EVALUATION OF INFILTRATION RATES OF THE FEDERAL UNIVERSITY OF TECHNOLOGY RESEARCH AND TEACHING FARM, GIDAN KWANO CAMPUS MINNA

BY

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MATRIC No. 2006/24113EA

DEPARTMENT OF AGRICULTURAL & BIORESOURCES ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

FEBRUARY, 2012.

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BEING A FINAL YEAR PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG.) DEGREE IN AGRICULTURAL & BIORESOURCES ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE

FEBRUARY, 2012.

DECLARATION

I hereby declare that this project is a record of a research work that was undertaken and written by me. It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communication, published and unpublished works of others were duly referenced in the text.

John, Teri Vandi

28/02/2012
Date

CERTIFICATION

This is to certify that this project entitled "Evaluation of Infiltration Rates of the Federal University of Technology Teaching and Research Farm, Gidan Kwano Campus, Minna" by John, Teri Vandi meets the regulations governing the award of the degree of Bachelor of Engineering (B. ENG.) of the Federal University of Technology, Minna, and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This Project is dedicated to Almighty God, the author and finisher of my Life. To my parent Mr. & Mrs. Tari John Vandi, Engr.(Deacon) Jonathan O. David, the CEO JOD Partnership LTD (Consulting Engineers Global), JONTA Nig. LTD (Engineers and merchants), VIHEDA RESOURCES Ltd. (Conglomerate) and Mrs Margaret J. David.

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Special thanks go to Almighty God for the gift of life and for sparing my life throughout this program. Baba God you too much ohhh

Independence is good, but interdependence has a higher value. Therefore this project research work is a direct or indirect contribution(s) of so many people towards its success.

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ABSTRACT

The project was conducted to determine the general soil classification of the farm plot and to evaluate the infiltration rates characteristics of the farm plot. Soils that have reduced infiltration have an increase in the overall amount of runoff water. This excess water can contribute to local and regional flooding of streams and rivers or results in accelerated soil erosion of fields or stream banks. In most cases, maintaining a high infiltration rate is desirable for a healthy environment. However, soils that transmit water freely throughout the entire profile or into tile lines need proper chemical management to ensure the protection of groundwater and surface water resources. Observations were made based on the following indices. Viz, the average infiltration rate of the research farm which is also the field capacity of the farm is 14.74cm/hr. The size particle distribution classify the farm soil to be sandy loamy. However, from the study carried out on seven (7) different units of the farm plot, irrigation and other agricultural practices would be mathematically certain for optimum yield, considering the values obtained.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Anywhere in the world, a portion of the water that falls as rain, drizzle, glaze, rime, hail, or snow infiltrate into the sub surface soil and rock. How much infiltrates depends greatly on a number of factors.viz; (Stephen, 2009)

- Vegetative cover, root development, and organic content
- Moisture content
- Soil structure and texture
- Porosity and permeability
- Soil bulk density and compaction
- Slope, landscape position, and topography.

Some water that infiltrates will remain in the shallow soil Layer, where it will gradually move vertically and horizontal through the soil and subsurface material. Eventually it may enter a stream by seepage into the stream bank. Some of the water may infiltrate deeper, recharging ground-water aquifers. If the aquifers are porous enough to allow water to move freely through it, people can drill wells into the aquifer and use the water for their purposes. Water may travel long distances or remain in the ground-water storage for a long period before returning to the surface or seeping into other water bodies, such as streams and oceans.

Infiltration can be viewed as the process by which water on the ground surface enters the soil (USDA-NRCS, 1998).

Infiltration is governed by two forces, gravity and capillary action. While smaller pores offer greater resistance to gravity, very small pores pull water through capillary action in addition to and even against the force of gravity.

Infiltration rate in soil science is a measure of the rate at which a particular soil is able to absorb rainfall or irrigation. It is measured in centimetre per hour or millimetres 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. (USDA-NRCS, 1998)

The rate of infiltration of soil in the field is affected by five major factors: (i) aggregation (Tisdall and Adem, 1986), (ii) surface seal (Moore, 1981), (iii) bulk density (Patel and Singh, 1981), (iv) natural channels or macropores (Thomas and Phillips,1979), and (v) restrictive layers below the surface (Schuh et al., 1984). Others are; soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity all play a role in dictating infiltration rate and capacity. For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly. Vegetation creates more porous soils by both protecting the soil from pounding rainfall, which can close natural gaps between soil particles, and loosening soil through root action. This is why forested areas have the highest infiltration rates of any vegetative types. The top layer of leaf litter that is not decomposed protects the soil from the pounding action of rain, without this the soil can become far less permeable. In chaparral vegetated areas, the hydrophobic soils in the succulent leaves can be spread over the soil surface with fire, creating large areas of hydrophobic soils. Other conditions that can lower infiltration rates or block them include dry litter that resists re-wetting, or frosts can lower infiltration. If soil is saturated at the time of an intense freezing period, the soil can become a concrete frost on which infiltration rates would be around zero. Even though, any of these infiltration reducing conditions would not be over an entire watershed, there are most likely gaps in the concrete frost or hydrophobic soil where water can infiltrate.

1.2 Statement of the Problem

Soil can be an excellent temporary storage medium for water, depending on the type and condition of the soil. Proper management of the soil can help maximize infiltration and capture as much water as allowed by a specific soil type. If water infiltration is restricted or blocked, water does not enter the soil and it either pond on the surface or runs off the land. Thus, less water is stored in the soil profile for use by plants. Runoff can carry soil particles and surface applied fertilizers and pesticides off the field. These materials can end up in streams and lakes or in other places where they are not wanted. It is therefore, pertinent to evaluate the infiltration rate and characteristics of the soils before using such farm fields for effective research work.

1.3 Objectives of the Study

The objectives of this study are as follows:

1. To determine the general soil type of the Research and Teaching farm plots of the Federal University of Technology, Gidan Kwano Campus, Minna.
2. To evaluate the infiltration rate characteristics of the research farm plots.

1.4 Justification of the Study

Soils that have reduced infiltration have an increase in the overall amount of runoff water. This excess water can contribute to local and regional flooding of streams and rivers or results in accelerated soil erosion of fields or stream banks. In most cases, maintaining a high infiltration rate is desirable for a healthy environment. However, soils that transmit water freely throughout the entire profile or into tile lines need proper chemical management to ensure the protection of groundwater and surface water resources. Soils that have reduced infiltration can become saturated at the surface during rainfall. Saturation decreases soil strength, increases detachment of particles, and enhances the erosion potential. In some areas that have a steep slope, surface material lying above a compacted layer may move in a mass, sliding down the slope because of saturated soil conditions. Decreases in infiltration or increases in saturation above a compacted layer can also cause nutrient deficiencies in crops. Evaluation of soil intake characteristics of the Federal University of Technology, Minna Research farm plots will help explain the soil water balance and soil hydraulics properties. The double ring infiltrometer may be used for determining the rate of infiltration and capacity for irrigation and drainage planning, studies, and design. Determination of intensity of artificial precipitation and the hydraulic properties.

1.5 Scope of the Study

This study is limited to the evaluation of infiltration rates and soil analysis of the selected soil units in the teaching and research farm of Federal University of Technology Minna, (Gidan Kwano Campus) Niger State, Nigeria. The results obtained are also limited to the month of (June, 2011), due to time constraint. However, the results can be used as a guide to soil characterization of other areas.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Infiltration

Infiltration is the process by which water enters the soil. It separates water into two major hydrologic components - surface runoff and subsurface recharge. The assessment of runoff risk has assumed an increased importance because of concerns about the associated pollution hazards. Accurate determination of infiltration rates is essential for reliable prediction of surface runoff. As environmental impact assessments are concerned with long-term effects, it is essential that the infiltration data on which they are based should be reasonably stable over decades.

2.1.1 Infiltration Rate

In soil science is a measure of the rate at which a particular soil is able to absorb rainfall or irrigation. It is measured in centimetre per hour or millimetres 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 is affected by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity all play a role in dictating infiltration rate and capacity. For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly. Vegetation creates more porous soils by both protecting the soil from pounding rainfall, which can close natural gaps between soil particles, and loosening soil through root action. This is why forested areas have the highest infiltration rates of any vegetative types.

The top layer of leaf litter that is not decomposed protects the soil from the pounding action of rain, without this the soil can become far less permeable. In chaparral vegetated areas, the hydrophobic soils in the succulent leaves can be spread over the soil surface with fire, creating large areas of hydrophobic soils. Other conditions that can lower infiltration rates or block them include dry litter that resists re-wetting, or frosts can lower infiltration. If soil is saturated at the time of an intense freezing period, the soil can become a concrete frost on which infiltration rates would be around zero, but any of these infiltration reducing conditions would not be over an entire watershed, there are most likely gaps in the concrete frost or hydrophobic soil where water can infiltrate. Once water has infiltrated the soil it remains in the soil, percolates down to the ground water table, or becomes part of the subsurface runoff process.

The relationship between rainfall intensity and infiltration rate is important in determining the generation of overland flow. If rainfall intensity (cm/hr) is below the infiltration capacity, then the infiltration rate equals the rainfall intensity and all the rainwater passes the soil surface to become soil water. If rainfall intensity is greater than the infiltration capacity, then infiltration rate equals the infiltration capacity and the excess rainfall becomes overland flow Rainfall intensity will vary throughout a storm event, having short periods of very intense downpours followed by less intense showers. Rainfall. intensity may exceed infiltration capacity during the down-pours, but not during the showers. During the periods of light or no rainfall, the soil can actually recover some of its infiltration capacity as the soil drains and soil storage capacity is returned. The type, timing, and spatial pattern of rainfall over a watershed will greatly influence how much overland flow is generated during a storm.

2.1.2 Process of Infiltration

When precipitation reaches the ground, it can infiltrate into the ground, be stored as soil moisture eventually to be released back into the atmosphere through evapotranspiration, or if the soil profile has reached capacity, become runoff and enter the surface hydrological system.

Whether the precipitation percolates into the soil or runs off the surface is dependent on the physical parameters associated with the following factors:

- The precipitation regime – intensity, type (rain or snow), frequency, primary season;
- Site attributes – slope, surface roughness, soil hydraulic conductivity;
- Cover – type and density of vegetation, percent of surface covered;
- Practices – structural improvements constructed to control surface water.

Several of these factors remain unchanged with site development (e.g. rainfall intensity and duration); others are subject to drastic alteration. These factors can include the complete removal of all vegetation, changes to the slope and surface roughness, changes to the soil's hydraulic conductivity from mixing and re-grading, and the installation of water control structures.

