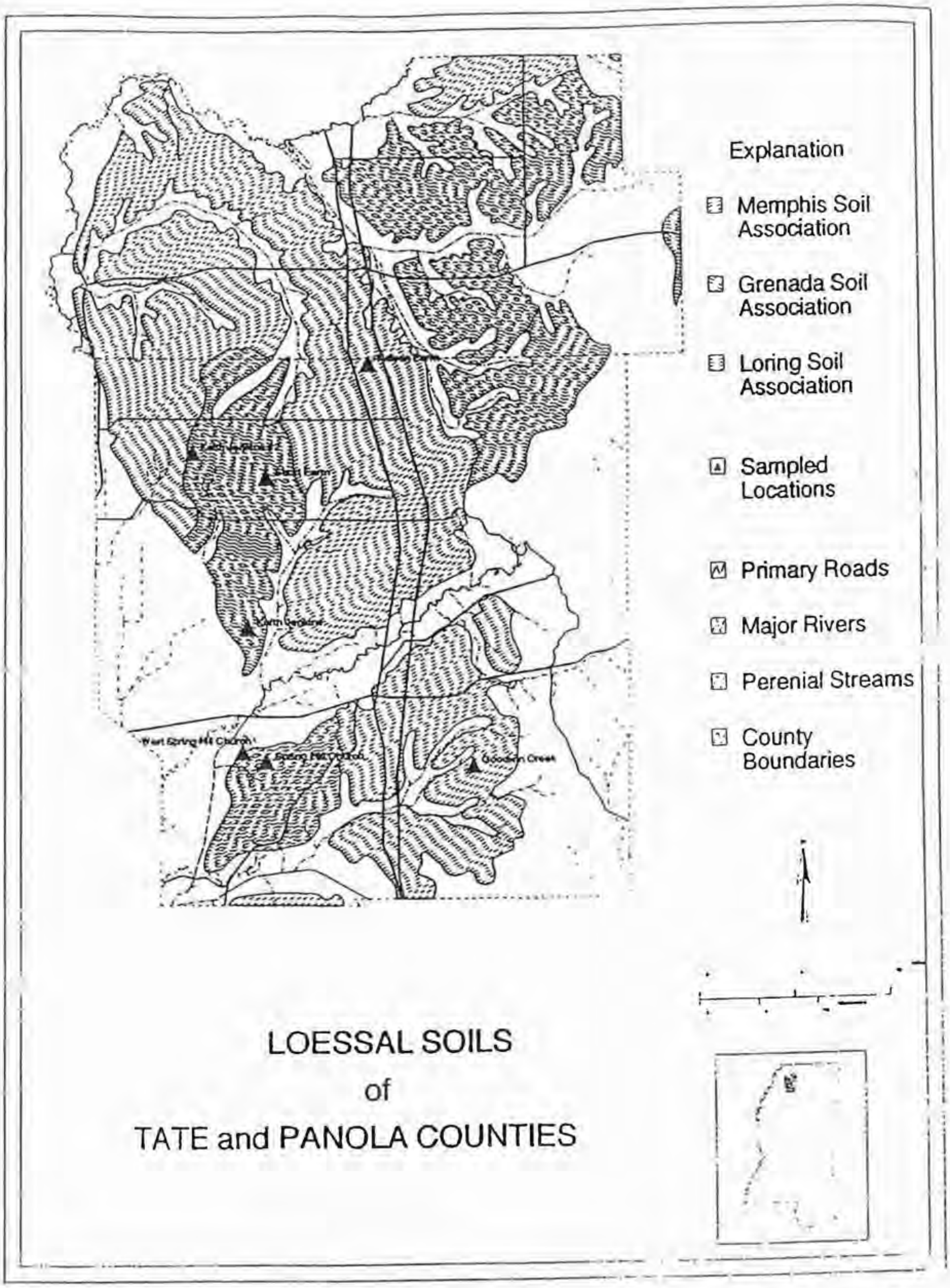

Figure #1 Distribution of Loessal Soils and Site Locations in Tate and Panola Counties of Mississippi (Base Data from MARIS)

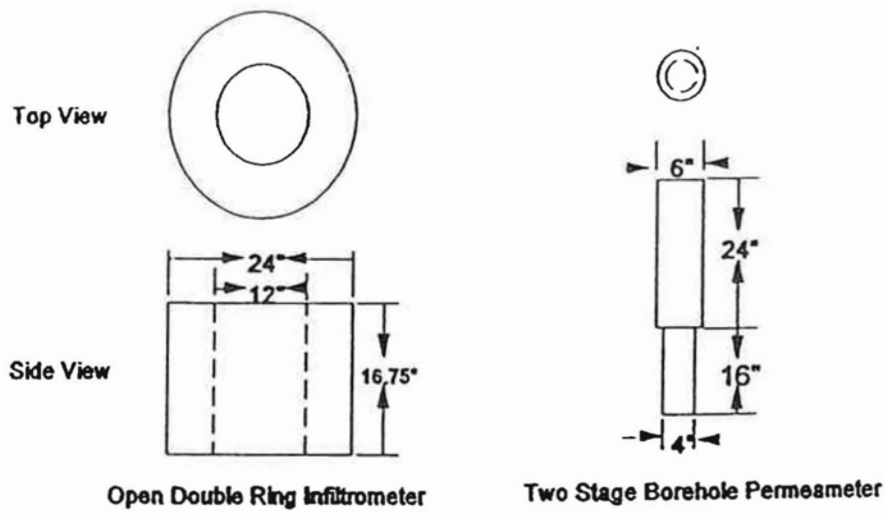

Figure 2. Skematic Sketch of Infiltrometer Equipment.