AG : BOT/85/011
FIELD DOCUMENT 19

Soil Mapping and Advisory Services

Botswana

METHODS FOR THE MEASUREMENT OF PHYSICAL PROPERTIES OF SOIL

MANUAL

FOOD & AGRICULTURE
ORGANIZATION OF THE
UNITED NATIONS

UNITED NATIONS
DEVELOPMENT
PROGRAMME

REPUBLIC OF
BOTSWANA

GABORONE, JANUARY 1990

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Methods for the measurement of physical properties of soil

Manual

by

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Gaborone, 1990

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METHODS FOR THE MEASUREMENT OF PHYSICAL PROPERTIES OF SOILS

1. INTRODUCTION

The evaluation of land for its agricultural potential involves considerations of possible interactions between soil, water, crops, climate and management practice. The physical properties of soil that are relevant for these considerations have to be measured and used along with other required data for the land evaluation procedure. Perhaps, the most significant of these properties are those determining the entry of water and its movement and its retention in the soil, soil aeration, and soil structural stability. Consequently methods for the measurement of infiltration, hydraulic conductivity, bulk density, moisture retention and aggregate stability are described in detail. This information, when collected for the agriculturally important soils and stored in the data base along with the morphological and chemical characteristics, can be used for both, reliable land evaluation exercise, and for agricultural planning as well.

Table I gives the physical properties which are measured and the properties and land qualities that can be derived from the measured values. Although there are alternate methods available for measuring most of these soil properties, each one differ in the level of accuracy of the results and the circumstances to which it is most suited. The methods described here are ones which are commonly used and which give results that are reliable for land evaluation purposes.

Table 1

Measured and derived soil physical properties

Measured properties	Derived properties and land qualities
Infiltration	Rainfall acceptance
Hydraulic Conductivity	Total Porosity
Bulk density	Macro porosity
Moisture retention	Pore size distribution
Aggregate stability	Aeration
	Field Capacity
	Wilting point
	Moisture availability
	Erodibility

The procedures given are those commonly adopted for the measurement of soil physical properties and described extensively in the literature. However, some modifications are made to suit local conditions.

1.1 Soils and Site Selection

The selection of a soil profile for characterization is based on the information available from soil surveys and soil mapping that have been completed. Typical soils that are considered agriculturally important or that occur extensively are selected on the recommendation of the soil surveyor. As the same type of soil may occur in many different parts of the country, the location is decided on the basis of accessibility, availability of water for infiltration and other facilities necessary for carrying out the measurements with reasonable accuracy.

2. METHODS

2.1 INFILTRATION (The double ring infiltrometer method)

2.1.1 Introduction

Infiltration is the vertical entry of water at the surface and its subsequent movement downward in the soil. The purpose of the double ring infiltrometer method is to characterize the vertical entry of water at the soil surface and should not be confused with hydraulic conductivity or permeability which is a measure of the ability of a soil to transmit water in all direction, horizontally as well as vertically.

Infiltration characteristics of soils provide useful information on acceptance of rainfall into soil, water logging of land, and erosion hazards. It is required for designing on-farm irrigation system such as optimum field length, duration of irrigation etc.

The principle of the method is to observe the fall of water level in the inner of two cylinders driven concentrically into the soil surface. The use of double rings with measurements confined to the inner ring minimizes error due to flow divergence other than vertical. In this way, the experiment recreates on a small scale the real required conditions.

The measurements can be carried out on the top soil as well as on each of the subsoil horizons and substratum. In the latter case, since the soil above the horizon is removed,the outer cylinder is replaced by the pit walls. It is generally accepted that the infiltration is regulated by the least pervious layer at shallow depth. If such a hard subsurface horizon exists in the profile, one additional measurement of infiltration should be carried out on top of this layer after removing the soil above it.

Infiltration rates are generally high during the initial stages and reduces to a constant value, with time. Infiltration measurements should be continued for at least four hours even if the readings indicate that the constant rate has been reached earlier.

The method is not well suited to strongly cracking soils such as vertisols. If the area enclosed by the cylinder has a large crack interconnected with a system of cracks outside the cylinder, the infiltration will be too high. If no cracks are enclosed, the infiltration will be too low as cracks are intrinsic feature for such soils. In vertisols, the cracks close up completely during wet seasons due to soil expansion. Infiltration rates of vertisols in such conditions will be almost zero as typical for heavy clays. Consequently as a a general practice no infiltration measurements are made on vertisols.

Measurements should be replicated at least three times at each site and reported so that the degree of variability in the infiltration characteristics can be known.

It is recommended to make the tests close to a sampled profile or to sample and describe the profile close to the tests, so that complete data on the soil are available. In any case, factors influencing the infiltration rate should always be recorded including texture, surface crusting, presence of a compact horizon, vegetation, moisture condition and history of land use.

2.1.2 Equipment

- 3 inner and 3 outer steel cylinders, 25cm high with a diameter of 28, 30 and 32 cm for the inner cylinders and 58, 60 and 62 cm for the outer cylinders respectively. The surfaces of each cylinder are smooth and one end of each cylinder is beveled from outside to inside.
- 1 steel driving plate for inner cylinder and for outer cylinder.
- Vessels for storing and transporting water (drums, buckets, mugs).
- Heavy hammer.
- 3 scales.----with readings at least 1mm.
- Duster, cloth or plastic sheet.
- Auger and spade.
- Scissors or shears for clipping vegetation.
- Watch or stop watch.
- Recording sheets, graph paper

2.1.3 Procedure

Install the pairs of cylinders concentrically with each pair 3 to 10 meters apart on sites representative of the soil to be tested. Sites near or on foot paths, close to base of trees, near or on old termite mounds, or visible cracks or insect holes should be avoided.

Clip vegetation and remove loose material which would float. Drive the cylinders into the soil to a depth of 10 to 15 centimeters by placing the driving plate over the cylinder and hitting with the hammer on the central point. The penetration of the cylinders into the soil must be uniform and vertical. To achieve this, draw a line along the outer circumference of the cylinders, parallel to and above the cutting edge, to which the cylinders are to be driven into the soil.

Rotate the direction of the hammer blows and observe the distance between the soil surface and the circular line around the cylinder to ensure uniform penetration.

Draw a vertical line on the inside of the inner cylinder from the ground surface to the top of cylinder and a short horizontal line intersecting the vertical line at a height to which water is to be filled (about 10-15cm from ground surface). The horizontal line is the reference mark from which water intake is measured by placing the scale along the vertical line. Get everything ready for all the replicates before starting the test. (Figure 1)

Place a plastic sheet (or duster or cloth) on the bottom of the inner cylinder to dissipate the force of water and reduce turbidity and dispersion of soil while filling the cylinders with water.

Fill the outer cylinder to a depth of 8 - 12cm. Then carefully but quickly fill the inner cylinder up to the horizontal mark. Quickly remove the plastic, taking care not to disperse the soil in the process and record the time. Do the same for the replicates allowing sufficient time interval (1 - 2 min) between starting times for replicates so that the time for taking readings do not overlap.

Take measurements of water intake in the inner cylinder from the reference line after 5, 10, 20, 30, 45, 60, 90, 120, 180, and 240 minutes. These times are only indicative and observations can be variably spaced depending on the rapidity of the infiltration.

If the water level becomes too low (below 3 cm.) refill the inner cylinder carefully but quickly with a mug or a tin just after reading has been taken. Use the hand or float a small plastic sheet to break the force of water. Very often with soils of high intake rates, initially refilling has to be done for each time interval to prevent water level going down too low for the following interval. It has been observed that the longest interval before refilling is 15 minutes for sandy soils.

Water in the outer cylinder should be kept at approximately the same level as the inner one. It is important that it should never be filled higher than the inner cylinder to avoid water in the inner cylinder rising.

The recording should be entered in the form prepared specially for the purpose (sample attached). Preliminary calculations can also be done in the field as there will be ample time between measurements especially in soils with slow intake rates.

After the test period, the cylinders are removed and an augering made through the center of the cylinder to check the depth of wetted soil. This procedure is essential if a compact sub-surface horizon is present and restriction to infiltration is suspected. In this case a single infiltration measurement is repeated on top of the compact horizon.

