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ASSESSING AND MONITORING SITE SOIL CONDITION FOR ITS INFLUENCE ON PADDY FIELD SOIL WATER BALANCE

By

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DECLARATION

I, Samuel Sando Johnson the under signed, declare that this thesis is my original work and has not been presented for a degree in any other University. All sources of material used for this thesis have been duly cited and acknowledged.

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DEDICATION

This work is dedicated to Rev. Fr. Garry Jenkins the man who taught me the values of life and my deceased Aunty Kayndah and sister Massa Johnson who saw the early importance of my education.

ABSTRACT

Suitability of site soil for paddy rice cultivation would mean assessing the site soil for its engineering properties, soil hydraulic properties and moisture storage characteristics. These properties invariably affect moisture loss by way of seepage and percolation, moisture storage for plant use and soil compaction characteristics of soils that can be used in forming bunds in paddy fields. Bunds are constructed as part of paddy field water management system to control and retain water for plant use and tillage practices. The effectiveness of the site soil for these functions must be tested at the inception of the project and also monitored during the operational life of the project. As farmers use the soil for cultivation and as harvesting and storage facilities, the soil may degrade due to compaction, loss of plant nutrients and deterioration of the bund structure. Four representative sites were selected for study of the soil properties such as sand, silt and clay contents, hydraulic conductivity, soil compaction tests at depths 0 – 20 cm, 20 – 40 cm and 40 – 60 cm. Due to continuous cultivation, it was also important the present state of the paddy field soil be assessed for any damaging changes in soil structure. Saturated hydraulic conductivity is affected by the degree of soil densification and therefore a relationship between saturated hydraulic conductivity and dry bulk density was established and their effect on seepage losses ascertained. Results show that the sand, silt and clay content at the 0 – 20 cm layer at the sampling sites WP 18, WP 19, WP 21 and WP 22 were 83.63%, 8.17% and 8.20% respectively, indicating a loamy sand soil. That of the 20 – 40 cm layer was 82.05%, 5.75% and 12.20% sand, silt and clay respectively. For the 40-60 cm layer, it was 80.33%, 3.39% and 16.28% sand, silt and clay respectively. The compaction characteristics as represented by the maximum dry density were in the range of 1.846 to 2.03g/cm^3 for the top 60 cm soil. The measured hydraulic

conductivity of remoulded soil of dry bulk density in the range of 1.30 to 2.03g/cm^3 showed that increasing dry bulk density resulted in a decreasing saturated hydraulic conductivity and the relationship could be represented by a linear function $K_s = -2.4023 + 10.508$, and $R^2 = 0.0021$. Soil mapping of the paddy fields to monitor the state of degradation by compaction due to continuous cultivation in the top 0 – 5 and 5 – 10 cm showed that the dry bulk densities were in the range 1.3 g/cm^3 to 1.5 g/cm^3 well below the root limiting range for sandy loam soils of above 1.7 g/cm^3. The condition of the bund soil was assessed and the range of dry bulk density encountered was 1.2 g/cm^3 to 1.7 g/cm^3 for the 0 – 9 cm layer and 1.3 g/cm^3 to 1.8 g/cm^3 for the 9 – 18 cm layer. Seepage potential decreased with increasing dry density of the bunds. For densities between 1.2 and 1.8 g/cm^3, the seepage potential dropped from 35% to 3.63%. It can be concluded that the higher the level of compaction and its closeness to the Proctor's maximum dry density, the lower the seepage potential. Paddy field water balance study shows that on the average 84.04% of the inflow water (irrigation and rainfall) was lost to seepage and percolation losses and 15.96% was actually used for plant growth. The study generally forms the basis for evaluating the performance of water management in rice paddy fields to address leakages from paddy fields and improve water use efficiency.

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ACRONYMS

AASHTO American Association of State Highway and Transportation Officials

ACQUASTAT Global Information Systems of Water and Agriculture of FAO

AfDB African Development Bank

ArcGIS Geographic Information System

ASRP Agriculture Sector Rehabilitation Project

ASTM American Society for Testing and Materials

AWD Alternate Wetting and Drying

EC Electric Conductivity

ERF Effective Rain Fall

FAO Food and Agricultural Organization

FWT Field Water Tubes

GIDA Ghana Irrigation Development Authority

GPS Global Positioning System

GWT Ground Water Tubes

IRRI International Rice Research Institute

ISSS International Soil Science Society

MOA Ministry of Agriculture

MoFA Ministry of Food and Agriculture

PVC Polyvinyl Chloride

SRI Savannah Research Institute

SWC Soil Water Content

USDA United States Department of Agriculture

WRI Water Resource Institute

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Rice (Oryza sativa *L*) is Liberia's staple food and one of the main staple foods in the world. It has also become the second most important staple food in Ghana. Its consumption keeps increasing as a result of population growth, urbanization and change in consumer habits (MoFA, 2000). Policy strategies over the years have sought to promote rice production to address food security and poverty reduction issues in Ghana (Oteng-Darko *et al*., 2012).

Valley bottom irrigated rice is grown in bunded fields (paddies) that are continuously flooded from crop establishment to close to harvest.

Bouman *et al.* (2007) reported that because of the flooded nature of lowland rice, the fields require a lot of water. Worldwide, research has shown that about 133 million ha of lowland rice is harvested annually of which some 79 million ha are equipped with irrigation facilities. The estimated water use by evapotranspiration of all harvested rice fields in the world is some 859 km^3 per year. According to research, it takes on average 1,432 liters (1.432 m^3) of evapotranspired water to produce 1 kg of rough rice (IRRI, 2009). Irrigated rice receives an estimated 34-43% of the total world's irrigation water, or about 24-30% of the entire world's developed fresh water resources (IRRI, 2009). Sound water management practices are needed to use water wisely and maximize rice yield so that the competing sectors can also be served by the same global or local quantity available. Suitable site for paddy rice cultivation are needed so that water losses by way of seepage can be reduced. Site soil characteristics study is important for several reasons among which are: Soil texture, its physical and biological properties including site soil characteristics to determine the suitability for rice cultivation.

(Acheampong *et al.* 2012) stated that around 75% of Ghana's rice is produced by 78% of small to medium-scale farmers in rain-fed lowland/inland valley systems which are characterized by alternate wetting and drying to exacerbate weed infestation. The average rice yield in this ecology is 2.0 t/ ha but the achievable yield is 8.5 t/ha. Good soil and water management in the inland valley rice production system (Sawah Technology) improves weed management to increase productivity and profitability.

The rice plants generally have shallow root systems. Water deficiency or drought stress has been recognized as the most important limiting factor to wetland rice production. It is the main cause of low and variable yields in paddy cropping systems. Water deficiency may happen at any time during the cropping season of rainfed wetland rice. The damage on rice crops varies with the developmental stage during which water deficiency occurs and the duration of the water deficiency.

1.2 STATEMENT OF THE PROBLEM

Over the years, preliminary investigations on soil and water to assess the physical, chemical and biological variations in the soil before cropping paddy, have not been practiced by farmers. Failure of farmers to engage the services of Soil Scientists or Soil and Water Engineers as well as Geomatic Engineers because of the cost involved, despite the benefits, leads them to myriad problems being left unsolved.

Every farmer's interest is to increase yield, but this expectation has proven futile over the years because of inadequate knowledge on soil and water management issues related to production and sound agronomic practices of rice cultivation. The physical, chemical and biological properties of the soil are of paramount importance in paddy rice farming. A good yield of lowland rice depends on its soil and water balance management and agronomic practices. Substantial increment in the productivity of water used in agriculture is essential to meet goals of food and environmental security. Research has shown that lowland rice fields are extremely sustainable and able to produce continuously high yields with constant availability of water supply, even under continuous double or triple cropping each year. Though there is evidence that lowland rice yields several folds more than upland rice, most rice farmers prefer growing the latter since less work, time and resources are required in the latter. Though there is general awareness about the risks involved in upland rice cultivation as against the lowland rice, farmers continue to cultivate upland rice.

1.3 JUSTIFICATION

Most traditional lowland farmers lack the adequate knowledge involving the management of soil and water on their fields. Simple appropriate technology on soil and water management of paddy fields is studied to assist farmers manage water on their fields. Water available for crop use depends on several factors. These are; the soil texture which influences the water storage or retention characteristics of the soil, the soil hydraulic properties and also the seepage and percolation losses through the fields and bunds. The others are the bund structure and level of compaction which influence seepage losses through the bunds. The distribution of soil water saturation inside the bund generally depends on the type of bund. Water saturation in farmers' field is high because their bunds are earth bunds. Although soil bunds are difficult to maintain, they are the most common bunds constructed by many paddy farmers in Ghana. Soil bunds are beneficial to environmental and ecological conservations, and they are simple and inexpensive to construct. However, it is difficult to maintain due to the hydraulic nature of soils which causes their regular deformations. Farmers loosely pile soils for bunds construction with less compaction. Comparing with the concrete bunds, it has the advantage of durability and low seepage. In paddy rice cultivation, more attention should be on amount of water inflows to the field by rainfall or irrigation as well as outflows from the fields by seepage, percolation, evaporation, and transpiration while ensuring sufficient water for the crop. A hydraulic conductivity model is developed to aid practices of paddy farming by peasant farmers. When water is ponded on the field part of it is lost to deep percolation and seepage, part is used up by the plant by transpiration and the rest by way of evaporation. Proper water management practices in paddy rice fields must consider water inflows and outflows as a way of monitoring leakages and losses. It also gives opportunity to study losses and institute suitable management practices that will increase water use efficiency in order to increase water productivity. It is important to quantify all the water flow paths and see where losses can be minimized. This must be brought to the attention of the farmers so that the needed management action can be taken.

1.4 OBJECTIVES

1.4.1 MAIN OBJECTIVES

The main objective of this study was to assess soil physical properties affecting water flow and retention in a paddy field and also to assess the bund structure and its relation to seepage losses by lateral flows and in-field losses by percolation losses. Finally, to assess the spatial distribution of soil physical properties mainly soil bulk densities, particle density and soil moisture content using geographical positioning systems (GPS) with ArcGIS software to produce maps of the physical properties covering the entire field.

1.4.2 SPECIFIC OBJECTIVES

The specific objectives include the following:

- Mapping and assessing soil physical properties that affect moisture retention and flow at depths 0-5 cm and 5-10 cm
- Assessing the bund soil condition using dry bulk density and degree of saturation
- Assessing paddy soil characteristics at representative sites of the study area at depths 0 – 20, 20 – 40 and 40 – 60 cm.
- Developing a model showing the relationship between saturated hydraulic conductivity and dry bulk density
- Evaluating seepage potential of the bunds
- Assessing the water balance equation for determination of water losses in paddy fields

1.4.3 RESEARCH QUESTIONS

The following were the main research questions investigated:

- What is the range of soil physical properties namely:

  Soil moisture content, wet and dry bulk densities, porosity and air filled porosity at depths 0 – 5 and 5 – 10 cm at the paddy field?
- What will be the hydraulic and moisture holding characteristics of the paddy soil?
- What are the compaction characteristics of representative site soils?
- What is the relationship between saturated hydraulic conductivity and dry bulk density of representative site soils?
- What are the infiltration characteristics of the paddy field soils?
- What is the range of degree of saturation and dry bulk density of bunds soils at the site?
- What is the seepage potential of the bund soil?

1.4.4 SCOPE OF PROJECT

The focus of the present study was on the water balance study of valley bottom rice fields. This involves the testing of the soil physical properties on paddy fields including bunds and monitor the inflow and out flow of irrigated water. The Global Positioning System (GPS) can help in this work by storing the sampled points and coordinates and producing maps that portray the variability of soil physical properties across the paddy fields which show the spatial variations in soil conditions.

1.4.5 LAYOUT OF THE THESIS

The work reported in this volume is in five chapters. Chapter one contains an introduction that gives a background to water balance study of paddy fields, and identifies the problem statement, the main and specific objectives, the research questions, scope of the project and layout of the thesis. Chapter Two discusses the literature review. Chapter Three is a report on the methods of data collection. The processing of the data is discussed extensively here. Chapter Four gives the results and analysis of the results. Chapter Five gives the main conclusions drawn from the project and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses the subject of water balance study of valley bottom paddy fields. There is no single requirement of plant life which is more vital than provision of water. Therefore, adequate quantities of water should be readily available within the root zone of all kinds of plant life. If such water is not present in the soil naturally, it may be applied by irrigation or be derived directly from rainfall during the crop season. Rainfall is said to be beyond man's control. According to estimates, one third of the earth's surface receives less than 250 mm of yearly rainfall and the other one third receives only 250 to 500 mm. This shows that we cannot depend upon rainfall completely for growing of rice and other crops. Necessity for adopting some irrigation methods cannot be over-emphasized. Emphasis is laid on water management of paddy fields considering soil, agronomic practices and climatic conditions. Furthermore, the major losses associated with the water balance and uses on paddy fields have also been outlined.

2.2 PURPOSES OF IRRIGATION SCHEMES

Irrigation schemes are always introduced for the welfare of the people of any particular region. Every region in Ghana has its own climatic, topographic and other characteristics due to which introduction of this artificial flow supply of water in any particular region may disturb the natural balance to produce some ill effects.

2.3 PERCOLATION AND SEEPAGE THROUGH PADDY BUNDS

The soil and water distribution of a paddy field can be illustrated by figure 3.1. (Wopereis *et al.,* 1994) divided the water distribution into four layers:

1. Variable head of irrigated or precipitated ponded water,
2. A low flow resistant muddy layer (puddle soil),
3. A high flow resistant plow sole layer (hard pan), and
4. A non-puddled subsoil layer (subsurface soil)

Chen-Wuing Liu *et al.,* (2001) stated that the heterogeneous four-layer soil complicates the infiltration process since the depth of the standing water gradually decreases as the water moves downward. The muddy layer, which contains a mixture of soil particles and irrigation water, becomes saturated. Additionally, they further stated that the plow sole layer, which has a low hydraulic conductivity, retains the infiltrated water within the muddy layer and remains saturated. Therefore, the highly hydraulically conductive non-puddle subsoil layer receives less water and is unsaturated. Detailed data on the hydraulic characteristics of each layer is necessary to simulate infiltration in the paddy field.

Suzuki *et al.,* (2001) measured ground water levels to estimate percolation and runoff based on a hydrologic process model, and they discussed the relationship between water balance and rice yield. Tsubo *et al.,* (2005, 2006) also measured ground water levels, estimated percolation, and calculated water balance to determine the characteristics of water productivity. Soil texture particularly clay content, is the primary factor in determining downward water loss, and it could determine the water productivity of rainfed paddy fields (Tsubo *et al.,* 2007). Quantifying the change in soil water content (SWC) in the dry season can help clarify the beginning of standing water period in the rainy season.

The potential and actual seepage and percolation flow through bunds during construction are important to evaluate for construction management purposes. Most soils for paddy cultivation are clayey and generally of uniform size (homogeneous). The rate of seepage and percolation in a bund with homogeneous soil material can be calculated by the following Casagrandre's formula. When bund is on permeable foundation, seepage is the sum of the seepage through the bund and through the foundation beneath the bund.

$$q = k\left(\sqrt{h^2 + w^2} - w\right) + K_1\left(\frac{h}{w}\right)(H) \qquad 2.1$$

Where:

q = seepage/percolation flow per cm length of bund (cm/s)

K = permeability coefficient of the bund (cm/s)

K_1 = permeability coefficient of the permeable foundation (cm/s)

H = height of water level against bund, cm

W = effective width of bund, cm

When the bund is on impermeable foundation, the equation becomes:

$$q = k\left(\sqrt{h^2 + w^2} - w\right) \qquad 2.2$$

From the two formulas, measurement of the permeability of the soil material for bunding and the foundation, thickness of foundation, should be done using acceptable engineering methods. The height of water level in the paddy field and the effective width of the bund must also be determined.

2.4 IRRIGATION EFFICIENCY

Irrigation efficiency is of paramount importance in flooded rice cultivation. Efficiency relates the amount of water used by the plant to the amount of water extracted from the water source; it measures the amount of water lost from the system (Han-Chen Huang *et al.*, 2003).

2.5 ANALYSIS OF SOIL WATER BALANCE

A water balance equation determines the efficiency of water usage in a paddy field;

Water Inputs/Inflow = Water losses/Outflow

$$R + I = E + T + S + P + D + d_w \qquad 2.3$$

Where R is rainfall, I is the irrigation supply, E is evaporation, T is transpiration, S is lateral seepage, P is percolation, D is surface drainage or runoff and d_w is the change in ponded water depth or water storage in the soil profile; all in mm/day.

Chen-Wuing Liu *et al.* (2005) estimated the extent of paddy field infiltration in Taiwan by adopting a one-dimensional Darcy-based soil/water balance model SAWAH

(Simulation Algorithm for Water Flow in Aquatic Habitats). He further showed that ground water recharge from paddy field can be estimated via a field water balance equation (equation 3). In this study, the water balance equation is modified and expressed as

$$d_w = (R + I) - (ET + SP + D) \qquad 2.4$$

Where R is Rainfall, I is Irrigation, ET is Evapotranspiration which is obtained from the automatic weather station, SP is lateral Seepage and percolation, D is Over bund flow, surface drainage or run-off (D is ignored because its parameters did not occur during the study), d_w is change in ponded water depth or water storage in the soil profile, all in cm/day. When the budget includes the rice and the soil rhizosphere, the storage d_w includes both ponded water and water content in soil profile.

Equation 1 represents the rate of the vertical movement of water beyond the root zone to the water table, while lateral seepage represents the rate of the movement of subsurface water between fields. The infiltration equals the summation of the lateral seepage and the percolation. Since flooded paddy rice fields perform many functions, such as ecological and environmental conservation, as well as rice production, losses due to percolation and seepage from a flooded paddy field can be regarded as sources of ground water recharge and should not be considered to be irrigation losses in current water resources management.

The water balance of a place, whether it is an agricultural field, watershed, or continent, can be determined by calculating the input, output, and storage changes of water at the earth's surface. The major input of water is from precipitation and output is evapotranspiration. The geographer C. W. Thornthwaite (1899-1963) pioneered the water balance approach to water resource analysis. He and his team used the water-balance methodology to assess water needs for irrigation and other water-related issues.

An understanding of water balance is necessary to appreciate the role of various management strategies in minimizing the losses and maximizing the utilization of water, which is the most limiting factor of crop production in semi-arid tropics (Hanks and Ashroft, 1980).

Water requirements of the plants are met by the supplies from soil, which acts as a reservoir for water. The amount of water held by soil depends on the inputs and losses from the system and holding capacity of the soil. Important sources of water in the field are generally rainfall and irrigation. Losses of water include surface runoff from the field, deep percolation out of root zone or drainage, evaporation from the soil surface and transpiration from the crop canopy.

2.5.1 SOIL WATER BALANCE EQUATION

(ICRISATE, 2003) described soil water balance as a financial statement of income and expenditure which accounts for all quantities of water added, removed or stored in a given volume of soil during a given period of time. The soil water balance equation thus helps in making estimates of parameters which influence the amount of soil water.

Using the soil water balance equation, one can identify the periods of water stress/excess which may have adverse effect on crop performance. This identification will help in adopting the appropriate management practices to alleviate the constraint and increase the crop yields. Hence the soil water balance equation in its simplest form of expression is:

Change in soil water storage= Inputs of water – Losses of water

2.5.2 ADDITION OF WATER TO THE PADDY FIELD

Water was added to the paddy field in three measurable ways: Rainfall (R), Irrigation (I) and contribution from the ground water table (C). The contribution from the ground water was significant when the ground-water table was near the surface. Otherwise the groundwater contribution tends to zero.

Water Inputs = $R + I + C$ 2.5

2.5.3 REMOVAL OF WATER FROM THE PADDY FIELD

Water was removed from the paddy field through evaporation (E) from soil surface or transpiration (T) through the plant together known as evapotranspiration (ET), seepage (S) and deep percolation (P). The rain water received at the soil surface during the growing season was inadequate to experience surface drainage, run-off or over bunds flow (D). Therefore, the mentioned factors were ignored and considered zero in the equation. The losses of water from the paddy field can then be represented by the following equation.

Outflow = $ET + SP + D$ 2.6

2.5.4 CHANGE IN SOIL WATER CONTENT

The change in the soil water content is the difference between the water added and water withdrawn will now read:

Change in Soil water $d_w = (R + I) - (ET + SP)$ 2.7

Soil water refers to the amount of water held in the root zone at a given time. This amount can be measured from equation 2.7. The change in soil water from one measurement to another depends on the contribution of components in the equation.

2.6 TYPES OF BUNDS

Han-Chen Huang *et al.* (2003), reported that there are five types of bunds classified according to material of construction and they are: soil bund, concrete bund, gravel-parked bund, concrete-covered soil bund and plastic-covered soil bund. The soil bund is made of native soil. When it is in contact with ponded water over a long period, the bund's soil may become loose, slippery and hard to maintain. A concrete bund is built directly from premixed concrete slurry. The concrete bund is durable, easy to maintain and allows practically no water seepage. It is higher and narrower than the soil bund. The gravel-parked bund is primarily used in terraced paddies. An impermeable clay layer is first smeared homogeneously on the surface of the slope to reduce the seepage of flooded water through the bund. Similarly sized gravels are then packed on top of the clay layer on the slope surface. The gravel-packed bund is less durable than the first two types of bund. With large volumes of runoff water, the gravel packed bund is likely to break. The concrete-covered soil bund is typically built along a drainage channel to protect the bund's inside wall. The plastic-covered soil bund prevents irrigation water from seeping through and softening the soil.

2.6.1 BUNDS HYDRAULIC CONDUCTIVITY

According to Han-Chen Huang *et al.*, (2003), the hydraulic conductivity of soil underneath a bund determines whether the lateral seepage flow field is of the downward or horizontal type. They further stated that if the plow sole extends to the bottom of the bund, then the seepage is horizontal; otherwise it is downward.

2.6.2 PERCOLATION AND SEEPAGE THROUGH PADDY FIELDS

Paddy fields are typically flooded before rice seedlings are transplanted. After numerous cultivations, a hard pan of 50 to 100mm thickness often emerges at the interface between the topsoil and subsoil.

Chen *et al.* (2002) reported that the hard pan is the least permeable soil layer in the rice paddy. The hard pan can limit the infiltration of ponding water into the subsoil. Paddy fields are surrounded by bunds, and overland runoff from the field occurs only when the height of floodwater exceeds that of the bunds. Thus, water balance and nutrient loss mechanisms from paddy fields are different from those in other types of agricultural fields. Walker and Rushoton, (1984) found that a water balance could not be achieved if evapotranspiration, storm runoff, surface drainage, and vertical percolation through the plow layer were considered the only sources of floodwater losses from paddy fields. Bouman *et al,* (1994) further showed that lateral seepage was the only other possible source for floodwater losses. Figure 3.10 depicts bund seepage losses as being monitored by the ground water tube. Zawawi M.A.M. *et al.* (2010) reported that in general, percolation rates may range from 1mm per day in well-puddled heavy soils to 20mm per day or more in light textured soils.

2.7 SOIL AND CROPS

2.7.1 SOIL

Soil is a cap or covering on the solid crust of the earth's land mass. It is a heterogeneous mixture of loosely packed broken rock together with some organic matter and minerals forming the topmost portion of the earth's land mass of varying depths. It is responsible for supporting the plant's life. The main constituents of soil are the particles size, air and water. Soil acts as a store of the plant nourishing food. Plants derive water, which is the most important requirement of plant's life, through the medium of soil. The soil crust makes it possible for growing plants to secure their bracings and anchorages through the roots below the surface of the earth. In the presence of air and water plant nourishing foods are set free in the soil after completion of chemical reactions. Some harmful products present in the soil are also neutralized during the chemical reactions. Soil is the home of multiplying bacterial life which together with other forms of life is busy in making the soil richer in organic matter and suitable for the healthy growth of the crops.

2.7.2 SUITABILITY OF SOILS FOR CROP PRODUCTION

Not all soils are suitable for crop growing. Therefore, selection for cultivation of a particular crop should depend on the soil texture, structure and its chemical characteristics. Study has shown that soil under cultivation should be neutral; that is the pH value of the soil should be about 7. Soil should be rich in organic as well as inorganic matter. But soils containing either chloride or carbonate or sulphate of sodium or magnesium or potassium are useless for cultivation.

Soil is never made up of only one group. Depending upon the percentage of clay, it is termed as light, medium or normal and heavy. Research has shown that a soil with less than 20% clay is useless for growing crops.

Light soil (2 to 10% clay) is very good for cultivation of most of the crops with ordinary water requirement, e.g. millets, pulses, sesame, mustard, groundnut etc. Normal soil (10 to 20%) is very good for cultivation of most of the crops with ordinary water requirement, e.g. cotton, wheat, maize, oil seeds, gram, peas, potato, vegetables etc.

Heavy soil (40% and above clay) does not allow quick drainage of water. Hence it is suitable for crops which require large quantities of water at regular intervals, e.g. rice, sugar cane etc.

2.8 SOIL PHYSICAL PROPERTIES

2.8.1 COLOR CLASSIFICATION OF SOILS

Irrigation Design Manual, (2003) a manual for the planning and design of irrigation systems reported that the color of the soil can give an indication as to the irrigability of the soil. Soils colored red, red-brown and yellow-brown are in most cases irrigable depending on the depth of the soil and its location. The soils should undergo a chemical analysis for the best recommendation, and the colour of the soil alone should not be relied upon. Soil colour is an important property and gives fairly correct information regarding type of soil. Colour of the soil depends upon its composition, porosity and also its age. Soil containing organic matter has grey, black or brown colour. Diffusion of iron oxide gives red and yellow colour.

2.8.2 SOIL TEXTURE

Texture is defined as the relation between the amount of sand, silt, and clay occurring in the soil. The sizes of particles of soil and their ranges show the texture of the soils. The soil particles are classified according to their sizes into three main groups so far as the agricultural engineer is concerned. The groups are sand, silt and clay as per USDA (United States Department of Agriculture) and ISSS (International Soil Science Society) classifications (Table 2.1).

Table 2.1 Soil particle size distribution ranges

Particle size distribution ranges for USDA and ISSS		
Group	**USDA**	**ISSS**
Sand	0.05 to 2mm	0.02 to 2mm
Silt	0.002 to 0.05mm	0.002 to 0.02mm
Clay	< 0.002mm	< 0.002mm

Sand has gritty feel to fingers. Silt has a feel of flour to eyes whereas clay particles cannot be distinguished by naked eyes. The soil is never fully made up of only one group.

2.8.3 SOIL STRUCTURE

Soil structure refers to the way in which the individual sand, silt and clay particles bond to form larger soil units or aggregates. Many types of soil-structures are recognized and very common of these are granular, prismatic, columnar, laminar, block and plate.