The process of infiltration can continue only if there is room available for additional water at the soil surface. The available volume for additional water in the soil depends on the porosity of the soil and the rate at which previously infiltrated water can move away from the surface through the soil. The maximum rate that water can enter a soil in a given condition is the infiltration capacity. If the arrival of the water at the soil surface is less than the infiltration capacity, all of the water will infiltrate. If rainfall intensity at the soil surface occurs at a rate that exceeds the infiltration capacity, Ponding begins and is followed by Runoff over the ground surface, once depression storage is filled. This runoff is called Horton overland flow. The entire hydrologic system of a watershed is sometimes analyzed Using hydrology transport models, mathematical models that consider infiltration, runoff and channel flow to predict river flow rates and stream water quality.

2.2 Research Findings

Infiltration rate usually shows a sharp decline with time from the start of the application of water. The constant rate approached after a sufficiently large time is referred to as the steady-infiltration rate. The process is described by the equations of Kostiakov (1932) and Horton (1940), which show a decreasing infiltration rate as a function of time.

Green and Ampt (1911) and Phillip (1957) developed mathematical solutions to physically based theories of infiltration. The Green-Ampt theory considers water to move downwards as piston flow. The system is assumed to consist of a uniformly wetted near-saturated transmission zone above a sharply defined wetting front of constant pressure head. Application of the Darcy equation for saturated flow through porous media to this simple system yields:

$$I = K\,(H + L - h)/L \qquad (2.1)$$

Where: I is infiltration rate,

K is hydraulic conductivity,

H is pounding depth,

h is pressure head at wetting front and

L is depth to wetting front.

As the wetting front deepens, the value of the pressure head (h) becomes relatively insignificant compared to the depth (L) and the infiltration rate (i) approaches the hydraulic conductivity (K) of the transmission zone.

Ponding depth affects infiltration most at the beginning of infiltration while L is small. As infiltration progresses and the depth to wetting front (L) increases, the effect of Ponding depth decreases and eventually becomes negligible when L is sufficiently deep Bouwer, (1966). The mathematical and physical analysis of the infiltration process developed by Phillip (1957b) separates the process into two components - that caused by a sorptivity factor and that influenced by gravity. Sorptivity is the rate at which water will be drawn into a soil in the absence of gravity; it comprises the combined effects of adsorption at surfaces of soil particles and capillarity in soil pores. The gravity factor is due to the impact of pores on the flow of water through soil under the influence of gravity. The Phillip model takes the form of a power series but in practice an adequate description is given by the two-parameter equation:

$$i = \frac{1}{2} S t^{-\frac{1}{2}} + A \qquad (2.2)$$

where: i is infiltration rate,

S is sorptivity,

t is time and

A is a gravity factor related to hydraulic conductivity.

The sorptivity (S) is influenced by the initial and final moisture contents. As the moisture content approaches saturation, sorptivity tends to zero and the infiltration rate becomes equal to the field saturated hydraulic conductivity. This implies that the steady infiltration rate reached after a long time should be largely independent of the antecedent moisture content (Phillip, 1957b).

The theoretical analyses outlined above imply that the steady infiltration rate is a function of the pore configuration of the soil. Soils derived from shale, sandstone or limestone, containing little or none of the swelling clay mineral montmorillonite (Kiely, 1971), are predominant in Ireland. Consequently the steady infiltration rate should remain stable over time unless the soil structure is altered by animal or machine traffic.

Horton, (1940) suggested that infiltration capacity rapidly declines during the early part of a Storm and then tends towards an approximately constant value after a couple of hours for the remainder of the event. Previously infiltrated water fills the available storage spaces and reduces the capillary forces drawing water into the pores. Clay particles in the soil may swell as they become wet and thereby reduce the size of the pores. In areas where the ground is not protected by a layer of forest litter, raindrops can detach soil particles from the surface and wash fine particles into surface pores where they can impede the infiltration process.

2.3 Infiltration Calculation Methods

Infiltration is a component of the general mass balance hydrological budget. There are several ways to estimate the volume and/ or the rate of infiltration of water into a soil. Many estimation methods of infiltration are widely used.

2.3.1 General Hydrologic Budget

The general hydrologic budget, with all the components, with respect to infiltration F. given all other variable and infiltration is the only unknown, simple algebra solves the infiltration question.

$$F = B_I + P - E - T - ET - S - R - I_A - B_0 \qquad (2.3)$$

Where:

F = infiltration, which is based as length

B_I = is the boundary input, which is essentially the output watershed from adjacent, directly connected impervious areas.

B_0 = is the boundary output, which is also related to the surface runoff, R, depending on where one chooses to define the exit point or points for the boundary.

P = is precipitation

E = is evaporation

ET = is evapotranspiration

S = is the storage through either retention or detention areas.

I_A = is the initial abstraction, which is the short term surface storage such as puddles or even possibly detention ponds depending on the size.

R = surface runoff.

The only note on this method is one must be wise about which variables to use and which to omit, for doubles can easily be encountered. An easy example of double counting variable is when evaporation, E, and the transpiration, T, are placed in the equation as well as the evaporation, ET. ET has included in it T as well as a portion of E.

2.3.2 Kostiakov's Equation

Kostiakov (1932) proposed the following equation for estimating infiltration,

$$i(t) = \alpha\, t^{-\beta} \qquad (2.4)$$

Where; i is the infiltration rate at time t, and

α $(\alpha > 0)$ and β $(0 < \beta < 1)$ are empirical constants.

Upon integration from 0 to t, Eq. 4 yields Eq. 5, which is the expression for cumulative Infiltration, $I(t)$.

$$I(t) = \frac{\alpha}{1-\beta}\, t^{(1-\beta)} \qquad (2.5)$$

The constants α and β can be determined by curve-fitting Eq. 4 to experimental data for cumulative infiltration, $I(t)$. Since infiltration rate, I, becomes zero as $t \to \infty$, rather than approach a constant non-zero value, Kostiakov proposed that the Esq. 4 and 5 can be used only for $t < t, max$

Where; t is equal to $(\alpha / K_S)^{(1/\beta)}$, and

Ks is the saturated hydraulic conductivity of the soil.

Kostiakov's equation describes the infiltration quite well at smaller times, but becomes less accurate at larger times (Philip, 1957; Parlange and Haverkamp, 1989).

2.3.3 Mezencev's Equation

In order to overcome the limitations of Kostiakov's equation for large times, Mezencev's (Philip, 1957) proposed the following as modifications to Esq.2.4 and 2.5 Mezencev's proposed infiltration estimated by

$$i(t) = if + \alpha t\text{-}\beta \tag{2:6}$$

And

$$I(t) = if\,t + \frac{\alpha}{1-\beta}\,t(1\text{-}\beta) \tag{2.7}$$

where i_t is the final infiltration rate at steady state

2.3.4 Horton's Equation

Horton (1940) proposed to estimate infiltration in the following manner,

$$I(t) = I_{(f)} + (I_o - I_f)\,e^{-\gamma t} \tag{2.8}$$

And

$$I(t) = if\,t + \frac{1}{\gamma}\,(i0 - if)(1\text{-}e^{-\gamma t}) \tag{2.9}$$

Where:

i_0 and i_f are the presumed initial and final infiltration rates, and

γ is an empirical constant.

It is readily seen that *i(t)* is non-zero as *t* approaches infinity, unlike Kostiakov's equation. It does not, however, adequately represent the rapid decrease of *i* from very high values at small *t*, (Philip, 1957). It also requires an additional parameter over the Kostiakov equation. (Parlange and Haverkamp 1989), in their comparison study of various empirical infiltration equations, found the performance of Horton's equation to be inferior to that of Kostiakov's equation. Ultimately, the infiltration rate reaches a constant value known as the saturated soil infiltration rate, Rubin and Steinhardt, (1963) and Rubin et al. (1964) showed that the final infiltration rate reached under these conditions is equal to the vertical hydraulic conductivity of a saturated soil. Several assumptions about boundary conditions must be met, however, including a constant hydraulic gradient with depth and flow through the soil column, which is vertical (no lateral component).

2.3.5 SCS Equation

The USDA Soil Conservation Service, (1957) developed an equation for rainfall-runoff Relationship based on daily rainfall data as input:

$$R = \frac{(P-0.2Fw)2}{P+0.8Fw} \quad (2.10)$$

Where; P is the daily rainfall,

R is the runoff, and

F_w is a statistically derived parameter bearing some resemblance to the initial soil moisture deficit.

Infiltration is calculated as the excess of rainfall over runoff:

$$I = P - R \quad (2.11)$$

2.3.6 Boughton's Equation

Boughton, (1966) modified the rainfall-runoff relationship of USDA-SCS (1957) given by Eq. (2.10) as follows:

$$R = P - F_r \tan\left(\frac{P}{Fr}\right) \quad (2.12)$$

Where; F_r is an empirical parameter; however, some success has been reported when interpreted as the initial soil moisture deficit (Dunin, 1976). Infiltration is calculated using Eq. (2.11).

2.3.7 Holtan's Equation

The empirical infiltration equation devised by Holtan (1961) is explicitly dependent on soil water conditions in the form of available pore space for moisture storage:

$$I(t) = i_f + ab\,(\omega - I)^{1.4} \quad 2.13$$

Where; a is a constant related to the surface conditions varying between *0.25* and *0.8*,

b is a scaling factor,

ω is the initial moisture deficit or the pore space per unit area of cross section initially available for water storage (cm), and

I is the cumulative infiltration (cm) at t.

This equation has been found to be suitable for inclusion in catchment models because of soil water dependence, and satisfactory progress has been reported for runoff predictions (Dunin, 1976).

2.4 Soil Sampling

2.4.1 Initial Soil Moisture Content

The water storage capacity and percolation rate of the soil profile operate together to influence infiltration rate. Think of the sponge which is absorbing spilled water. There is some finite amount of water the sponge can hold before one must ring it out in the sink. The amount of water a sponge can hold depends upon the size of the sponge and how porous it is. Soil is essentially the same. The amount of water a soil can hold depends basically upon how deep and how porous it is. The deeper and more porous a soil profile is, the more pore space available for storing water. Thus, initial soil water content, the amount of water in the soil when rainfall begins, plays a large role in determining infiltration rates during a storm. A soil which is half full of water only has half of its storage capacity available. A 3 inch storm falling on saturated soil will generate much more overland flow than the same storm falling on dry soil. Recall that percolation rate is the rate at which water is removed vertically from the soil via gravity flow. The greater the percolation rate, the faster the soil is drained, the faster storage capacity is recovered, and the more soil pore space available for infiltrating rainwater. The presence of an impervious soil layer, such as a clay layer at 3 feet, can reduce percolation rates within a soil profile. There is the need to have basic knowledge on the capacity of soil to retain available irrigation water. Some soil produce crops despite the lapse of many days, and sometimes weeks during their growing season, between periods of rainfall is an evidence of their capacity to store available water, since all growing plants require continuous water.

