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DETERMINATION OF INFILTRATION RATE USING DOUBLE RING INFILTROMETER ON A SANDY-LOAM SOIL IN A SEMI-ARID REGION OF BORNO STATE

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Abstract: *The research was carried out to determine the infiltration rate of a sandy-loam soil within the Ramat Polytechnic Teaching and Research Farm using a constructed double ring infiltrometer. Infiltration is the movement of water into the soil under the driving forces of gravity and capillarity and limited by viscous forces involved in the flow into soil pores as quantified in terms of permeability or hydraulic conductivity. Infiltrometer tests were used to measure infiltration rates in-situ at three points. Result shows that infiltration rate was 0.432cm/hr which is in agreement with the published data of 0.40-0.45cm/hr. The results obtained in this study were within the bounds of variability found in literature. It is hereby recommended that knowledge of this research work will play major role in controlling the problems of surface runoff, pollution, irrigation and drainage management.*

Keywords: *Determination, Infiltration, Double Ring, Infiltrometer, Sandy-loam*

INTRODUCTION

Infiltration is the movement of water into the soil under the driving forces of gravity and capillarity and limited by viscous forces involved in the flow into soil pores as quantified in terms of permeability or hydraulic conductivity. The rate of this process determines how much water will enter the root zone and how much, if any, will run off (Hillel, 2004). The infiltration is sensitive to the near surface conditions of the soil, as well as the antecedent water conditions, organic matter content, among others. The rate of infiltration normally declines rapidly during the early stage of a rainstorm even and reaches a constant value after several hours of rainfall. Fielder (2012) reported that the major soil and water characteristics affecting infiltration rates are: the initial moisture content, condition of the surface, hydraulic conductivity of the soil profile, texture, porosity, and degree of swelling of soil colloids, organic matter, and vegetative cover, duration of irrigation or rainfall and viscosity of water. Of these, soil texture is predominant. Soil structure also affects the rate of water movement into the soil; well-structured soils have optimum infiltration rates at varying moisture levels. The proportion of water from rainfall or snowmelt that enters the soil depends on "residence time" (how long the water remains on the surface before running off) and the infiltration rate. These are affected by vegetation and many soil properties (Fielder, 2012).

According to USDA (2001), the properties that affect infiltration that cannot be readily changed by management include texture, minerals in the soil, soil layering and soil depth. A fully saturated soil could therefore be considered as an impermeable layer. A low soil temperature will slow the infiltration or fully prevent it if the soil is frozen. Vegetation increases the infiltration by making the soil more porous due to the movement of the roots in the soil (USDA, 1998). The plant life also protects the soil from the pounding forces of direct rainfall which otherwise might break apart soil aggregates resulting in clogging of the open pore spaces at the soil surface and thus reducing its infiltration abilities (Khoury-Nolde, 2008). Quantification of infiltration phenomenon is therefore of great importance in water sheds management, particularly in prediction of flooding, soil erosion and pollutants transport that are all dependent on the amount of created runoff that are in turn dependent on infiltration phenomenon (Tsanis, 2006).

In Maiduguri and environs, hydrological problems such as flooding, erosion, pollution and soil management have been militating against many socio-economic efforts of farmers. Current knowledge of infiltration processes into soils has not been adequate to address such problems. Research work toward minimizing such problems would be very essential. Published data on infiltration rates may not be accurate due to variation in their soil mineralogy and or percentage soil separates. In view of this, there is the need to determine the site specific infiltration rate for the study area.

Objectives

The specific objectives of the study are as follows:

i. To construct the double ring infiltrometer
ii. To run infiltration tests on the sandy-loam soil
iii. To compare the result obtained with the published data

Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is most often measured in millimeters per hour or inches per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil. The rate of infiltration can be measured using an infiltrometer.

Richards (1952) defines infiltration as the downward movements of water into soils and may be defined for rain or ponded conditions as" the maximum rate at which a soil, in a given condition at a given time, can absorb rain or "the rate at which a soil will absorb water ponded on the surface at a shallow depth when the ponded area is infinitely large or when adequate precautions are taken to minimize the effect of divergent flow at the borders.

Akan and Houghtale (1992) refers infiltration as the process by which rainwater passes through the ground surface and fills the pores of the underlying soil surface and subsurface of soil conditions influence the filtration rtes. The surface conditions determine the availability of water, while the subsurface conditions govern the ability of the available water to infiltrate. The rate of rainfall means the availability of water at the ground surface, the infiltration capacity means as the maximum rate at which water can infiltrate into the soil. It means the ability of available water to infiltrate.