2.8.4 SOIL PROFILE

Typical soil profile of a puddle rice soil consists of:

a). ponded water layer

b). a muddy layer with little or no resistance to water flow

c). a compacted layer with large resistance to water flow

d). non-puddled subsoil

Seepage rates in soil are affected by the physical characteristics of the field bunds, state of maintenance, length of the bunds, depth of the water table and the surrounding drains, ditches, or creeks.

2.8.5 SOIL MOISTURE STORAGE

Soil moisture storage refers to the amount of water held in the soil at any particular time. The amount of water in the soil depends on soil properties like soil texture and organic matter content. The maximum amount of water the soil can hold is called the field capacity. Fine grain soils have larger field capacities than coarse grain (sandy) soils. Thus, more water is available for actual evapotranspiration from fine soils than coarse soils. The upper limit of soil moisture storage is the field capacity; the lower limit is 0 when the soil has dried out.

2.8.6 SOIL CHEMICAL PROPERTIES

Electrical conductivity (EC) is used to appraise soil salinity. Plants vary considerably in tolerance to salts, and salinity can also affect the hydraulic properties of soil. pH is a useful indicator of other soil properties. High levels of exchangeable sodium cause increased dispersion and swelling, reducing water movement i.e. hydraulic conductivity/permeability and affecting aeration, whereas high exchangeable calcium flocculates colloids and reduces swelling tendencies.

2.8.7 PERMEABILITY

It is that property of the soil which allows water to move through the soil mass. The permeability of the soil is defined as the velocity of flow under unit hydraulic gradient. Permeability of a soil is affected by its texture, structure, and temperature changes. Irrigated rice requires heavy soils with a low permeability so as to reduce water losses. Permeability can be reduced to a certain extent by intensive puddling of the soil. Rice has a high tolerance to acidity with optimum pH between 5.5 and 6. Rice is moderately tolerant to salinity.

2.8.8 FLOWS INVOLVED IN WATER BALANCE

Water balance is greatly influenced by the water loss/outflow terms, because farmers usually irrigate in accordance with the consumption and requirement of their plots. Although the water loss/outflow and the water gain/inflow are inseparably related, water application normally follows the fluctuation of water consumption. Evapotranspiration (ET) is influenced by meteorological conditions and stage of growth. Percolation (P) consists of horizontal and vertical components. Horizontal percolation flows through topsoil over the plow layer and seeps into the field drainage canal or adjacent lower field plots. Vertical percolation passes through the plow layer and finally joins the ground water, which may come to the surface far from the plot site or recharge nearby stream. The percolation rate is determined by the hydraulic conditions of the plot, such as the hydraulic gradient between the ponded water and the water table in the drainage canal or groundwater, and permeability of the soil and bunds. Evapotranspiration and percolation are the major consumptive elements in the paddy field plot with vertical percolation accounting for a large part of fluctuation in total consumption.

2.8.9 ONE DIMENSIONAL FORM OF DARCY'S EQUATION

For flow in one dimension, Darcy's law is given by

$$q_s = -k_s \frac{d}{d_s}(h+z) = -k_s \frac{dH}{d_s} \qquad 2.8$$

Where H is termed the total soil water pressure or potential

For horizontal flow

$$q_x = -k_x \frac{d}{dx}(h+z) = -k_x \frac{dh}{dx} - k \cancel{\frac{dz}{dx}}$$

$$q_x = -K_x \frac{dh}{dx} \qquad 2.9$$

For vertical flow

$$q_z = -K_z \frac{d}{dz}(h+z) = -K_z \frac{dh}{dz} - K_z \cancel{\frac{dz}{dz}}^{\,1}$$

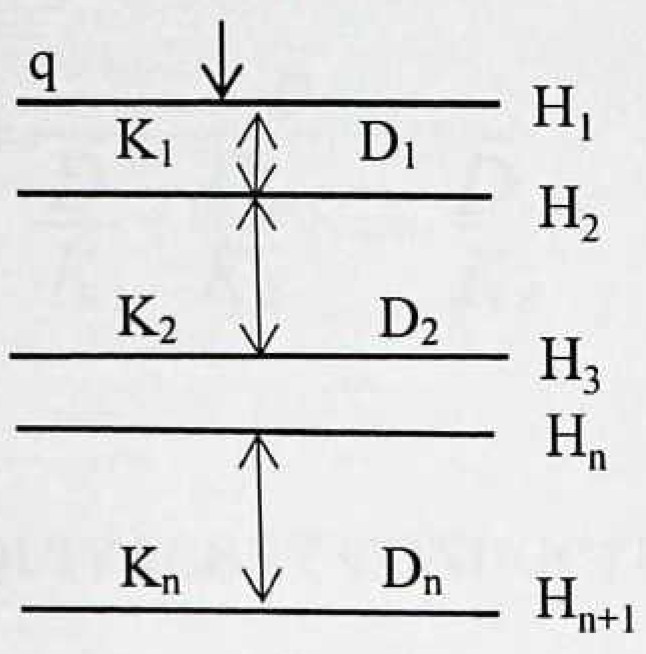
$$q_z = -k_z\left(\frac{dh}{dz}+1\right) \qquad 2.10$$

Flow in layered soils

An equivalent conductivity can be developed for flow in layered soils.

2.8.10 EQUIVALENT CONDUCTIVITY FOR VERTICAL FLOW

When flow is perpendicular to a series of soil layers, the flux through each layer is the same.



$$q = K_1 \frac{(H_1 - H_2)}{D_1}$$

$$q = K_2 \frac{(H_2 - H_3)}{D_2}$$

$$q = K_n \frac{(H_n - H_{n+1})}{D_n}$$

These equations can be rearranged to give:

$$H_1 - H_2 = q \frac{D_1}{K_1}$$

$$H_2 - H_3 = q \frac{D_2}{K_2} \cdots\cdots\cdots H_n - H_{n+1} = q \frac{D_n}{K_n}$$

Adding both sides of these equations yield

$$H_1 - H_{n+1} = q \left[\frac{D_1}{K_1} + \frac{D_2}{K_2} + \ldots + \frac{D_n}{K_n} \right]$$

By rearranging this equation

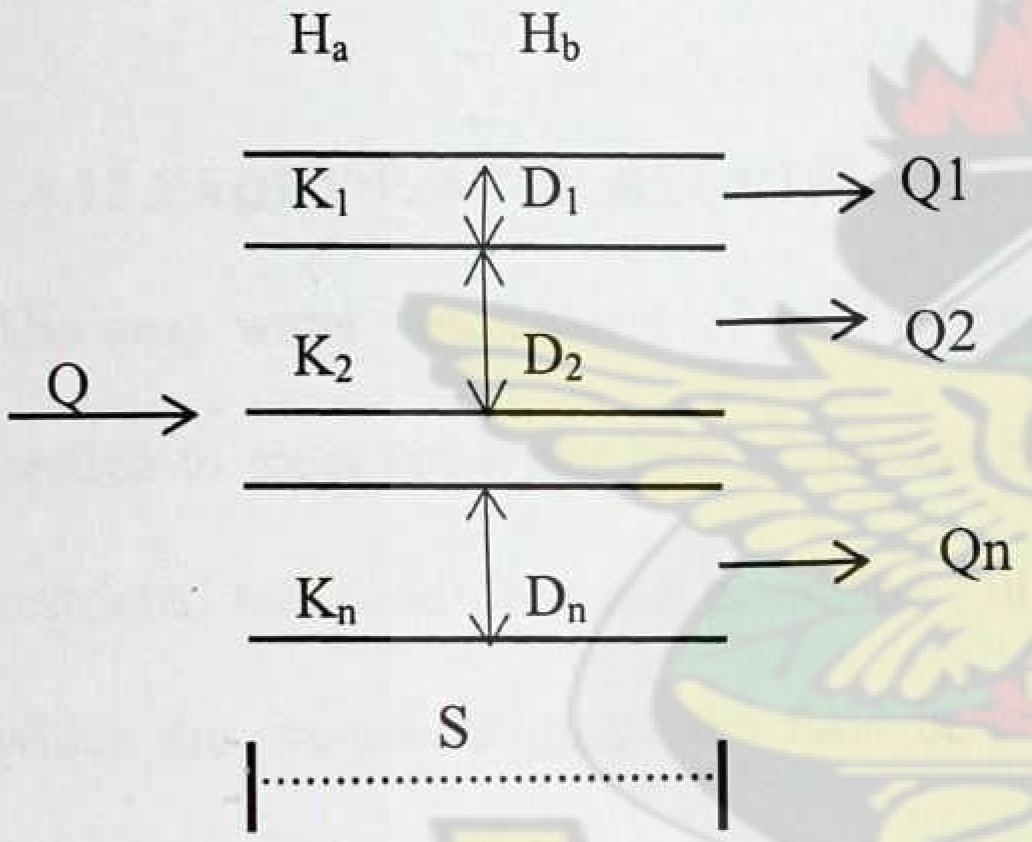
$$q = k_e \frac{(H_1 - H_{n+1})}{D}$$

Where $D = D_1 + D_2 + \dots D_n$

And $K_e = \dfrac{D}{\dfrac{D_1}{K_1} + \dfrac{D_2}{K_2} + \dots + \dfrac{D_n}{K_n}}$ 2.11

2.8.11 EQUIVALENT CONDUCTIVITY FOR LATERAL FLOW

When flow is parallel to a series of soil layers, the discharge through unit thickness of the system is the sum of the discharges through the layers.



$$Q = Q_1 + Q_2 + \dots Q_n$$

$$Q = \left[D_1 K_1 \frac{H_a - H_b}{S} + D_2 K_1 \frac{H_a - H_b}{S} + \dots + D_n K_n \frac{H_a - H_b}{S} \right]$$

$$Q = Dq = [D_1 K_1 + D_2 K_2 + \dots + D_n K_n] \frac{H_a - H_b}{S}$$

$$q = K_L \frac{H_a - H_b}{S}$$

Where

$$K_L = \frac{D_1 K_1 + D_2 K_2 \cdots + D_n K_n}{D_1 + D_2 + \ldots + D_n} \quad 2.12$$

2.8.12 WATER RESOURCES FOR PADDY FIELD IRRIGATION (WR)

Lee *et al.,* (2005) reported that more than 90% of the world's rice is produced and consumed in Asia. Global rice demand in 2020 is projected to increase by 35% over the 1995 level. With this projected increase, the constraints on water resources will be further aggravated since most of the rice is produced with irrigation.

2.8.13 PADDY WATER REQUIREMENT

The crop water requirement of paddy rice can be defined as the total depth of water needed to meet the water loss of disease free crop, growing in large fields under non-restricted soil conditions and achieving full production through the following processes which are pre-saturation on the field before cultivation, evaporation from field before and after direct seeding, evapotranspiration by paddy during the growth period to maturity, and percolation or infiltration loss. By depending upon texture and structure of the soil, depth of water table, depth of field submergence and intensity of puddling, a considerable amount of water in flooded rice is lost as percolation. Kung *et al.,* (1965) reported that WR of rice in Thailand ranged from 520 to 2549mm out of which 127 to 273mm was percolation.

2.8.14 PRE-SATURATION WATER REQUIREMENT

Theoretically, the WR for pre-saturation of paddy range from 150 to 200mm but it can be as high as 650 to 900mm when its duration is 24 to 48 days Zawawi *et al*., (2010). Period of pre-saturation of paddy at Anum Valley Bottom Irrigation project did not exceed one month. For standing water depth, an average of 100mm was used for the pre-saturation period. The average of 5 - 10 mm was used as the initial depth of flooding of the plots by the farmers.

2.9 STAGES OF PADDY GROWTH

According to IRRI, (2009), reported that the cycle of most rice varieties is completed within 110 to 210 days. The growth of rice plant is divided into three phases which are vegetative, reproductive, and ripening phases.

2.9.1 EARLY VEGETATIVE STAGE

After crop establishment, continuous ponding of water generally provides the best growth environment for rice and will result in the highest yields. Flooding also helps to suppress weed growth, improves the efficiency of use of nitrogen and, in some environments, it helps protect the crop from fluctuations in temperatures. After transplanting, water levels should be around 3 cm initially, and gradually increase to 5-10 cm with increasing plant height. With direct wet seeding, the soil should be kept just at saturation from sowing to some 10 days after emergence, and then the depth of ponded water should gradually increase with increasing plant height. With direct dry seeding, the soil should be moist but not saturated from sowing till emergence; else the seeds may rot in the soil. After sowing, flush irrigation is applied if there is no rainfall to wet the soil. The soil is saturated when plants have developed 3 leaves, and the depth of ponded water gradually increased with increasing plant height.

Under certain conditions, allowing the soil to dry out for a few days before re-flooding can be beneficial to crop growth. In certain soils high in organic matter, toxic substances can be formed during flooding that can be removed through intermittent soil drying. Intermittent soil drying promotes root growth which can help plants resist lodging better in case of strong winds later in the season. Intermittent soil drying can also help control certain pests or diseases that require standing water for their spread or survival, such as golden apple snail. Farmers often practice a period of 7-10 days “mid-season drainage” (during which the soil is left to dry out) during the active tillering stage. This practice should reduce the number of excess and nonproductive tillers, but these benefits are not always found. Intermittent soil drying is also used in the System of Rice Intensification (SRI) and is suggested to lead to improved soil health. Other research, however, shows that non-flooded soil promotes the occurrence of certain soil pests such as nematodes. Figures 2.1, 2.2 and 2.3 show early vegetative stage, reproductive stage and ripening stage respectively of paddy at the Anum Valley Irrigation project, Nobewam.

Figure 2.1 Early vegetative stage of paddy growth (Nobewam)

Figure 2.2 Reproductive stage of paddy (Nobewam)

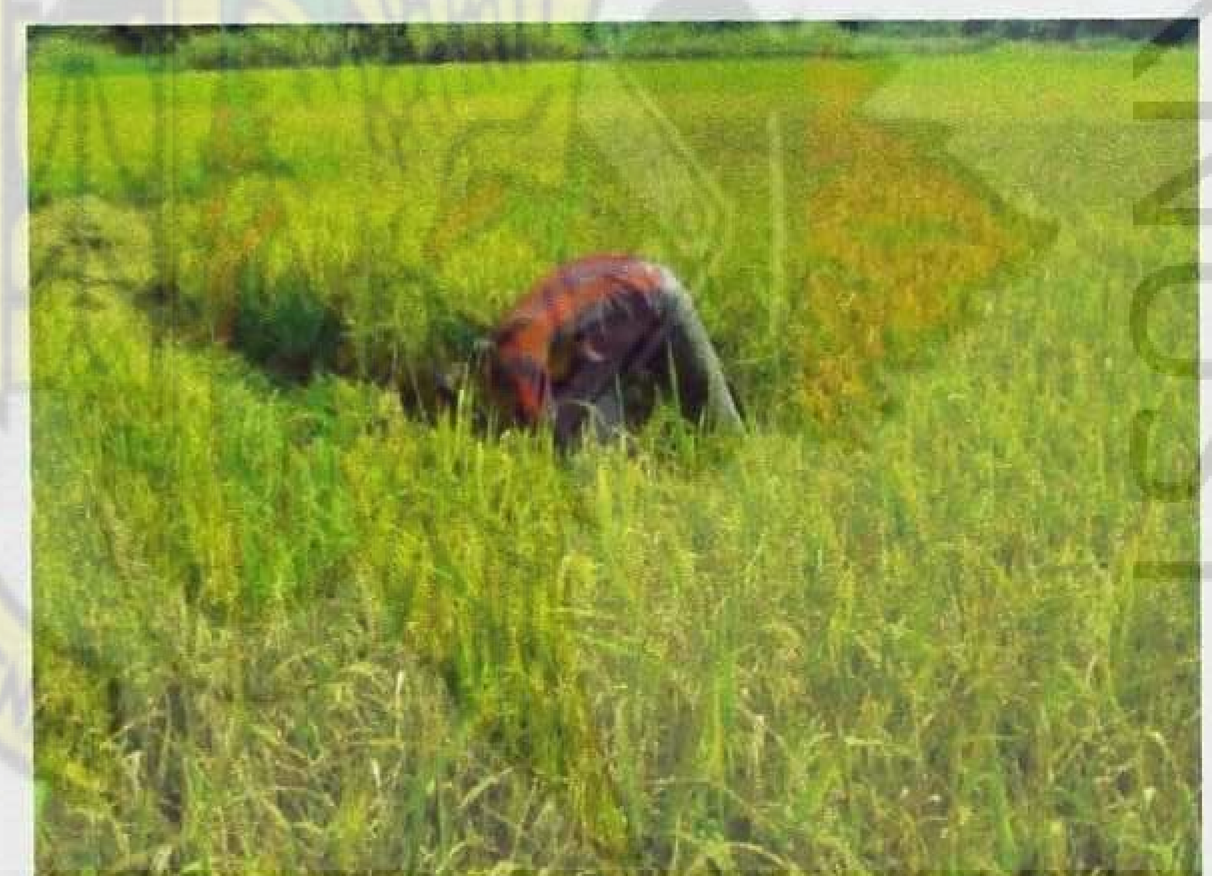


Figure 2.3 Farmer harvesting paddy (Nobewam)

2.9.2 REPRODUCTIVE STAGE

Lowland rice is extremely sensitive to water shortage at the flowering stage, and drought effects occur when soil water contents drop below saturation. Drought at flowering results in increased spikelet sterility, decreased percentage filled spikelets, and, therefore, decreased number of grains per panicle and decreased yields. The water level is maintained in the fields at 5 cm at all times during this stage.

2.9.3 RIPENING STAGE

This period does not necessarily require flooding. Soil saturation of 80–90% is sufficient during this stage. However, for easy operations, keeping the fields flooded may still be the simplest management approach. Draining the fields some 10-15 days before the expected harvest date hastens maturity and grain ripening, prevents excessive nitrogen uptake, and make the land better accessible (because it is dryer) for harvest operations.

2.9.4 GHANA'S LOWLANDS AND RICE CULTIVATION

Ghana's lowlands mostly comprise floodplains and inland valleys occurring throughout the whole country. These lowlands have been characterized to be heterogeneous in morphology, soil type, vegetation and hydrology. Lowland soils therefore occur across all the six agro-ecological zones of the country (Table 2.2). The country has over one million hectares of lowlands (Wakatsuki *et al.*, 2004a, b) which can be developed for effective and sustainable rice cultivation, beside the pockets of areas used for dry season vegetable production.

Table 2.2 Characteristics of Ghana's agro-ecological zones (AQUASTAT FAO, 2005)

Zone	Rainfall (mm/yr)	Portion of total area (%)	Length of growing season (days)	Dominant land use systems	Main food crops
Rain forest	2200	3	Major season: 150-160	forest, plantations	roots, plantation
			Minor season: 100		
Deciduous forest	1500	3	Major season: 150-160	forest, plantations	roots, plantation
			Minor season: 90		
Transition zone	1300	28		annual food and cash crops	maize, roots, plantain
Guinea savannah	1100	63	180-200	annual food and cash crops	sorghum, maize
Sudan savannah	1000	1	150-160	crops, livestock	millet, sorghum, cowpea
Coastal savannah	800	2	Major season: 100-110	annual food crops	roots maize
			Minor season: 50		

2.9.5 GHANA'S RICE CONSUMPTION RATE

According to Ofori *et al.* (2010), the estimated national rice consumption in Ghana stands at 561,400 metric tons per annum while locally produced rice is 107,900 metric tons per annum leaving a gap of 453,500 metric tons per annum which has to be imported in to the country. He further stated that with a population growth rate of 2.5% and an annual rice demand growth rate of 8.9%, a supply of 1.6 million tons of rice will be needed annually in Ghana by 2015. The situation is therefore alarming as the dependency on imports will increase. There exists suitable rice production ecologies in

Ghana and local capacity to produce rice can be enhanced in order to decrease dependency on imports.

2.10 EFFECTIVE RAINFALL

According to agriculturists, effective rainfall is the amount of water available for crop growth from rainfall except surface runoff loss. Effective rainfall during irrigation seasons depends on rainfall amount, rainfall intensity, topography, soil infiltration rate, soil moisture and water management practices. For the purpose of this study, surface runoff in this study area is considered zero since the paddy field is flat. Azwan *et al.*, (2010) reported that effective rainfall on paddy fields can be calculated as in the equation below:

$ERF = 0.6xRF$ If RF<50mm

Where EFR is effective rainfall (mm/week) and RF is rainfall (mm/week). The weekly rainfall is calculated by using the summation of the rainfall in the whole growing season. The daily rainfall data for the calculation was obtained from the automatic weather station installed at the experimental site. During the growing season, there was a high level of water scarcity. The Anum River serves as a source of water for irrigation.

2.10.1 EVAPOTRANSPIRATION (ET)

It is the combined transfer of water into the air by evaporation and transpiration. Actual evapotranspiration is the amount of water delivered to the air from these two processes. Actual evapotranspiration is an output of water that is dependent on moisture availability, temperature and humidity. Actual evapotranspiration is "water use", that is, water that is actually evaporating and transpiring given the environmental conditions of a place. Actual evapotranspiration increases as temperature increases, as long as there is water to evaporate and for plants to transpire. The amount of evapotranspiration also depends on how much water is available, which depends on the field capacity of soils. In other words, if there is no water, no evaporation or transpiration can occur. The evapotranspiration during the growing season was gathered from the automatic weather station.

2.10.2 POTENTIAL EVAPOTRANSPIRATION (PE)

It is the environmental conditions at a place which create a demand for water. Especially in the case for plants, as energy input increases, so does the demand for water to maintain life processes. If this demand is not met, serious consequences can occur. If the demand for water far exceeds that which is actually present, dry soil moisture conditions prevail. Natural ecosystems have adapted to the demands placed on water.

Potential evapotranspiration is the amount of water that would be evaporated under an optimal set of conditions, among which is an unlimited supply of water. In other words, potential evapotranspiration or "water need" would be the water needed for evaporation and transpiration given the local environmental conditions. One of the most important factors that determine water demand is solar radiation. As energy input increases the demand for water, especially from plants increases. Regardless whether there is, or isn't, any water in the soil or not, a plant still demands water. If it does not have access to water, the plant will likely wither and die.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

The following items were used for the study:

- Hand held GPS Garmin 550 was used to pick coordinates of sampling points and elevations which aided the ArcGIS software in producing the maps
- Davis instruments Vantage Pro2 Weather Station (Wireless) recorded the meteorological data
- Permeameter, four fold type (DIK-4012) was used to determine the laboratory hydraulic conductivity/permeability of soils
- Mini-disc infiltrometer for in-situ determination of hydraulic conductivity of the paddy field surface
- Soil sampler/auger for sampling of soil from the top 18cm of the bunds and paddy field.
- Cylindrical cores with dimensions of 5 cm diameter and 5.1 cm height were inserted in an enclosed cage of the sampler to sample undisturbed soils.
- Electronic Balance for the determination of both wet and dry weight of soils
- Cylindrical mould 101.6 mm internal diameter and height 116.43 mm of capacity 943 cm^3 with detachable base plate and removable collar of 6 cm height
- Rammer 2.5kg having a flat circular face 50.8 mm diameter equipped with suitable guide sleeve for a free fall of 30.5 cm

- Sample extruder consisting of a jack, lever, frame etc. was used to extrude samples from the mould.
- Balance with approximate capacity of 11.5 kg, when used with 152.4 mm mould with sensitivity of 5 gm.
- Drying oven, thermostatically controlled capable of maintaining temperatures of 105±5 ˚C for drying wet samples
- Straight edge of hardened steel about 250 mm length
- ASTM sieves conforming to the requirement of AASHTO M 92
- Mixing tools such as pan, spoon, trowel, spatula etc for thoroughly mixing soil with water
- Containers made of corrosion resistant material with close fitting lids, one container each for one moisture content determination
- Stop watch for time keeping of the in-situ and laboratory hydraulic conductivity
- Graduated cylinder for water measurement
- PVC pipes 4"diameter and 6" diameter (perforated with 5mm diameter holes at 2cm intervals)
- Polythene bags for the collection of bund soil
- Sacks for packaging of samples
- Mallet for the installation of the field water tubes in the subplots
- Auger of 1m length was used to aid the installation of ground water tubes on bunds
- Trowel was used to clear soils from within the field water tubes
- Measuring tapes were used for field measurements

- Computer
- Printer

3.2 SOFTWARE

The following software's were used in the data analysis and schematic drawing of the research field: ArcGIS 10, Microsoft Excel and AutoCAD.

3.3 THE STUDY AREA

The Anum Valley Bottom Irrigation Project hosts the experimental site. It is located at Nobewam near Konongo in the Ashanti Region. The area of study covers 1.0037 ha of valley bottom land with average bund dimension of 0.7 m height, 0.8 m width. The texture of the surface soil is loamy sand (classification method of FAO). Geographically, it is located on latitude 6˚37'27.1" N and longitude 1˚17' 14.7"W of the semi-deciduous forest zone of Ghana with elevation of 630.07'; strategically, it is situated between two districts namely: Asante Akim North and Ejisu Juaben.

Like most other projects, irrigation has a wide range of benefits and is often reflected in the welfare gain by farmers due to increased crop and multiplier effect on national incomes and food security (WRI, 1992). The Anum Bottom Valley Irrigation Project has been very beneficial to farmers since its establishment in 1989. The annual averaged yield rice production of the field is 3.87 t/ha with 7.2t/ha as GIDA targeted yield (Ofori *et al.*, 2010). Though many of the hydraulic structures have failed due to poor maintenance and with high level of bunds deterioration, farmers still use the facility.

The Anum Valley Bottom Irrigation Project is divided into two distinct areas, namely areas A and B. Area A is 35 ha and is irrigated by means of pumps. Area B has the potential area of 89 ha and used to be irrigated by gravity via a diversion weir but the entire facility is now destroyed by illegal miners. The main crop is rice and it is usually grown in the main season and vegetables in the minor season.

Because of the cost of running the pumps at the Annum Valley Irrigation Project, farmers unknowingly practice Safe Alternate Wetting and drying method.

The annual average precipitation is 1200 mm with the Anum and the Oweri rivers serving as source of water for irrigation by means of pump and gravity. For the purpose of this study, the meteorological data used are those collected by the automatic weather station installed at the site during the study. The type of irrigation practiced is surface irrigation with basins. Each basin covers an area of 50 m x 20 m.

3.4 METHODS

3.4.1 DATA COLLECTION

The hand held GPS Garmin 550 was used to obtain the geographical coordinates and elevations of the sampled position of soils from the bunds and the paddy field. The spatial analysis maps of the soil physical properties were developed. Field and ground water tubes were installed to characterize the water environment on the bunds and the paddy field respectively.