When designing irrigation and drainage system the capacity of soil to store available moisture for the growing crops needs is of great importance. The term 'soil moisture content' is used to refer to the water that may be evaporated from soil by heating to between 105°C and 110°C until there is no further weight loss. Gardner (1957)

2.4 Factors Affecting Infiltration

Many factors influence the shape of the infiltration curves. These factors can generally be grouped as rainfall characteristics, soil properties, vegetation, and land use. Rainfall intensity is a major factor determining infiltration rate and overland flow.

2.4.1 Soil texture

Is the percent of sand, silt, and clay in a given soil.

2.4.2 Soil structure

Refers to how the soil particles in a soil profile are arranged into soil colloids or aggregates. Sands have the largest individual pore spaces, while clays have the largest total pore volume. Although clays are more porous than sands, clays have much smaller individual pores than sands, resulting in smaller pathways for water to flow through. Thus, sands will have greater infiltration rates than clays. Soils with a loose, friable structure have high infiltration rates.

2.4.3 Soil porosity

Is generally defined as the percentage of the soil profile composed of pore space The interconnectivity of soil pores as well as total porosity determines the pathway available for water to enter and pass through a soil profile. As porosity and soil pore interconnectivity increase, infiltration rate increases.

2.4.4 Soil bulk density

Is related to porosity and hydrologic condition Bulk density is often used to assess if and how compacted a soil has become due to some land use or other disturbance. Soil bulk density is the mass or weight of dry soil per unit soil, usually expressed as grams per cubic centimeter (g/cm^3). Soil bulk density is determined by taking a soil sample of known volume, drying and weighing the sample. A soil with a low bulk density will generally have a better hydrologic condition than a soil with a high bulk density.

2.4.5 Soil organic matter

Is instrumental in building and maintaining soil structure which in turn improves infiltration Soil structure is crucial to maintaining soil porosity and the connectivity of soil pores. In general, as organic matter content increases, infiltration rate increases.

Many soils contain macrospores. Macrospores are large, connected pathways through the soil. They can be rodent tunnels, worm holes, root channels, shrinkage cracks, fissures between rocks, etc. Macropores can lead to extremely high infiltration rates and rapid soil water transport. (USDA, 1998)

2.4.6 Vegetative cover

Over the soil surface is extremely important in maintaining and improving infiltration rates. Cover can take the form of tree canopy, brush, grass, or litter. Litter covering the soil surface can be viewed as two distinct layers, the top which is undecomposed plant material and the bottom which is decomposed material behaving much like mineral soil. The lower layer can have a substantial storage capacity, over 200% by weight in some cases.

Raindrops impact the soil surface with some level of energy. When the soil surface is bare this raindrop energy detaches soil particles and reduces soil structure. Detachment of soil particles and loss of soil structure at the soil surface reduces the number and size of pores at the soil surface available to infiltrate water. (USDA, 1998)

2.4.7 Pores

Continuous pores that are connected to the surface are excellent conduits for the entry of water into the soil. Discontinuous pores may retard the flow of water because of the entrapment of air bubbles. Organisms such as earthworms increase the amount of pores and also assist the process of aggregation that enhances water infiltration.

2.4.8 Organic Matter

An increased amount of plant material, dead or alive, generally assists the process of infiltration. Organic matter increases the entry of water by protecting the soil aggregates from breaking down during the impact of raindrops. Particles broken from aggregates can clog pores and seal the surface and decrease infiltration during a rainfall event. (USDA-NRCS, 1998)

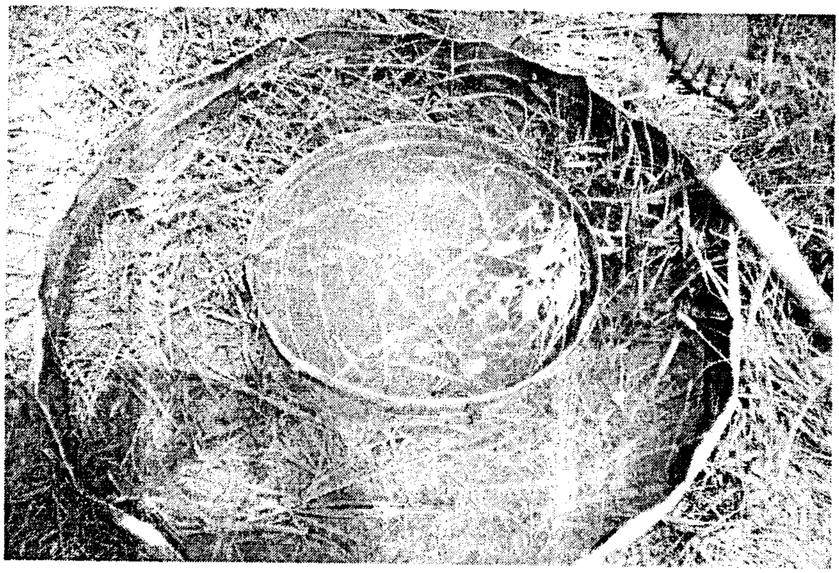

Plate 2.1: Infiltration Process at Unit 3

2.5.0 Factors Affecting Infiltration Rate

Infiltration rate depends upon the physical condition of the soil and the hydraulics of water in the profile, both of which change with time. Hydraulic conductivity (*k*) refers to the soil's intrinsic ability to transmit fluid (also termed permeability). In general, hydraulic conductivity of soil horizontally (*kh*) is much higher than hydraulic conductivity of soil vertically (*kv*). The rate of infiltration is generally a function of hydraulic conductivity (*k*), hydraulic gradient (*i*), and infiltration area (*A*), as expressed empirically by Darcy's Law for one dimensional saturated flow (Darcy, 1856).

$$Q = kiA \tag{2.14}$$

Where,

Q = the flow rate;

k = hydraulic conductivity

i = the hydraulic gradient; and

A = the wetted area of soil

Because *kv* is often half or less than half of *kh*, the direction that water flows is seldom straight down. Also, hydraulic gradient (*i*) can be considered to be equal to 1 so long as the wetting front moves vertically downward. This will be true only when depth to groundwater or low hydraulic conductivity soil layer is sufficient (609.6cm or more depending on the type and size of infiltration system). When the wetting front encounters the groundwater table or a soil layer with low hydraulic conductivity the vertical hydraulic gradient can rapidly approach zero, resulting in greatly reduced infiltration and groundwater mounding. The Point A to Point B concept requires the engineer to consider not just where the infiltration process starts, but also where it ends.

2.5.1 Infiltration Measurement

The steady-state infiltration rate in the inner ring was determined according to (ASTM D-3385) standard methodology. Using the double ring infiltrometer and Applying Darcy's law and assuming a hydraulic gradient of one, the saturated hydraulic conductivity is equivalent to the steady state infiltration rate.

2.5.2 Limitation of Double Ring Infiltrometer

The process of placing the ring devices into the soil causes some serious limitation to double ring infiltrometer. In driving the ring into the soil, some degree of disturbances of the natural soil condition is caused, the resulting disturbances is manifested as shattering or compaction which may be caused by large variation in infiltration rates between replicated runs. Another limitation is the soil – metal interface which may cause unnatural seepage planes which result in abnormally high infiltration rates. (Musa, 2003) The relatively high volume of water required, and experimental duration can also be a disadvantage (Johnson, 2006; Asleson, 2007)

2.5.3 Uses of infiltration

The infiltration rates can be used to determine the duration of iiirigation. The irrigation time can be estimated from furrow infiltrate rate. The furrow infiltration rate can be expressed as (Benami and Ofen, 1993):

$$I=KT^{n}+a \qquad (2.15)$$

Where, I is the instateneous infiltration rate, mm/hr. T is the time of wetting, min: k, n the soil constants and a is the terminal intake . in mamy soil, the soil constant can be negligible, thus:

$$I = KT^{n} \qquad (2.16)$$

On integrating eqn. (2.15), the depth of water that will infiltrate a soil,

$$Di = \int_0^{Ti} I dt = \frac{1}{60}\int_0^{Ti} KTn\ dt$$

$$Di = KT^{n+1}/\ 60(n+1) \qquad (2.17)$$

Hence,, $Ti = [\frac{60Di\ (n+1)}{k}]^{1/n+1}$ (2.18)

Where, Ti is the duration of irrigation needed to apply Di in mm.

Equation (2.18) can be used to compute Ti when Di, K, and n are known. In order to determine n and k equation (2.18) can be rewriiten as:

$$Log\ I = \log K + n \log T \qquad (2.19)$$

Equation (2.19) defines a straight line on the log-log paper. Therefore, n is simply the slope of the infiltration line while, the intercept with the y- axis is the value of K. (as shown in Appendix D)

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Materials

3.1.1 Descriptions of Experiment Sites

The Federal University of Technology permanent site is known to have a total land mass of eighteen thousand nine hundred hectares (18,900 ha) which is located along kilometre 10 minna – bida road, south – East of minna under Bosso local Government area of Niger state. It has a horse – shoe shape stretch of land, laying approximately on longitude of 06^o 27' E and latitude of 09^0 31' N. The entire site is drained by river Gwakodna, weminate, Grambuku, Legbedna, Tofa and their tributaries. They are all seasonal rivers and the most prominent among them is river Dagga. The most prominent of the features are river dagga, Garatu Hill and Dan Zaria Dam (Musa, 2003).

3.1.2 Soil of the Area

The major soil found in this area is the sandy loam type with a sparse distinction of the sandy – clay soil and sandy soil. This has so far encouraged the residents of Minna metropolis and neighbouring villager to use the land for agricultural activities such as farming and grazing by the nomadic cattle rarer.

3.1.3 Vegetation and land use

Minna falls within the semi – wood land or tree forest vegetation belt with derived grass or shrub land known as the transition belt, which lies between the savannah grasses/ shrub land of the north and the rain forest of the south. Due to intensive fallow type of agricultural practice and grazing of the land, the area is dominated by stunted shrubs; interspersed with moderate height tree and perennial foliage. Similarly, due to human activities and land use abuse which is characteristics of most expanding urban centre in Nigeria, the site is fast losing its remaining tree species to development. Along some river courses and lowland areas, the vegetation is more wooded and resembles some forest affinities. The area is still being used as farm and grazing land by the residents of minna and its environs (Musa, 2003).