Infiltration is the volume of water passing into the soil per unit of area per unit of time and has the dimensions of velocity (L^3 L^{-2} T^{-1}). The term infiltrability refers to the infiltration rate resulting when water at atmospheric pressure is made freely available at the soil surface (Hillel, 1982). Infiltrability is thus dependent upon soil conditions (surface controlled) such as moisture, matric potential, pre- size distribution, whereas the infiltration rate is supply controlled. The infiltration rate can be greater than the infiltrability if water is ponded sufficiently deep on the soil surface or the infiltration rate can be smaller if water is supplied at a lower rate than the infiltrability. If a shallow layer of water is instantaneously applied and maintained at the surface of an initially unsaturated soil, the full range of soil infiltrability may be measured.

The determination of the inlfiltrability of a soil is an important parameter for irrigation, erosion studies and many engineering projects. Infiltration can be considered as a three-step sequence: surface entry, transmission through the soil and depletion of storage capacity in the soil (Chou, 1964). Surface entry is influenced by such properties as surface vegetation, soil texture, porosity, structure and the stability of the soil aggregates. Transmission rates depend upon texture, porosity, pore size distribution, soil stratification, antecedent soil moisture content, salinity and biotic activity. Storage capacity depends upon porosity and changes in pore size distribution in the soil profile.

Difference between Seepage, Percolation and Infiltration

Infiltration The process in which water is absorbed by soil of any area during a rainfall. Infiltration is a process which is also used to measure the speed with which water enters the soil in case of rain or when water is supplied to the ground through human made means.

The speed of infiltration in the amount of water absorbed per hour. This amount is in inches or in millimeters the infiltration capacity of a soil is high at the beginning of a storm and has an exponential decay as the time elapses. The rates of water being absorbed are measured through an instrument which is called “infiltrometer”. There are two types of infiltrometers.

1. Flooding type infiltrometer
2. Rainfall simulator

Percolation

It is the descending motion of infiltered water through soil and rock layers. Infiltration occurs closer to the surface of the soil. Infiltration delivers water from the surface into the soil and plant rooting zone while percolation moves it through the soil profile to replenish ground water suppliers or become part of sub-surface run-off process. Thus, the percolation process represents the flow of water from unsaturated zone to the saturated zone.

Seepage

Seepage is the flow of water under gravitational forces in a permeable medium. Flow of water takes places from a point of high head to a point of low head. The flow is generally laminar. For example, water enters the ground surface at the upstream side of a retaining structure like a dam and comes out at the downstream side.

Factors that Affect infiltration

The proportion of water from rainfall or snowmelt that enters the soil depends on residence time, how long the water remains on the surface before running off and the infiltration rate. These are affected by vegetation and many soil properties.

Soil Properties

The properties that affect infiltration and cannot be readily changed are as follows;

i. Texture: Water moves more quickly through the large pores and spaces in a sandy soil than it does through the small pres in a clayey soil. Where the content of organic matter is low, texture plays a significant role in the susceptibility of the soil to physical crusting.

ii. Clay mineralogy: Some types of clay develop cracks as they dry. These cracks rapidly conduct water to the subsurface and seal shut once the soil is wet.

iii. Minerals in the soil: High concentrations of sodium tend to inhibit the development of good structure and promote the formation of surface crusts which reduce the infiltration rate. Calcium improves soil structure.

iv. Soil Layers: Subsurface soil, including a subsoil of dense clay, cemented layers and highly contrasting layers such as coarse sand over loam, can slow water movement through soil and thus limit infiltration.

v. Depth: Soil depth controls how much water the soil can hold. When soil above an impermeable layer, such as bedrock, becomes saturated, infiltration ceases and runoff increase. The properties that affect infiltration and can be readily changed or a shift in vegetation.

Infiltration Rate

The infiltration rate is generally highest when the soil is dry. As the soil becomes wet, the infiltration rate slows to the rate at which water moves through the most restrictive layer, such as a compacted layer or a layer of dense clay. Infiltration rates decline as water temperature approaches freezing, little or no water penetrates the surface of frozen or saturated soils.