Thirty-six points of the bunds were randomly sampled for the determination of soil dry bulk density, degree of saturation, moisture content and porosity at depths 0-9 and 9-18 cm. The soil was sampled using an auger of 18 cm length.

3.4.2 PADDY FIELD SOILS

For the spatial distribution of basic soil physical properties stainless steel cylindrical core of 5 cm diameter and 5.1 cm height was placed in an enclosed cage of the auger and then driven into the soil. In all eighteen (18) sampling points were selected from the entire paddy cultivated field and soil samples were taken at depths 0 – 5 cm and 5 – 10 cm for the determination of spatial distribution of soil physical properties.

3.4.3 REPRESENTATIVE SITE SOIL SAMPLING

Four sampling points representative of properties of the site soil were selected for the determination of hydraulic conductivity, particle size analysis, organic matter content, organic carbon and compaction (Proctor) tests including sand, silt and clay content. Soil samples were taken at depths, 0 – 20, 20 – 40 and 40 – 60 cm. The purpose of the proctor test was to ascertain the level of compaction that could be attained if farmers' paddy bunds were compacted to the densest degree and compared with what pertains on farmers' field or at site.

The wet weight of soils sampled from the experimental site were determined and recorded and oven dried for sixteen to eighteen hours at a temperature of 105±5°C to constant mass at the Department of Agricultural Engineering. Dry weight was recorded to determine:

- Soil moisture content
- Wet bulk density
- Dry bulk density
- Porosity
- Air-filled porosity

3.5 SOIL PHYSICAL PROPERTIES CALCULATIONS

3.5.1. DRY-BULK DENSITY CALCULATION (ρb)

The bulk density is the mass of the dry soil per unit of total volume. The oven dried soil sample was reweighed after allowing it to cool for an hour. The bulk density (ρb) of soil is determined with the aid of the following equation:

$$\rho_{bd} = \frac{M_t}{V_t} \qquad 3.1$$

Where,

ρ_{bd} = Bulk density

$Ms(g)$ = Weight of dry soil determined after oven drying

$V_t cm^3$ = Total volume of sampled soil

Considering 234.10g of soil weight (Ms) at a depth of 5cm and (Vt) volume of cylindrical cone as 100.1cm^3~~, we have~~:

$$\rho_{bd} = \frac{128.6}{100.1} = 1.3\ g/cm^3$$

(For further calculations, refer to Appendix 9)

3.5.2 SOIL MOISTURE CONTENT DETERMINATION

This test is done to determine the water content in soil by oven drying. The water content (Mw) of a soil sample is equal to the mass of water divided by the mass of dry soil (Ms).

$$W = \frac{Mw}{Ms} \qquad 3.2$$

Where

$Mw = Mt - Ms$

Mt = Weight of wet soil = 148.4g and Ms = weight of oven dry soil = 128.60g at 5cm depth of the paddy field.

Mw=1484−1286

= 19.8g

$$W = \frac{19.8}{128.6}$$

W =0.15

(For further calculations, refer to Appendix 9)

3.5.3 WET BULK DENSITY CALCULATION (ρw)

The wet bulk density is the mass of the wet soil per unit of total volume. The total volume of sample was determined based on the volume of the cylindrical core. The bulk density (ρw) of soil is determined with the aid of the following equation:

$$\rho w = \frac{Mt}{Vt} \qquad 3.3$$

Where, $Mt = Mw + Ms$

ρw = Wet bulk density

$Mt(g)$ = Weight of wet soils determined after being brought from the field by weighing it on the electronic balance.

V_t (cm^3) = Total volume of sampled soil

$Mw = 19.8g$ Water content of the soil, $Ms = 128.6g$ weight of oven dry soil sampled at 5cm depth.

$Mt = 19.8 + 128.6$

$= 148.4g$

$$\rho_w = \frac{148.4}{100.1} = 1.5g/cm^3$$

3.6 POROSITY AND AIR-FILLED POROSITY OF SOILS

3.6.1 POROSITY

Soil porosity is a popular way of expressing a soil's structural condition. The soil pores contain the soil, air and water. The air-filled porosity provides a guide to a soil's aeration status which may be related to air diffusion and the potential for plant root respiration.

Porosity can then be obtained from the below equation.

$$n = 1 - \frac{\rho_{bd}}{\rho_s}$$

Having $\rho_{bd} = 1.3 g/cm^3$ as dry bulk density obtained at 5 cm depth of the paddy field and $\rho_s = 2.65 g/cm^3$ as the soil density obtained from literature,

$$n = 1 - \frac{1.3}{2.65} = 0.5$$

(For further calculations, refer to Appendix 9)

3.6.2 AIR FILLED POROSITY

Air-filled porosity or free air space (FAS) is the volume of air-filled pore space in a soil at given moisture content, and is found by subtracting the volumetric water content of a sample from its total porosity. The air-filled porosity can be obtained from the below equation.

$$f_a = n - \rho b x W$$

Where

f_a = Air-filled porosity

ρb = Particle density

W = Moisture content

$$W = \frac{Mw}{Ms} = 0.15, \quad \rho_{bd} = 1.3 g/cm^3 \text{ and } n = 0.5$$

$$f_a = 0.5-(1.3x0.15) = 0.31$$

(For further calculations, refer to Appendix 9)

3.7 DATA INPUT INTO ArcGIS

Paddy field soil physical properties results, coordinates and elevations were imported into a Microsoft Excel spread sheet and saved. Data were entered into ArcGIS for spatial analysis.

After importation of the sampled coordinates, they were converted to shape-files. This process was by right clicking the table of content and selecting "export data". The exported data then added to the map as new layer. Interpolation of the data was by clicking on the spatial analyst followed by interpolated to raster. The option used was the Kriging method. The various soil physical properties (bulk density, moisture content, and particle densities) were plotted using the same procedures for the two depths. Figure 3.1 and 3.2 depict two of the final products.

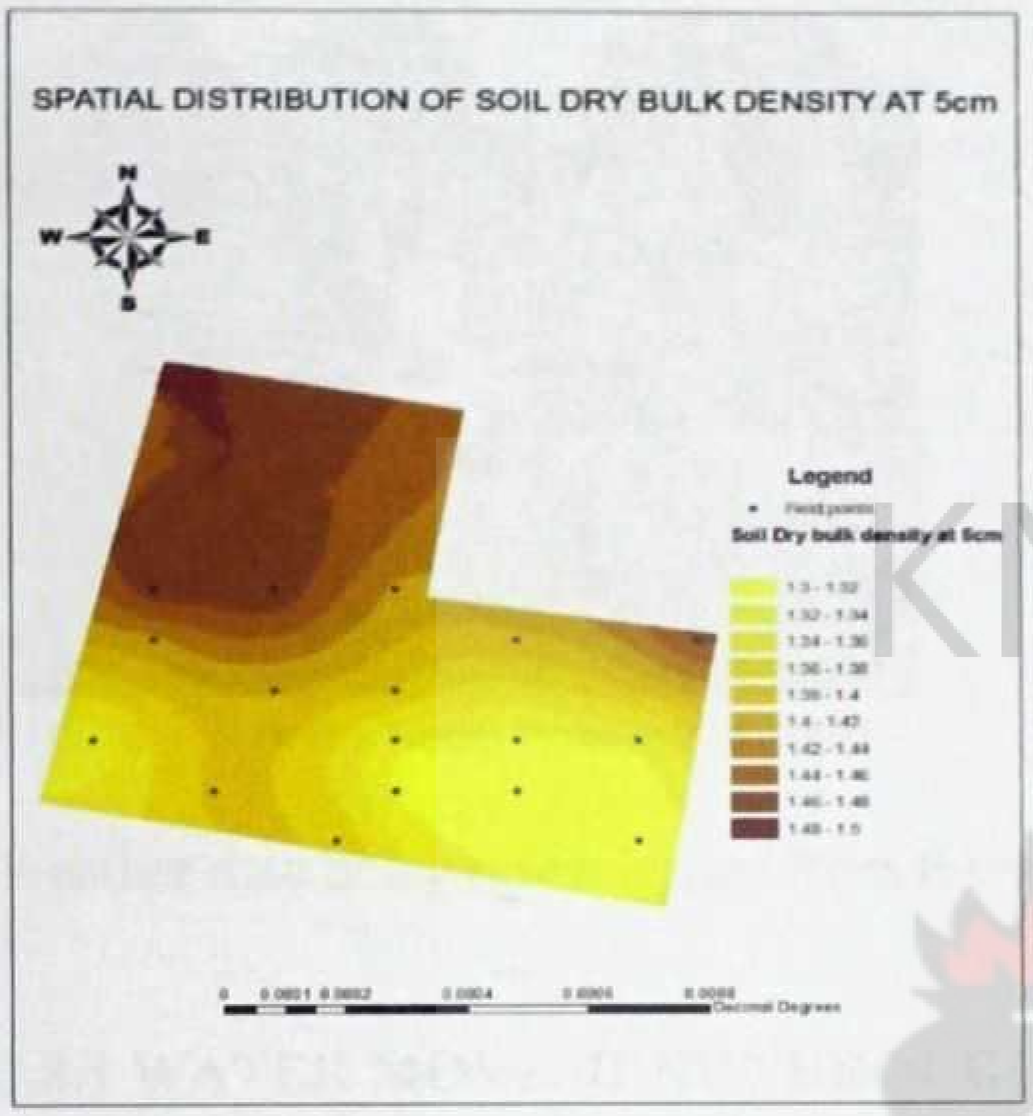


Figure 3.1 Final product of maps

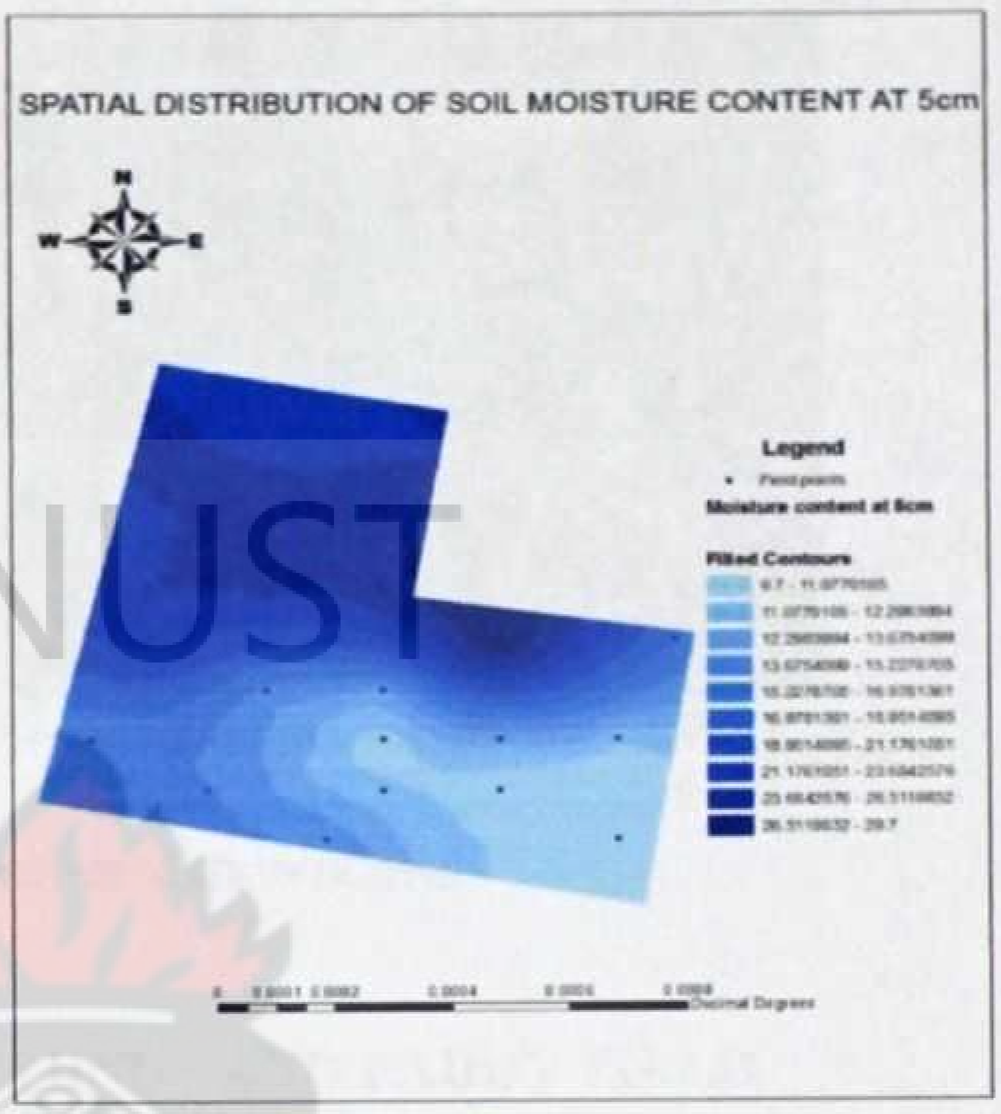


Figure 3.2 Final product of maps

3.7.1 STATISTICAL ANALYSIS

Microsoft excel was used to determine the maximum, minimum, mean, median, standard deviation, coefficient of variation and the area covered by the various soil physical properties and water environment relative to the study area.

3.8 WATER AND METEOROLOGICAL DATA

Meteorological data were obtained from the automatic weather station WEATHERLINK Vantage Pro-2 Davis instrument (Davis Instruments Corp, USA) as shown in Figures 3.3 and 3.4. The instrument was installed at the experimental site and hourly data recorded during the growing season. Data were downloaded to the laptop weekly. Daily hourly values of air temperature, dew point, wind speed, rain fall and rate, solar radiation, and evapotranspiration (ET) and others environmental factors were recorded.

Figure 3.3 Automatic weather station

Figure 3.4 data logger for (AWS)

Weather data being down loaded from the weather station consol

3.8.1 WATER MOVEMENT THROUGH BUNDS AND PADDY FIELD

For the purpose of monitoring lateral water flows through the bunds and in-field vertical flows by percolation, field water tubes and Ground water tubes were designed and installed. The field water tubes measured the outflows or leakages by way of deep percolation and seepage through the fields. The groundwater tubes measured the outflow by way of lateral flows through the bunds. The tubes were used to characterize the water environment in the paddy field and its water management. Irrigated water was lost as surface evaporation, plant transpiration, deep percolation and seepage/lateral losses through bunds and the paddy field. The data were recorded daily at 0900 hours GMT during the growing season.

3.8.2 FIELD EXPERIMENTAL LAYOUT

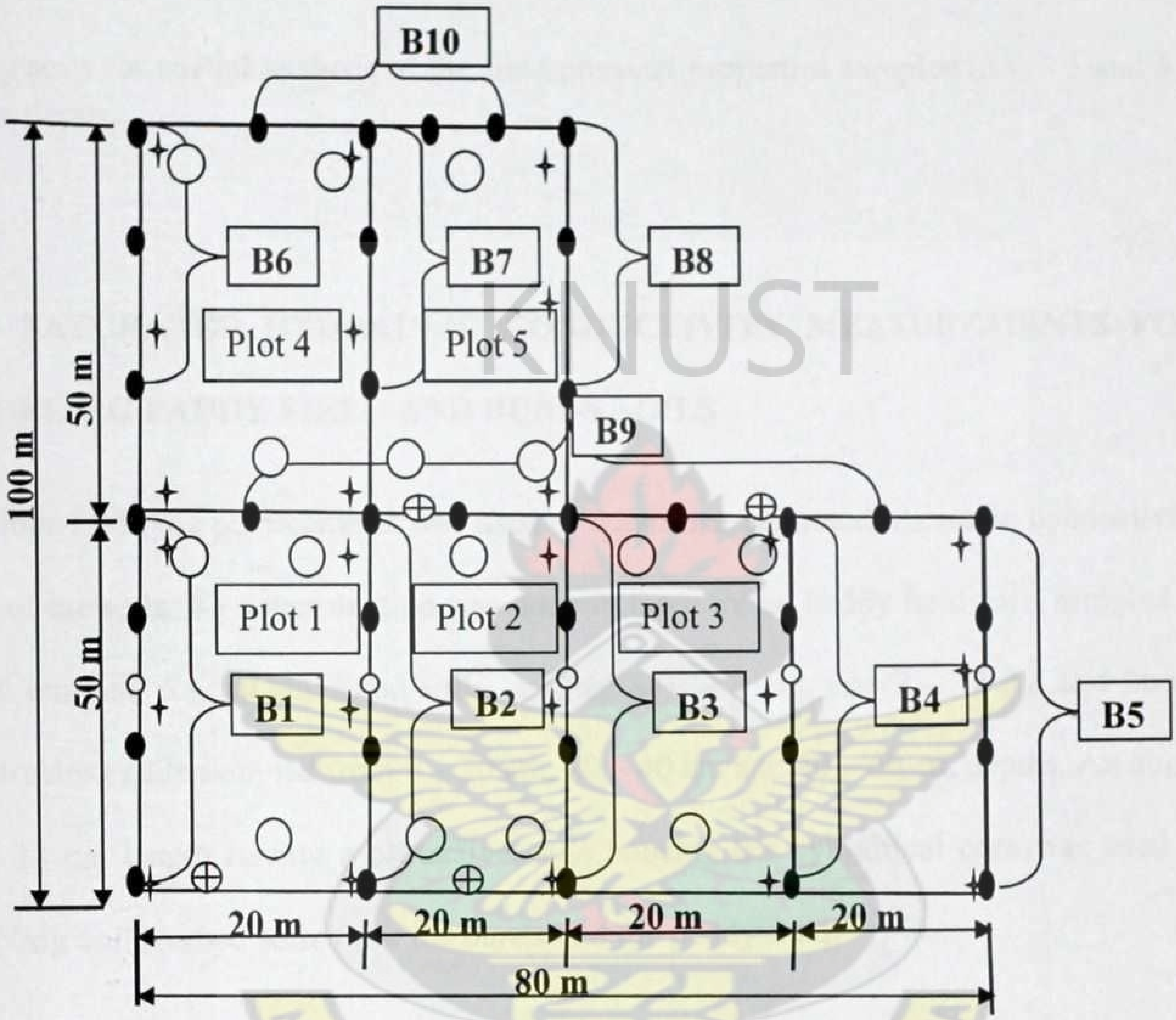


Figure 3.5 Experimental site layout

○ 6"diameter PVC Field-water tubes installed in the field to monitor the daily infiltration rate of the field

o 4"diameter PVC Ground water tubes installed in the bunds to monitor lateral flows through bunds to adjacent plots

● Bund soils sampled at 0 – 9 and 9 -18 cm depth for physical property determination of the bunds

- Soil sampled from the paddy field at the depths of 0 - 20, 20 - 40, and 40 – 60 cm as bunds construction and paddy soils for modified proctor, hydraulic conductivity, organic matter and organic carbon determination

- Paddy soils for spatial analysis of the field physical properties sampled at 0 – 5 and 5 – 10 cm depth

3.8.3 SATURATED HYDRAULIC CONDUCTIVITY MEASUREMENTS FOR MODELING PADDY FIELD AND BUNDS SOILS

The four-fold type permeameter was used to determine saturated hydraulic conductivity (Ks) of the soils. Ks determination was done in three folds: Paddy field soils sampled at 0 – 5 cm, and 5 – 10 cm, bund soils sampled at 0 – 9 cm, and 9 – 18 cm and bunds construction soils sampled from 0 – 20 cm, 20 – 40 cm and 40 – 60 cm depths. An augur with 18 cm length having a protective cage housing the cylindrical core was used in sampling undisturbed soils from the bunds and the paddy field.

3.9 FIELD-WATER TUBES (FWT)

The daily water loss from the paddy field by means of seepage and percolation was measured in a 35 cm long and 15cm diameter PVC tubes. Five plots were selected and the tubes were installed in a triangular position about 1.0 m away from the bunds in each subplot to 20 cm below the soil surface. The bottom 20 cm of the tubes were perforated with 0.5 cm diameter holes at 2 cm intervals (Figure 3.6). Data gathered from the three tubes were summed and averaged to represent the water environment classification of a particular subplot. The tubes measured the vertical and lateral flows (seepage and percolation) of the field water.

Figure 3.6 Field water tube (FWT)

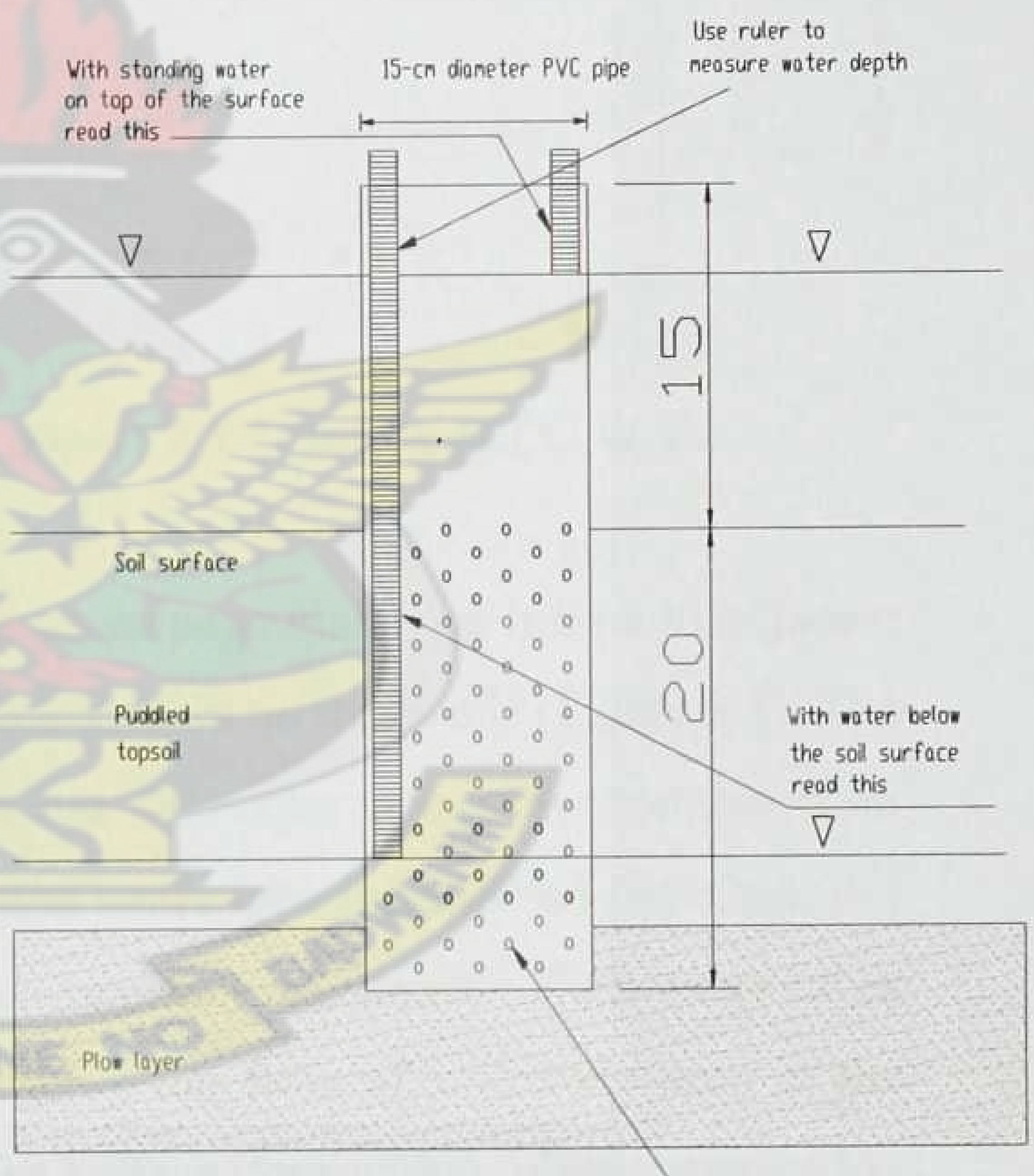


Figure 3.7 Schematic of F.W.T

Field water tube installed in the subplots showing hidden water beneath soil surface and it's schematic

3.9.1 GROUND-WATER TUBES (GWT)

The Ground-water level was measured from the ground water tubes installed on five main bunds using 5cm diameter, 150cm long PVC tubes similarly perforated in the bottom 50cm length installed below the soil surface. These tubes considered the lateral flow and seepage through the bunds (Figures 3.8) of each bund.

Figure 3.8 ground water tube (GWT)

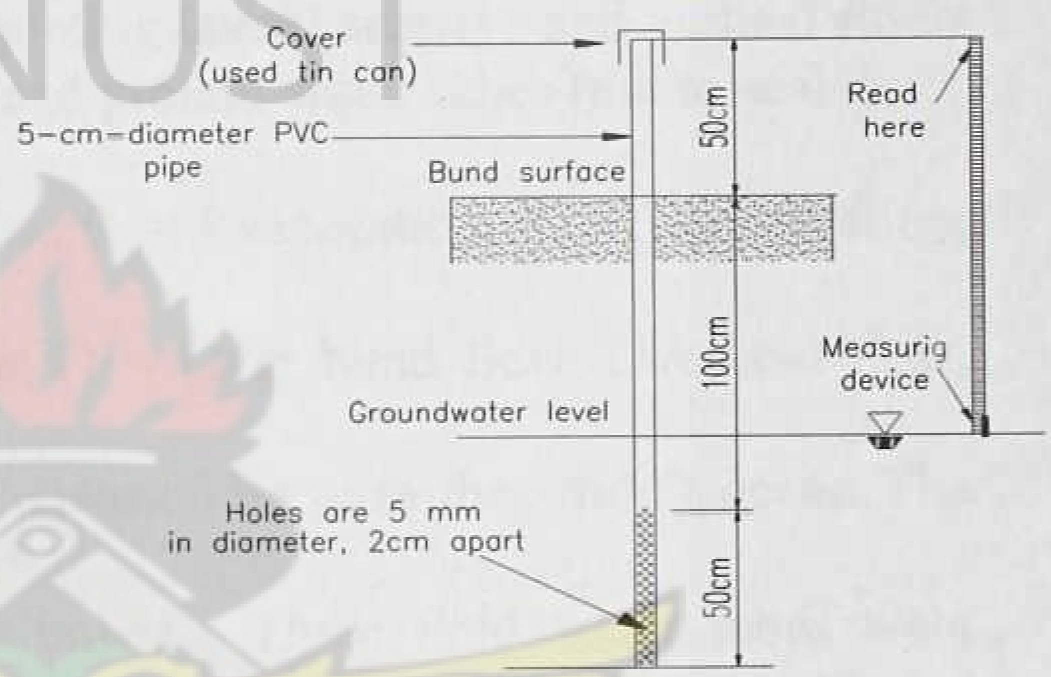


Figure 3.9 Schematic of G.W.T

The daily water loss through the bunds by lateral seepage including inflow to adjacent plots was measured from the installed ground-water tubes on the bunds (Figure 3.8). The ground water tubes each had a cover can to avoid the occurrence of evaporation from within the tube. Figures 3.8 and 3.9 show ground water tube installed on the bund. For the purpose of the water balance equation, two important instruments Field water tubes and Ground water tubes were designed to observe the flow of irrigated water in the paddy field. Water in the paddy field was lost as surface evaporation, plant transpiration including deep percolation, seepage (lateral) losses through bunds and the paddy field. The instruments installed monitored the daily seepage losses while the automatic weather station gathered the meteorological data.