3.1.4 Climate

3..1.4.1 Rainfall

The rainfall of minna starts between the months of May to the month of October, except on rear occasions to November. It has been recorded to reach its peak between the months of July and august. At the end of the raining season the harmatan ushers in the dry season which can last up to 2 months.

3.1.4.2 Temperature

The maximum temperature period in this area is usually between the months of February, March and April which gives an average of minimum temperature record of 33°C and a maximum of temperature of 35°C, and it can fall as low as 29°C during the raining season (Minna Airport Metrological Centre, 2009)

3.1.4.3 Study Location

The area of study is the research and teaching farm of the permanent site of Federal University of Technology, Gidan kwano Campus, Minna. The map of the study location is shown at Appendix E

3.1.4.4 Description of the Equipment

The double ring infiltrometer is a simple instrument that is used to determine the rate of infiltration of water into the soil. The rate of infiltration is determined as the amount of water per surface area and time unit, which penetrates the soil. This rate can be calculated on the basis of the measuring results and the Law of Darcy. The standard set of the double ring infiltrometer consists of a number of sets of stainless steel rings with different diameters (inner 300mm and 600mm) several measurements can be executed simultaneously, yielding a very reliable and accurate mean result. As vertically infiltrated water runs away to the sides, the outer ring of the infiltrometer serves as a separation. The measurements exclusively take place in the inner ring through which the water runs virtually vertical. To achieve good measuring results it is important to take into account several factors that may influence the measurement: the surface vegetation, the extent to which the soil has been compacted, the soil moisture content and the soil layers (strata). The best measuring results are obtained at 'field capacity' of the soil.

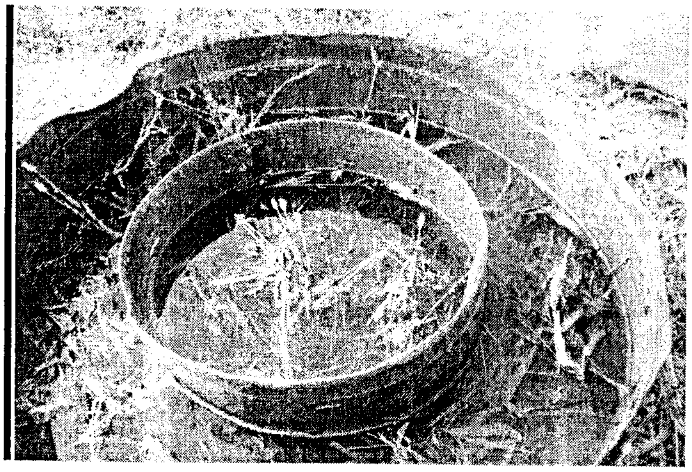

Plate 3.1: Double Ring Infiltrometer Setup at the Farm Site.

3.1.4.5 Site Selection

It is important to note that the areas/sites surveyed were not large enough to be referred to as soil series but as soil unit, because the survey was more or less a point arbitrary selection. The following guideline was used to select the points using Global Position System (GPS).

3.1.4.6 Soil Parameters

1. Bulk density.

2. Soil moisture.

3. Soil infiltration Capacity.

4. Soil Texture.

3.2.0 Methods

The soil properties that were determined include; the soil infiltration (rate) capacity, the soil Bulk density, soil moisture content (MC) and soil texture.

3.2.1 Infiltration Measurement

The infiltrometer rings were placed using the global positioning system (GPS) from each other and the measurement were taken to the nearest centimetre (cm). The rings were then driven into the ground by hammering a wooden bar placed diametrically on the rings to prevent any effects around the bottoms of the rings. The rings where placed two days prior to the day when the infiltration measurements are to be taken. In areas where grasses existed, they were cut as low as possible with a cutlass so that the float (rule) could have free movement while care was taken not to uproot grasses.

Water from Jeri-cans was poured into the infiltrometre compartments simultaneously and as quickly as possible. As soon as the Jeri-cans were emptied, the water level from the inner cylinder was read from the rule and the local time was also noted. Readings were taken at intervals of 0 minutes, 2minutes, 5 minutes, 10 minutes, 15 minutes, 20 minutes, 30 minutes, 45 minutes, 60 minutes, 75 minutes, 90 minutes, 100 minutes, and finally at 120 minutes. The water level at both compartments (the inner and outer ring) were constantly kept equal by adding water as needed, most especially into the outer compartment.

At each site, soil sample was taken from the surface layer (0 -50cm) in the area outside the outer ring, for the determination of initial moisture content and bulk density.

3.2.2 Bulk Density

Bulk Density is related to porosity and hydrologic condition. It is often used to assess how compacted a soil has become due to some land use or other disturbance. Soil bulk density is the mass or weight of dry soil per unit soil, usually expressed as grams per cubic centimetre (g/cm^3). (Encyclopaedia Americana, 2011). Soil bulk density is determined by taking a soil sample of known volume, drying and weighing the sample. A soil with a low bulk density will generally have a better hydrologic condition than a soil with a high bulk density.

It is also viewed as the density of the bulk soil in its natural state, including both the particles and pore spaces. Bulk density is divided into wet bulk density and dry bulk density. Wet bulk density of a soil is the mass of the soil including any water present in the soil per unit volume expressed;

$$Dw = \frac{MT}{VT}$$

Where;

MT = Total mass of soil,

VT = Total volume of soil, and

Dw = Wet bulk density.

In which dry bulk density is the mass of Oven dry soil per unit volume of moisture soil expressed as;

$$Dd = \frac{MS}{VT}$$

Where;

Ms= mass of soil solid,

Vt = total volume of the soil,

Dd = dry bulk density.

Wet bulk density, dry bulk density and moisture content are related as follows;

$$Ps \frac{110\,(e)}{100+w}$$

Where: Ps = dry bulk density.

e = wet bulk density.

w = moisture content of soil.

Bulk density of soil is affected by the compaction, when a soil undergoes compaction its bulk density increase. High soil bulk density can introduce problem to agricultural activities and landscape management (Jeff, 2007)

3.2.3 Moisture Content

The moisture content of the soil per site was obtained by pushing a core sampler (50mm diameter and 50mm high) into the ground and was gradually brought out. The end were scraped with a knife and the content emptied into moisture cans of known weights and covered immediately. In the laboratory, the cans were weighed and dried in an oven at 105°C for 24hours, after which they weighed again. The moisture content (MC) of the soil was obtained from;

$$MC = \frac{(weight\ of\ wet\ soil+can) - (weight\ of\ dry\ soil+can)}{weight\ of\ dry\ soil+can} \times 100$$

3.2.4 Particle size distribution

Infiltration rates are directly related to a soil's grain size distribution, which is the range and percentage of soil particle diameters. Soils with small grains such as clays and silts will drain slower than soils with large grains such as sands and gravels. In particular, the percentage of clay, which expands as it soaks up sizable amounts of water, reduces infiltration rates. Silts, which may be the same size as clay, can actually have relatively high infiltration rates.

The method employed for the determination of particles size distribution is the dry sieve analysis.1000g of soil sample was weighted in a pan and was poured in the top most sieve the set which are (5.00, 3.350, 2.360, 2.00, 1.180, 850μm, 600μm, 425μm, 150μm, 75μm, and pan). The whole setup was mechanically vibrated with a sieve shaker for a period of 2 – 3minutes. And thereafter each sieve together with its content were then weighted. The weight of the empty sieve which had earlier weighed was then subtracted from the combined weight of soil retained and sieve. These gave the actual soil retained in each of the sieve. The procedure was repeated for the entire samples. The advantage of this method is its relatively inexpensiveness and minimal soil disturbance. The only limitation of this method is that it does not take into account the density or the stratigraphy of the soil (Jeff, 2007).

The percentage retained and the percentage passings after sieve shaking process were computed from the experiments:

$$\% \text{ Retained} = \frac{weight\ of\ soil\ retained}{original\ sample} \text{ X } 100 \quad (3.1)$$

$$\% \text{ passing (finer)} = 100 - \% \text{ Retained.} \quad (3.2)$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The results of all measurements are presented in tables.

4.1 Initial Moisture Contents

The analysis of the initial moisture content of the experiment sites is given below:

Table 4.1 Initial moistures content of the experimental site (0-50cm)

Soil units	Weight of wet sample (g)	Weight of oven dry sample (g)	(MC) %
1	167.46	146.44	14.40
2	171.27	149.18	14.80
3	119.81	111.09	7.80
4	148.21	133.48	11.00
5	159.25	139.36	14.30
6	168.38	148.54	14.20
7	154.65	139.88	10.60

4.2 Bulk Density of Farm plot

The bulk density obtained is presented in table 4.2

Table 4.2 The Bulk Density of The Research Farm Plots

Soil units	Wet Bulk Density (g/cm^3)	Dry bulk density (g/cm^3)
1	1.364	1.193
2	1.749	1.543
3	0.926	0.858
4	1.489	1.341
5	1.548	1.355
6	1.323	1.153
7	1.259	1.139

4.3 Infiltration Rates Values

The infiltration and infiltration rates curves of the Federal University of Technology, research and teaching farm Gidan kwano campus, Minna are presented in tables as follows:

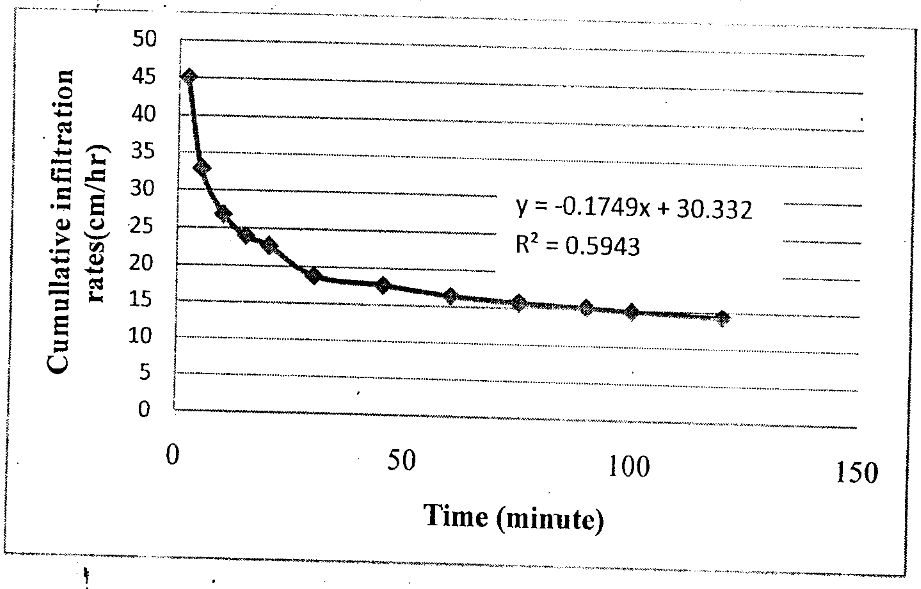

Fig. 4.3.1 **Infiltration rates curve at Unit I**

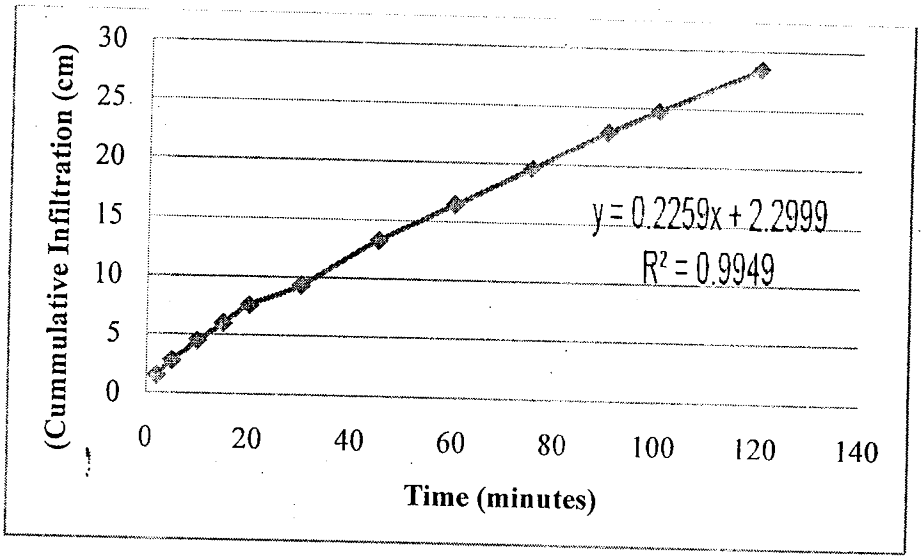

Fig. 4.3.1A **infiltration Curve at unit I**

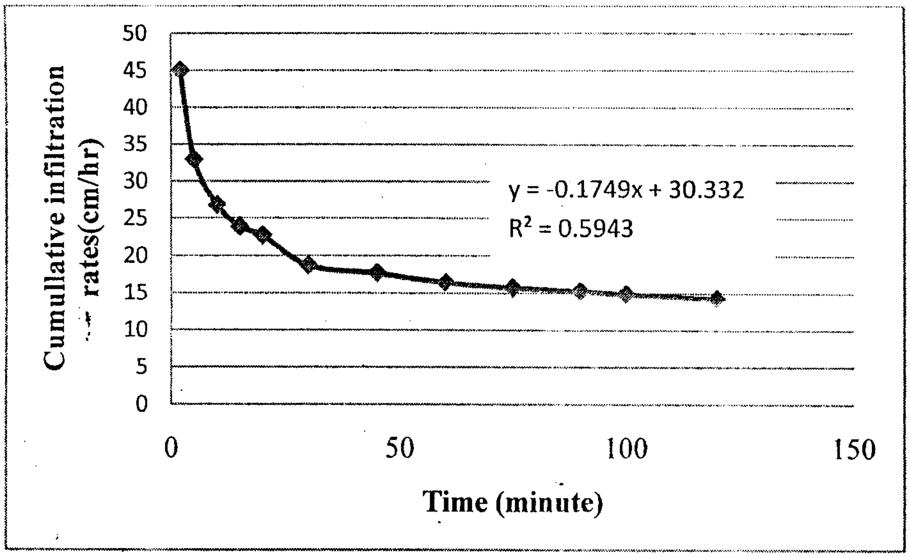

Fig. 4.3.1 **Infiltration rates curve at Unit I**

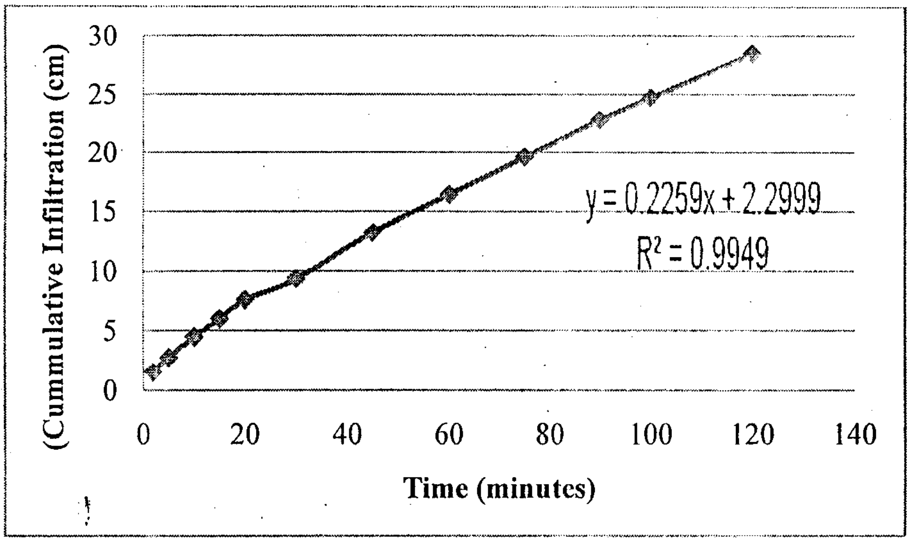

Fig. 4.3.1A **infiltration Curve at unit I**

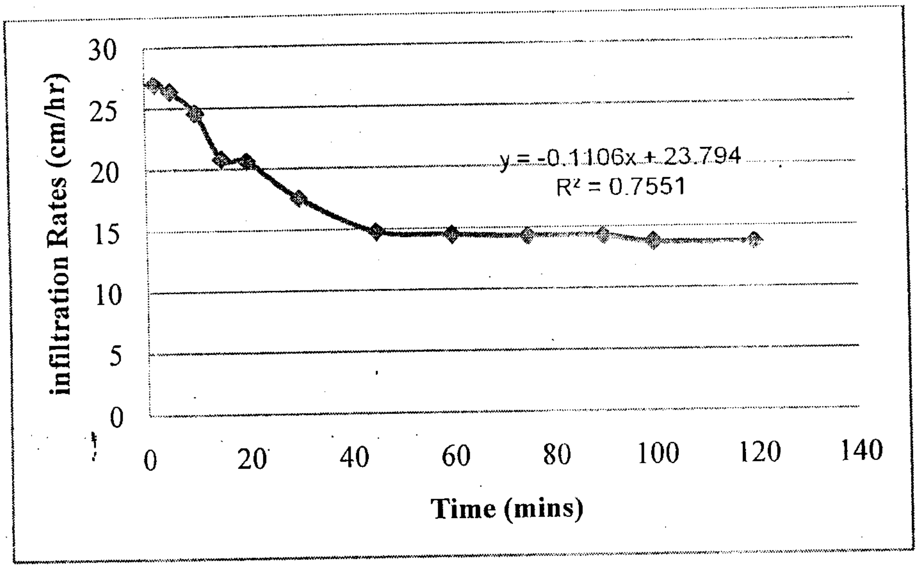

Fig. 4.3.2 **Infiltration rates curve at unit II**

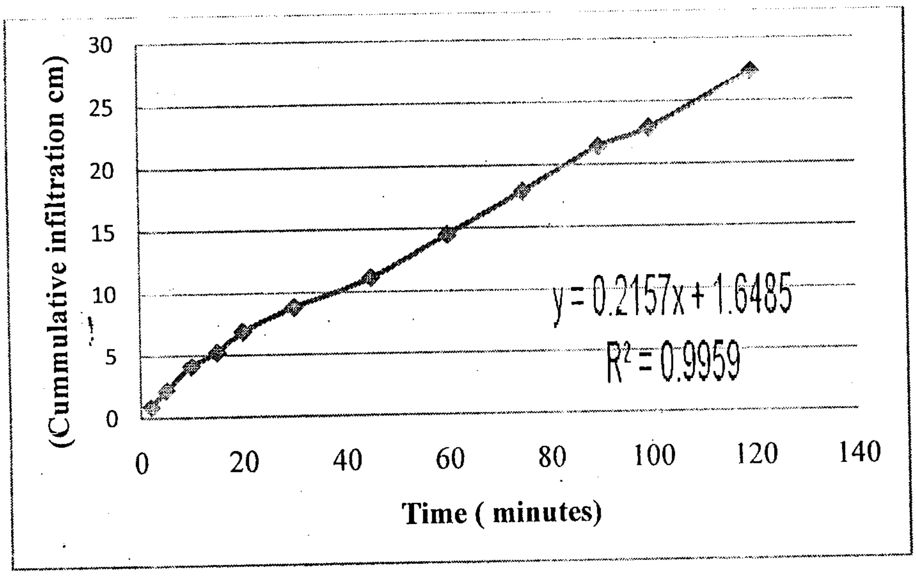

Fig. 4.3.2A **Infiltration Curve at unit II**

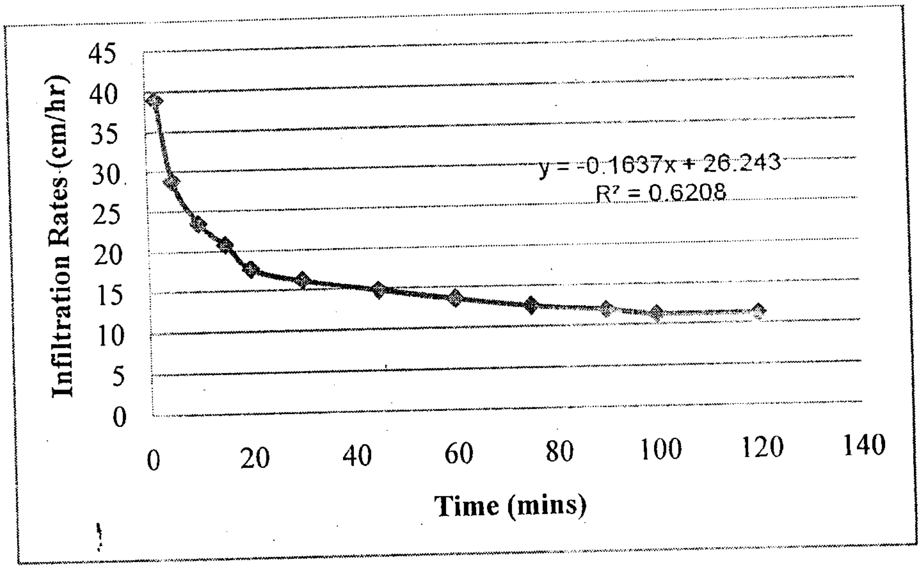