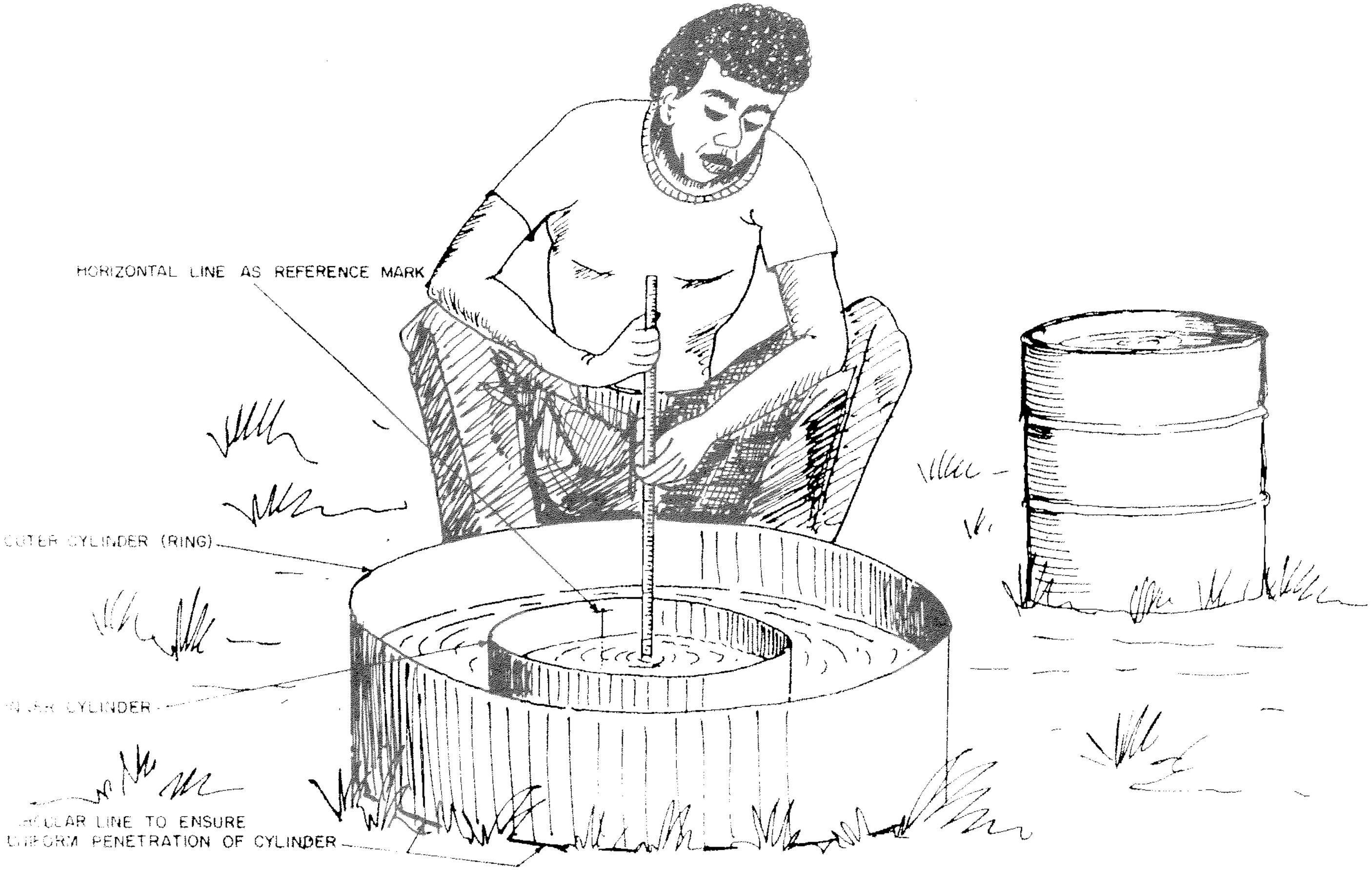


Figure 1 : Double ring infiltrometer set up to measure infiltration characteristics of soil

PROJECT FAO BOT/85/011

CYLINDER INFILTRATION TEST DATA

DATE 27/4/89 SOIL PROF NO. SH 0903 CL. Chromic Luvisol UNIT G14 SOIL MOISTURE slightly moist DRAINAGE well drained

LOCATION (~~SHT. NO.~~) 5km. S.E. of Shoshong LAND USE improved dryland farming AUTHOR O. Dikinya

ELAPSED TIME	CYLINDER 1				CYLINDER 2				CYLINDER 3				CYLINDER 4				CYLINDER 5			
	TIME OF READING	GAUGE READING	INTAKE	ACCUM. INTAKE	TIME OF READING	GAUGE READING	INTAKE	ACCUM. INTAKE	TIME OF READING	GAUGE READING	INTAKE	ACCUM INTAKE	TIME OF READING	GAUGE READING	INTAKE	ACCUM INTAKE	TIME OF READING	GAUGE READING	INTAKE	ACCUM
MIN.		CM.	CM.	CM.		CM.	CM.	CM.		CM	CM	CM		CM	CM	CM		CM	CM	CM
0	10.00	0	0	0	10.01	0	0	0	10.02	0	0	0								
5	10.05	2.4	2.4	2.4	10.06	2.3	2.3	2.3	10.07	3.3	3.3	3.3								
10	10.10	4.5 rf	2.1	4.5	10.11	4.3 rf	2.0	4.3 7.7	10.12	6.0 rf	2.7	6.0								
20	10.20	3.9 rf	3.9	8.4	10.21	3.4 rf	3.4	11.1	10.22	4.6 rf	4.6	10.6								
30	10.30	3.3 rf	3.3	11.7	10.31	3.4 rf	3.4	15.3	10.32	4.5 rf	4.5	15.1								
45	10.45	5.0 rf	5.0	16.7	10.46	4.2 rf	4.2	18.7	10.47	5.9 rf	5.9	21.0								
60	11.00	4.6 rf	4.6	21.3	11.01	3.4 rf	3.4	22.9	11.02	5.3 rf	5.3	26.3								
80	11.20	5.5 rf	5.5	26.8	11.21	4.2 rf	4.2	27.3	11.22	5.6 rf	5.6	31.9								
100	11.40	5.0 rf	5.0	31.8	11.41	4.4 rf	4.4	31.2	11.42	5.0 rf	5.0	36.9								
120	12.00	4.0 rf	4.0	35.8	12.01	3.9 rf	3.9	35.1	12.02	4.4 rf	4.4	41.3								
140	12.20	4.0 rf	4.0	39.8	12.21	3.9 rf	3.9	38.7	12.22	4.4 rf	4.4	45.7								
160	12.40	4.2 rf	4.2	44.0	12.41	3.6 rf	3.6	42.2	12.42	4.5 rf	4.5	54.6								
180	13.00	4.0 rf	4.0	48.0	13.01	3.5 rf	3.5	45.5	13.02	4.5 rf	4.5	59.1								
200	13.20	4.5 rf	4.5	52.5	13.21	3.3 rf	3.3	48.9	13.22	3.5 rf	3.5	62.6								
220	13.40	4.3 rf	4.3	56.8	13.41	3.4 rf	3.4	52.5	13.42	3.6 rf	3.6	66.2								
240	14.00	4.1	4.1	60.9	14.01	3.6	3.6	52.5	14.02	3.5 rf	3.5	69.7								

REMARKS (PHYSIOGRAPHIC POSITION, TOPOGRAPHY, VEGETATION ETC.) intermediate part of almost flat topography, bare soil on cultivated land. Subsurface was moderately wet.

2.1.4 Data Computation

Field measurements on infiltration rate invariably yield data in terms of cumulative intake. The cumulative intake ,denoted as F, is defined as the total volume of water that has infiltrated through a unit of horizontal area of soil surface over a given period of time measured from the beginning of infiltration.

It is known that cumulative infiltration (F) can be expressed as a function of time (t) according to the equation:

$$F = at^n \quad (1)$$

where a and n are constants for a given soil at a given moisture content.

If the logarithm of cumulative infiltration is plotted against the logarithm of elapsed time as a graph, then :

$$\text{Log } F = \log a + n \log t \quad (2)$$

which is the equation of a straight line and indeed a straight line is generally obtained on the graph paper.

In homogeneous soils, deviations from a straight line can result from inadvertent delay in the first reading when the water has already started infiltrating, presence of small cracks and biogenic holes and excessive evaporation. In heterogeneous soils deviations from a straight line occur every time the wetting front reaches a different layer.

Usually the data for the replicates conducted on the experimental site are reported individually or averaged to characterize a particular soil. This is done with the following method: The results of the cumulative infiltration in cm. of the three replicate tests are plotted against the elapsed time in minutes separately on the same sheet of graph paper in logarithm. The points for all three replications generally should be close enough together. If one cylinder gives values widely different from the others (perhaps because of hidden insect burrows, worm galleries, etc.), the values of this replicate should be rejected. Once the lines are determined for the three replicates, the values of 'a' and 'n' can be measured or calculated from the graph. The value of 'log a' can be read at the intersection of the straight line and the 'Y' axis. As it can be seen on the graph, the value of 'a' is also that of the cumulative intake after one minute and is thus not dimensionless. The slope coefficient of the straight line gives the value of 'n'. To determine the value of 'n', take 2 points arbitrarily on the straight line and determine their co-ordinates (x_1,y_1 : x_2,y_2). The value of 'n' is given by $(y_1-y_2)/(x_1-x_2)$ and is dimensionless. Once 'a' and 'n' are determined, the cumulative infiltration can be computed for any time using formula (1). Note that, as the units used on the graph are the cm and the minute, these dimensions must also be used in the formulas. Pocket calculators able to compute exponential equations are not always available. The use of logarithmic transformation is then again required.