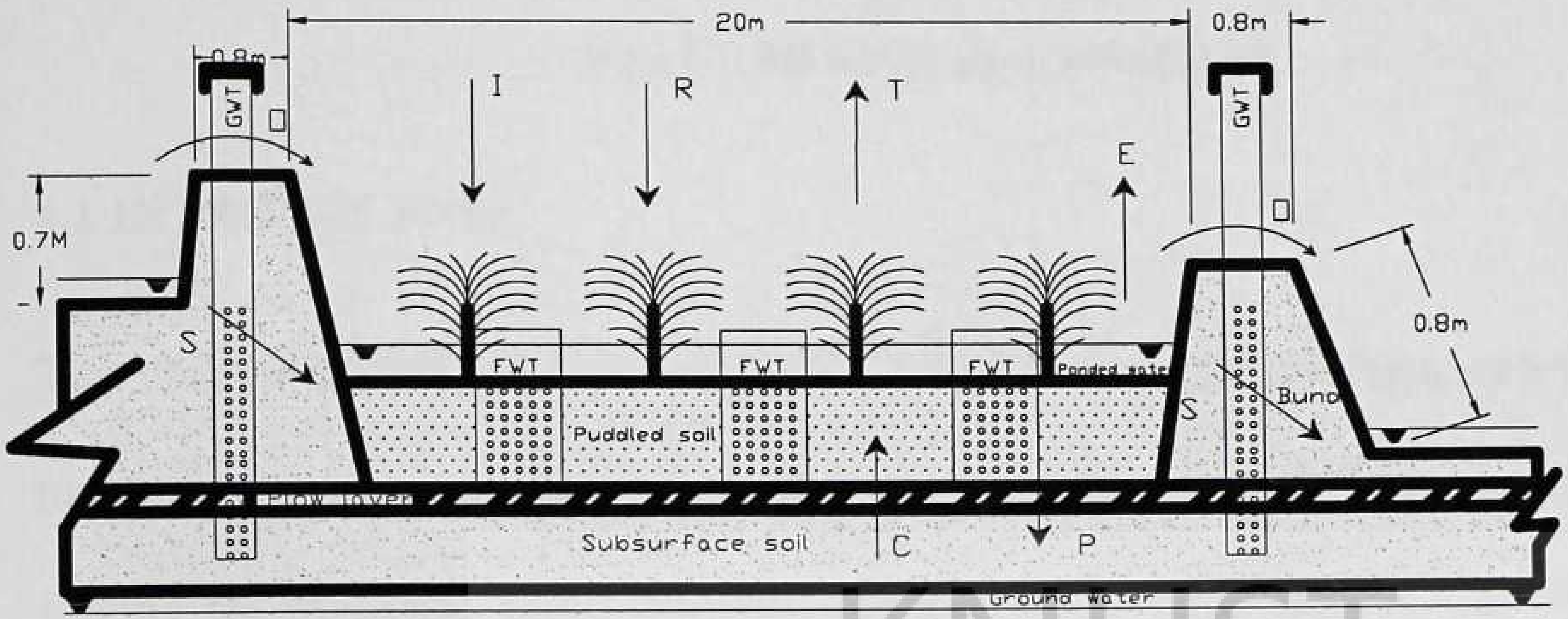


Figure 3.10 Paddy Field Schematic diagram depicting lateral seepage and vertical flows through bunds and paddy field with field-water and ground-water tubes (not to scale).

R = Rainfall, I = Irrigation, C = Capillary rise, E = Evaporation, T = Transpiration, S = Seepage in and out flow, P = Percolation, O = Over bund flow. Overland flow, surface drainage or run-off was ignored in the equation because they didn't occur. The study concentrated on five subplots and five bunds. Three field water tubes were installed triangularly on each subplot at least a meter away from the bunds. Daily seepage and percolation rate (daily water use) of the field were measured from the field water tubes, whilst the ground water tubes measured vertical and lateral seepage through bunds as shown in the experimental site layouts diagram and field schematic. The three field water tubes for each of the five plots were averaged to characterize field infiltration rate by seepage and percolation (Appendix 4 Figures and data) of individual plots.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter discusses the study's results obtained on soil water balance and agronomic practices of paddy crop at Anum Valley Bottom Irrigation Scheme. The study aimed at finding out the water gains and losses (water balance) considering soil texture of both bunds and paddy field and meteorological impact. Modeling of the soil physical properties and spatial analysis maps were produced to give researchers and farmers a fair idea of the soil status.

4.2 SPATIAL DISTRIBUTION OF PADDY SOIL PHYSICAL PROPERTIES

4.2.1 DRY BULK DENSITY OF SOIL AT 0 – 5 AND 5 - 10 CM

Figures 4.1 and 4.2 are the spatial distribution of soil dry bulk density of sampled cultivated paddy fields at 0 - 5 and 5 – 10 cm depths at the time of sampling. Table 4.1 is the summary statistics of soil dry bulk densities. The range of bulk density for the 0 – 5 cm depth was 1.3 g/cm^3 to 1.5 g/cm^3 while for the 5 – 10 cm depth range of soil dry bulk density was from 1.2 g/cm^3 and 1.7 g/cm^3. (Table 4.1 and Figure 4.1 and 4.2) including the mean value of 1.40 and 1.45. The standard deviation which is an indication of the closeness of values to the mean was 0.08 and 1.25 and the coefficient of variation which is an indication of how far the values are from the mean was 5.78 and 86.11. The median values from the statistical table are 1.3 and 1.5.

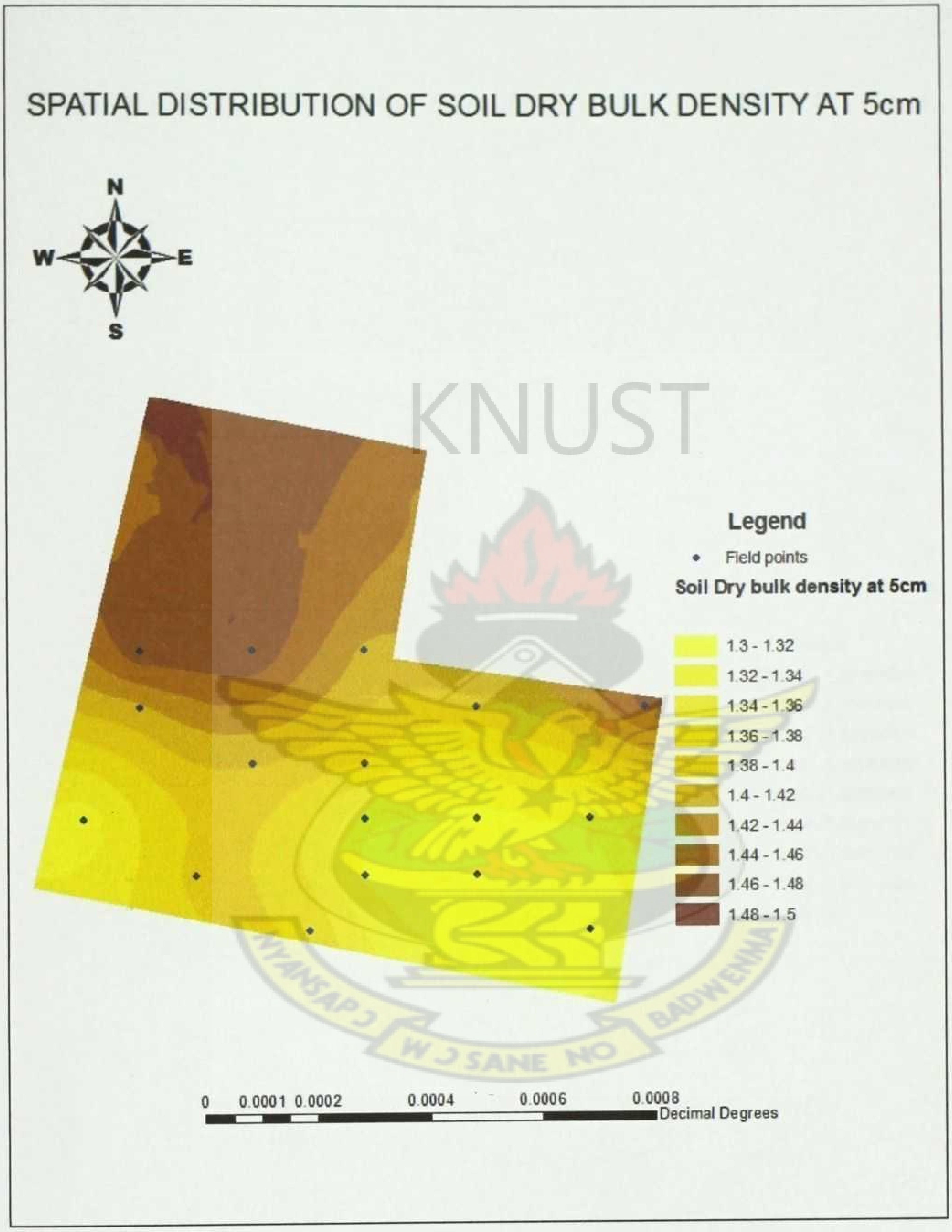


Figure 4.1 Spatial distribution of soil Dry bulk density at 0-5 cm depth

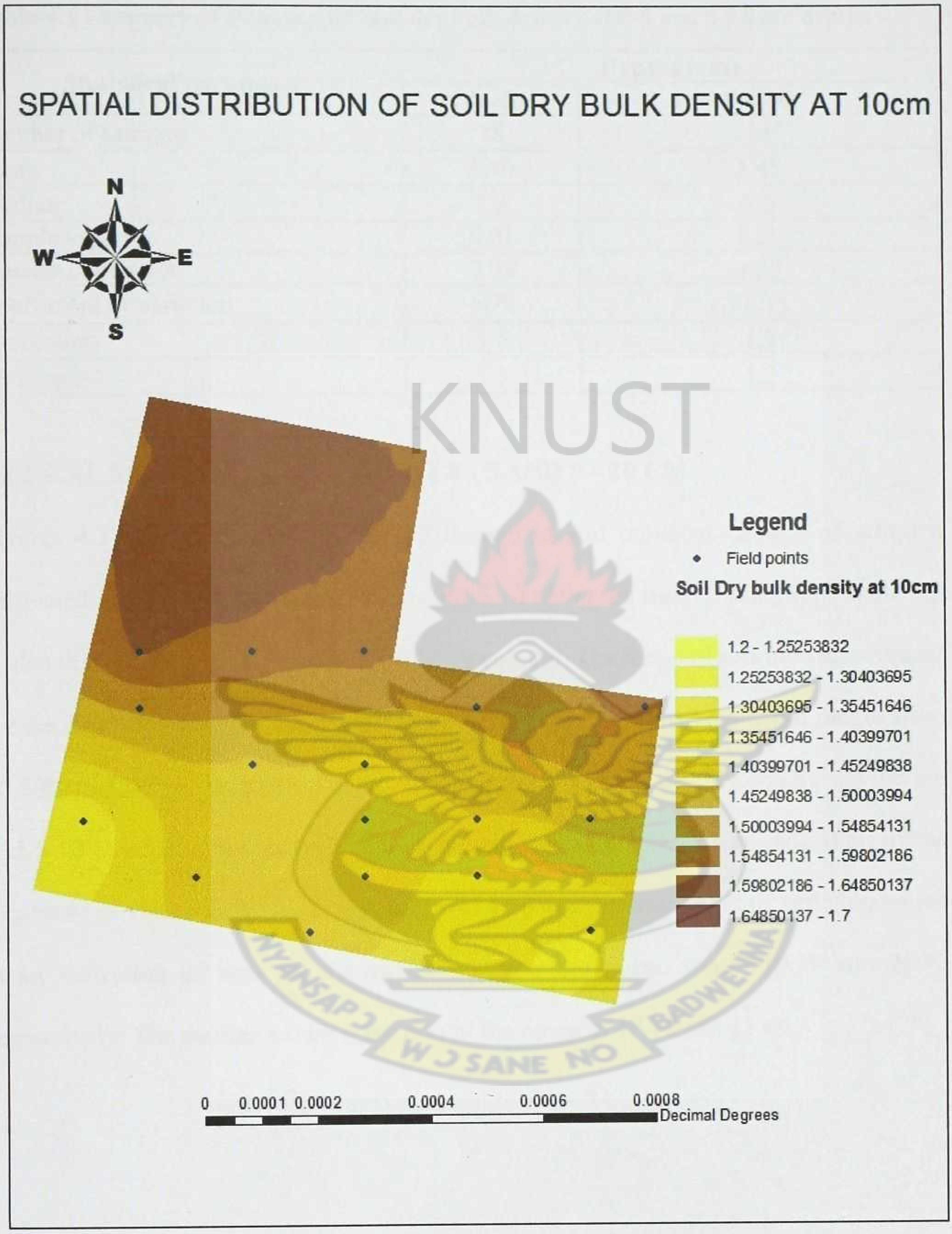


Figure 4.2 Spatial distribution of soil Dry bulk density at 5-10 cm depth

Table 4.1 Summary of statistics for soil dry bulk density at 0-5 and 5-10 cm depths

Statistical parameter	Depths (cm)	
	0 - 5	5 – 10
Number of samples	18	18
Mean	1.40	1.45
Median	1.3	1.5
Sample variance	0.01	1.56
Standard deviation	0.08	1.25
Coefficient of variation	5.78	86.11
Maximum	1.5	1.7
Minimum	1.3	1.2

4.2.2 SOIL MOISTURE CONTENT AT 0 - 5 AND 5 – 10 CM

Figures 4.3 and 4.4 are the spatial distribution of soil moisture content of sampled cultivated paddy fields at depths 0-5 cm and 5-10 cm at the time of sampling. Table 4.2 is also the summary statistics of soil moisture content. The range of soil moisture content for the depth 0 – 5 cm was from 9.7% to 29.7% while the 5 – 10 cm depth ranges from 10.50% to 23.60% respectively. The mean values were 5.65 and 17.05% for the 0-5 cm and 5-10 cm depths respectively. The standard deviation which is an indication of the closeness of values to the mean was 6.75 and 4.56 and the coefficient of variation which is an indication of how far the values are from the mean were 119.39 and 26.72 respectively. The median values were also in the range of 17.70 and 13.60.

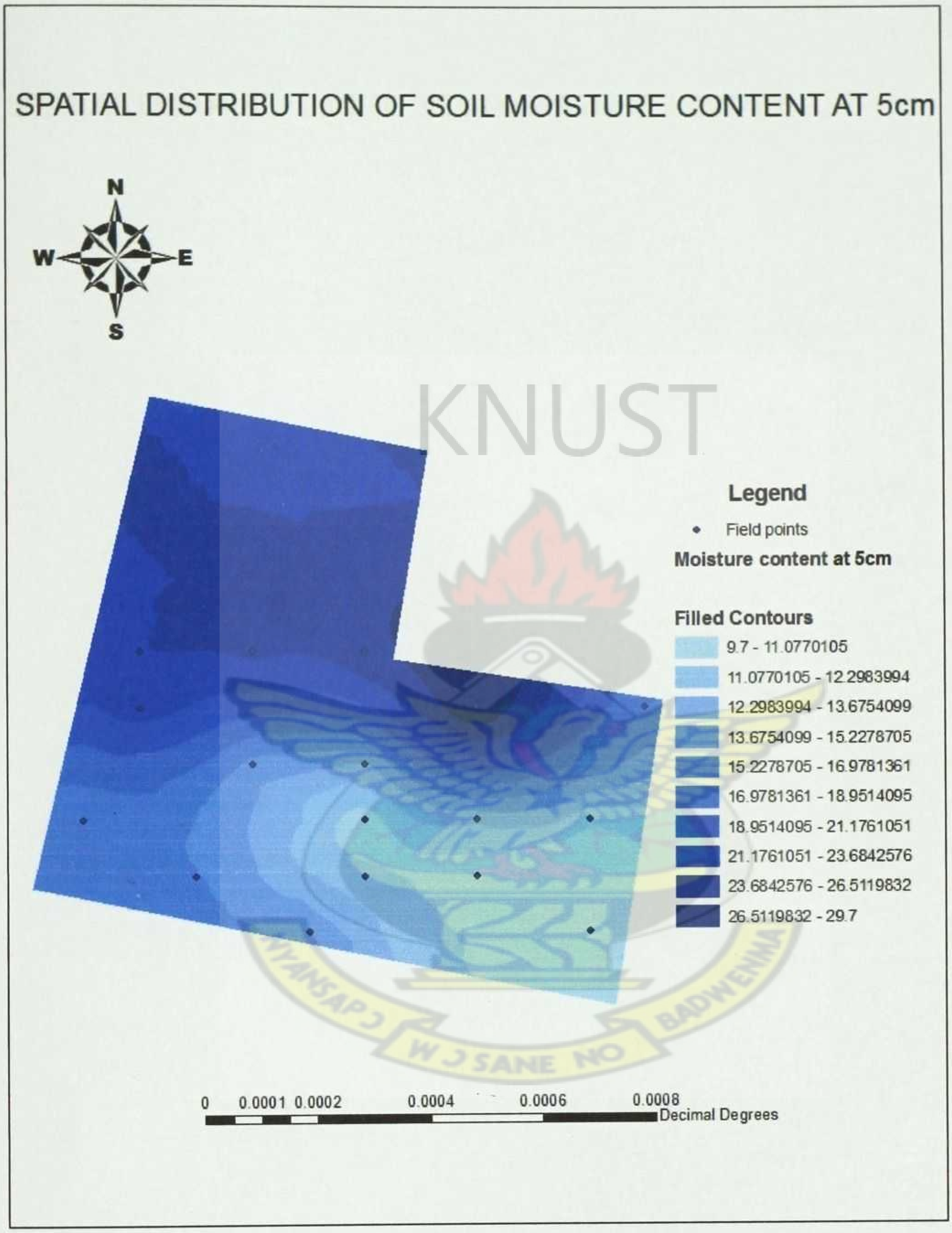


Figure 4.3 Spatial distribution of moisture content at 0-5 cm depth

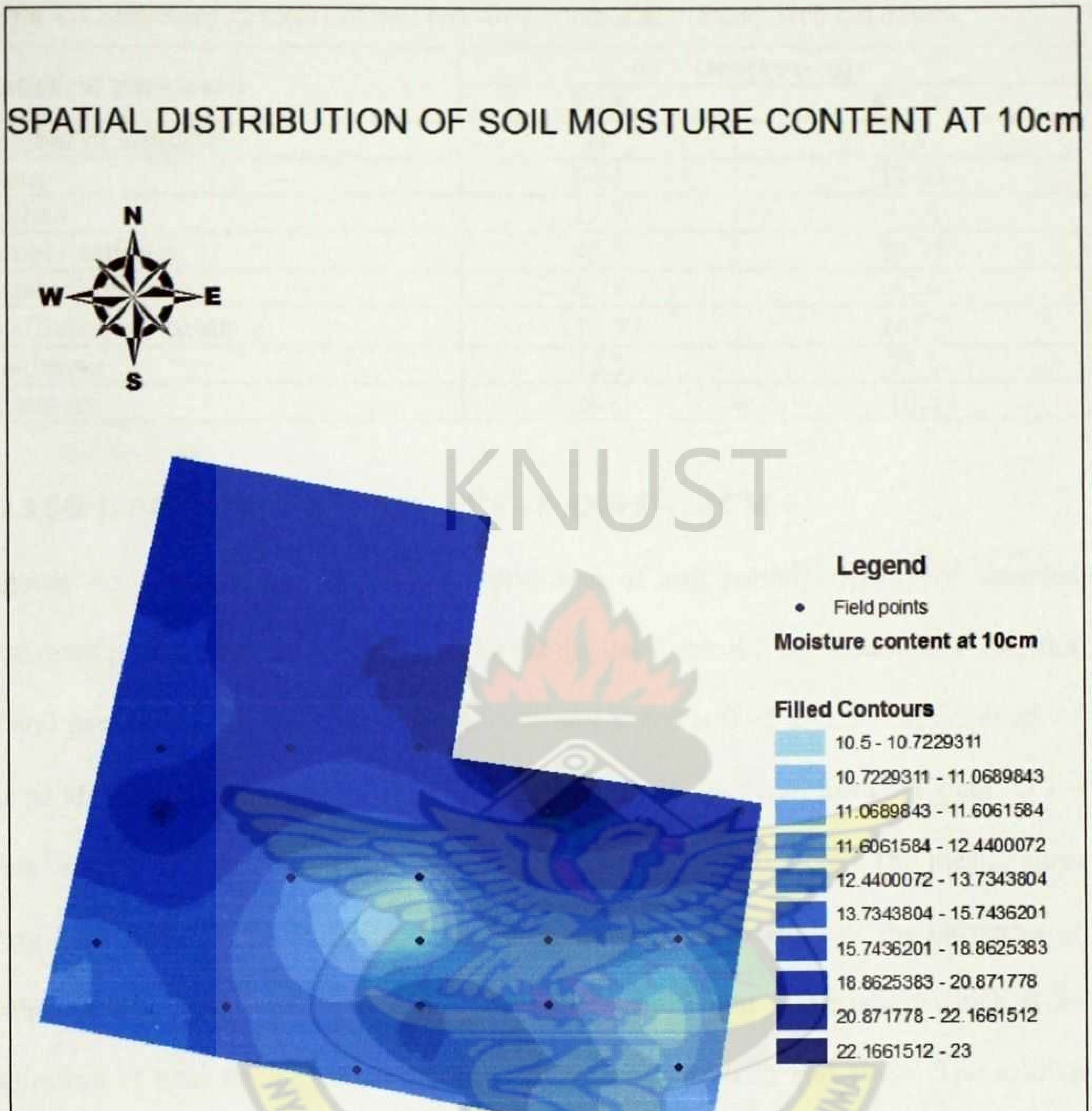


Figure 4.4 Spatial distribution of soil moisture content at 5-10 cm depth

Table 4.2 Summary statistics of soil moisture content at 0-5 and 5-10 cm depths

Statistical parameter	**Depths (cm)**	
	0 - 5	**5 – 10**
Number of samples	18	18
Mean	5.65	17.05
Median	17.7	13.6
Sample variance	45.5	20.75
Standard deviation	6.75	4.56
Coefficient of variation	119.39	26.72
Maximum	32.5	23.6
Minimum	9.7	10.5

4.2.3 SOIL PARTICLE DENSITY AT 0 – 5 AND 5 – 10 CM

Figures 4.5 and 4.6 are the spatial distribution of soil particle density of sampled cultivated paddy fields at 0-5 cm and 5-10 cm depths. Table 4.3 is the summary statistics of soil particle density at the two depths. The soil tested at 0 - 5 and 5 – 10 cm depth of the paddy field showed that the particle density for 0 – 5 cm depth from 1.4 g/cm^3 to 1.9 g/cm^3 while the 5 – 10 cm depth ranges from 1.4 g/cm^3 to 2.0 g/cm^3. The mean values were 1.65 and 1.7, the standard deviation which is an indication of the closeness of values to the mean were 0.15 and 0.18 and the coefficient of variation which is an indication of how far the values are from the mean were 9.25 and 10.84. The median values were also 1.6 and 1.7.