Fig. 4.3.3 **Infiltration rates curve at Unit III.**

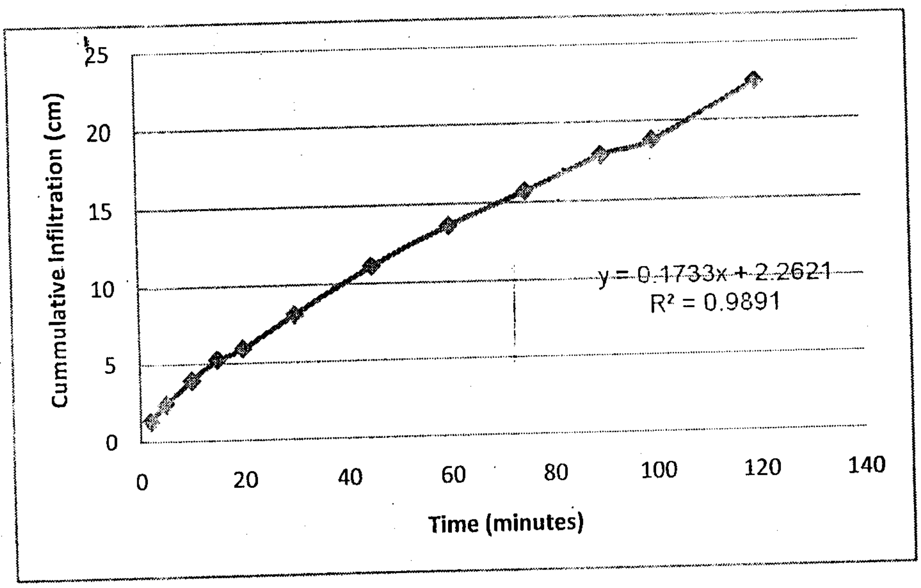

Fig.4.3.3A **infiltration Curve at Unit III**

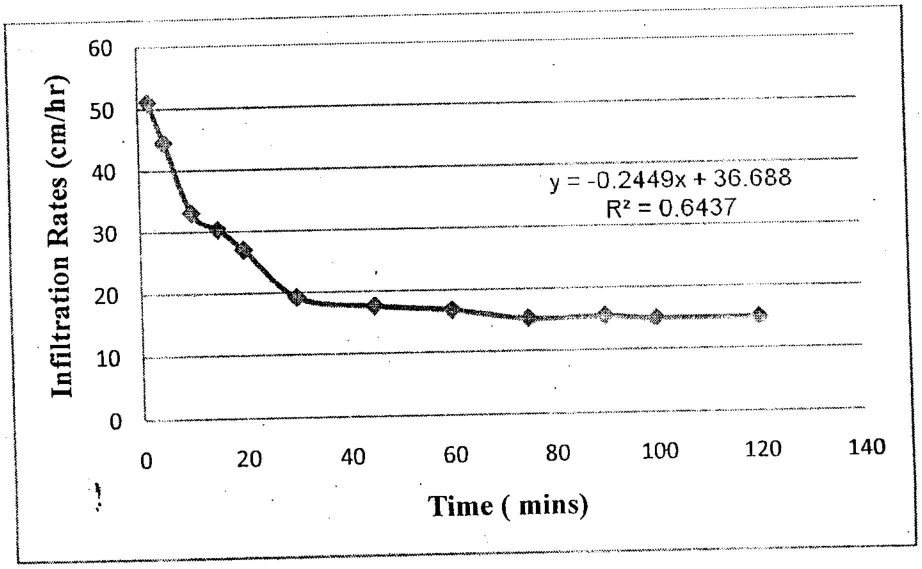

Fig. 4.3.4 **Infiltration rates curve at Unit IV.**

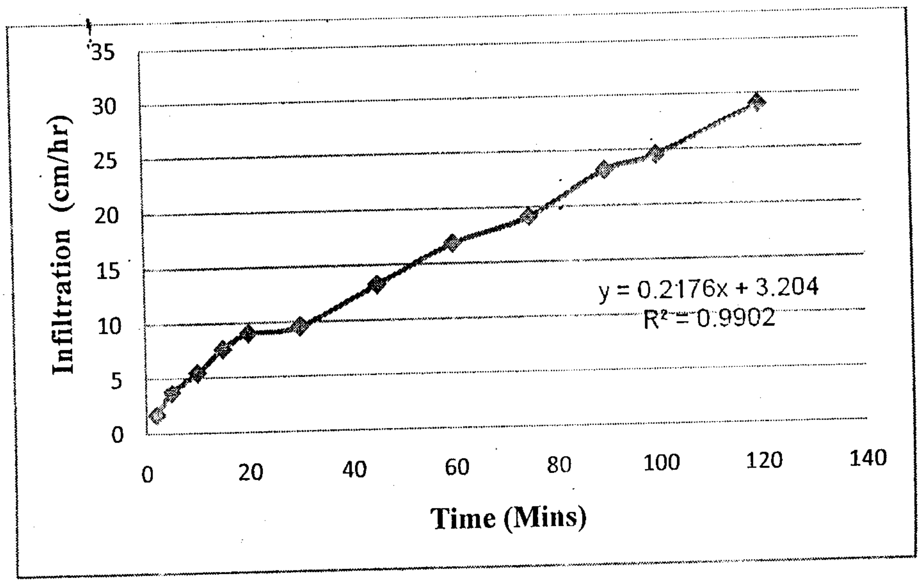

Fig. 4.3.4A Infiltration curve at Unit VI

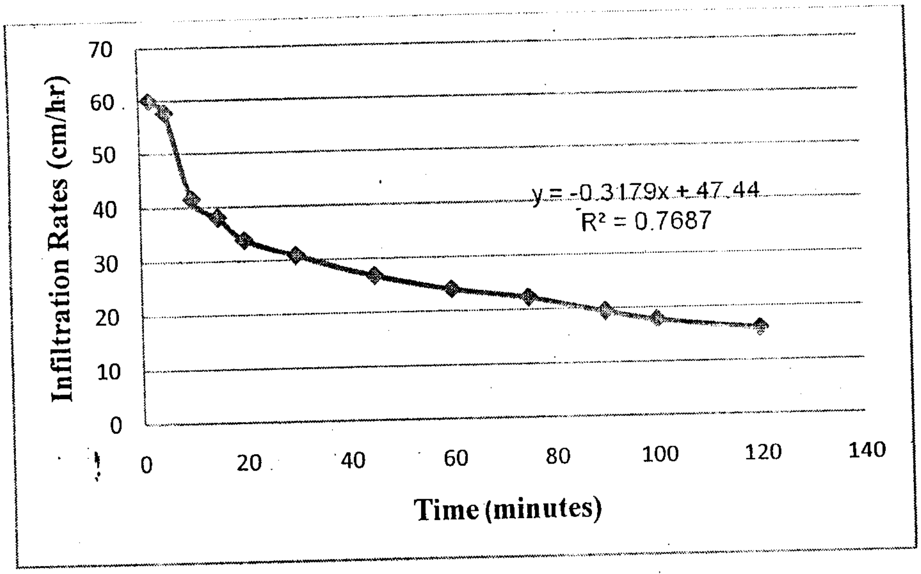

Fig 4.3.5 Infiltration Rates curve at Unit V.

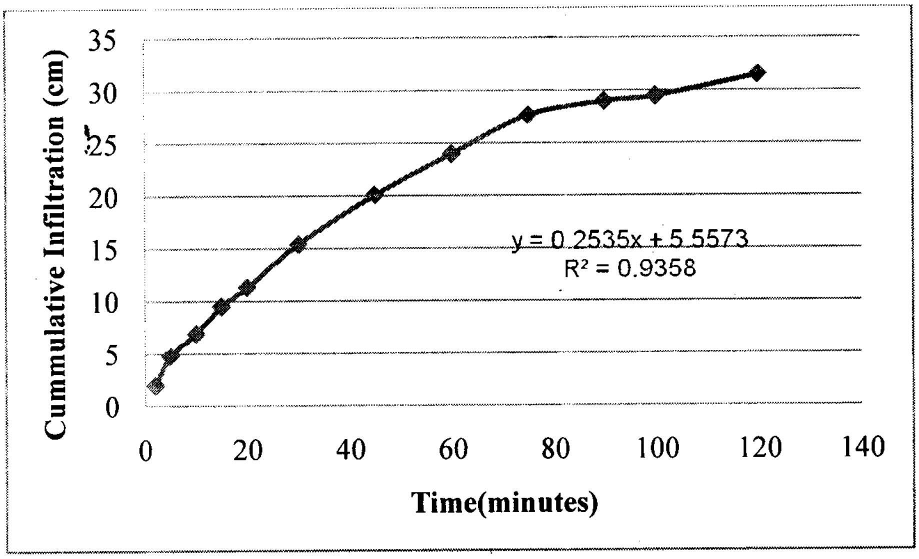

Fig. 4.3.5A infiltration curve at Unit V.

4.3.6 Unit 6

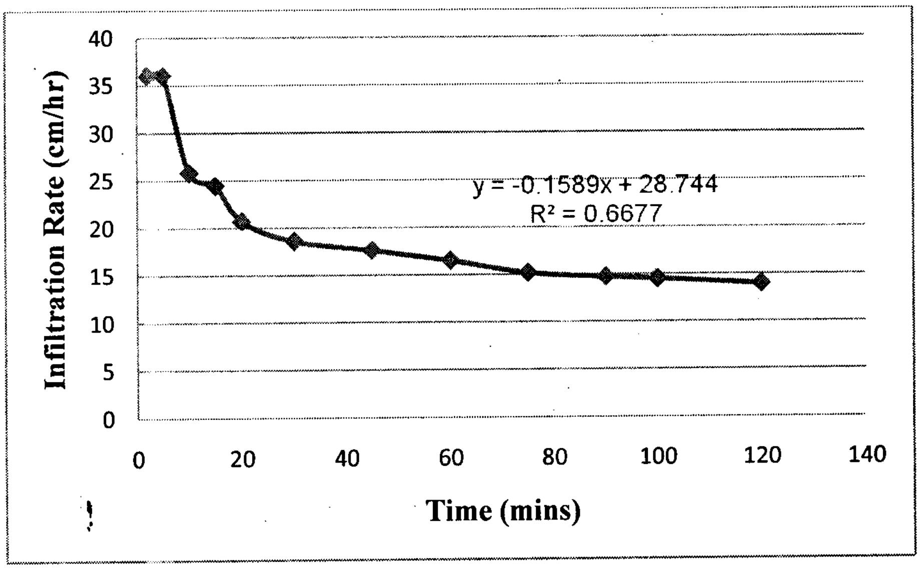

Fig. 4.3.6 Infiltration rates curve for the soil at Unit VI.