The instantaneous infiltration rate (noted Iinst) is defined as the volume of water infiltrating through a horizontal unit area of soil surface at any instant of time. In other words, Iinst at a certain time is the variation of the cumulative infiltration at that time for an infinitely small time and is obtained by differentiating equation (1) with respect to t or:

$$Iinst = \frac{dF}{dt} = a\ n\ t^{n-1} \qquad (3)$$

It follows:

$$Iinst = \frac{F \times n}{t} \qquad (4)$$

With equation (3) or (4), the instantaneous infiltration rate can be calculated for any time. The values obtained show generally a rapid decline in the beginning followed by a more stable very slow decline after some 3 to 4 hours of infiltration.

The basic infiltration rate (noted Ibas) is defined as the relatively constant rate that develops after some hours. The term "relatively constant" is used for a change in infiltration rate of less than 10 per cent as compared with the proceeding hour, or:

$$Iinst\ (t) - Iinst\ (t+1) < 0.1\ Iinst(t) \qquad (5)$$

where t is expressed in hours.

This criterion is used to set up the differential equation.

$$\frac{d\ Iinst}{dt} = -0.1\ Iinst \qquad (6)$$

The left-hand term gives:

$$\frac{d\ Iinst}{dt} = \frac{d(ant^{(n-1)})}{dt} = (n-1)ant^{(n-2)} \qquad (7)$$

The right-hand term of (6) gives:

$$0.1\ Iinst = 0.1\ a\ n\ t^{(n-1)} \qquad (8)$$

Substituting (7) and (8) into (6) gives

$$tbas = t = -10(n-1) \qquad (9)$$

where tbas, is defined as the time necessary to reach the basic infiltration rate is expressed in hours. The basic infiltration rate is obtained by calculating the instantaneous infiltration rate for the value of tbas expressed in minutes.

Another characteristic quantity sometimes used is the average infiltration rate (noted Iav) which equals the cumulative infiltration divided by the time since infiltration started, or:

$$Iav = \frac{F}{t} = a\ t^{(n-1)} \qquad (10)$$

2.1.5 Example

The results and calculation of an actual infiltration test are as follows. The readings taken for 3 replicates are shown in the attached form. As the infiltration rates were high, the maximum possible time interval was only 20 minutes. After the reading at the end of 20 minutes, the inner cylinder had to be refilled (rf). The cumulative intake from the beginning of the test are shown in the column under " Accum.Intake" i.e. accumulated intake.

The graph (Figure 2) shows the plot of the logarithm of elapsed time (x - axis i.e. log t) versus logarithm of accumulated intake (y - axis i.e. log F). The 'a' value, 'n' value, tbas and Ibas are calculated for the graph of replicate 3.

a) The co-ordinates of the two arbitrary points on the graph are (2,1.57 : 1,0.8).
Thus slope of graph $= n = \frac{(1.57 - 0.8)}{2 - 1} = 0.77$

b) Substituting the value of n and the co-ordinates of one of the points in equation (2)

$$\log a = \log F - n \log t$$
$$= 0.8 - .77$$
$$= 0.03$$

$$a = \text{antilog } 0.03$$
$$= 1.07$$

c) $t\ bas = -10(n-1) = -10(.77-1)$
$= 2.3hr.$

d) Using $Iinst. = ant^{n-1}$ for tbas i.e. 2.3x60 min.

$$tbas. = 1.07 \times 0.77 \times (2.3 \times 60)^{-0.33}$$
$$= 0.162 \text{ cm./min.}$$
$$= 9.7 \text{ cm./hr.}$$

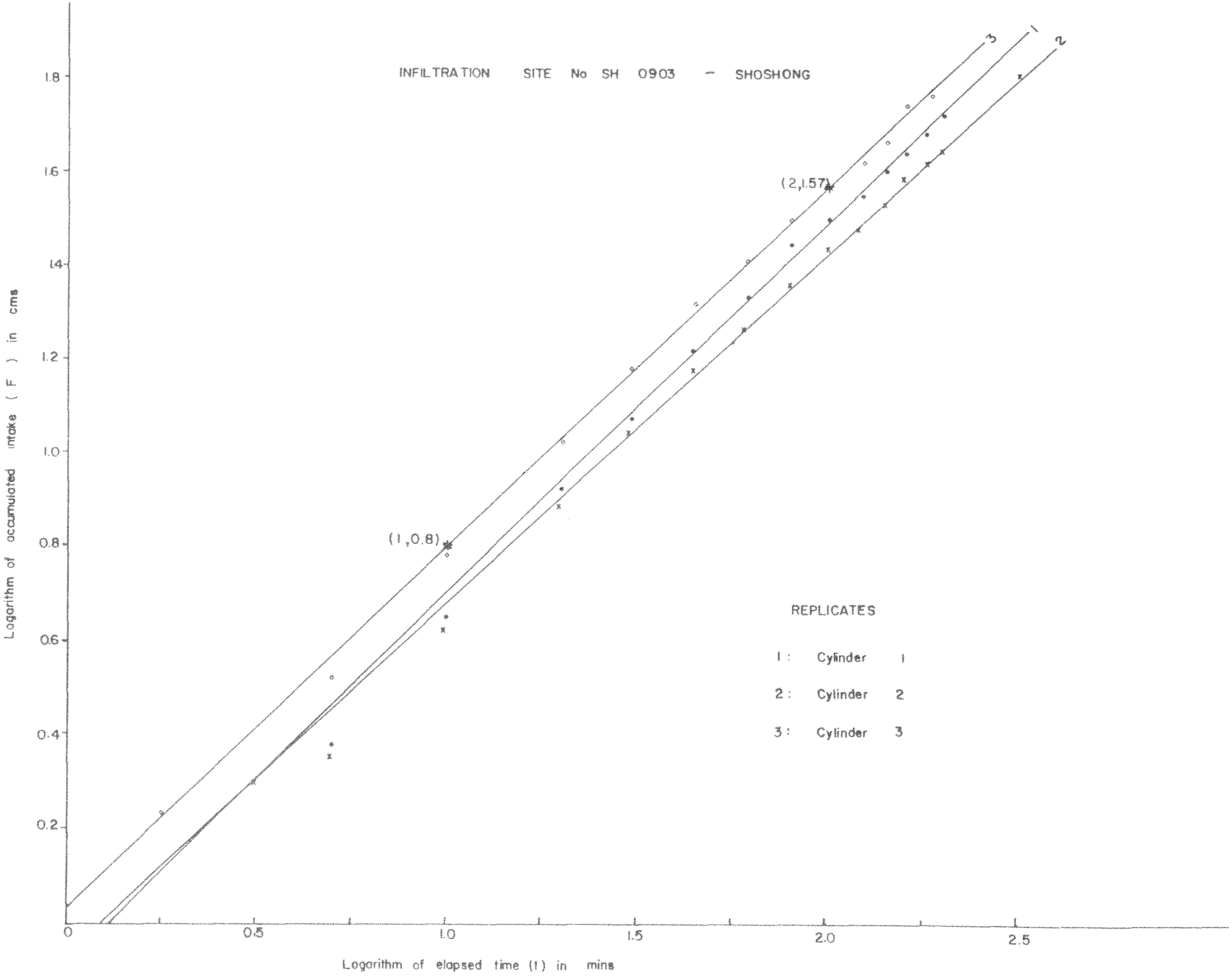


Figure 2 : Logarithmic plot of accumulated intake versus elapsed time of an infiltration test

2.2 BULK DENSITY (core method)

2.2.1 Introduction

Soil bulk density is defined as the ratio of the mass of a given sample to its bulk volume which include soil particles and pore spaces in the samples. Bulk density is required (1) for determining compactness as a measure of soil structure, (2) as an indicator of aeration status and (3) to convert soil moisture and nutrient values from gravimetric to volumetric basis. Bulk density is determined by obtaining an undisturbed soil sample of known volume and dividing the oven dry soil mass by the field volume of the sample. In most agricultural work, bulk density is expressed as grams per cubic centimeter ($g.cm^{-3}$). The common laboratory method use a core or a clod. The bulk density of a clod will be greater than that determined on a core because the former excludes inter-clod pore space. Consequently the core sampling is the preferred method.