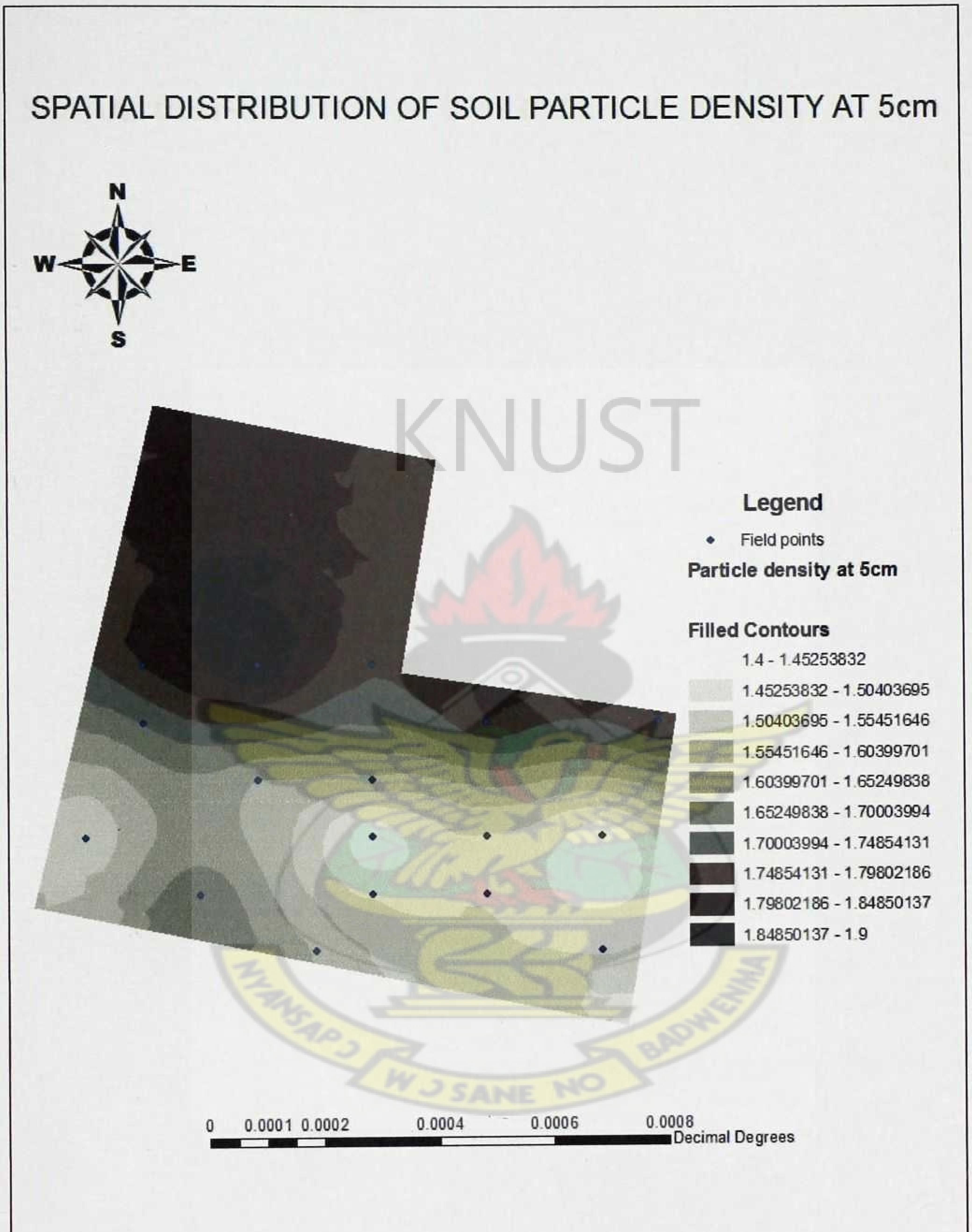


Figure 4.5 Spatial distributions of soil particle densities at 0-5 cm depth

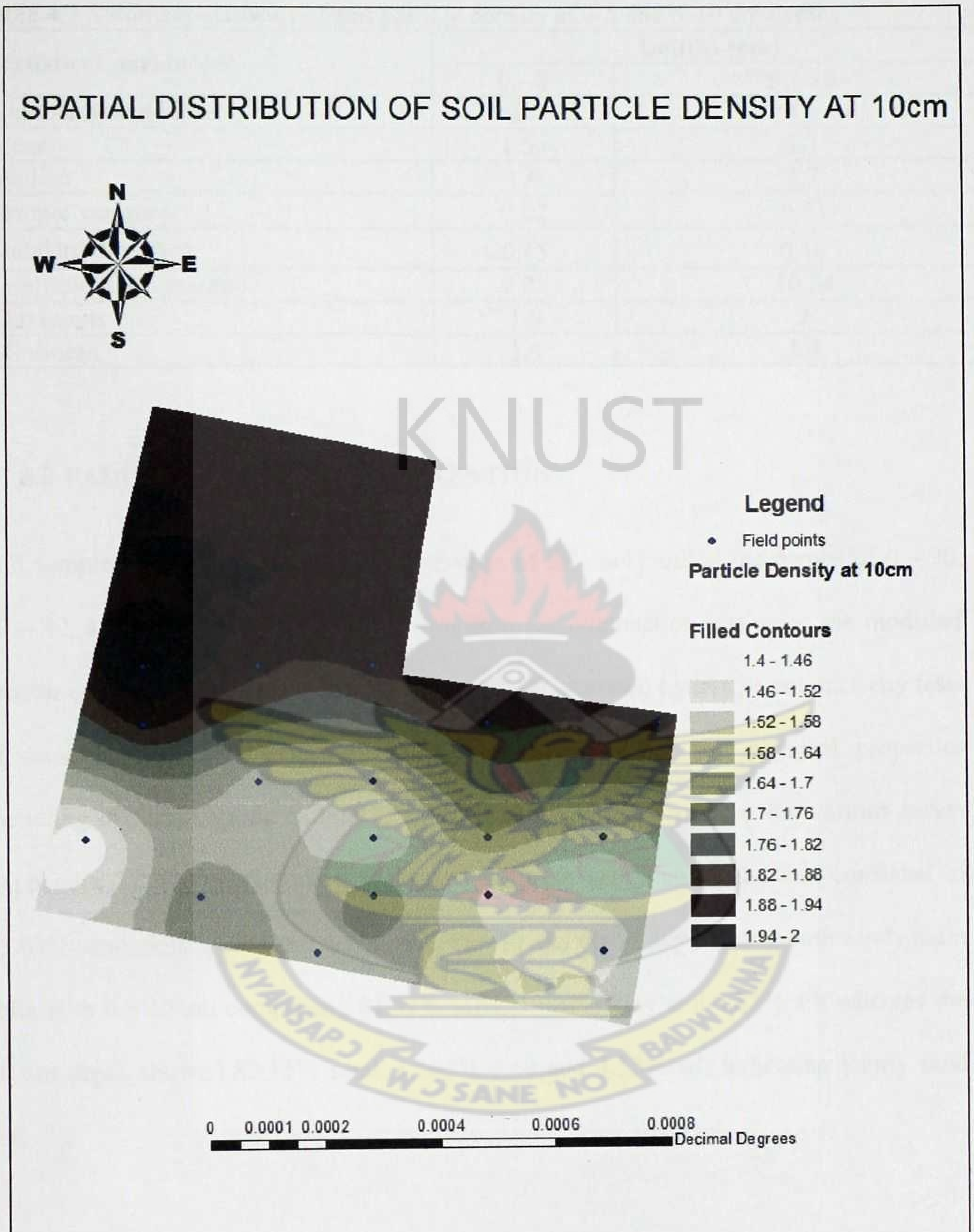


Figure 4.6 Spatial distributions of soil particle densities at 5-10 cm depth

Table 4.3 Summary statistics of soil particle density at 0-5 and 5-10 cm depths

Statistical parameter	**Depths (cm)**	
	0 - 5	**5 – 10**
Number of samples	18	18
Mean	1.65	1.7
Median	1.6	1.7
Sample variance	0.02	0.03
Standard deviation	0.15	0.18
Coefficient of variation	9.25	10.84
Maximum	1.9	2
Minimum	1.4	1.4

4.3 PADDY SOILS CHARACTERIZATION

Soil sampled from the four representative sites of the study site at the depths of 0 – 20, 20 – 40, and 40 – 60 cm were used to perform the compaction test using the modified proctor compaction test as per AASHTO standard, saturated hydraulic conductivity tests of remoulded samples and also for the determination of soil physical properties including texture, organic carbon, organic matter and soil texture at the various layers (Appendix 7). The results show that the top 20 cm was loamy sand and consisted of 83.63% sand, 8.26% clay and 8.11% silt. The 40 and 60 cm layers were both sandy loam soils with the 40 cm comprising 81.97% sand, 13.22% clay and 4.82% silt whereas the 60 cm depth showed 82.15% sand, 15.82% clay and 3.33% silt indicating loamy sand soil.

4.3.1 PERCENTAGE OF SAND AT 0 – 20, 20 – 40, AND 40 – 60 CM DEPTH

Table 4.4 is the summary statistics of percent sand and lies within 82.5% (minimum) to 84.76% (maximum), 79.34% (minimum) to 84.76% (maximum) and 77.36% (minimum) to 83.3% (maximum) for 0-20 cm, 20 – 40 cm and 40-60 cm depths respectively. The mean values are also 83.63%, 82.06% and 80.33% for 0-20 cm, 20-40 cm and 40-60 cm respectively. The median values are 83.63%, 82.77% and 81.38% for 0-20 cm, 20-40 cm and 40-60 cm respectively. The standard deviation which is indicative of the closeness of values to the means is 0.96, 6.67 and 6.76. The coefficient of variation shows how far the values are from the mean is 1.15, 3.15 and 3.24. The values in charts 4.1, 4.2 and 4.3 are indication of the quantity of sand found within the 0 - 20, 20 – 40 and 40 - 60 cm layers in terms of percentage ranging from 82.5% to 84.76%, 79.34% to 84.76% and 77.36% to 83.3%.

Table 4.4 Summary of statistics for sand percentage at 20, 40 and 60 cm

Statistical parameter	Depths (cm)		
	0 - 20	**20 - 40**	**40 - 60**
Number of samples	3	3	3
Mean	83.63	82.05	80.33
Median	83.63	82.77	81.38
Sample variance	0.92	6.67	6.76
Standard deviation	0.96	2.58	2.6
Coefficient of variation	1.15	3.15	3.24
Maximum	84.76	84.76	83.3
Minimum	82.5	79.34	77.36

Figure 4.7, 4.8 and 4.9 showing the distribution of sand at the 0-20 cm, 20-40 cm and 40-60 cm depths and sampling points WP 18, WP 19, WP 21 and WP 22.

Figure 4.7 percentage of sand at 20 cm

Figure 4.8 percentage of sand at 40 cm

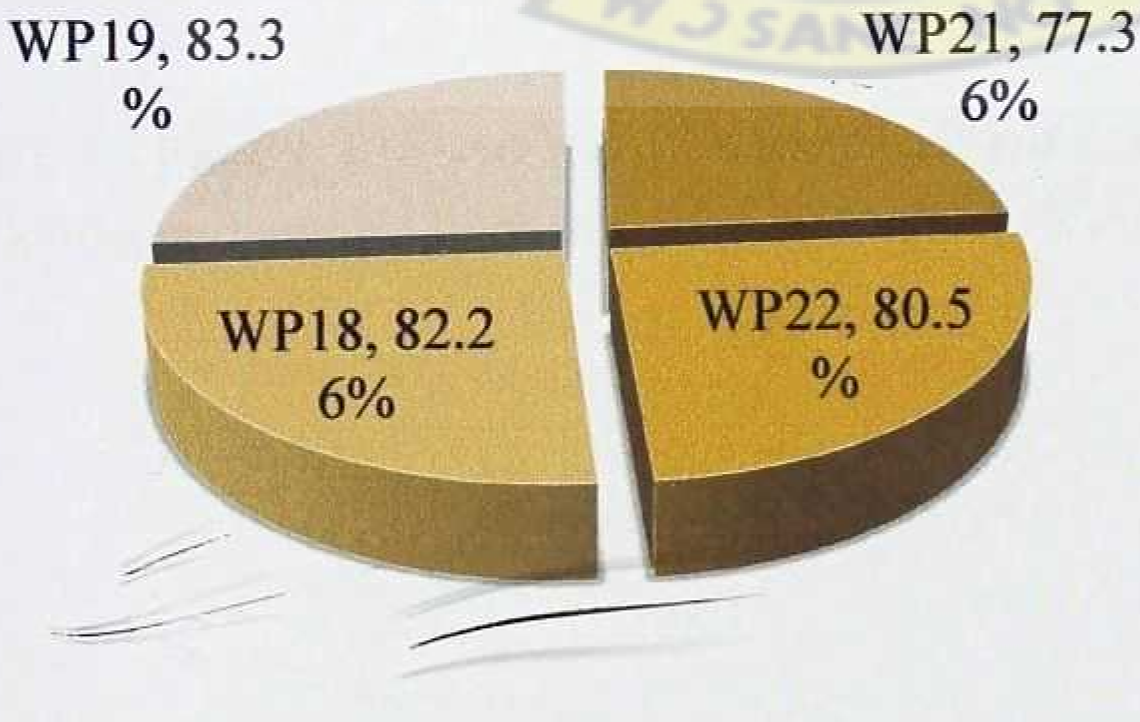


Figure 4.9 percentage of sand at 60 cm

4.3.2 PERCENTAGE OF SILT AT 0 – 20, 20 – 40, 40 - 60 CM DEPTH

The percentage of silt obtained from the field at 0 – 20, 20 – 40 and 40 – 60 cm depth lies within 5.88% to 1.46%, 2.48% to 7.98% and 1.42% to 5.36% inclusive of the mean values of 8.17%, 5.23% and 3.39% (Table 4.5). The median values from the statistical table are 8.05, 4.4 and 3.26. The standard deviations which are indicative of the closeness of values to the means are 1.96, 2.43 and 1.76. The coefficient of variation shows how far the values are from the mean, and the values are 23.98%, 46.49% and 52.01%. The values in charts 4.4, 4.5 and 4.6 are indication of the quantity of silt found within the 0 - 20, 20 – 40 and 40 - 60 cm layers in terms of percentage ranging from 5.88% to 1.46%, 2.48% to 7.98% and 1.42% to 5.36%.

Table 4.5 Summary of statistics for silt percentage at 0-20, 20-40 and 40-60 cm

Statistical parameter	0-20 cm	20-40 cm	40-60 cm
Number of samples	3	3	3
Mean	8.17	5.23	3.39
Median	8.05	4.4	3.26
Sample variance	3.84	5.91	3.11
Standard deviation	1.96	2.43	1.76
Coefficient of variation	23.98	46.49	52.01
Maximum	10.46	7.98	7.36
Minimum	5.88	2.48	5.36

Figures 4.10, 4.11 and 4.12 show the distribution of silt at the 0-20 cm, 20-40 cm and 40-60 cm depths and sampling points WP 18, WP 19, WP 21 and WP 22.

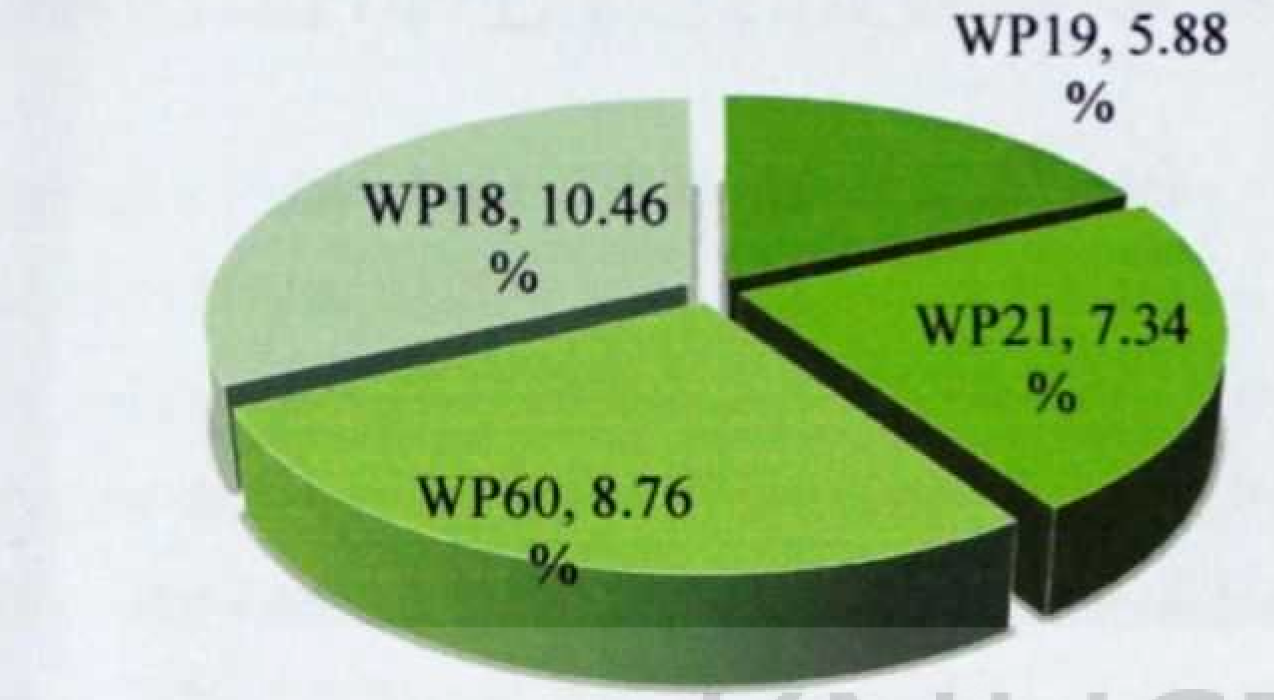


Figure 4.10 percentage of silt at 20 cm

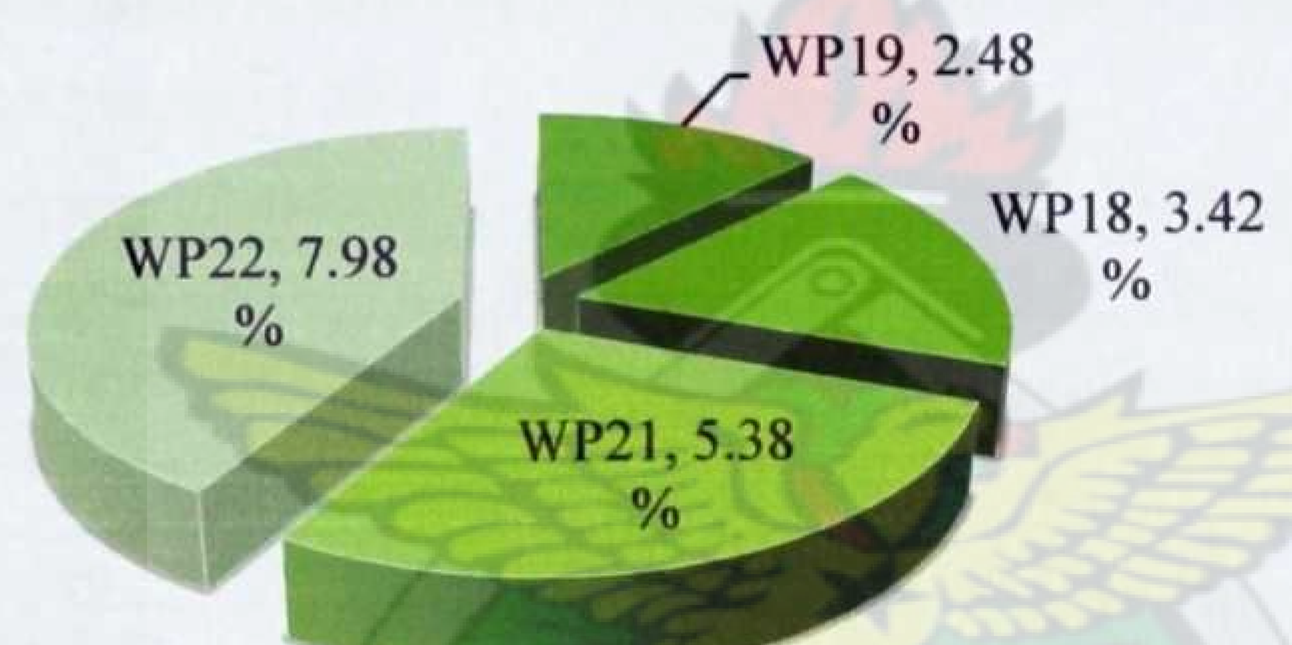


Figure 4.11 percentage of silt at 40 cm

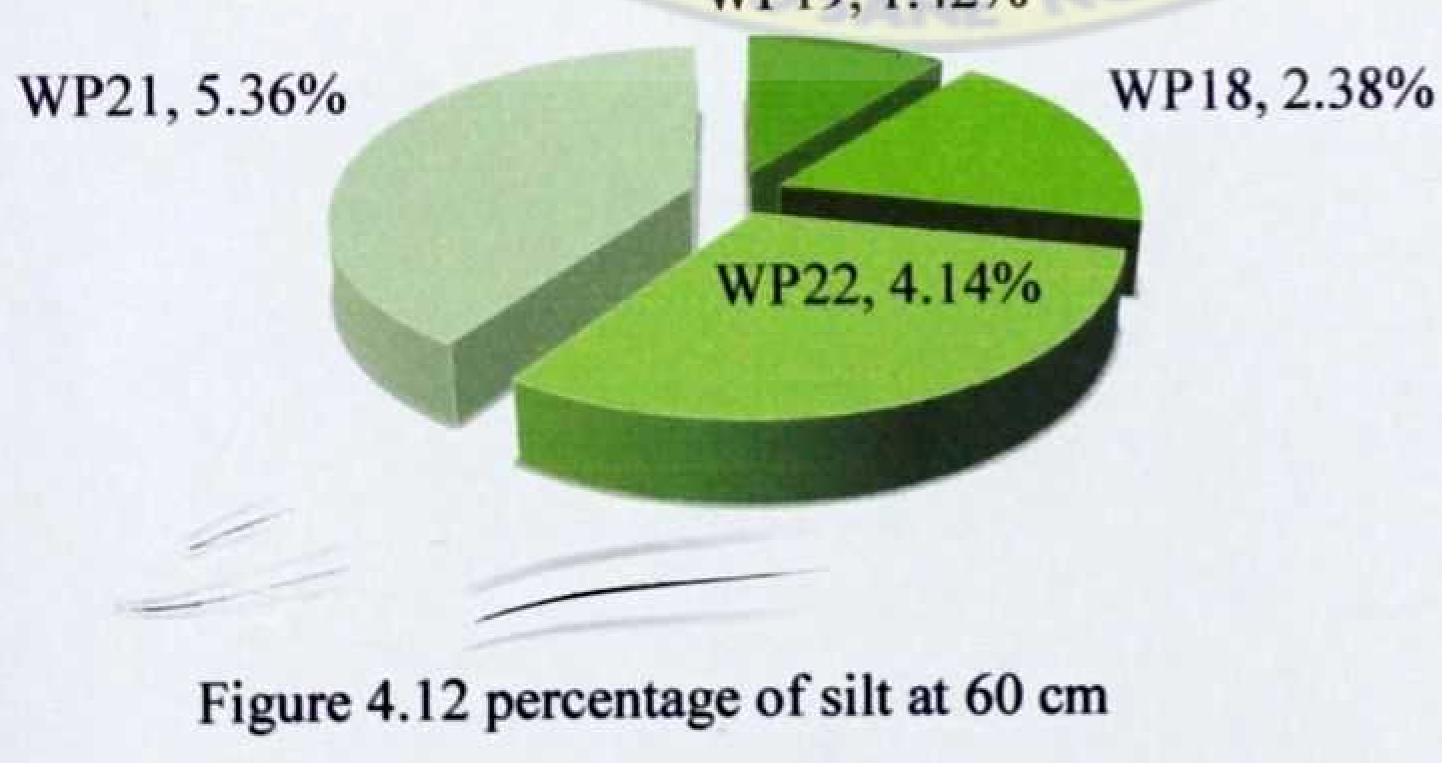


Figure 4.12 percentage of silt at 60 cm

4.3.3 PERCENTAGE OF CLAY AT 0 – 20, 20 – 40, 40 - 60 CM DEPTH

The percentage of clay obtained from the field lies within 7.04% to 9.36%, 9.04% to 15.36% and 15.28% to 17.28% at 0 – 20, 20 – 40 and 40 – 60 cm depth respectively. The mean values are 8.2%, 12.2% and 16.28% for 0-20 cm, 20-40 cm and 40-60 cm respectively as shown on Table 4.6. The median values are 8.32%, 14.24% and 15.36% respectively. The standard deviation which is indicative of the closeness of values to the means are 1.27%, 2.96% and 0.97%. The coefficient of variation shows how far the values are from the mean and the values are 1.62, 8.77 and 0.95. The values in charts 4.7, 4.8 and 4.9 are indication of the quantity of clay found within the 0 - 20, 20 – 40 and 40 - 60 cm layers in terms of percentage ranging from 7.04% to 9.36%, 9.04% to 15.36% and 15.28% to 17.28%.

Table 4.6 Summary of statistics of clay percentage at 0-20, 20-40 and 40-60 cm depths

Statistical parameter	0-20 cm	20-40 cm	40-60 cm
Number of samples	3	3	3
Mean	8.2	12.2	16.28
Median	8.32	14.24	15.36
Sample variance	1.62	8.77	0.95
Standard deviation	1.27	2.96	0.97
Coefficient of variation	15.54	24.27	5.98
Maximum	9.36	15.36	17.28
Minimum	7.04	9.04	15.28

Figures 4.13, 4.14 and 4.15 show the distribution of silt at the 0-20 cm, 20-40 cm and 40-60 cm depths and sampling points WP 18, WP 19, WP 21 and WP 22.