An equation of the form Y = Mx + C was also obtained from the soil units.

Where:

M = slope

C = intercept

X = variable (time)

Table 4.3 Regression table showing the steady infiltration rates at various units.

Units	Regression Equation	R^2 values
1	y = -0.1749x + 30.332	0.5943
2	y = -0.1106x + 23.794	0.7551
3	y = -0.1637x + 26.243	0.6208
4	y = -0.2449x + 36.688	0.6437
5	y = -0.3179x + 47.44	0.7687
6	y = -0.1589x + 28.744	0.6677
7	y = -0.677x + 87.925	0.7177

From the above equations it can be observed that the values obtained for the intercept were negative which may be due to the fact that water was being given off from the soil during the rainy season which gives a clear indication that water (irrigation) is not required during the raining season on the farm plot for any research purposes (Musa, 2003).

The R square values gotten from the curve fittings as presented in table 4.1. It could be observed that an average of 83.65% was obtained. Which is almost the same compared to the study carried out by Musa (2003) on the same farm site.

4.5 Particle size Distribution of the Farm plot

Table 4.4 Particle Size Distribution Analysis from the farm plot

Soil unit	Depth	Percentage clay	Percentage silt	Percentage sand
1	0 – 50cm	19	31	50
2	0 – 50cm	45	35	20
3	0 – 50cm	22	40	38
4	0 – 50 cm	17	39	44
5	0 – 50 cm	30	30	40
6	0 – 50 cm	19	36	45
7	0 – 50 cm	15	32	53

4.2 Discussions

4.2.1 Moisture content

The moisture contents of the plots were almost the same, before the commencement of infiltration test. This indicates that the water holding capacity of the farm plot is the same, therefore irrigation scheduling for the farm plots will be uniform. Except for unit seven that had lower moisture content which is due to the dryness of the initial soil sample. With a high infiltration rate of about 132.00cm/hr. the drier the soil, the greater the rate of entry of water because the gradient of the matric potential is then of greater magnitude. This implies that the unit is predominantly sandy soil. It was observed that the farm plot has high moisture content, and it was due to the month in which the test was carried out (wet season June). That buttress the fact that the water table during the Raining season is high, therefore the practical implication of these values is that during a heavy downpour of rainfall, flood (erosion) may be experienced, if proper drainage system is not provided.

4.2.2 Bulk density of the plot

The bulk density were taken for both the wet and dry basis, the bulk density as presented on Table 4.2 can be observed that the values of wet bulk density was relatively higher than the dry bulk density due to the presence of water in the soil sample. Similarly, table 4.2 shows that the entire Units have bulk density well above 1 g/cm^3 except for unit 3 which is slightly less than 1g/cm^3 both for wet and dry. This was attributed to the abundance of grass roots at the surface. It indicates that compaction by machines or human activities were negligible prior to the time of sampling. Consequently, the unit may not favour the growth of some research crops, because the soil moisture movement within the unit profile is retarded and the rate of clay formation and carbonate accumulation may be high at that unit. Most mineral soils have bulk densities between 1.0 g/cm^3 and 2.0 g/cm^3 (Birkeland, 1984). The value obtained at unit 3 shows that the bulk density for the farm plot is not uniformly distributed, that is why crop of the same variety may produce different yield (bad) even though it was planted on the same farm plot.

4.2.3 Infiltration Rates Values

Table 4.3.1, – 4.3.7 shows the infiltration rates curve for the entire soil units. While table 4.31A – 4.3.7A shows the infiltration curves at the different Units

The infiltration rate values obtained at unit I Appendix B-1 shows that the unit recorded an initial value of 45cm/hr and the field capacity of the unit was 14.3cm/hr which it attained at the 100 - 120minutes. Units I,IV, V, and VI the unit field capacity was obtained at the 120 minutes. Which is approximately 14.74 cm/hr. This value is essential in the design and construction of irrigation and drainage purposes on the farm plots.

A closer look at Appendix B-2 shows that the final infiltration rates of unit II was 11.20cm/hr. It also recorded a high dry Bulk density of 1.543g/cm^3 and wet bulk density of 1.749g/cm^3, high moisture contents of 14.8% as compared to other Units. Boardman et al (1990) noted that bulk density increase is closely associated with decrease in infiltration capacity. These differences as compared to other units may be due to the water level being near to the surface or clayed nature of the soil at that unit. The combination of these may lead to low subsurface oxygen level, decrease microbial activities and eventually a decline in plant health. It was however, discovered that the water table will be low, because much of the surface water will evaporate back into the atmosphere (hydrological Cycle). The practical implication of these values on crop production is that the plot has to undergo tillage operation (secondary) to effectively carry out credible crop production research. This will reduce water logging.

The infiltration rates at unit VII Appendix B-7 indicates that plants planted along this unit may suffer water deficiency since the water retaining capacity of the unit is low. It also shows that surface and sub-surface applied; pesticides, herbicides and fertilizer may be leached into the ground water, with nothing left for the plants, thereby polluting the ground water aquifer. This renders the underground water contaminated with high chemical deposit (Nitrogen, Potassium, and Phosphorus). This may cause human diseases when consumed in large Quantities.

4.2.4 Particle Size Distribution Analysis

The sieve analysis gave a clear indication that the soil of the farm is predominantly sandy. Unit 1,3,4,5,6, shows a loamy sandy structure, while Unit 2 showed a clayed Nature.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. The infiltrarion rates were determine with an average field capacity of 14.74cm/hr. This is essential in design and construction of irrigation/ drainage purposes.

2. The soil type of the Federal University of Technology Minna, Teaching and research farm plot is mostly sandy loam.

5.2 Recommendations

1. The high values of moisture content recorded at the farm plots during the study, indicates that the farm plot is vulnerable to flood (water erosion) during a heavy down pour. Therefore, an adequate drainage system should be provided across the farm plot: this will serve as the long term solution to infiltration.

2. The high infiltration recorded at some of the units, shows that any source of water close to the farm may not be fit for human consumption (drinking, bathing, etc) due to the leaching of chemicals contained in the fertilizer or pesticide or herbicides used on the farm. It is therefore recommended that any source of water needed for domestic purposes should be far away from the farm sites.

3. More studies should be carried out from time to time; this will help in the design and planning of irrigation and drainage purposes. Because the infiltration rates of soil changes with land used and time (usually a decade).

4 Other methods of infiltration rates determination should be carried out on the farm plots, so as to validates the results obtained from this study.

5. The farm should be ameliorated before undertaking any crop production; this will serve as the short term solution to infiltration.

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APPENDICES

Appendix A

Table 4.0 Arbitrary unit on the farm plots using GPS

Units	Elevation(m)	Coordinates (degrees)	Date	Local Time
1	244.00	N 09° 31'896" E006°27'323"	27 /06/2011	07 : 30 am
2	240.00	N09°31'880" E 006°27'324"	28/06/2011	8 : 00 am
3	240.00	N 09°31'884" E 006°27'362"	29/06/2011	8 : 25 am
4	242.00	N 09°31'903" E 006°27'369"	30/06/2011	8 :25 am
5	239.00	N 09°31'905" E006°27'398"	1/07/2011	8 : 40 am
6	246.00	N 09° 31'923" E006°27'408	1/07/2011	8 : 00 am
7	240.00	N 09°31'943" E 006°27'375"	1/07/2011	8 : 30 am

Appendix B-1

Table 4:1 Infiltration measurement at unit 1

Time (min)	Cumulative infiltration (cm)	Infiltration Rates (cm/hr)
0	-	-
2	1.50	45
5	2.74	32.88
10	4.46	26.76
15	5.98	23.92
20	7.57	22.71
30	9.34	18.68
45	13.24	17.65
60	16.40	16.40
75	19.60	15.68
90	22.82	15.21
100	24.71	14.83
120	28.47	14.24

Appendix B-2

Table 4.2 Infiltration Measurements at Unit II

Time (min)	Cumulative infiltration (cm)	Infiltration rates (cm/hr)
0	-	-
2	1.30	39.00
5	2.40	28.80
10	3.90	23.40
15	5.20	20.80
20	5.90	17.70
30	8.10	16.20
45	11.10	14.80
60	13.60	13.60
75	15.70	12.56
90	17.90	11.93
100	18.80	11.28
120	22.40	11.20

Appendix B-3

Table 4.3 Infiltration Measurements at Unit III

Time (min)	Cumulative Infiltrations (cm)	Infiltration rates (cm/hr)
0	-	-
2	0.90	27.00
5	2.20	26.40
10	4.10	24.60
15	5.20	20.80
20	6.87	20.61
30	8.80	17.60
45	11.10	14.80
60	14.50	14.50
75	17.90	14.32
90	21.40	14.26
100	22.90	13.74
120	27.30	13.65

Appendix B-4

Table 4.4 Infiltration Measurements at Unit IV

Time (min)	Cumulative infiltration (cm)	Infiltration rates (cm/hr)
0	-	-
2	1.70	51.00
5	3.70	44.40
10	5.50	33.00
15	7.60	30.4
20	9.00	27.00
30	9.60	19.20
45	13.20	17.60
60	16.80	16.80
75	19.10	15.28
90	23.20	15.47
100	24.50	15.00
120	29.00	15.00

Appendix B-5

Table 4.5 Infiltration Measurements at Unit V

Time (min)	Cumulative infiltration (cm)	Infiltration rates (cm/hr)
0	-	-
2	2.00	60.00
5	4.80	57.60
10	6.90	41.40
15	9.50	38.00
20	11.30	33.90
30	15.40	30.80
45	20.10	26.80
60	24.00	24.00
75	27.70	22.16
90	29.00	19.33
100	29.5	17.70
120	31.50	15.75

Appendix B-6

Table 4.6 Infiltration Measurement at Unit VI

Time (min)	Cumulative infiltration (cm)	Infiltration rates (cm/hr)
0	-	-
2	1.20	36.00
5	3.00	36.00
10	4.30	25.80
15	6.10	24.40
20	6.90	20.70
30	9.30	18.60
45	13.20	17.60
60	16.50	16.50
75	19.00	15.20
90	22.10	14.73
100	24.20	14.52
120	28.00	14.00