Vegetation

A high percentage of plant cover and large amounts of root biomass generally increase the infiltration rate Different plant species have different effects on infiltration. The species that form a dense root may can reduce the infiltration rate. In areas of arid and semi-arid range land, the infiltration limiting layer commonly is confined to the top few millimeters of the soil particularly in the open spaces between plant canopies. These areas receive few inputs of organic matter which build soil structure. Also, the impact of raindrops in these areas can degrade soil structure and form physical crusts.

Infiltration Methods

Numerous methods have been developed for measuring infiltration rates of soils in the field. These methods may be classified into three groups:

1. Rainfall simulators in which infiltration is determined as the difference between water applied and runoff.
2. Instruments which impound water in a confined area, maintaining a constant head of water.
3. Watershed methods which allow determination of infiltration from rainfall and runoff data.

Rainfall infiltrometers

Basically a rainfall infiltrometer simulates rainfall with the use of special spray nozzles set a certain distance (usually 2 to 3m) above the soil surface. The soil surface tested is usually enclosed so that once runoff commences it can be collected at an opening and the volume measured with time. The difference between the application rate and the runoff rate is taken to be the infiltration. Bernard (1965) lists four conditions that should be met to produce accurate and representative measurements of the soil infiltration rate using rainfall infiltrometers: the distribution of drop sizes must be uniform over the plot area; the artificial rainfall must be similar to the natural rainfall being simulated in respect of drop size, drop velocity, intensity range and total energy value; the plot area must be large enough to sample the population and give reproducible results) approximately ($1m^2$); and the artificial rainfall must be applied not only to the plot but also to an adequate buffer area around the plot.

Many of these instruments, originally designed to measure the erosivity of soil, have been redesigned to apply water at lower rates so that runoff is minimized. Simulators range from simple telephone booth sized installations to ones that require a semi-trailer truck to move. Cost can be expensive especially if rain characteristics such as intensity, drop size, drop distribution and velocity are to be accurately simulated. The normal length of an infiltration test employing a rainfall infiltrometer is 30 to 120 minutes with the infiltration rate becoming constant after 20 to 60 minutes.

The main advantage with rainfall infiltrometers is that, they simulate the action of rain upon the soil surface. Unprotected soil surfaces will thus reflect surface sealing effects while those with vegetation will reflect the interception of the rain by the canopy (Par and Bertrand, 1960).

Flooding Infiltrometer

Flooding infiltrometer enclose an area and pond water to a specified depth. The infiltration rate is calculated from the drop in water level per unit time or the amount of water required to maintain the specified depth or head of water required to maintain the specified depth or head of water per unit time. Flooding infiltrometers measure the maximum rate of entry of water into the soil. They do not simulate raindrop activity, they measure water penetration rather than rainfall infiltration. Usually there is a buffer zone of water around an inner compartment of water to correct for lateral movement of water (due to matric potential); thus the inner compartment will be a measurement of the true vertical infiltration rate.

Basin Infiltrometer

The basin infiltrometer usues soil from the outside of the basin to construct the paired dykes, thus not disturbing the soil within the dyked areas. The sizes of the plots, $1m^2$ up to 0.2ha usually accounts for any local soil variation thus reducing the need for replication (Bertrand and pass, 1960). These sizes also reduce errors due to lateral flow especially when a buffer compartment is built. The disadvantage to this type of infiltrometer is the site disturbance and the necessary power equipment and labour to construct the basins and to supply the water.

Ring-type Infiltrometer

The ring infiltrometer is perhaps the most common type of infiltrometer used. It is inexpensive to construct and operate, it requires relatively little water compared with the basin infiltrometer and only one person can set up and run several tests simultaneously. The simplicity of its design allows for ease in replication and operation.

Lateral flow is the most serious limitation to the use of ring infiltrometers (Hills, 1971). The proportion of lateral flow to vertical flow is dependent upon rings sizes, antecedent soil moisture, texture, stratification, soil structure and time. Higher antecedent soil moisture contents result in the gravitational potential (vertical and lateral). Finer textures and the presence of stratification results in increase of lateral flow relative to vertical flow. The double ring system providing the most accurate results while correcting for lateral flow while at the same time permitting easy portability and installation is one with an outside ring diameter of 0.60m and an inside ring diameter between 0.20m and 0.40m (Swartzendruber and Olson, 1961). Larger rings do provide greater accuracy but are too cumbersome for one person to move and install.