Figure 4.13 percentage of clay at 20 cm

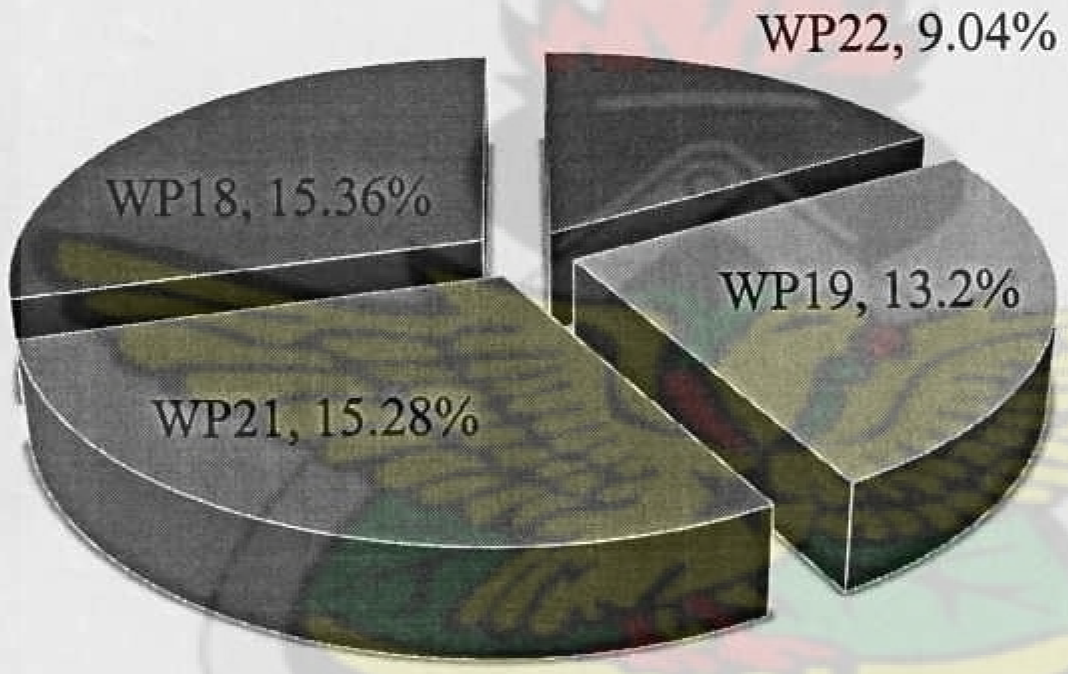


Figure 4.14 percentage of clay at 40 cm

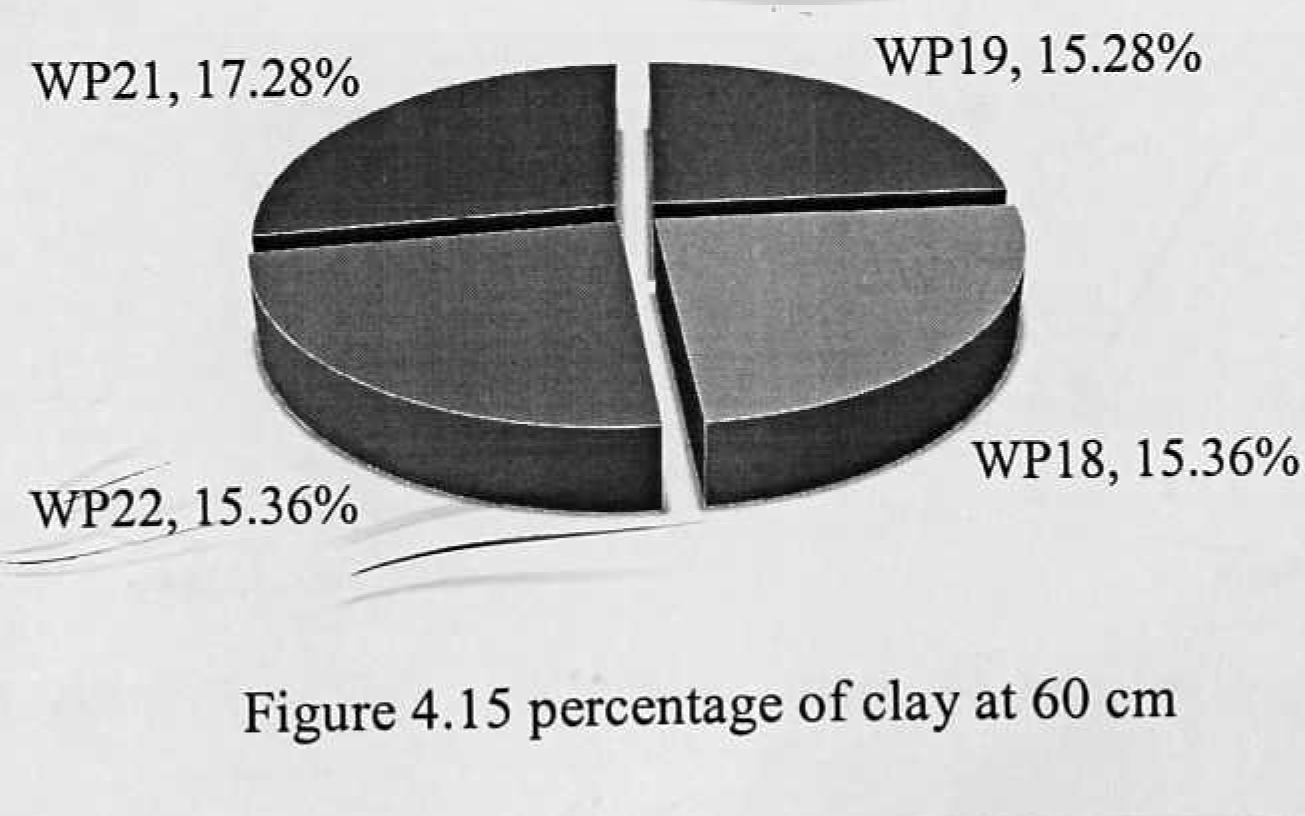


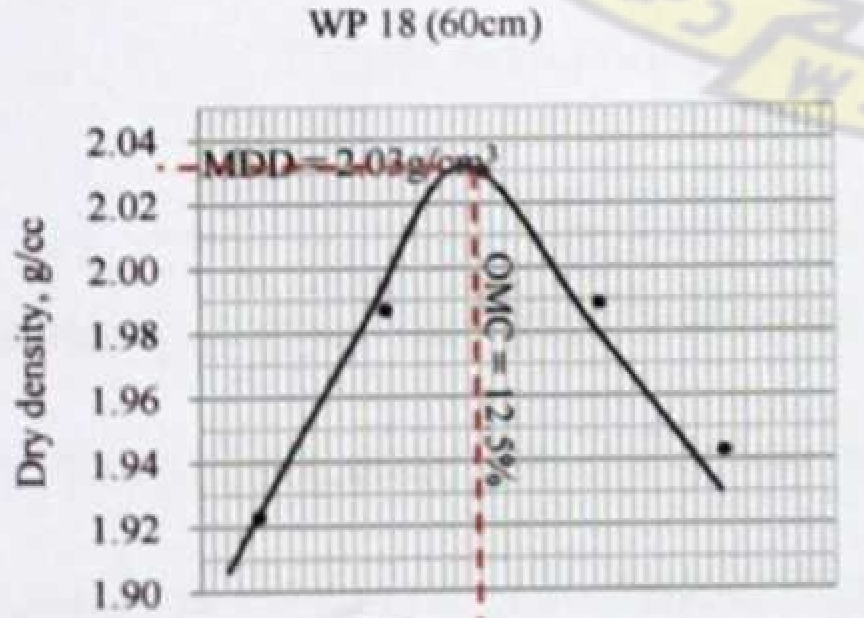
Figure 4.15 percentage of clay at 60 cm

4.4 MODIFIED PROCTOR'S COMPACTION TEST

Compaction test was performed to determine the compaction characteristics of representative site soil. The optimum moisture content and the maximum dry bulk density of the soil at depths 0-20 cm 20-40 cm and 40-60 cm were determined and are shown in Table 4.7.

Table 4.7 Summary of modified Proctor's compaction test results at 0-20, 20-40 and 40-60 cm depths and at four representative site soils.

Depth (cm)	WP 22		WP 21		WP 19		WP 18	
	OMC %	MDD gm/cm³	OMC %	MDD gm/cm³	OMC %	MDD gm/cm³	OMC %	MDD gm/cm³
0 - 20	13.0	1.912	15.5	1.836	13.5	1.86	14.5	1.846
20 - 40	13.0	1.936	13.8	1.910	12.5	1.96	12.5	1.922
40 - 60	13.2	1.916	12.6	1.94	12.96	1.96	12.5	2.03



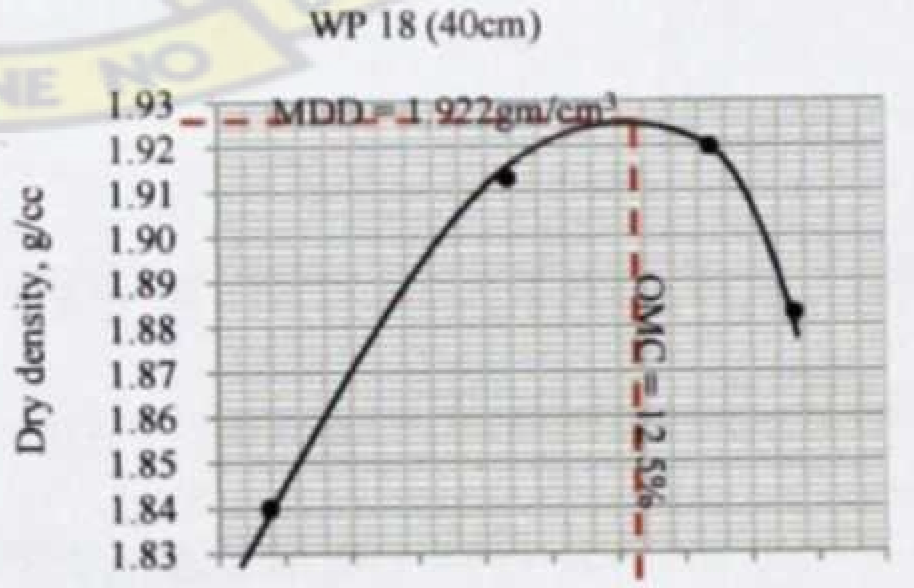


Figure 4.16 and 4.17 typical compaction curves (Appendix 1 soil layers compaction curves)

During bund formation or construction there are three options open to the farmer or the construction engineer as to the type of soil to use. The Proctor's maximum dry density for the 0-20 cm, 20-40 cm or 40-60 cm layer could be used as the benchmark for the degree of compaction.

4.4.1 WATER LOSSES THROUGH THE PADDY FIELDS

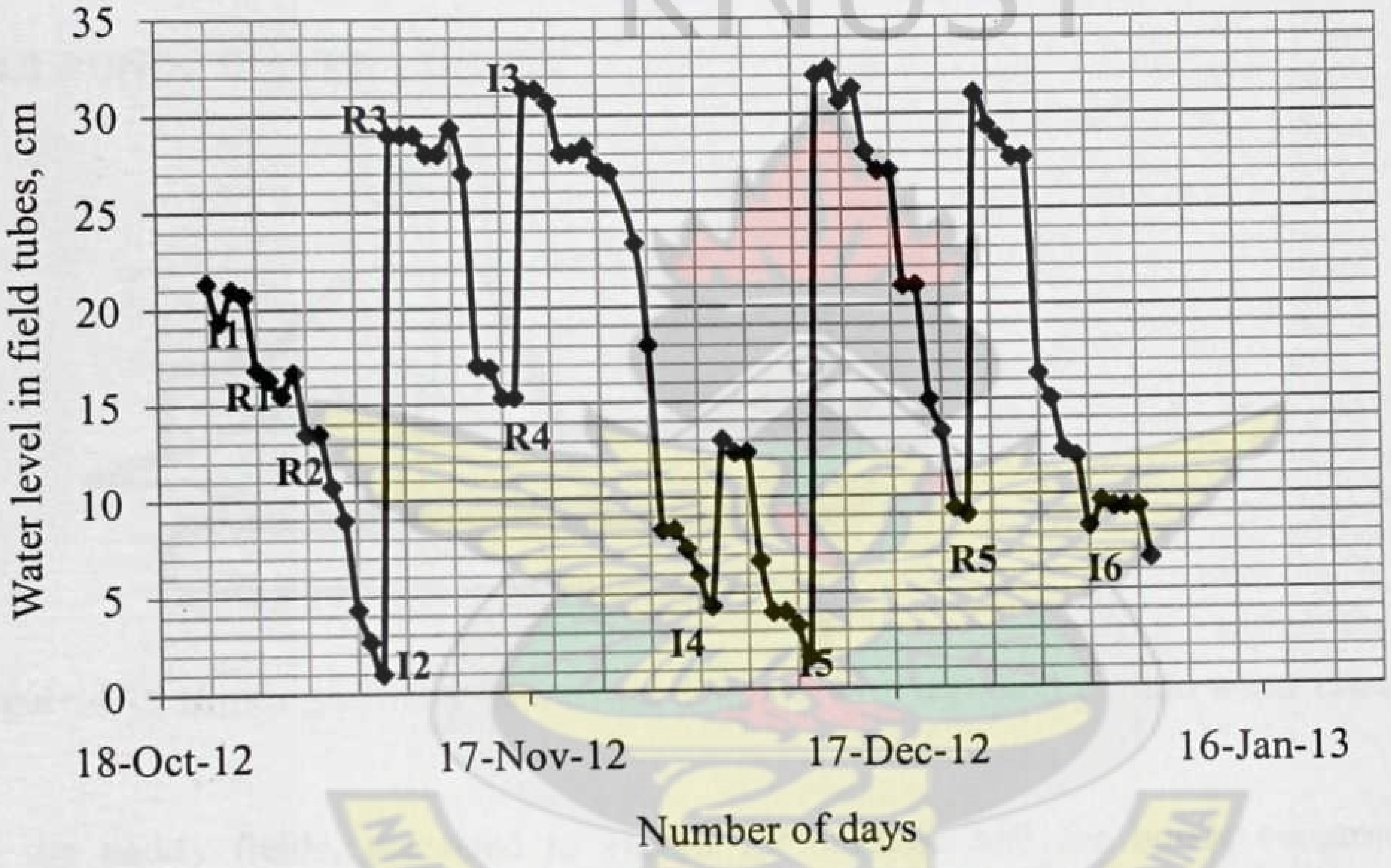


Figure 4.18 paddy field water use of plot 1

The rising arm of the graph indicates either irrigation water (I) application or rainfall (R). The falling arms are indication of water loss or leakage from the paddy field by means of seepage and percolation. The end of the graph shows field drained during the ripening stage and harvesting.

4.4.2 HYDRAULIC CONDUCTIVITY OF BUNDS

Hydraulic conductivity of soil refers to the ease with which water can flow through a soil profile. This property is necessary for the calculation of seepage flow through earth dams, canals, bunds or under sheet pile walls, the calculation of the seepage rate from paddy fields, waste storage facilities (landfills, ponds, etc.), and the calculation of the rate of settlement of clayey or fine grain soil deposits.

4.4.3 BUNDS WATER LOSSES

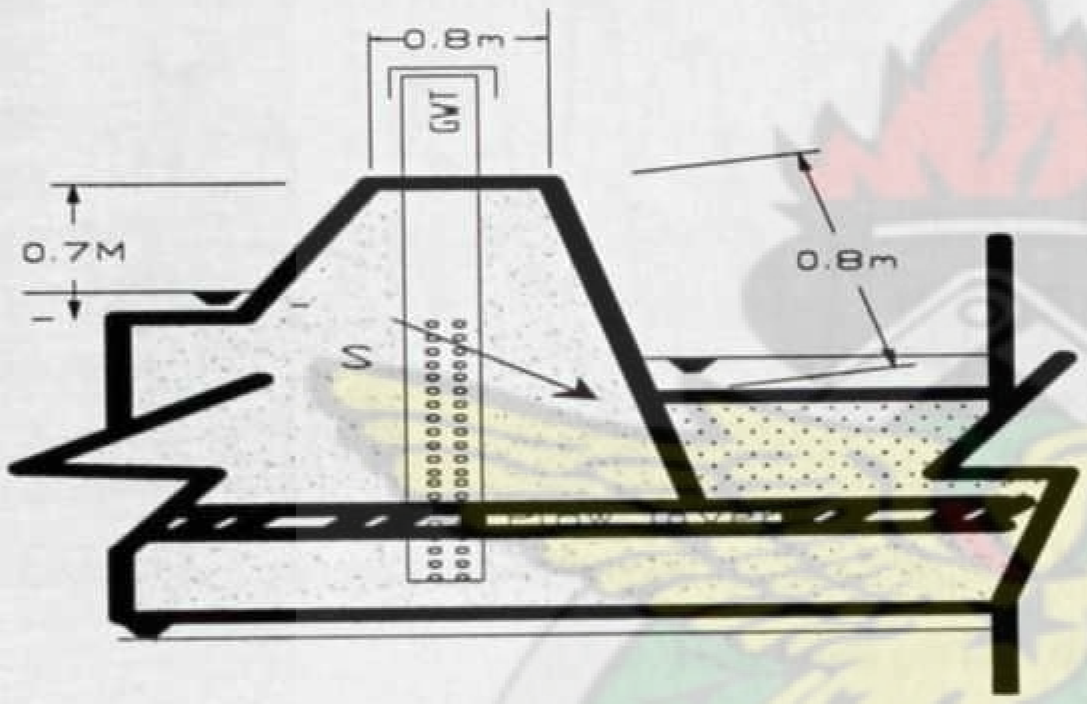


Figure 4.19 Bunds geometry Schematic diagram with installed ground water tube

In the paddy fields, the need to search for suitable soil for bunds construction is important. Bunds serve as mini water retaining structures or barriers. Changes or deterioration in bund structure allows for increased seepage losses. Water also flows from the sub-layers of the bunds by capillary action depending on the water level in the paddy field and the height of the bunds. Very low bund heights results in increased capillary action and increased saturation of the bund top layers. High ponding depths in paddy fields also contribute to increased capillary rise in the bunds and hence losses by evaporation from the bund surface. Water losses through the bunds depend on the following:

a. Bund structure which herein refers to the level of compaction during formation or construction

b. deterioration due to cracks or burrows formed by rodents or crabs

c. deterioration due to age or long term use which may affect the physical condition of the soil

Figure 4.20 is a graphical representation of a typical ground water tube was similar to that of the field water tubes as consideration was given to the rising and falling arms of the graphs. The codes R1 to R5 were indications of the days of rainfall in the field which the graphs depicted whereas *I*1 to *I*6 indicated irrigation days.

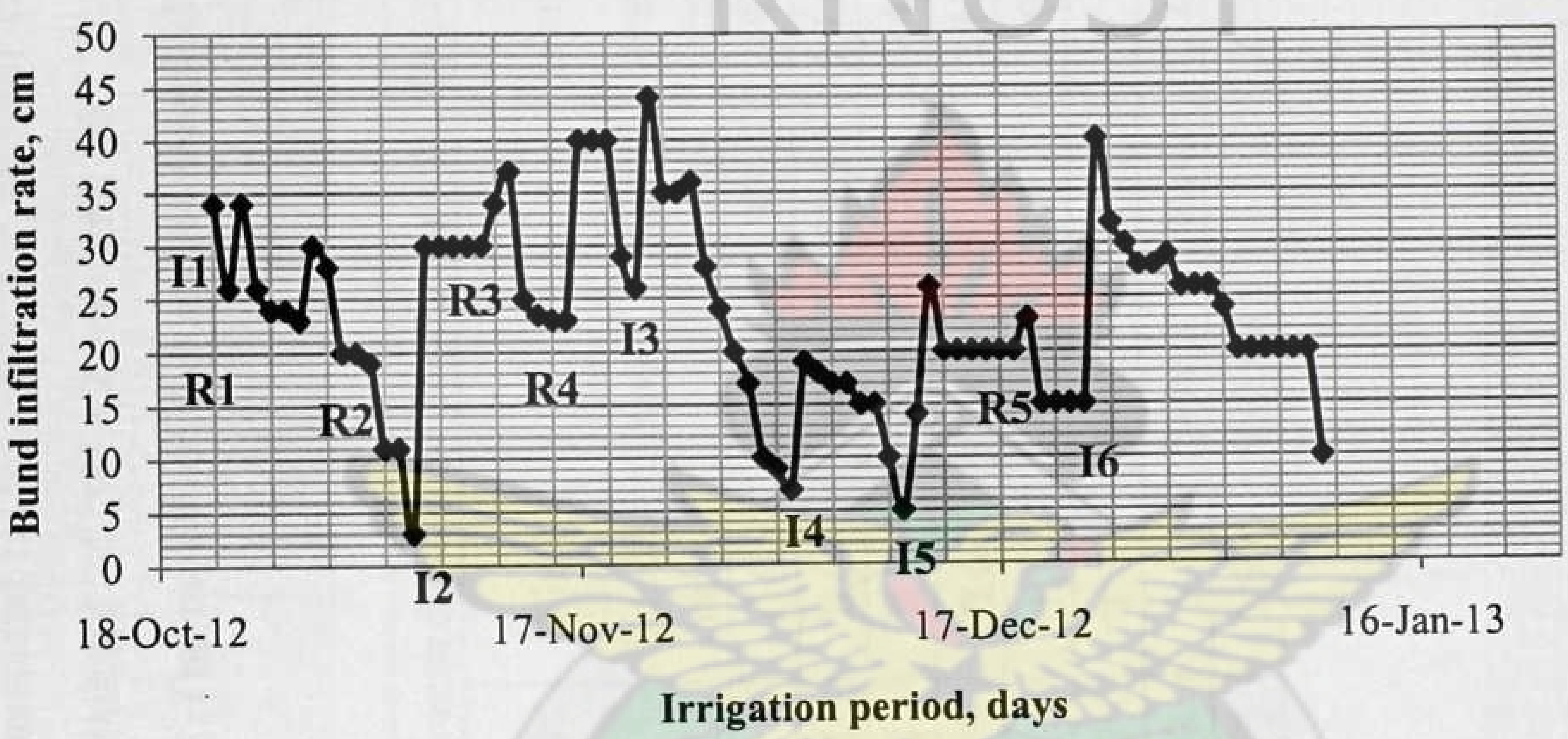


Figure 4.20 Typical ground water tube water use (Appendix 3 ground-water tubes)

4.5 WATER BALANCE METEOROLOGICAL COMPONENTS

The evapotranspiration (ET) and the rainfall data were measured by the automatic weather station at the experimental site. During the growing season, the weather station recorded the total rainfall of 241.42 mm and 269.12 mm ET starting September 26, 2012 to February 9, 2013 as shown in Table 4.8 and Figure 4.21. The month of November recorded the highest rate of rainfall proceeded by October during the growing season.

Table 4.8 Monthly climatological summaries

Summary of climatological data recorded from September 26, 2012- February 9, 2013													
Month	Temp Out °C	Max. Temp °C	Mini. Temp °C	Out Hum %	Dew Pt. °C	Wind Speed m/s	Bar hPa	Rain mm	Rain Rate mm	Solar Rad. W/m^2	Solar Energ y Ly	Max. Solar Rad. W/m^2	ET mm
12-Sep	24.8	25.2	24.5	89.8	23	0.9	992.3	30	35.6	286.6	27.7	537.7	11.09
12-Oct	25.2	25.7	24.8	88.2	23.2	0.9	988.3	59.2	29.93	352.6	30.3	578.2	91.11
12-Nov	25.7	26.2	25.1	87.3	23.4	0.8	987.4	93.38	44.9	389.3	33.5	595.2	46.8
12-Dec	25	25.5	24.5	87.6	22.7	0.6	989.9	57.64	20.38	313.4	27	428.2	38.4
13-Jan	23.2	24	22.4	73.2	18.1	1.1	949	0	0	283.9	24.4	337.5	79.69
13-Feb	25.1	26	24.2	73.7	18.9	1.1	989.2	1.2	1.7	308.6	26.5	367.9	2.03
Summation	149	152.6	145.5	499.8	129.3	5.4	5896.1	**241.42**	132.51	1934.4	169.4	2844.7	**269.12**
Average	24.83	25.43	24.25	83.30	21.55	0.90	982.68		22.09	322.40	28.23	474.12	

4.5.1 WATER BALANCE CALCULATIONS

The modified water balance equation $d_w = (R + I) - (ET + SP)$ derived from Chen-Wuing Lieu *et al.* (2003), was used to calculate the change in ponded water depth or water storage in the soil profile of the paddy field. Averaged results from the field and ground water tubes are shown in Tables 4.9 and 4.10 and were used to determine the seepage and percolation losses from both the fields and the bunds. The ground and field water tubes water use values were averaged (Table 4.11) to represent the inflow (irrigation) and outflow (water loss/seepage and percolation) values.

The negative values of the devices represented the loss by means of seepage and percolations where as the positive values were water gain either by irrigation or rainfall. The recorded rainfall from the weather station was subtracted from the water gain value of the devices giving a precise quantity of irrigation done during the growing season as calculated below.

Table 4.9 Average Field-water tubes values

Field-water tubes								
F.W.T No.:	Inflow (cm)	Outflow (cm)	Total Rainfall & Irrigation (mm)	Total outflow/SP (mm)	I (mm)	R (mm)	ET (mm)	d_w (mm)
1	138	111						
2	131	102						
3	88	86						
4	134	122	6,170	5,210	5,929	241.4	269.1	690.9
5	126	100						
Sum (cm)	617	521						

The total inflow/irrigation and rainfall (water gained) for the five sub plots during the growing season was 6,170 mm and the outflow/water loss (seepage and percolation) 5,210 mm through the field-water tubes.

Table 4.10 Ground-water tubes values

Ground-water tubes								
G.W.T No.:	Inflow (cm)	Outflow (cm)	Total Inflow (mm)	Total outflow/ SP (mm)	I (mm)	R (mm)	ET (mm)	d_w (mm)
1	181	135	10,810	9,060	10,568.6	241.42	269.12	1,480.9
2	177	155						
3	323	278						
4	163	131						
5	237	207						
Total (cm)	1081	906						
The total inflow/irrigation and rainfall (water gained) from the five bunds during the growing season was 10,810 mm and the outflow/water loss (seepage and percolation) 9,060 mm through the ground-water tubes.								

Table 4.11 Summary of Field and ground-water tubes

Summary of Field and Ground water tubes								
Averaged G.W.T. and F.W.T.	Inflow (cm)	Outflow (cm)	Total Inflow (mm)	Total outflow/SP (mm)	I (mm)	R (mm)	ET (mm)	dw (mm)
1	319	246	16,980	14,270	16,738.58	241.42	269.12	2440.88
2	308	257						
3	411	364						
4	297	253						
5	363	307						
Total (cm)	1,698	1,427						
The total inflow/irrigation and rainfall (water gained) for the five sub plots and bunds during the growing season was 16,980 mm and the outflow/water loss (seepage and percolation) 14,270 mm through the field and ground-water tubes as seen in the calculations.								

The change in soil water can then be calculated using summary results of field and ground water tubes (Table 4.10). The water loss (seepage and percolation) value is represented by outflow whereas the water gained (irrigation and rainfall) is represented by the inflow value. The total irrigation (I) during the growing season was determined by subtracting the total rainfall during the growing season from the total inflow value.

$$d_w = (R + I) - (ET + SP)$$

Using R = 241.42 mm, ET = 269.12 mm, I = 16,738.58 mm and SP = 14,270 mm

$$d_w = (241.42 + 16{,}738.58) - (269.12 + 14{,}270)$$

$$d_w = 16{,}980 - 14{,}539.12$$

$$d_w = 2440.88 mm$$

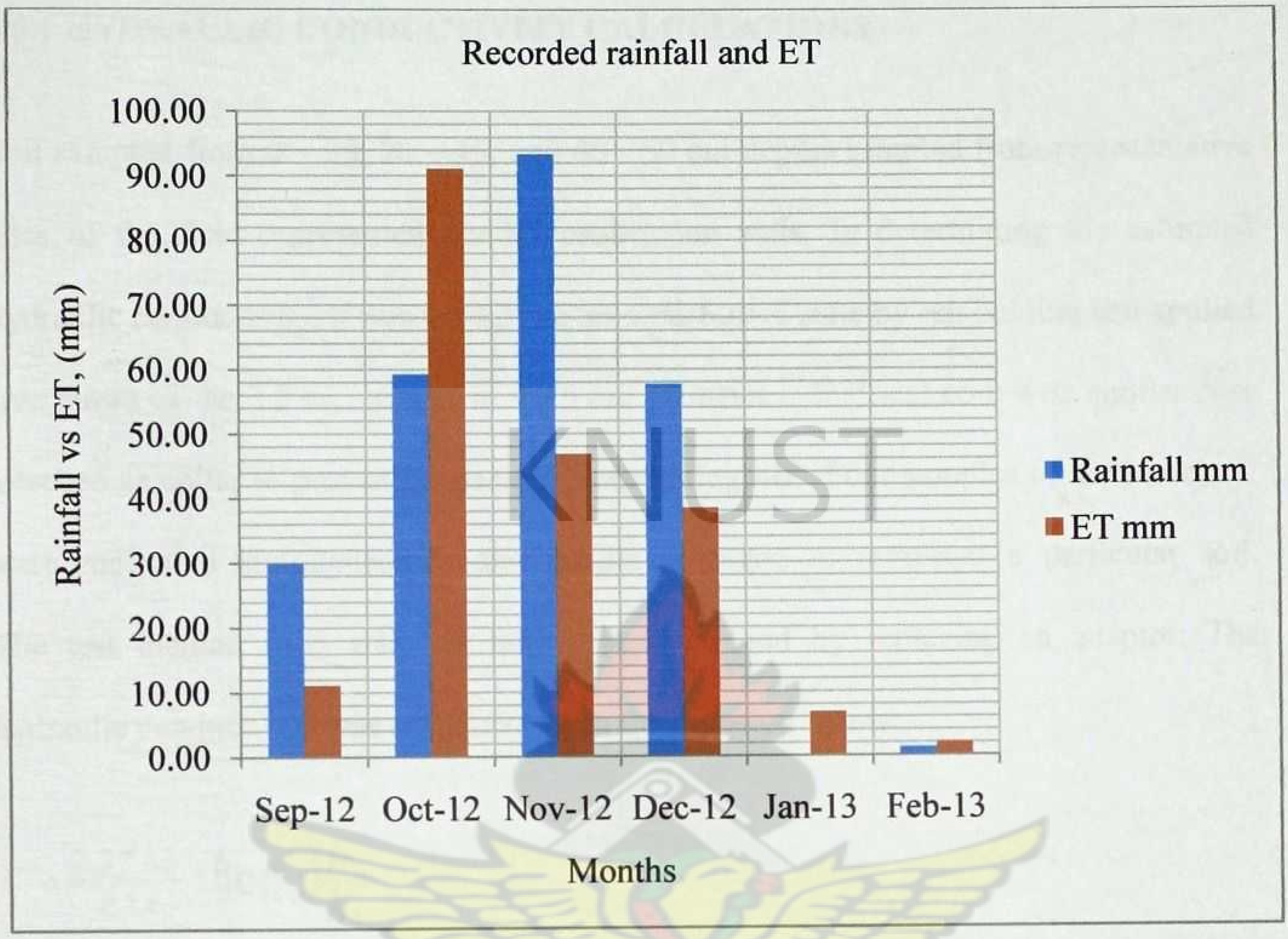


Figure 4.21 Rainfall and ET for the growing season

4.6 BUNDS AND PADDY FIELD HYDRAULIC CONDUCTIVITY MODELS

The four-fold type permeameter was used to determine saturated hydraulic conductivity (Ks) of the soils. Ks determination was done in three folds: Paddy field soils sampled at 0 – 5 and 5 – 10 cm, and bund soils sampled at 0 – 9, and 9 – 18 cm. Bunds construction soils sampled from 0 – 20, 20 – 40, and 40 – 60 cm depth from four selected points. An augur with 18 cm length having a protective cage housing the cylindrical core was used in sampling undisturbed soils from the bunds and the paddy field.