In swelling and shrinking soils such as vertisols, bulk density decreases with increase in moisture content and is never constant. Therefore it is necessary to give the moisture content of the soil for which bulk density is reported. For vertisols, due to its shrink-swell nature and extensive cracking, bulk density is estimated by other means. One such method is to determine the saturated moisture content of a clod or an undisturbed sample and use it with particle density value of soils to estimate bulk density. Some reliable empirical relationships have also been worked out linking bulk density of vertisols to 15-bar moisture content. This method will also be described later in the section. The core method is unsatisfactory in gravelly or stony soils.

In the core method, a cylindrical metal sampler is pressed or driven into the soil to the desired depth and is carefully removed to preserve the known volume of sample as it existed in situ. The sample is dried to 105°C and weighed.

2.2.2 Equipment

The equipments include the core sampling unit and auxiliary apparatus for digging, trimming, packing and transporting the sample. Oven and balance are required for determining the weight of oven dried soil sample.

- The core sampling unit is a set of manufactured equipment consisting of sampling cylinder, driving head and a heavy small mallet. The stainless steel, thin walled sampling cylinder is of diameter and height about 5cm. with a beveled cutting edge on one end. The diameter of the inside cutting edge and the height are of such dimensions that the inside volume is exactly $100cm^3$. Just behind the cutting edge, the inside diameter is increased by 1mm by machining out 0.5mm from the wall thickness. This modification is made locally to minimize friction between soil and the cylinder wall. The friction cause compaction of soil when sampling and also makes the extrusion of soil from the cylinder difficult.

- The driving head has a cylindrical base to be kept on the sampling cylinder and hammered on to the attached handle to drive the sampling cylinder into the soil.

- The steel mallet is about 60cm long with plastic end on the hammering sides to minimize vibration.

2.2.3 Procedure

Five replicate measurements of bulk density are made at each selected depth of the soil profile. It is always convenient to do the sampling near walls of the soil pit which is also used for describing the soil profile.

Select and mark the depth interval for sampling on the pit wall, by grouping adjacent horizons which are similar in texture, structure and compactness. Invariably such similar horizons have almost the same physical properties. The bulk density samples are taken from the central part of the largest of such group of horizons.

Excavate the soil above the first depth to be sampled and make a flat smooth horizontal surface, starting from the pit wall to about 30 -45 cm. away from it. The area of the flat surface should be sufficient to take about 20 core samples, as more core samples have to be taken for moisture retention work as described in the next section. Place the sampling cylinder on the surface thus made, avoiding visible cracks, insect holes, large roots or stones. Place the driving head on top of the sampling cylinder and drive the cylinder into the soil with steady blows of the hammer on the driving head. Care should be taken to hold the driving head steady during the hammering, so as to prevent shattering of soil in the cylinder. The sampling cylinder is driven to about 0.5 cm. more than the real height of the cylinder. Gently remove the driving head and check (a) whether the level of the soil surface inside and outside the sampler is the same. If the soil surface inside the cylinder is markedly lower than the outside surface, compaction of soil inside has occurred. Discard the sample and re-sample again. (b) whether the soil inside the cylinder protrudes sufficiently above the upper rim to allow trimming the soil up to the rim. If not, replace the driving head carefully and drive the cylinder further down to sufficient depth.

Excavate the soil around the sampling cylinders by a strong sharp knife, allowing sufficient soil below the lower rim for trimming the soil up to the rim. Trim the soil up to the rim on both sides so that the soil inside the cylinder is exactly of the same volume as the cylinder.

Transfer the entire soil sample to a heavy-gauge plastic bag or into a metal can with identifying labels for transport to the laboratory. Care should be taken not to spill any soil and also to collect all soil sticking to the spatula or fingers during transfer to the plastic bag. Repeat the procedure to collect the 5 replicates from the same depth. Once the sampling is over, excavate the soil further down to the next sampling depth and make a flat smooth horizontal surface and take the core samples as before. This procedure is repeated for all the selected sampling depths.

In the laboratory the soil samples in the bags are partially dried in air or in an oven at 40-50°C for a day with the mouth of the bag open. This procedure is adopted to dry the soil and the condensed moisture so that the soil does not stick to the bag. Transfer the soil carefully into the numbered moisture cans and dry in the oven at 105°C to constant weight (usually 48 hr.). Weigh the can and oven-dry soil. Empty the can and weigh the clean empty can.

2.2.4 Data Computation

Weight of can, lid + oven dry soil = W1(g)
Weight of empty can, lid = W2(g)
Volume of core sample = V(cc)
(Same as vol of sampling cylinders)

$$\text{Bulk density} = \frac{W1 - W2}{V}$$

2.2.5 Bulk density of vertisols

The core method is not normally used for vertisols and other cracking clays. The clod method (procedure available in literature) can be used as an alternate method for these soils.

The following formula given by Australian workers (1) can also be used to obtain a reliable estimate of bulk density of vertisols.

$$BD = \frac{1 - e}{\frac{1}{AD} + W_{max}} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where BD = Bulk density (g/cc)
e = air content (cm^3/cm^3) $\simeq$ .05 cm^3/cm^3

AD = particle density ($\simeq$ 2.65 g/cc)

W_{max} = $0.124 - 0.265D + 0.160D^2 + 1.284x(-15bar\ W)$

D = depth in meters e.g. 0 - 10cm = 0.1m.

-15bar W = gravimetric moisture content of vertisol at 15bar tension (g/g)

Alternately, a soil clod can be slowly wetted up to saturation on a tension table and moisture content determined. The saturated moisture content thus obtained can be used for W_{max} in equation (1) and making e = o.

Notes on the method

1 It is not necessary to use commercially manufactured equipment for bulk density measurements. Suitable equipment can be turned out in any workshop. The larger the volume of the core, the better the accuracy. However the volume is limited by other considerations. Too deep a cylinder cannot be used for small horizons. Too large a diameter causes cracking of soil within the cylinder. In any case, the volume should not be too small. Usually it ranges from 100 - 200 cc.

2 Sandy horizons and hard dry horizons are difficult to sample for bulk density accurately. Moist soils are the best for accurate sampling. Loose sandy soils can be made wet by pouring water over it and sampled after a few minutes. It is necessary to wet hard and dry horizons overnight for better sampling. If such horizons are encountered it is easier to wet all the horizons at the same time by having standing water over them overnight. The horizons can be sampled the following day. Excavate the soil as described earlier for sampling, but at several suitable positions around the pit according to the number of depth to be sampled. Depth of excavation should be about 10cm above the actual sampling depth. Form an earthen dyke along the edge of the pit wall thus forming a trough with the dyke and the excavated sides. Pour water into it and leave overnight. Bulk density samples can be obtained by removing the top 10cm of wet soil and sampling the moist soil below in the usual way. (Figure 3)

2.3 SOIL MOISTURE CHARACTERISTICS

2.3.1 Introduction

Soil moisture characteristics are determined from soil moisture retention curves which relate soil water content to soil water potential or soil water tension. Soil water potential can be thought of as a measure of the force with which water is held in the soil pores. It is the pressure of water in the soil pores relative to atmospheric pressure. The soil water potential is negative in unsaturated soil and is usually measured as the manometric height of water equivalent to this pressure. The logarithm of this manometric height of water, when expressed in centimeters, is referred to as pF.

In saturated soils, the water in the pores are at zero tension. In order to remove water from soil, energy must be expended to overcome the capillary and surface forces with which the water is retained in the soil pores. The smaller the diameter of the soil pore, the greater is the force. The force to remove water from the soil is applied by way of external air pressure or through suction imposed by a water column. Generally as the applied tension (i.e. force) is gradually increased from zero, the moisture content of the soil decreases due to the extraction of water initially in the larger pores and progressively by that in the smaller pores .