Holton's Infiltration Model

The infiltration process was thoroughly studied by Horton in the early 1930s. An outgrowth of his work was the following relation for determining infiltration capacity:

$$F_p = F_c + (F_o - F_c)e^{-kt}$$

Where:

F_p	=	infiltration rate into soil in hr (mm/hr)
F_c	=	minimum or asymptotic value of F_p in hr (mm/hr)
F_o	=	maximum or initial value of F_p in hr (mm/hr)
t	=	time from beginning of storm, sec
k	=	decay coefficient, sec

It indicates that if the rainfall supply exceeds the infiltration capacity infiltration tends to decrease in an exponential manner. Although simple in form, difficulties in determining useful values for F_o and k restrict the use of this equation. The area under the curve for any time interval represents the depth of water infiltrated during that interval. The infiltration rate is usually given in inches per hour and the time t in minutes, although other time increments are used and the coefficient k is determined accordingly.

MATERIALS AND METHODS

The study was carried out in the Ramat Polytechnic, Maiduguri Teaching and Research farm. Maiduguri is located at $130^0$5E and $110^0$5E and 345m above mean sea level with the mean annual rainfall of about 625mm and annual temperature of 28-32°C. It is located in the Ngadda basin, a seasonal stream that flows through Maiduguri. Land use at the site is characterized by permanent rain-fed cultivation of grain crops such as sorghum and millet. Dry season fadama irrigations are practiced at some points using small horse-powered pumps. Other land use activities include sand mining, grazing, urban house construction, gardening and orchards. The climate of Maiduguri is generally semi-arid with moderate variation in temperatures; the mean monthly minimum temperature is lowest 13.5°C during the period of strongest and most constant north east winds (Harmattan) in December and January and highest 24.7°C in April. The mean monthly maximum temperature is highest (40.2°C) prior to and during the onset of the rains in April and the lowest (31.3°C) during the peak rainy period of August.

Infiltration testing

The double ring infiltrometer constructed was used to perform the infiltration testing on the sandy-loam soil of the study area. Infiltration test was carried out at three points within the teaching and research farm. This experimental investigation measured infiltration rates in-situ to compare with published values for the study area.

RESULTS AND DISCUSSION

Results of the double ring infiltrometer; infiltration test performed on the sandy-loam soil in the Ramat Polytechnic Teaching and Research Farm are given. The resulting measurements represents infiltration rate, with relatively little impact of capillarity during the initial operation of the test. The infiltration rates in this soil reached a steady state value of between 0.432cm/hr which is consistent with previous measurements in similar soils (Estes, 2007; Stewart, 1964).

Table 4.1: Infiltration rate vs Time obtained

	Infiltration rate and Time obtained										
Infiltration point	1	2	3	4	5	6	7	8	9	10	11
F(cm/hr)	50.18	68.97	39.70	27.97	15.62	10.06	3.75	1.08	0.62	0.43	0.43
Ti(hrs)	0.25	0.25	0.25	0.25	0.25	0.28	0.34	0.40	0.47	0.54	0.61
F(cm/hr)	52.18	68.97	41.70	29.97	15.91	10.66	3.87	1.28	0.74	0.46	0.43
Ti(hrs)	0.25	0.25	0.25	0.25	0.25	0.29	0.36	0.40	0.42	0.45	0.55
F(cm/hr)	56.18	42.97	29.70	20.97	15.68	9.06	2.75	0.84	0.52	0.43	0.43
Ti(hrs)	0.25	0.25	0.25	0.25	0.25	0.25	0.29	0.34	0.39	0.45	0.47

Insitu infiltration rates were measured using a double-ring infiltrometer. Infiltration rates measured for the three test points demonstrated the clear influence of capillarity with infiltration rates decreasing as elapsed time progressed. Steady state infiltration rates measured at the range over an order of magnitude from a low of an average of 0.432cm/hr to a high of 50.33cm/hr. This level of variability in infiltration rates is not uncommon in soils of sandy- loam.

DISCUSSION

For the infiltration tests at all the three points, there were variations between rates in early readings. These variations were likely due to macro pore flow from voids beneath the double ring infiltrometer (DRI). Other known sources that produce over-estimation of measured infiltration rate using a DRI are separation of the soil from the wall of the DRI and lateral divergence (Bouwer, 1986). The results obtained in this study were within the bounds of variability found in Literature (Reynolds, 2013).

CONCLUSION

The soil of the test area was purely sandy-loam. The measured infiltration rates yielded the average basic infiltration rate of 0.43cm/hr which is in agreement with published data of 0.40 – 0.45 (Reynolds, 2013).

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