4.6.1 HYDRAULIC CONDUCTIVITY CALCULATIONS

Soil sampled from 0 – 20, 20 – 40, and 40 - 60 cm depths sampled from representative sites of the field represented bunds construction soils. In determining the saturated hydraulic conductivity, it was brought to an undisturbed state by remoulding and applied five blows of the 2.5 kg rammer in the 5 cm diameter cylindrical core with similar core attached as collar to protect the sample from falling off. Four samples of the same soil were measured simultaneously and results averaged to represent a particular soil. The test method used was the falling head method by replacing an adaptor. The hydraulic conductivity was calculated from the equation below:

$$K = \frac{2.3 * aL}{A * t} * (\log_{10}) \frac{h_1}{h_2}$$

K = Coefficient of permeability

a = Cross-sectional area of the standpipe in square centimeters

L = Average height of the soil sample in centimeters

A = Cross-sectional area of the soil sample in square centimeters

t = Elapsed time in seconds

h_1 = Height of water at the beginning of time increment in centimeters

h_2 = Height of water at the end of time increment in centimeters

Considering soil depth 0 - 20 cm of the bund soil and a = 0.503cm^2, L = 5.1cm, A = 19.6cm^2, t = 74.9sec., h_1 = 14.9cm and h_2 = 8cm

$$K = \frac{2.3 * 0.503 * 5.1}{19.6 * 74.9} * (\log_{10})\frac{14.9}{8}$$

$$K = 1.1x10^{-3} cms^{-1}$$

According to Singh *et al.*, (2011) and Koomson (2013), an empirical relationship for the general form of the model is given as:

$$K_s = A \times \rho_{db}^{B}$$

The equation establishes the relationship between bulk density and hydraulic conductivity. As bulk density increases, hydraulic conductivity decreases but at higher bulk density the rate of seepage degreased with hydraulic conductivity.

A and B are the model parameters which can be obtained by experimental results of measured hydraulic conductivity and dry bulk density. Using results from Appendix 8, the relationship between hydraulic conductivity, maximum dry bulk density and dry bulk density can be expressed using the linear function equations $y = -30.4X + 65.512$, $R^2 = 0.2801$ and $y = -2.4023X + 10.508$, $R^2 = 0.0021$.

Table 4.12 contains the input data used for validation and running of the hydraulic conductivity model of paddy field soil. Considering the linear function model (Figures 4.15 and 4.16), the rate at which Ks occurred depended on the soil bulk density.

Table 4.12 Field measured dry bulk density and Ks

MDD and Ks values		Bulk density and Ks values	
1.846	7	1.31	7
1.922	6	1.42	6
2.03	5	1.42	5
1.86	11	1.3	11
1.96	7	1.42	7
1.96	7	1.41	7
1.836	14	1.36	14
1.91	7	1.37	7
1.94	7	1.41	7
1.912	1.1	1.3	1.1
1.936	8	1.48	8
1.916	6	1.45	6

MDD and bulk density (g/cm^3) and Ks (cm/s

Figure 4.22 correlations between dry bulk density and saturated Ks

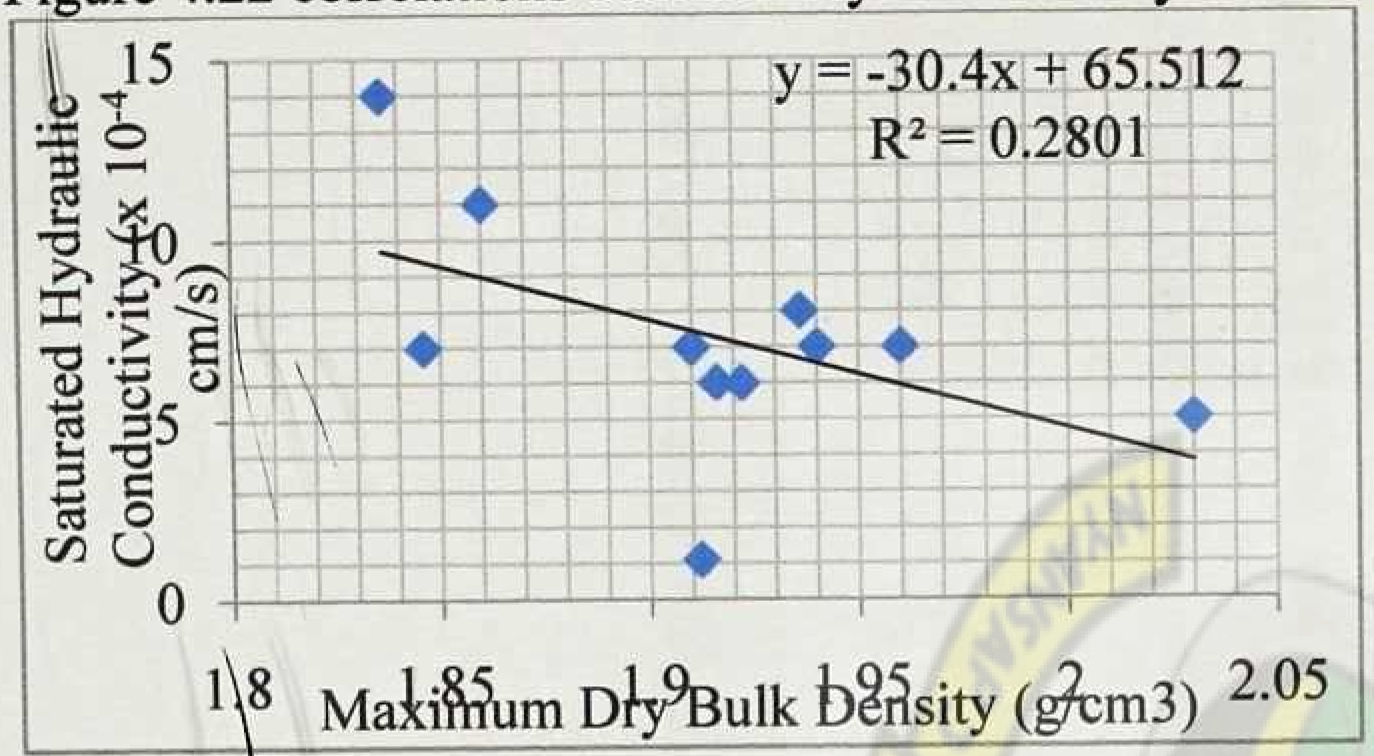
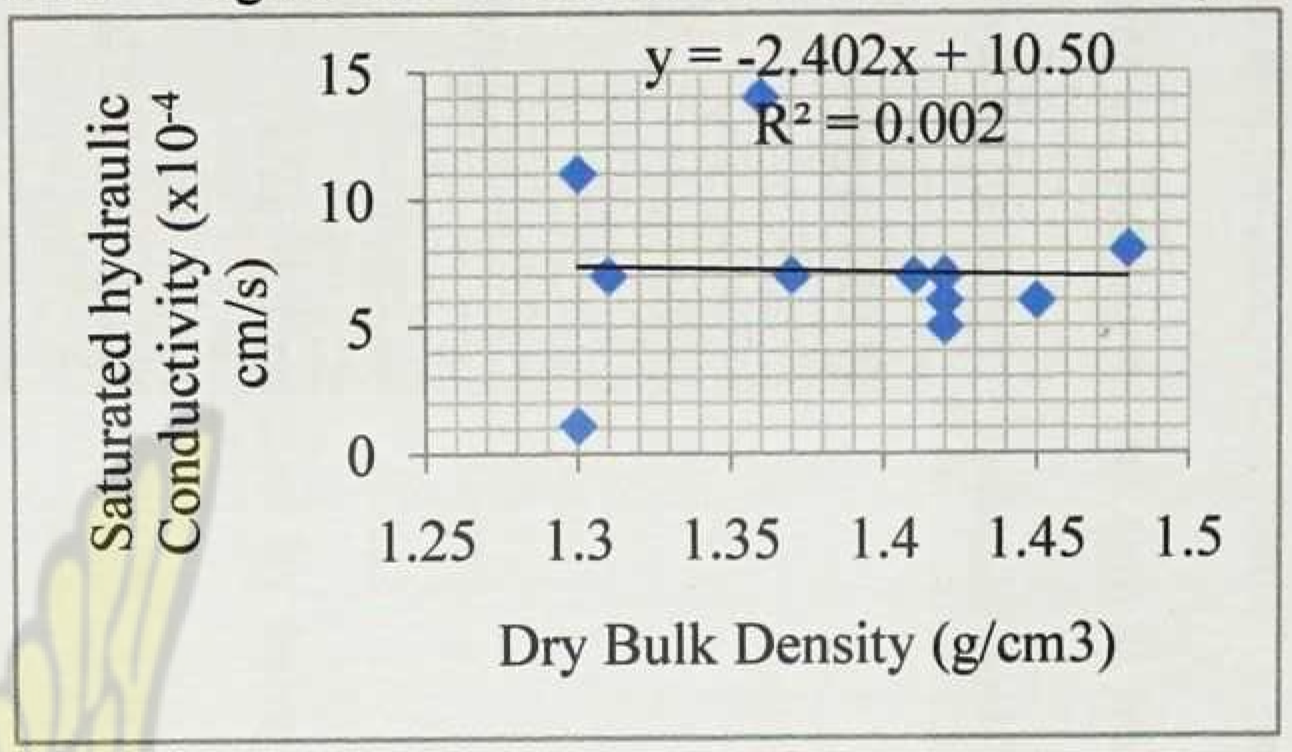
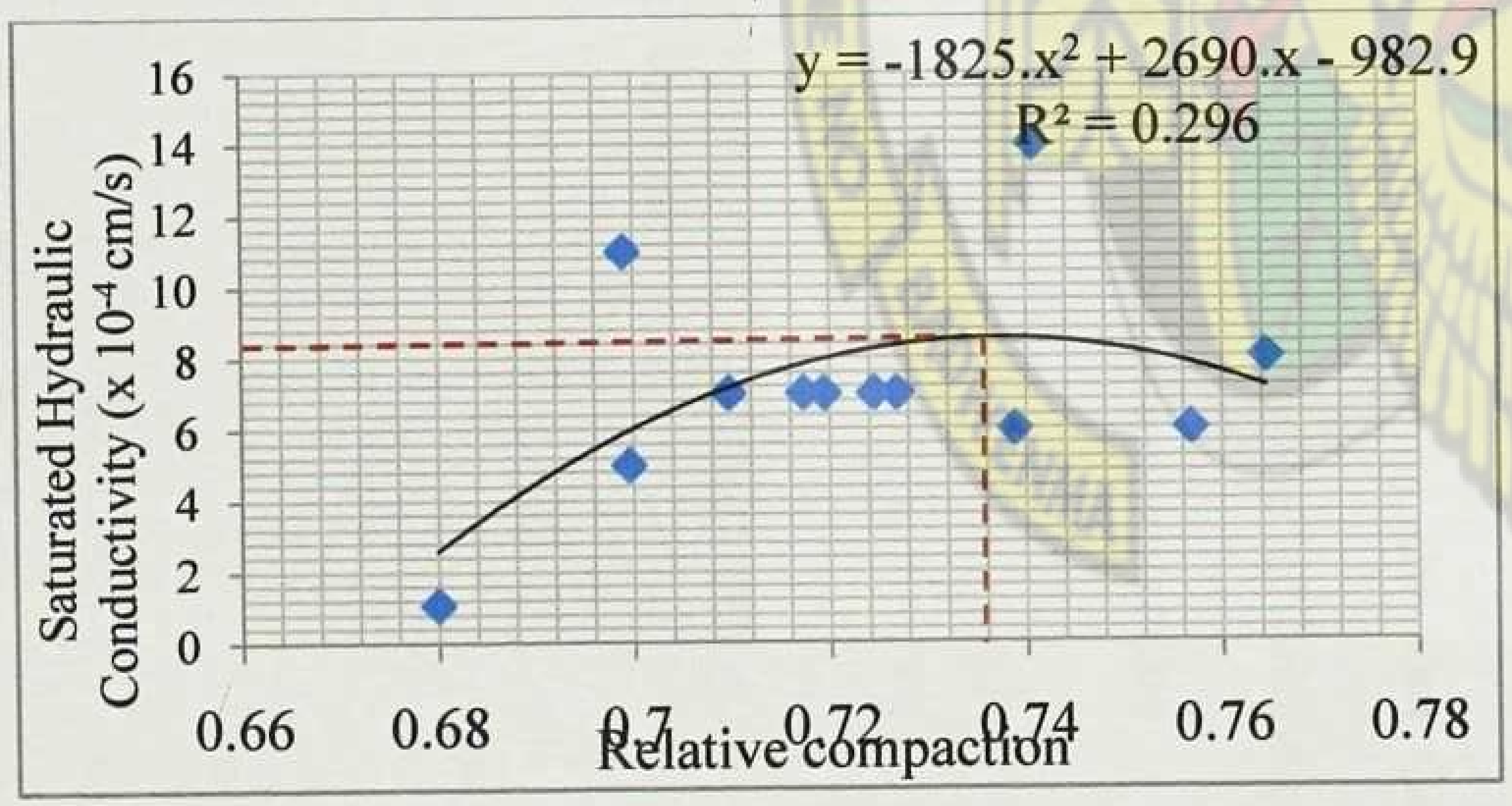


Figure 4.23 correlations between in-situ dry bulk density and Ks



For figures 4.22 and 4.23, are shown as expected that the saturated hydraulic conductivities decrease with increasing dry densities even though the correlation is stronger in the case of the maximum dry density. Figure 4.24 depicts the relative compaction considering the saturated hydraulic conductivity at its optimum compaction.



4.6.2 IN-SITU HYDRAULIC CONDUCTIVITY TEST USING THE MINI-DISK INFILTROMETER

Five points of the paddy field were selected before land preparation and conducted the in-situ hydraulic conductivity using the mini-disc infiltrometer. The purpose of this test was to determine the rate at which water seeps through the surface layer of the paddy soil in its natural states. The hydraulic conductivity was calculated from the equation (Decagon, 2011).

$$K = \frac{C_1}{A}$$

Where:

C_1 Was determined by using Excel spread sheet to form a quadratic equation and taking the gradient as C_1 ; it is the slope of the curve of the cumulative infiltration versus the square root of the time, and A is a value relating the van Genuchten parameters for a given soil type to the suction rate and radius of the infiltrometer disk as shown in Appendix 6. A can also be computed from the following equations:

$$A = \frac{11.65(n^{0.1} - 1)\exp[2.92(n - 1.9)\alpha h_0]}{(\alpha r_0)^{0.91}} \quad n < 1.9 \text{ Where,}$$

N and α are the Van Genuchten parameters for the soil,

r_o = the disk radius, and

h_o = the suction at the disk surface.

Using $C_1 = 0.0064$ and $A = 2.43$ for a loamy sand soil as obtained from appendix 7, the van Genuchten parameters for 12 soil texture classes and A values for a 2.25 cm dist radius and suction values form 0.5 to 6 cm.

Table 4.13 Mini disc infiltrometer calculations

Time (s)	Square root (t)	Volume (mL)	Infiltration (cm)
0		90	0
30	5.48	89	0.06
60	7.75	80	0.63
90	9.49	77	0.82
120	10.95	75	0.94
150	12.25	73	1.07
180	13.42	70	1.26
210	14.49	68	1.38
240	15.49	66	1.51
270	16.43	60	1.89
300	17.32	53	2.33

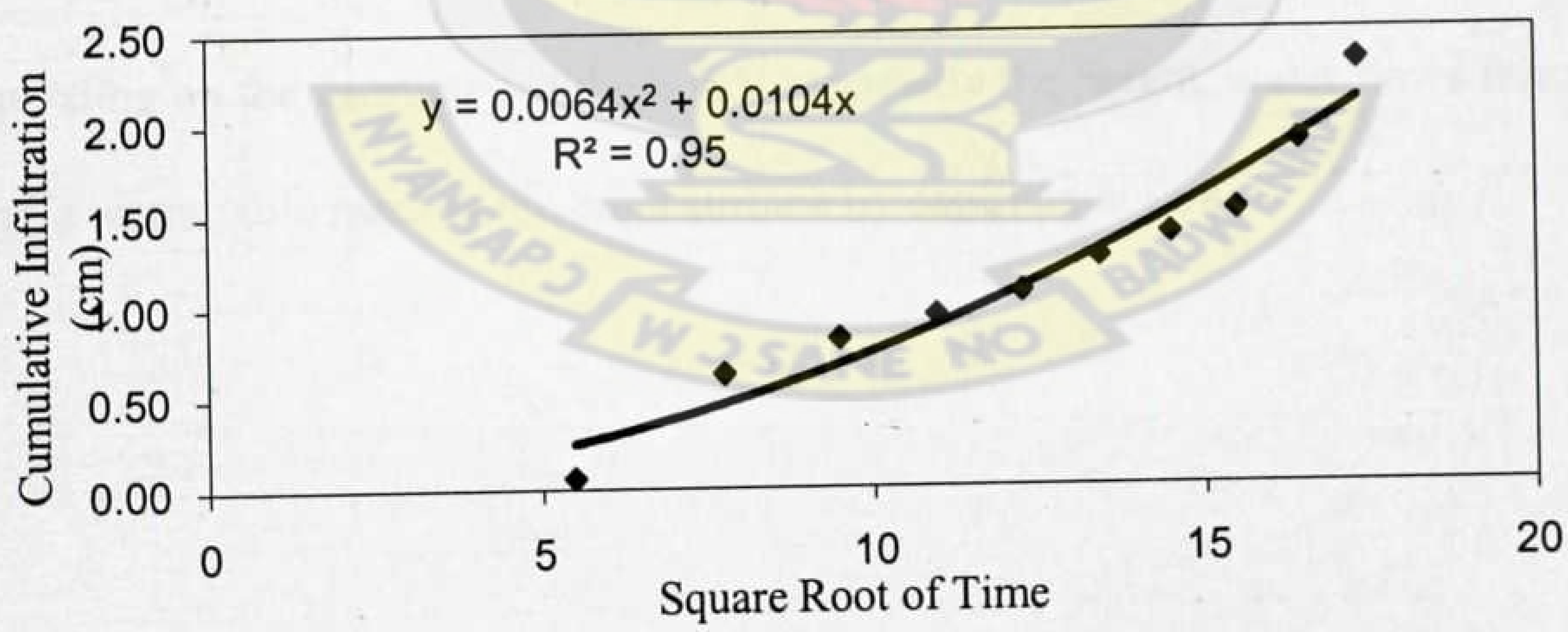


Figure 4.25 cumulative infiltrations gradient

$$K = \frac{0.0064}{2.43} = 2.63x10^{-3} cms^{-1}$$

(For further calculations, refer to Appendix 4)

4.6.3 BUNDS HYDRAULIC CONDUCTIVITY MODELS

Based on the proctor results obtained (Appendix 1), the highest maximum dry bulk density (MDD) from the proctor results (2.03 g/cm^3) was set as threshold to be the densest value at which the soil could be compacted on the farmer's field for bunds construction though in actual sense farmers cannot attain such density on the field by heaping the soil manually. Individual bunds were simulated using the linear function equation which was considered best based on its strongest correlations.

4.6.4 PROPERTIES OF BUNDS SOIL AT 0 – 9 AND 9 – 18 CM

The dry bulk density values sampled from the bunds were used in establishing a relationship between saturation hydraulic conductivity and dry bulk density as a way of assessing the seepage loss potential through the bunds. Figures 4.26 and 4.27 are the relationship between volumetric moisture content and degree of saturation. The results show that increasing moisture content results in increasing degree of saturation. Depending on the geometry of the bunds especially the height, water flows from the bund's water table reaches the bund surface by capillary action.

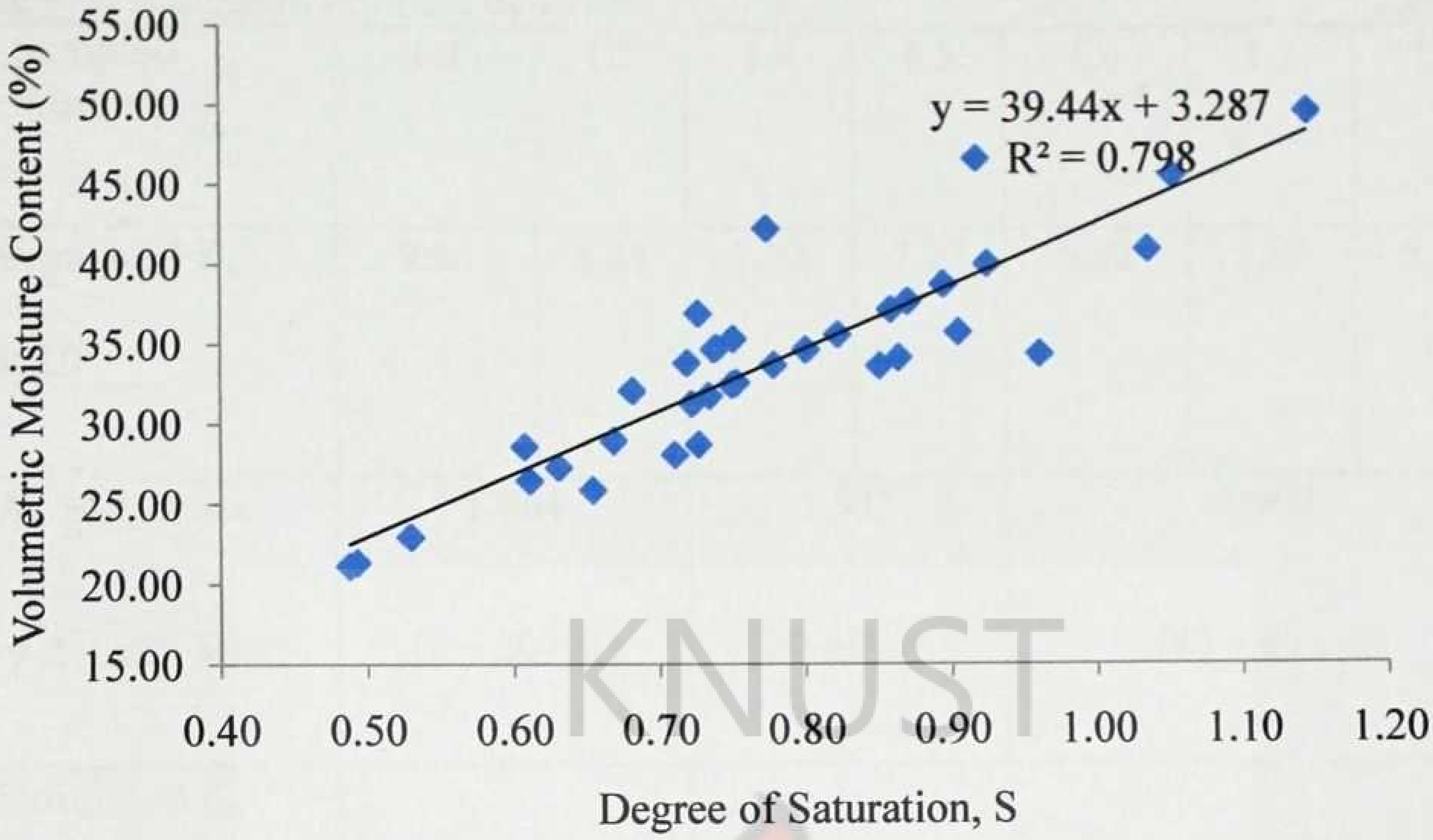


Figure 4.26 Volumetric moisture content and degree of saturation of sampled bunds at 0 – 9 cm depth during the time of sampling.