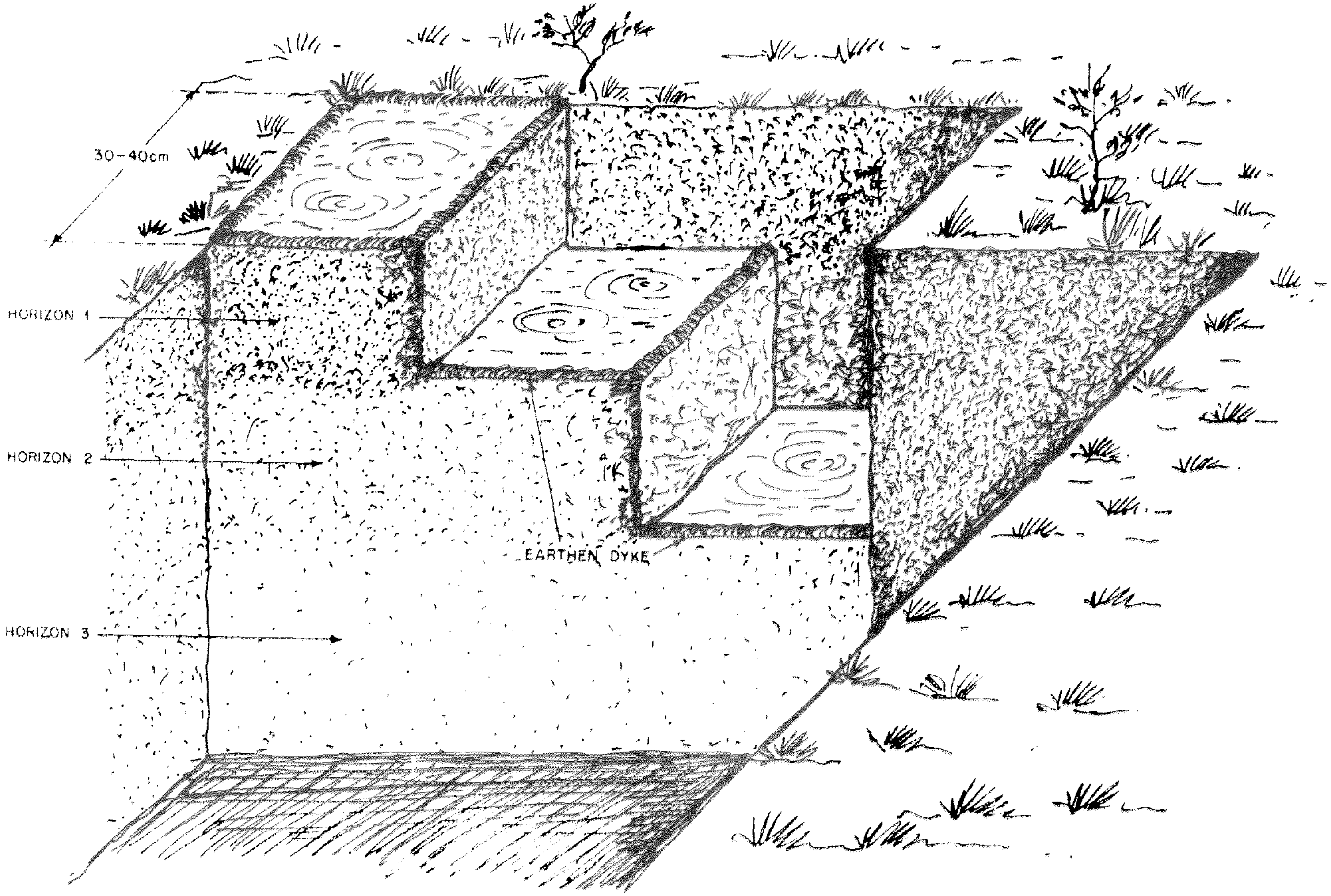


Figure 3 : Ponding arrangement for wetting 3 horizons of a soil profile for taking undisturbed core samples

Thus, the moisture content of the soil that is in equilibrium with the applied tension is the amount of water that can be retained in the soil pores against that tension. The volume of water that is released or extracted for each increment of tension also equals the total volume of pores within a given size range.

In determining soil moisture retention curve, the general principle is to drain saturated samples of soil to equilibrium under different applied air pressures or water suctions in special apparatus and find the corresponding oven dry moisture content. The graph of moisture content versus the corresponding applied pressure is the moisture characteristics of the soil.

2.3.2 Equipment

- Pressure plate apparatus. These are commercially available and consist of (a) Pressure chambers, one each for 0 - 5.0 bar pressures and 5.0 to 15.0 bar pressures. (b) Ceramic porous plates for 0 - 1.0 bar pressures, 1.0 -3.0 bar pressures, 3.0 - 5.0 bar pressures and 5.0 - 15.00 bar pressures.

- Source of regulated air pressure. Commercially available and consists of air compressor, pressure gauges, and pressure regulator valves conveniently mounted on a manifold.

- Sand Table. Commercially available, consisting of a rectangular metal tank with very fine sand to act as a porous medium. A manometric suction device is attached to the tank to impose water suction up to 200cm. of water column on the sand.

- Cylindrical metal core samples (same as described for bulk density)

- Moisture cans, balance and oven for determining moisture content.

2.3.3 Procedure

Moisture retention is determined on undisturbed core samples or crushed samples according to the magnitude of the tension used. To plot reliable moisture retention curve, moisture contents at .03, .05, 0.1, 0.3, 1.0, 3.0, 5.0, 15.0 bars tensions are determined in duplicate. If the duplicate values of moisture content do not agree within 2 percent, additional measurements are made to obtain consistent results. Undisturbed core samples are used for tensions between 0 and 1.0 bar as soil structure and macro-pores determine the water retention in this range of tensions. For tensions above 1 bar , crushed samples (<2mm) are used as texture of the soil determines the soil moisture retention in this range. Although core samples can be used for this higher range of tension, the higher times needed for soil cores to reach equilibrium makes the use of small amounts of crushed samples faster and more convenient.

Take twelve cylindrical core samples from each horizons for which bulk density samples were also taken. The procedure for obtaining the core samples is identical to that of bulk density, except that the soil volume need not be exactly equal to that of the sampler. It is important however that the soil sample is neither disturbed nor compacted so that it retains the field structural properties. The soil cores are preserved in the metal sampling cylinder itself by putting plastic covers on either end of the cylinders so that they could be transported to the laboratory wit minimal disturbance.

Take sufficient quantity (0.5kg) of bulk samples in plastic bags from the same horizons.

In the laboratory, saturate the soil by placing the soil core with the cylinder in a tray of water overnight. The water level should be kept about 0.5cm. above the base of the soil core.

Remove the core samples from the tray of water and place them on a 1.0 bar ceramic plate which too should have been soaked overnight in water. Alternatively the core samples can be saturated by placing the samples directly on the 1.0 bar ceramic plate which is then immersed in a tray/trough with water level about 0.5cm above the plate.

Place the ceramic plate and the samples in the appropriate pressure chamber. Make sure that the soil in the cylinder is in intimate contact with the ceramic plate. Very often errors in results arise due to inadequate contact of soil with the ceramic plate. This can be achieved by gently pushing out the soil by pressing the sample slightly at the top while wetting the base of core by a thin film of water. If the surface of contact is rough and uneven, then a thin layer of dry crushed loose sample of the same soil should be put on the plate and the soil core placed on top of it. The loose soil fill in the unevenness and ensure good contact. Care should be taken not to include the loose soil when determining the soil moisture content later.

Bolt the lid of the pressure chamber taking care to remove any dirt and grit on the rubber seal and the metal contact surfaces to prevent air leakage. Apply the selected pressure (0.1, 0.3, or 1.0), increasing by small increments. The end of the outflow tube should be immersed in a beaker of water to check for air leaks as well as to collect the outflow. Allow the soil sample s to equilibrate for not less than 48 hr.. During this period make periodic checks on the pressure gauge and the outflow tube for air leaks. Very regular and slow bubbling of air from the outlet is common especially at high pressures due to diffusion.

After equilibration at the imposed pressure, (usually 48 hr.) turn off the compressed air, release the pressure, open the pressure chamber and rapidly transfer the upper two-third portion of each sample to an aluminum moisture can placing the lid on immediately, until the apparatus is completely unloaded. Weigh the wet sample with can and lid, oven dry at 105°C for 48 hr., cool, and weigh the oven dry soil with can and lid. While drying in the oven, the can should be open and the lid placed on top of can leaving a small opening for the moisture to evaporate.

The sand table is used for measuring moisture retention below 0.1 bar. Saturate the soil core in a tray of water in the same manner as done for ceramic plates. Here too the soil cores can be saturated alternately by placing the cores on the sand table and raising the water level above the sand level to have standing water of about 0.5cm. above the base of the core. Usually the saturation procedure is done in tray of water instead of doing directly on the ceramic plates or sand table, mainly to save time. Because, while the saturation is going on overnight in a tray, the sand table and the ceramic plates can be occupied with the previous batch of samples for removal on the following day.

Place the soil core on the sand table ensuring good contact by following the same procedure as adopted for ceramic plates. Allow the samples to be on the sand table with a thin film of water for about 2 to 3 hours. Lower the manometric level to impose the selected tension (0.03 or 0.05 bar) on the soil samples. Strictly, at low tensions, the imposed tension value should include half height of the soil core. However in practice there is little or no difference in the results by assuming the tension to be the difference in height between the manometric level and sand surface, if the height of the core is less than 5cm.

After 48 hr. when the soil moisture had reached equilibrium with the imposed tension, remove the samples from the sand table and determine moisture content as for the ceramic plate samples.

For tensions between 1 bar and 15 bars, the bulk samples taken from the field are air dried, crushed and seived through 2mm seive and used for moisture retention measurements.

Place rubber or copper rings of 5cm diameter and 1 cm height on the appropriate ceramic plate which had been saturated by soaking overnight in water. Dump the soil samples into the ring using a spoon and level the soil up to the rim of the rings. Care should be taken to mix the sample well before use, to avoid segregation of particles of similar sizes in the container.