Appendix B-7

Table 4.7 Infiltration Measurement at Unit VII

Time (min)	Cumulative infiltration (cm)	Infiltration rates(cm/hour)
0	-	-
2	4.40	132.00
5	6.90	82.80
10	13.00	78.00
15	18.00	72.00
20	22.90	68.70
30	26.80	53.60
45	30.00	40.00
60	33.60	33.60
75	37.10	29.68
90	40.00	26.67
100	42.00	25.20
120	42.80	25.60

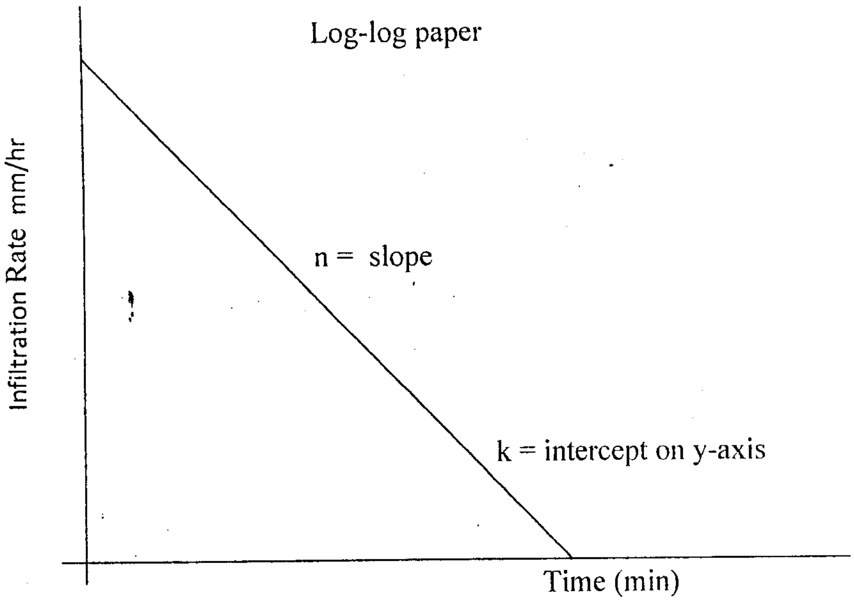
APPENDICE C

Table 4.8 Soil Classification

Name of soil separate	Diameter limits (mm)
Clay	less than 0.002
Silt	0.002–0.05
Very fine sand	0.05–0.10
Fine sand	0.10–0.25
Medium sand	0.25–0.50
Coarse sand	0.50–1.00
Very coarse sand	1.00–2.00

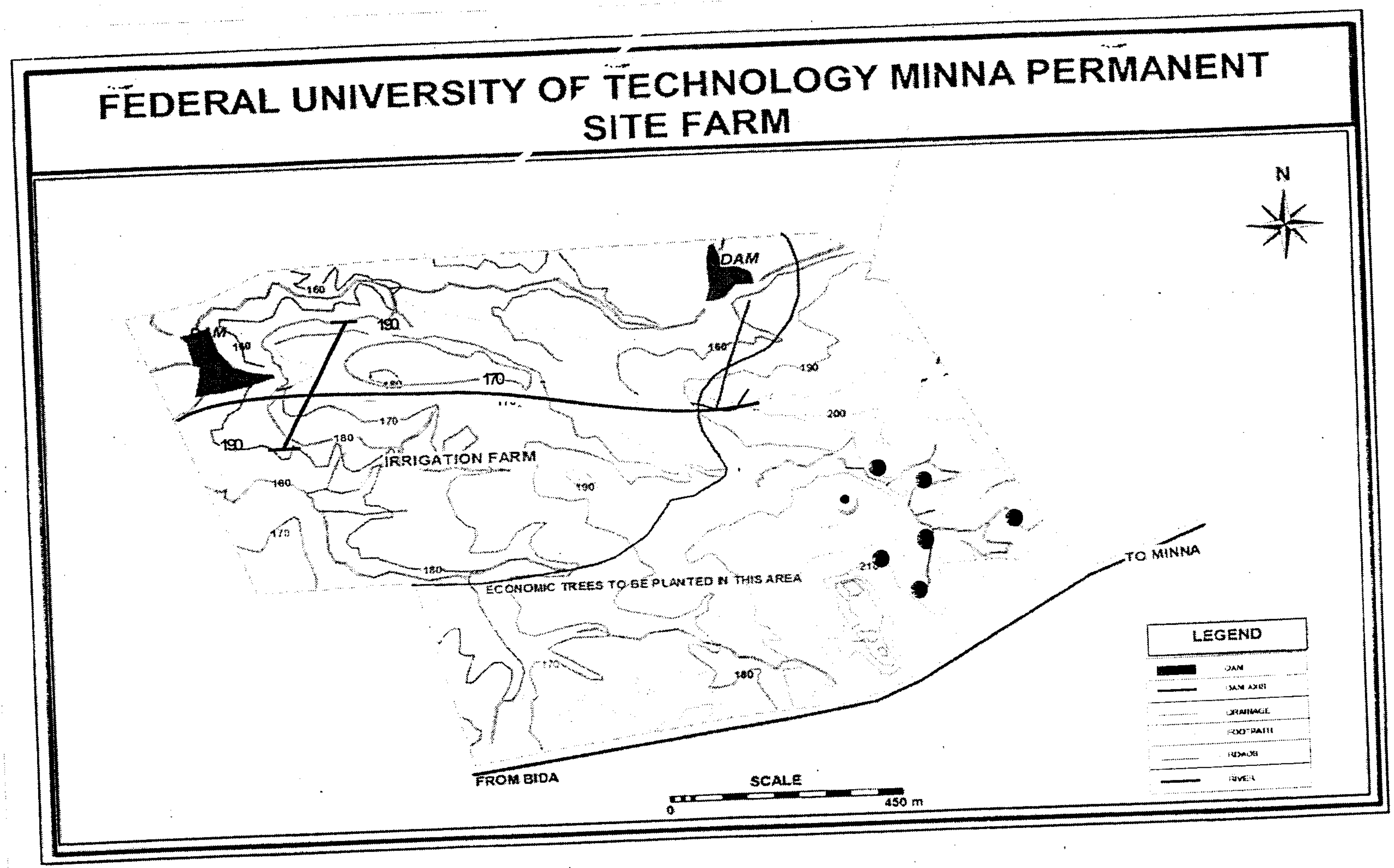
(USDA, 2008)

Appendix D



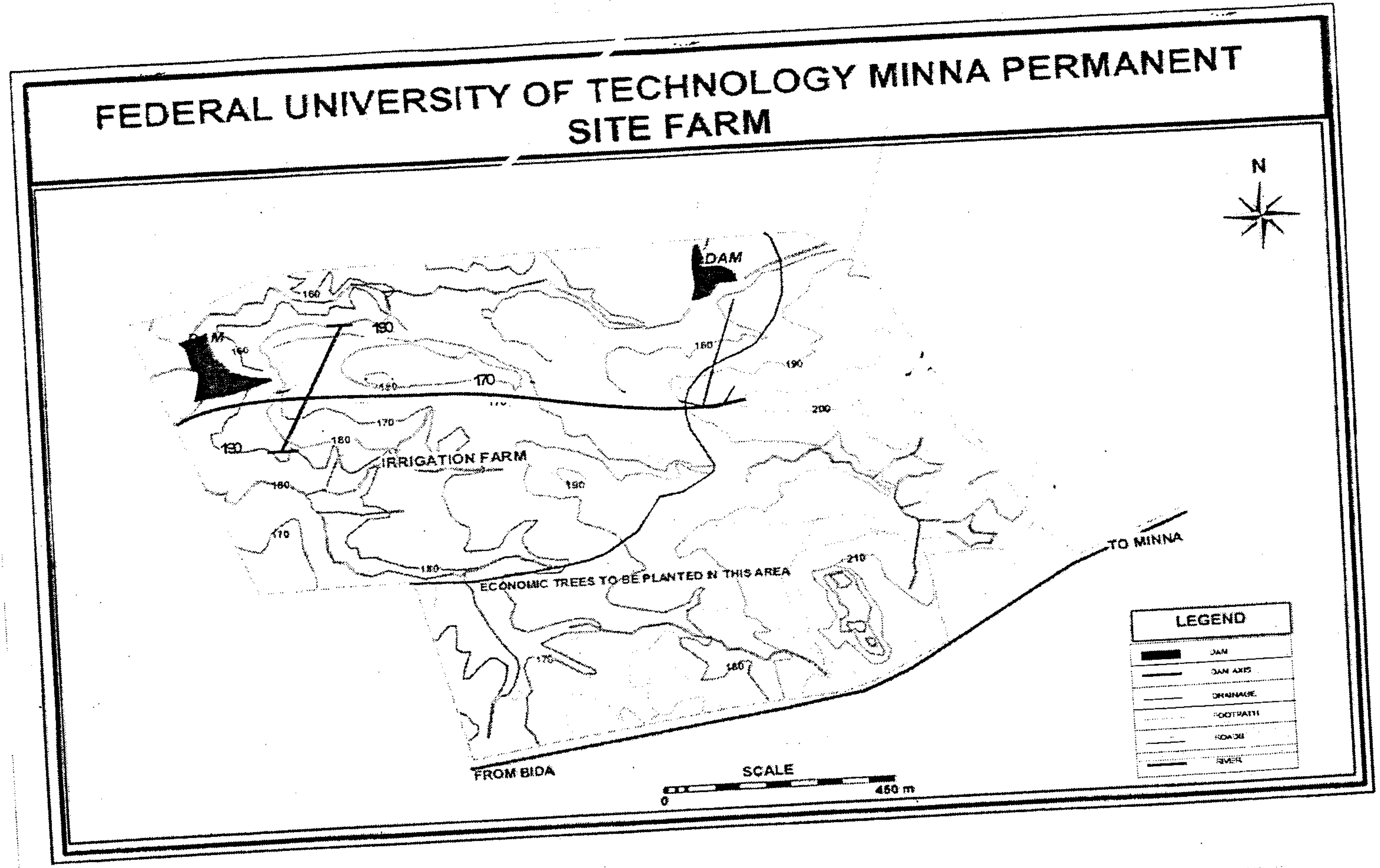
Determination of Soil Constants k and n.

Appendix E



Point on the farm plots showing the units

Appendix F



Map of the study location