Saturate the soil samples by putting water on the ceramic plate to flood the samples and leave overnight. The procedure can be carried out by having the plate either in a tray or in the pressure chamber itself. After saturation, close the pressure chamber, apply the selected pressure (3.0, 5.0, or 15.0 bars) increasing by small increments etc. following the same procedure as for the lower pressures. After 48 hr. remove the soil samples from the chamber and determine moisture content as before.

Notes on the method

1. Soil cores obtained from sandy soils tend to slip off the core samples especially when dry or saturated. Always hold the cores horizontal in the metal cylinder when moving them.

2. If the soils slake too much during saturation in the tray, and is dif-

ficult to handle, then either remove the water completely from the tray before removing the sample or saturate the cores on the sand table by wetting under a tension of 50 cm. and gradually reducing the tension to 0cm..

3 It is often observed that core samples of swelling and shrinking soils do not wet at all when kept in a tray for saturation in the usual manner. This probably is due to the initial high expansion of the soil core within the confined space at the base of the metal cylinder thus preventing capillary flow upwards. To overcome this problem, dry the core sample in air or in an oven at 50-60°C and extrude the soil core out of the metal cylinders. Due to the high clay content, the core comes out without breaking. Wet the extruded core on the sand table under a tension of 50cm. The bare cores saturated in this way can be used both in the pressure chamber and sand table in the usual manner. Sometimes the core cracks into 2 or 3 pieces. In such a case, the larger pieces can be used instead of the full core.

4 In vertisols, moisture retention measurements are made using large clods (>100 cc) as good core samples are difficult to obtain.

2.3.4 Data Computation

Moisture contents are determined on a gravimetric basis for each imposed tension. The data are presented in a tabulated form showing the mean gravimetric moisture content and the corresponding tension for each horizon. However, before presenting the final results, the data are checked by actually drawing the moisture characteristic curve. For each horizon a plot is made of volumetric moisture content versus logarithm of tension expressed in cm of water.

The following relationships are adopted:

vol.moisture content (cc/cc) = grav.moisture content (g/g)
x Bulk density (g/cc)

1.0 bar tension = 1020cm of water column

It may happen that although duplicate values agree within the stipulated 2 percent moisture content, one or more data points may not fall on a smooth moisture characteristic curve. Such results are rechecked and even measurements repeated to obtain results of acceptable accuracy.

2.3.5 Example

The results from actual soil moisture measurements made on three horizons of a soil profile are given in Table 2. In plotting the moisture retention curves as shown in Figure 4 the tensions expressed in bars are converted to logarithm of pressure expressed in centimeters of water column and the moisture content measured in gravimetric units are converted to volumetric units.

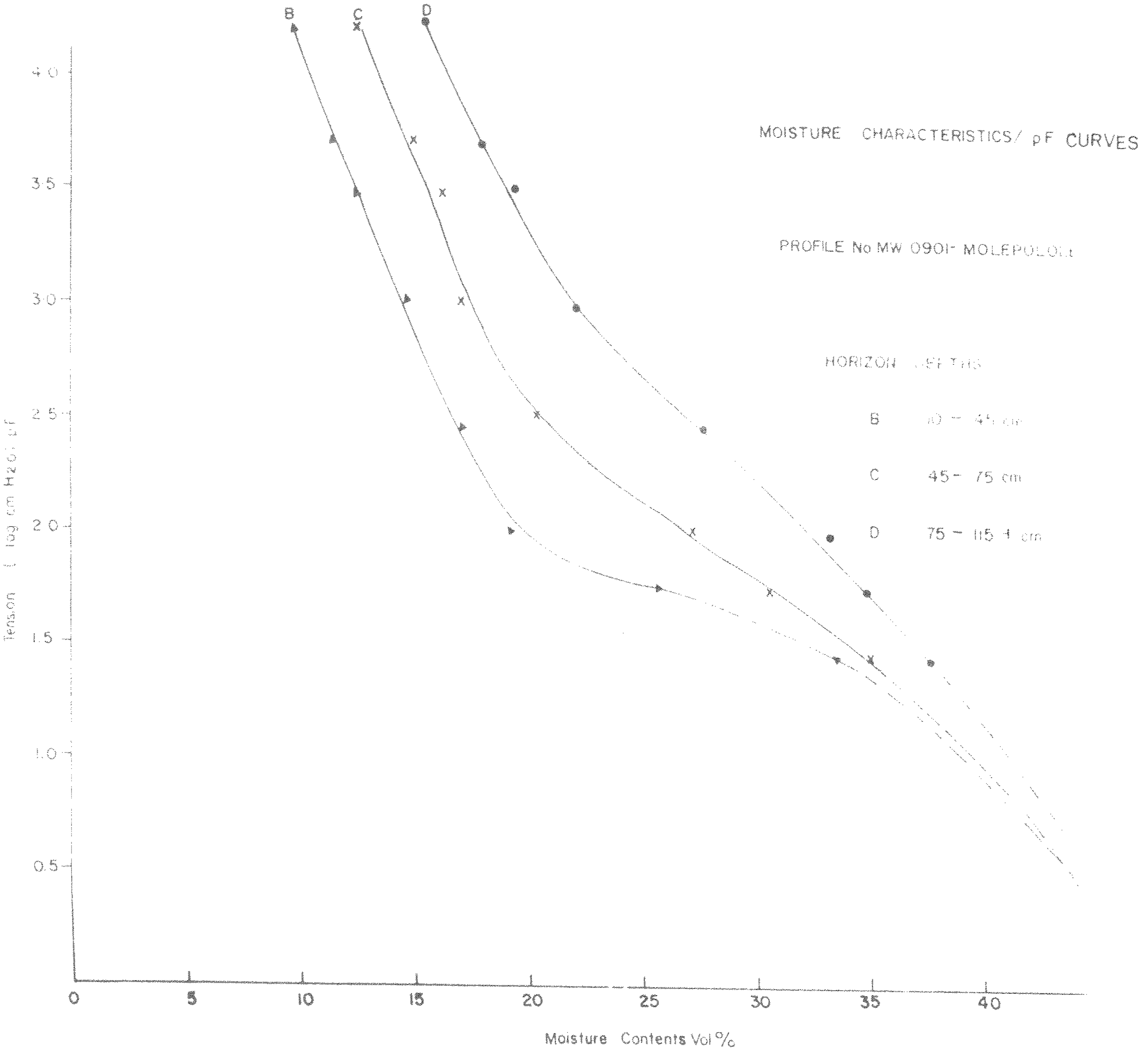


Figure 4 : Moisture retention curves

Table 2

Results of moisture retention measurement
Profile No 0901 - Molepolole

Tension		Horizons					
bars	log cm H_2O or pF	Depth 10-45cm Bulk density 1.37 g/cc		Depth 45-75cm Bulk density 1.47 g/cc		Depth 75-115cm Bulk density 1.38 g/cc	
		moisture content		moisture content		moisture content	
		g/g	cc/cc	g/g	cc/cc	g/g	cc/cc
.03	1.48	0.246	0.337	.238	.350	.272	.376
.05	1.70	0.188	0.257	.208	.306	.253	.349
0.1	2.0	0.141	0.193	.185	.272	.240	.331
0.3	2.48	0.124	0.170	.140	.205	.200	.276
1.0	3.0	0.106	0.145	.116	.170	.150	.220
3.0	3.48	0.091	0.125	.110	.162	.139	.192
5.0	3.70	0.083	0.114	.101	.149	.129	.179
15.0	4.2	0.070	0.096	.086	.126	.112	.153

2.4 STRUCTURAL STABILITY INDEX

2.4.1 Introduction

The method adopted to measure structural stability index is the same as given in the FAO Irrigation and Drainage Paper No 28, "Drainage Testing". When a dry sample of small aggregates of a structurally unstable soil is wetted suddenly by flooding, the aggregates slake and collapse. Consequently the relatively larger pores in the soil sample are eliminated or become much smaller in size. However, if similar soil sample is wetted slowly by water under a tension, slaking and collapse of the soil aggregate is almost nil or almost minimal. The degree of collapse of soil aggregates to fast wetting will depend on their relative stability. Therefore the relative stability can be assessed by comparing the degree of collapse of air dried soil aggregates when slowly wetted as opposed to rapid wetting. The collapse under the two kinds of wetting is estimated by its effect on pore size distributions which in turn is determined from moisture release characteristic.

Soil samples of aggregate sizes between 1mm and 2mm are used in the above experiment. However if the soil is sandy and have large proportions of single grains in the same size range, there will be no collapse and consequently the stability is apparently high. Therefore it will be useful to include in the results, the volume percent of single grains in the sample so that the contribution to the stability index by the single grain is known.

2.4.2 Equipment

- 100 ml measuring cylinder
- Haines apparatus. A flat porous plate with funnel manufactured as sintered glass funnel (coarse). The volume beneath the porous sintered glass plate is completely filled with water; water can flow through the porous plate but air is unable to pass back from the soil through the plate. Soil sample can therefore be wetted from below, saturated and subsequently drained. Haines apparatus is connected at its bottom end via a plastic tube to a burette. The difference in water level in the burette and the base of porous plate is the imposed suction or tension on the soil. The burette allows measurement of water that is sucked into the soil or drained from it. (Figure 5)

2.4.3 Procedure

Structural stability measurements are usually made in duplicates on soils from the surface horizon only.

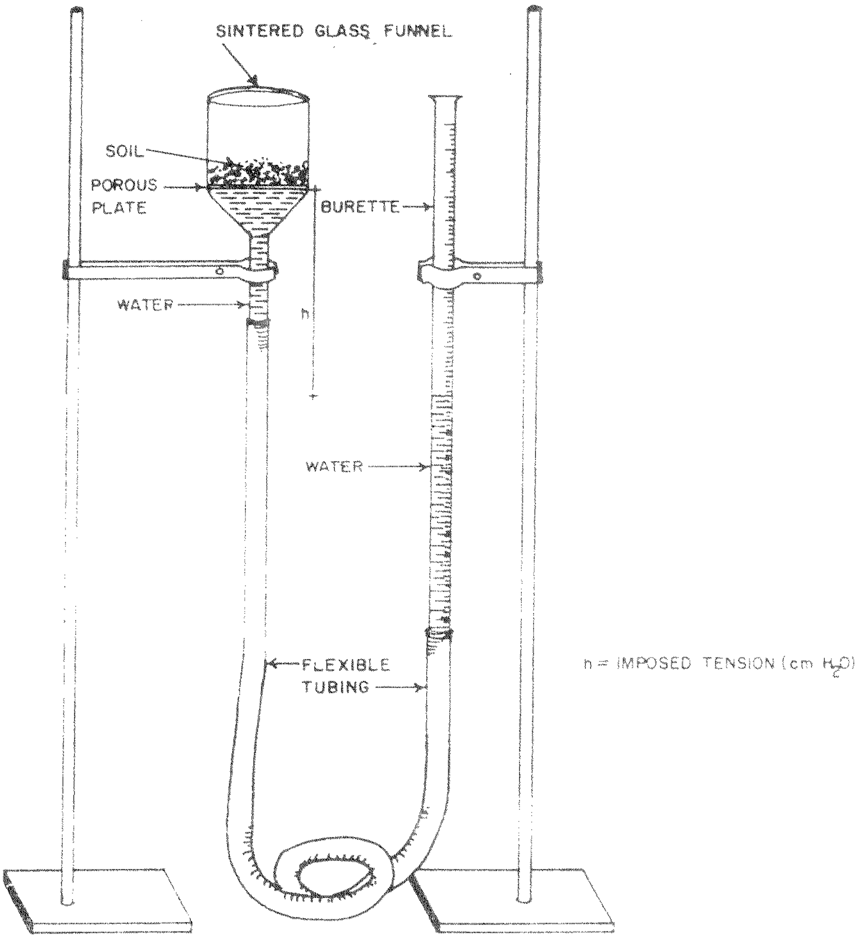
Break up lumps of air dry sample, sieve on a nest of 2mm and 1mm sieve. Collect sufficient amount of sample (>500 cc) which pass through 2mm and is retained on the 1mm. sieve, Cone and quarter about 250 cc of sample to obtain 4 sets of samples for measurements.

Adjust the tension on 4 Haines apparatus to 10 cm. suction. Measure out 50 cc of soil separately from 2 sets of samples by a measuring cylinder. Place the samples, one at a time uniformly on the porous plates of 2 Haines apparatus. Add water to burettes or raise the burettes to maintain the 10cm suctions as the soil absorbs water slowly through the porous plate till the absorption ceases. Cover the top of the Haines apparatus with a petri dish to prevent evaporation and leave for at least 24 hr. at 10cm tension.

After 24 hr., measure out 50 cc of soil separately from each of the remaining 2 sets of sample by a measuring cylinder. Place one of the sample uniformly on one of the remaining Haines apparatus. Raise the burette quickly to flood the soil sample to be water logged for about 20 sec.. Lower the burette below the porous plate and drain the water out of the soil sample. Raise the burette again and impose zero tension on the soil sample. (i.e water in the burette is in level with the porous plate). Some adjustments may be necessary periodically if the water level in burette changes slightly due to absorption or drainage. Repeat the fast wetting procedure with the other soil sample.

Raise the burettes of the 2 Haines Apparatus having the slowly wetted soil, one at a time, to flood the soil. Drain off the water by lowering the burette. Impose zero tensions as done for the fast wetted samples.

After equilibrium at zero tension, (when no change in water level in burette occurs), record the burette reading. Impose a tension of 5cm by lowering the



h = IMPOSED TENSION (cm H_2O)

FIG. 5: HAINES APPARATUS SET UP FOR THE MEASUREMENT OF SOIL STRUCTURAL STABILITY INDEX

burette. Water will drain from the soil and the burette is lowered further to maintain the 5cm tension.
This procedure is continued till drainage ceases and water level in the burette remains steady at 5cm tension. Record the burette reading. Burette is then lowered again to impose 10cm tension. Follow the same procedure as for 5cm tension and record the burette reading when drainage ceases. Repeat the procedure for 15, 20, 25cm tensions, recording the burette reading after drainage at each imposed tension.

The measurement can be carried out concurrently on all the 4 burettes after each one reaches equilibrium at zero tension, Throughout the experiment, the funnels of Haines apparatus should be closed with petri dishes and the tops of burettes covered with loose moist cotton wool to prevent evaporation.

2.4.4 Data Computation

For a pair of slow and fast wetting measurements, plot cumulative outflow in cc. versus imposed tension in cm of water. Measure the area enclosed within each curve and the tension axis up to 25 cm tension. (Figure 6) The ratio of area for fast wetted curve to the area for slow wetted curve is the structural stability index. The areas are estimated by counting the number of squares in the graph paper in which the plots are made.

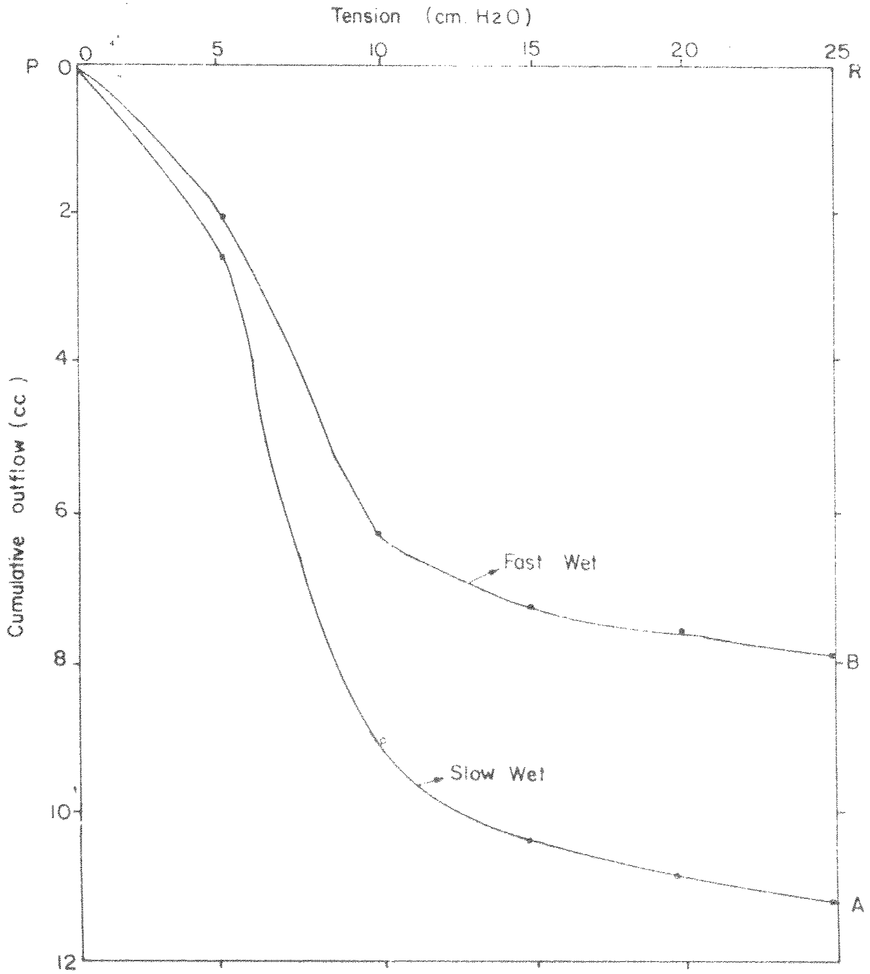
Notes on the Method

1 Agreement of results between duplicate measurements depends largely on the four sub-samples being uniform in respect of aggregate size distribution. Very often separation of aggregates into different size groups occur due to movement of the container in which the soil samples are stored. Therefore it is important that the four sub-samples of soil used for the measurement are obtained by the coning and quartering method of sufficient quantity of a bulk sample that has been thoroughly mixed.

2 The initial equilibrium time for 5cm and 10cm tension is of the order of 2 hr.. At subsequent tensions, equilibrium is attained within one hour. The drainage measurements for all the imposed tensions from 0cm to 25cm should preferably be completed within a working day to minimize evaporation losses. It is suggested that slow wetting of the two duplicate samples be done on the first day. Fast wetting followed by the imposition of zero tension on all four samples be done on the second day. Drainage at all the tensions be completed on the third day by starting the measurements early in the morning.

2.4.5 Examples

Table 3 and Figure 6 give the actual results from a structural stability index measurement.



Slow wet area = PAR

Fast wet area = PBR

Structural Stability Index = $\frac{PBR}{PAR}$

Figure 6: **Moisture release** curves for slow and fast wetted soil samples in structural stability measurements.

Table 3

Results of structural stability index measurements

Imposed tension cm H_2O	Slow wetting			Fast wetting		
	Brtt rdng	Otflw cc	Cmmltve outflw cc	Brtt rdng	Otflw cc	Cmmltve otlfw cc
0	42.4	0	0	41.4	0	0
5	39.8	2.6	2.6	39.4	2.0	2.0
10	33.3	6.5	9.1	35.1	4.3	6.3
15	32.1	1.2	10.3	34.3	0.8	7.1
20	31.6	0.5	10.8	33.9	0.4	7.5
25	31.2	0.4	11.2	33.5	0.4	7.9

In figure 6, the two moisture release curves show the plot of cumulative outflow versus the imposed tension for the slow and fast wetted aggregates. The area enclosed between the slow wetted curve and the tension axis up to 25cm of water column is given by PAR and similarly for the fast wetted curve, it is given by PBR.

Area PAR = 75.5 units
Area PBR = 53.5 units

$$\text{structural stability index} = \frac{\text{Area PBR}}{\text{Area PAR}} = \frac{53.5}{75.1} = \underline{0.71}$$

2.5 HYDRAULIC CONDUCTIVITY (Inversed auger hole method)

2.5.1 Introduction

Soil hydraulic conductivity is a measure of the ability of a soil to transmit water in all directions, horizontally as well as vertically. It is defined as the volume of water flowing through a unit cross sectional area per unit time per unit hydraulic gradient. The hydraulic gradient is the hydraulic head drop per unit distance in the direction of the flow. The hydraulic conductivity depends on the pore geometry of the soil which in turn depends on the structure as well as the texture of the soil. Therefore each soil horizon has its own hydraulic properties depending on its own pore geometry. Hydraulic conductivity values of soils are necessary for estimating seepage losses from irrigation canals, for designing sub-surface drainage for water logged areas and for applications in many irrigation designs.

The inversed auger hole method measures the saturated hydraulic conductivity of the soil above the water table. This method is described in French literature as the Porchet method. It consists of boring a hole to a given depth, filling it with water and measuring the rate of fall of the water level. The method is valid only when the hydraulic gradient in the soil is near unity. This condition is approached when the soil round the auger hole is near saturation: Therefore it is necessary to saturate the entire depth of soil around the auger hole by having water in the hole and allowing it to seep into the soil for sometime before beginning the measurements. The method, though approximate, is convenient where large quantity of water is a constraint.

2.5.2 Equipment

- Soil auger of radius 3 - 4 cm.
- Rigid plastic or metal tube of radius smaller than that of auger hole.
- Loose dry coarse sand (100cc)
- Suitable equipment to measure water level in auger hole. e.g. a float on a string and a measuring tape.
- Stop watch.
- Water container.

2.5.3 Procedures

Bore a vertical auger hole of known radius (r) to any desired depth over which saturated hydraulic conductivity is to be measured. Put dry coarse sand into the auger hole so that the bottom of the hole is filled to a depth of about 2cm. This avoids dispersion of soil when water is later poured into the hole. Insert the rigid plastic tube into the auger hole so that the bottom of the tube reaches the sand layer. Gently pour non turbid water through the tube to fill the auger hole up to the surface. Remove the tube and allow the water to infiltrate through the sides and bottom of the auger hole. Repeat this step several times till the soil around the auger hole is visibly wet. Allow the soil to drain completely under gravity.

Pour water through the plastic tube as done earlier into the hole to fill the depth (h) over which the saturated hydraulic conductivity is to be measured. Remove the tube and measure the rate of fall of water by recording the water level at successive intervals of time.

2.5.4 Data Computation

If the depth of water at time t sec.. after commencement of measurement is h cm. then t is given by:

$$t = \frac{-1.15}{k} r \log (h + r/2) + C$$

where k = saturated hydraulic conductivity
C = constant

Plot of t versus log (h+r/2) is a straight line
with slope equal to $\frac{-1.15}{k} r$

Saturated hydraulic conductivity

$$K = \frac{-1.15r}{\text{slope of graph}}$$

Notes on the method

1 Measurement of water level :- Water level in the auger hole can be measured by suspending an empty plastic bottle (float) of diameter less than that of the auger hole by a string vertically and measuring the total length of the string and bottle from a reference point above the ground surface. The bottle should float and the string should be taut when the measurements are taken. Generally the elapsed time is recorded for every 1-2cm drop in water level. Usually measurements can be completed in 20 to 30 minutes with about 10 readings. Measurements are repeated 2 times in heavy soils of low permeability and 4 times in light soils of high permeability. (Figure 7)

2 Complete and uniform saturation of soils around the auger hole cannot be achieved in reality, especially in the upper portion of the hole. In soils of high permeability, the water level may have to be maintained at the surface for sometime by frequent topping up as the water level goes down rapidly. In soils of low permeability, refilling may have to be done only once or twice and sometimes may have to be left overnight for the water to drain off completely.

3 The hydraulic conductivity determined by this method is a composite rate for the full depth from the initial water level but reflects primarily the permeability of the more permeable horizon.

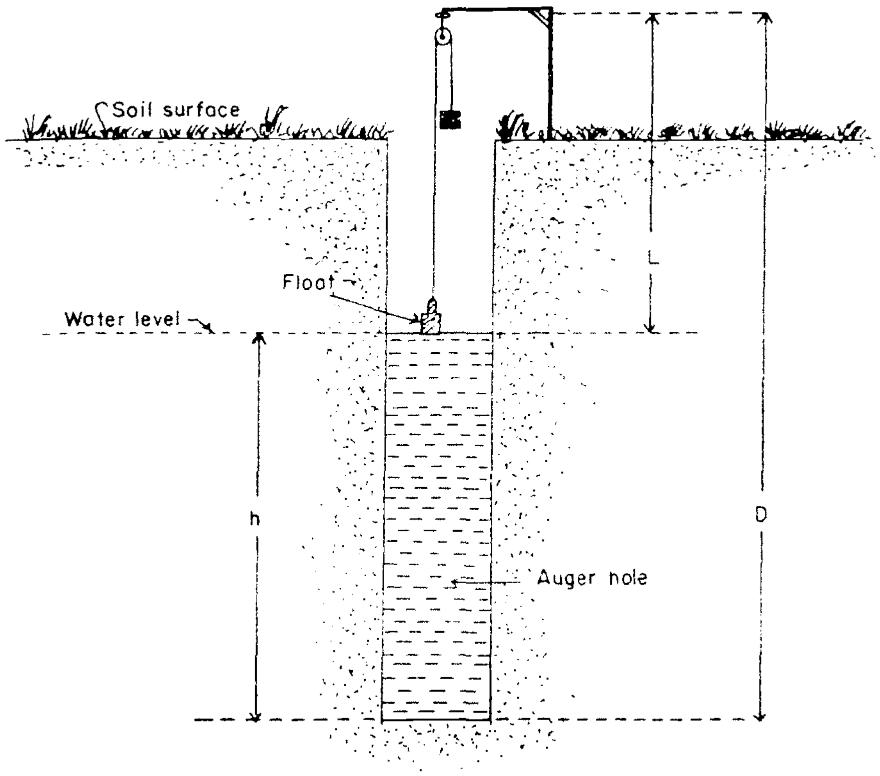


Figure 7 : Schematic representation of set up for measuring saturated hydraulic conductivity of soil by the u inversed auger hole method

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