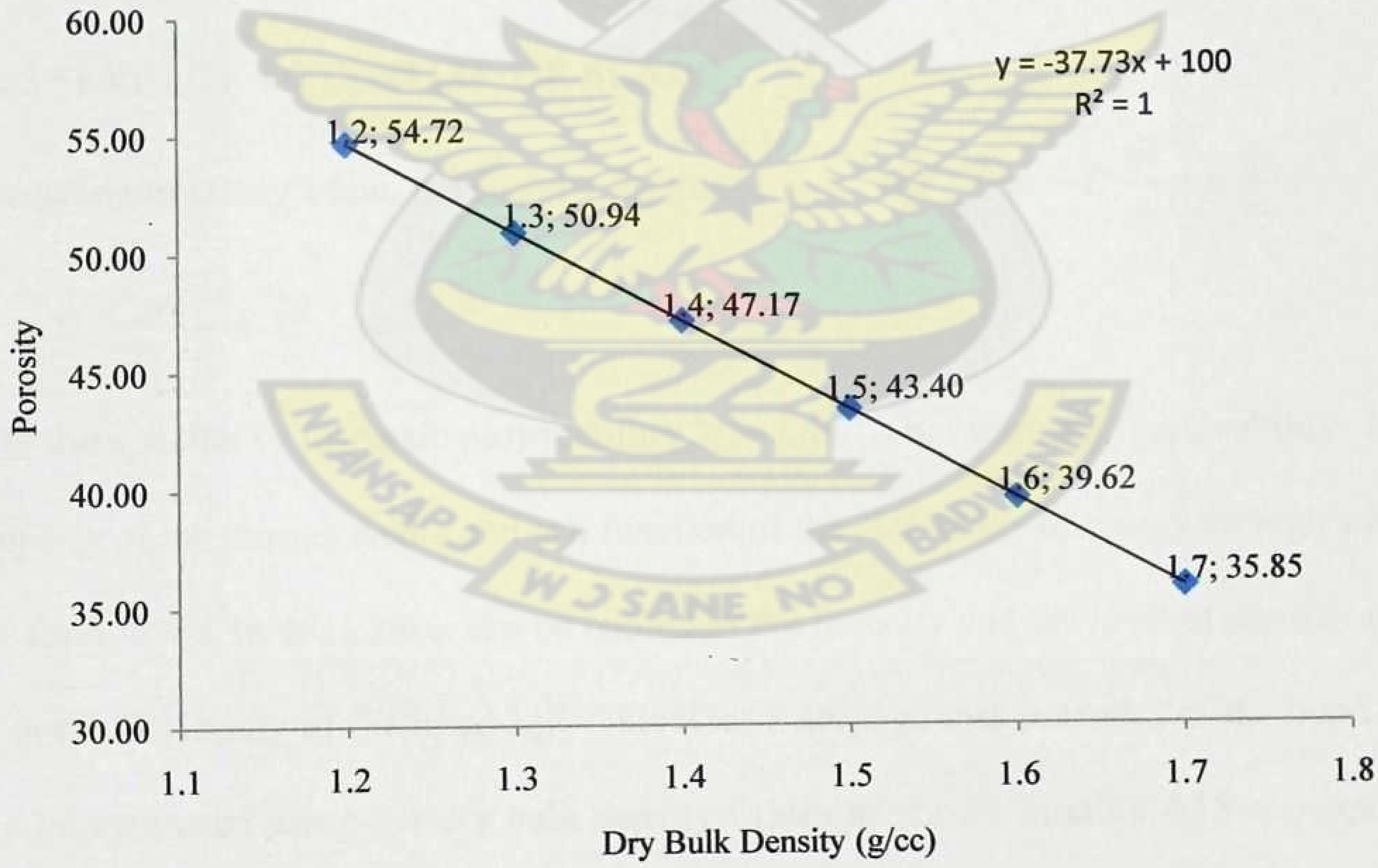


Figure 4.27 Porosity and dry bulk density of sampled bunds at 0 – 9 cm depth during the time of sampling.

From Figure 4.19, the ranges of dry bulk densities are as shown in (Appendix 6) and the corresponding hydraulic conductivity parameters.

Table 4.14 Ranges of dry bulk densities

Sampled bunds ρ_{db}	1.2	1.3	1.4	1.5	1.6	1.7	1.8
Simulated $K_s \times 10^{-4}$	9.95	8.84	7.93	7.17	6.52	5.96	5.48
Av. Maximum dry density MDD	1.864 (0 – 20 cm)		1.932 (20-40 cm)		1.962 (40 – 60 cm)		
Simulated $K_s \times 10^{-4}$	5.21		4.94		4.83		

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4.6.5 SEEPAGE POTENTIAL OF BUNDS

According to Darcy's law, the specific discharge $q = -K\frac{dh}{dL} = -C\frac{d^2}{\mu}\rho g\frac{dh}{dL}$

$$K = C\frac{d^2\rho g}{\mu} = k\frac{\rho g}{\mu}$$

k is the specific or intrinsic permeability. $k = Cd^2$. The intrinsic permeability is a property of the porous media and is a function of the size of the openings through which the fluid flows. In this case it can be related to the porosity and the level of densification or dry bulk density of the bund soil. Therefore a seepage loss potential of the bund soil can be estimated using the dry bulk density values as shown in table 4.15 appendix 9.

Seepage loss potential % $= \frac{\rho_{MDD} - \rho_i}{\rho_{MDD}} \times 100$

Assuming the farmer uses the top 0 – 20 cm depth soil to form the bunds the seepage potential could be evaluated with $\rho_{MDD} = 1.864$. If the top 20 – 40 cm layer soil is used in forming the bunds evaluation of the seepage potential will involve the use of ρ_{MDD} = 1.932, likewise ρ_{MDD} = 1.962 if the top 40 – 60 cm soil layer is used. The results show that the higher the dry bulk density the lower the seepage potential.

Seepage loss potential may also be expressed in terms of the saturated hydraulic conductivity for a given dry bulk density and that at the maximum dry density.

According to Darcy's law, specific discharge $q = -K\frac{dh}{dL} = u_s \times n_e$

$$K = -\frac{u_s n_e}{dh/dL}$$

u_s is the seepage velocity

n_e is the porosity of the flow medium

The specific discharge or flow through the bunds can also be related to the saturated hydraulic conductivity. Hence seepage loss potential can be expressed in terms of the saturated hydraulic conductivity of the bund soil.

For example, Seepage loss potential % = $\frac{K_{si} - K_{sMDD}}{K_{si}} \times 100$

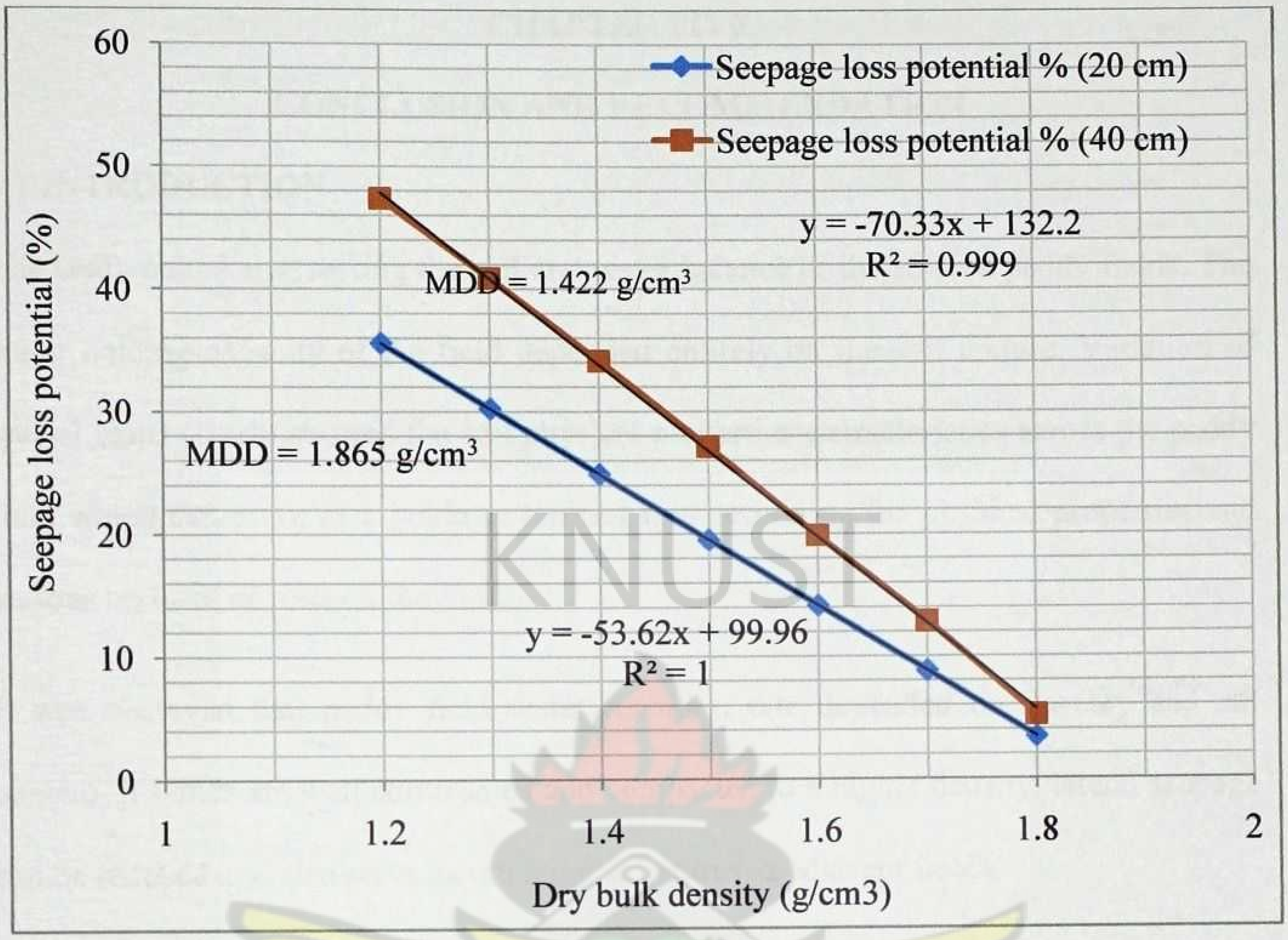

Figure 4.28 seepage losses potential for the 20 and 40 cm depth

Seepage loss potential in terms of saturated hydraulic conductivity is also shown in Figure 4.28. As the bulk density increases, seepage loss potential reduces and likewise as the bulk density decrease, the seepage potential increases.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

The study aimed at assessing the soil and water balance of the studied paddy fields. The water holding capacity of the field depended entirely on the soil texture. Variation of spatial maps clearly showed the soil physical properties characteristics across the paddy field which can serve as a guide to farmers in determining the physical properties and various textures of soils on the field.

It was observed that paddy field water retention rate depended on its clay and silt content. If bunds are well constructed and compacted to a higher density, lateral seepage can be reduced and also serve as retaining structures to adjacent fields.

5.2 CONCLUSION

The sand content of the site soil at the four selected representative sites, WP 18, WP19 WP 21 and WP 22 indicate on the average 83.63% sand, 8.17% silt and 8.20% clay for the top 20 cm indicating loamy sand soil. For the 20 – 40 cm layer, the sand content was 82.05%; silt content 5.75% and clay content 12.20% indicating sandy loam soil. For the 40 – 60 cm layer the sand content was 80.33%, silt content 3.39% and clay content 16.28% indicating sandy loam soil. This is the general textural characteristics of the soil at the representative sites. The compaction characteristics of the site soil also showed that the level of densification increases with depth for each sampled site. For example, site WP18 it was 1.846, 1.922 and 2.03 for 0 – 20, 20 – 40 and 40 – 60 cm respectively. The other sites are as follows: WP 19, 1.86, 1.96 and 1.96 for 0 – 20, 20 – 40 and 40 –

60 cm respectively; for WP 21, 1.836, 1.910 and 1.94 for 0 – 20 cm, 20 – 40 cm and 40 – 60 cm respectively and for WP 22, 1.912, 1.936 and 1.916 for 0 – 20, 20 – 40 and 40 – 60 cm respectively. The measured hydraulic conductivity for remolded soil samples over a wider range of dry bulk densities of 1.30 to 2.03 showed that increasing dry bulk density resulted in a decreased saturated hydraulic conductivity. The relationship is a linear function model. Models showing the relationships between saturated hydraulic conductivity and dry bulk density and maximum dry bulk density indicated linear function relationships as $K_s = -30.4X + 65.512 \;\; R^2 = 0.2801$ and $K_s = -2.4023X + 10.508 \;\; R^2 = 0.00021$. With the measured range of dry bulk densities of the bund soil, the simulated saturated hydraulic conductivity could be obtained using the model.

Soil mapping of the paddy fields to evaluate the status of the soil in terms of compaction damage through continuous cultivation shows that the dry bulk density of the top 0 – 5 cm is in the range 1.3 g/cm^3 and 1.5 g/ cm^3. The range of dry bulk densities is below the limiting range for loamy sand which is greater than 1.7 g/ cm^3. For the 5 – 10 cm layer the range of dry bulk density measured was 1.2 g/ cm^3 to 1.7 g/ cm^3, also below the growth limiting range.

The condition of the bund soil was assessed in terms of the level of compaction during bund formation or construction. The range of dry bulk density encountered for the 0 – 9 cm depth was 1.2 g/ cm^3 to 1.7 g/ cm^3. For the 9 – 18 cm layer the range of dry bulk density encountered was 1.3g/ cm^3 to 1.8 g/ cm^3. The degree of saturation measured for both 0 – 9 cm and 9 – 18 cm were mostly below 100%. In some fields bunds soil become saturated and trafficability can be difficult. Using the degree of saturation and dry bulk density for the top 0 – 9 cm and 9 – 18 cm depths it has been possible to understand the condition of the bund soil relative to the degree of densification that was achieved. Soil moisture migrates from the subsurface to the surface by capillary flow. The extent of flow depends also on the level of compaction of the bund soil and the depth of ponded water in the field. The study was about the degree of saturation of the top 18 cm of the bund soil as a way of monitoring moisture regime of the bunds.

Seepage loss potential was determined using the measured dry bulk density values and the Proctor's maximum dry bulk density values as the maximum densification the soil can be prepared. It was realized that all the measured dry bulk density values of the bund soil were below the Proctor's maximum level of densification. This shows that water losses through the paddy fields are high. The degree of losses as represented by the level of compaction and the saturated hydraulic conductivity are the indicators of seepage loss potential.

Results from the soil water balance study indicate that the total inflow from rainfall and irrigation for the cropping period was 16,738.58 mm and total soil moisture storage was 2440.88 mm. Therefore the amount of water used up by plant and also lost by way of seepage and percolation was 14,297.70 mm. The total inflow measured by the groundwater tube and field water tube was 14,270 mm. The percentage of the total inflow was 84.04% . This shows that 84.04% of the water input by irrigation and rainfall was lost to deep percolation and seepage losses and 15.96% was used for crop growth.

5.3 RECOMMENDATION

Adequate monitoring and evaluation of water management practices are needed in order to achieve an increased in overall efficiency of paddy fields.

Based on the outcome of the study, it should not be assumed that farmers have access to required information on soil and water management including best agronomic practices of the rice crop. Therefore, there is a need for farmers to be supported with more adaptive and applied research on water use efficiency.

It is also recommended that the maps showing soil variability applied to be better field management of the paddy rice.

Further research is recommended for continuation of this work in determining the soil chemical and biological status of the paddy field. The results attained can be used in assisting farmers in knowing the level of fertility of their paddy fields which will enhance yield.

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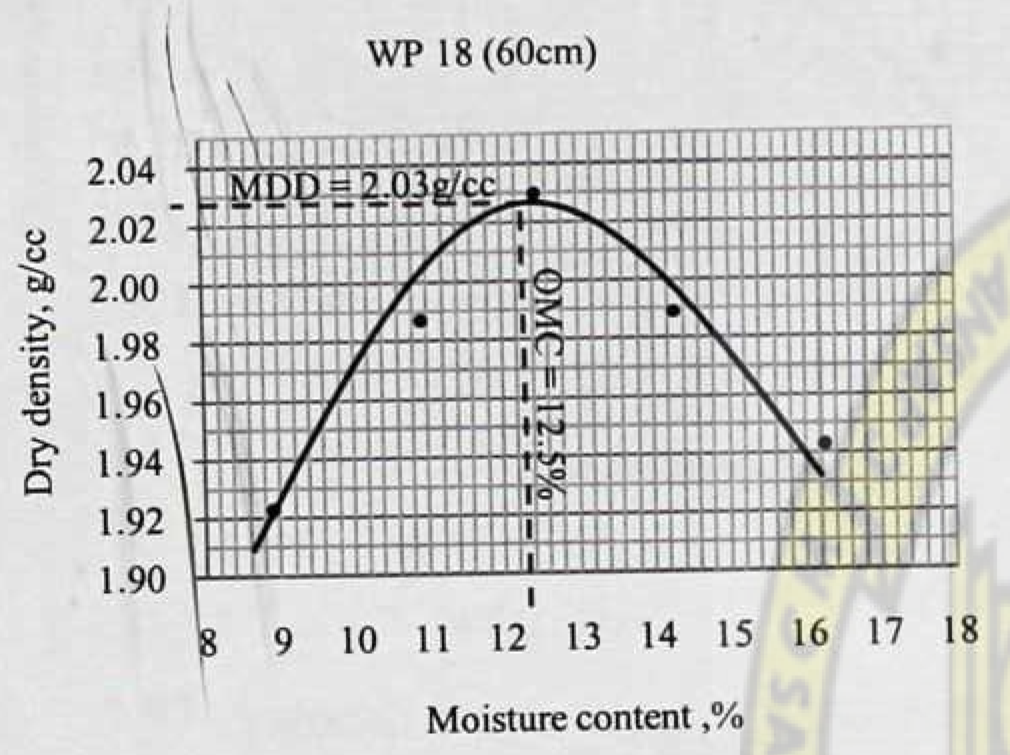
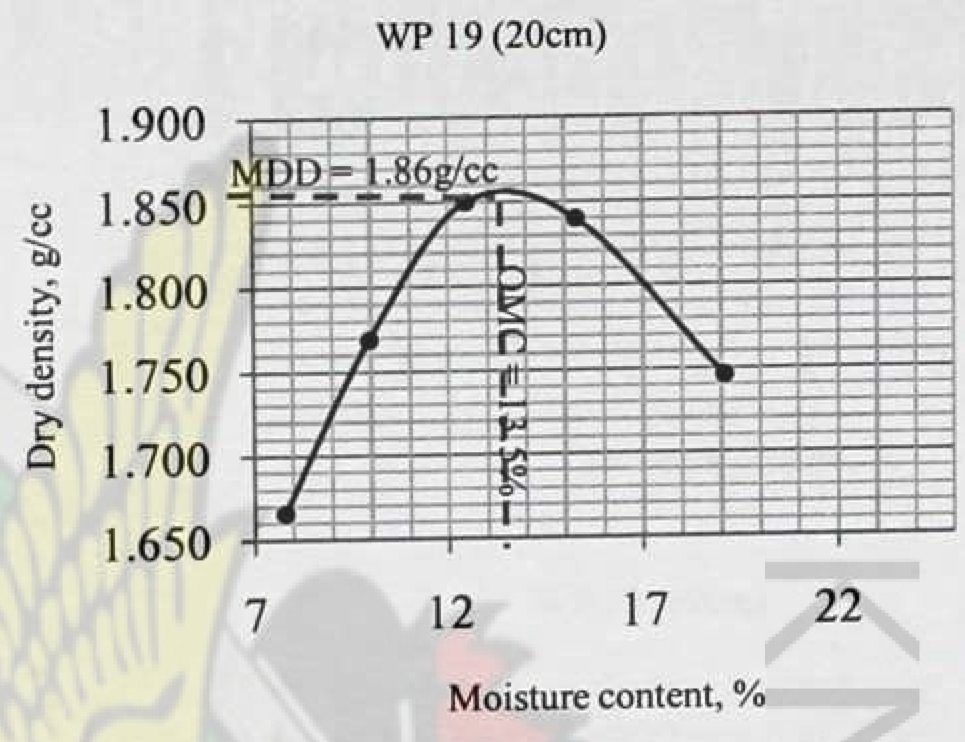
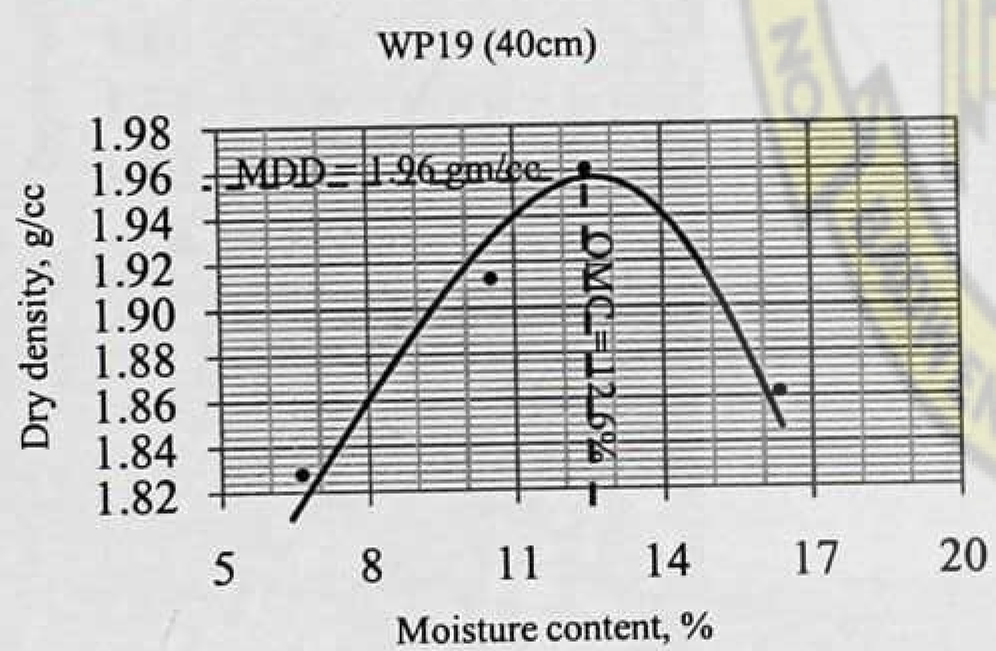
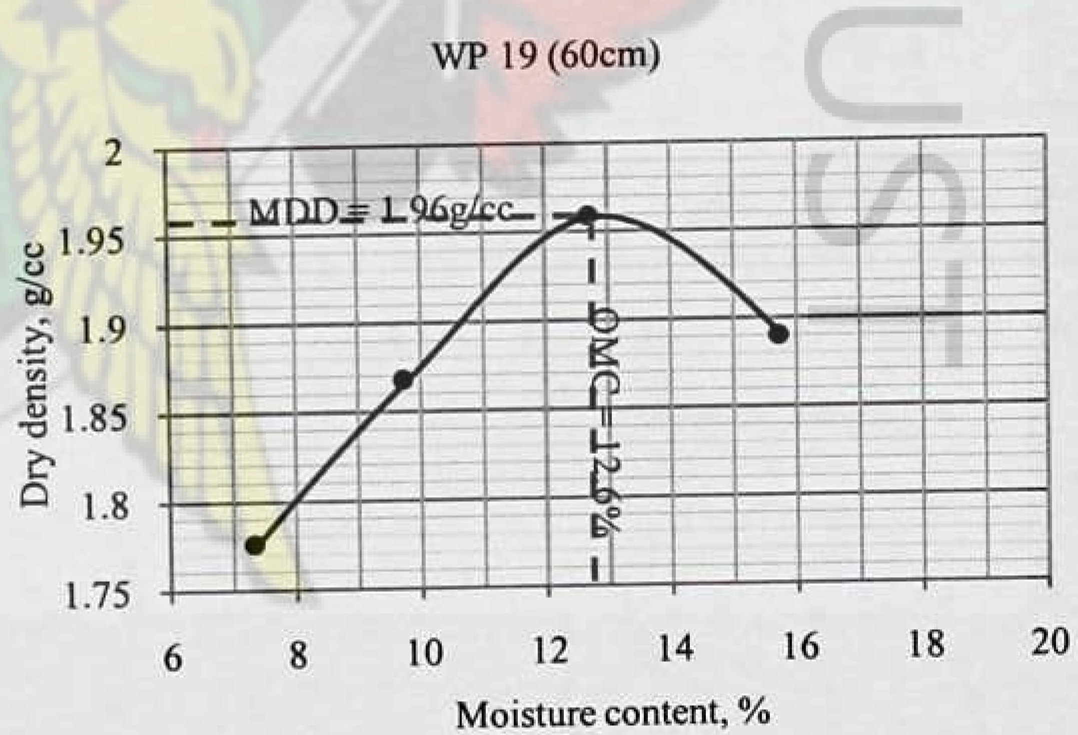
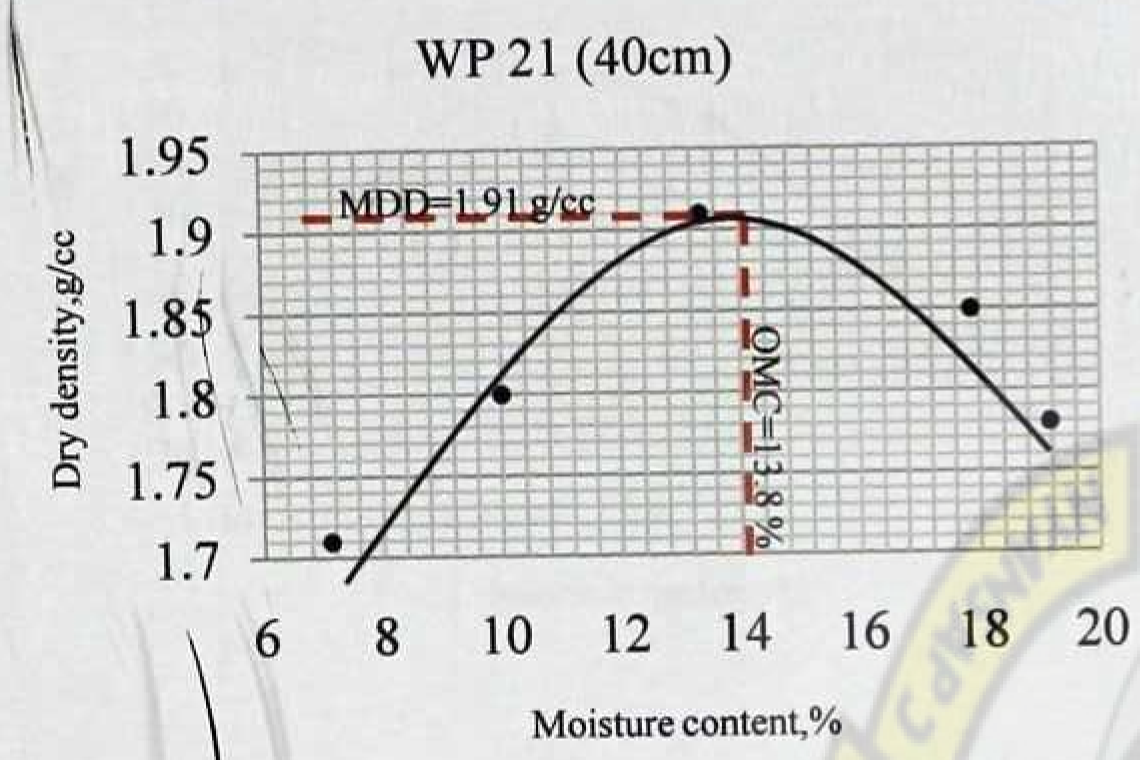
APPENDIX 1 SOIL MODIFIED COMPACTION CURVES

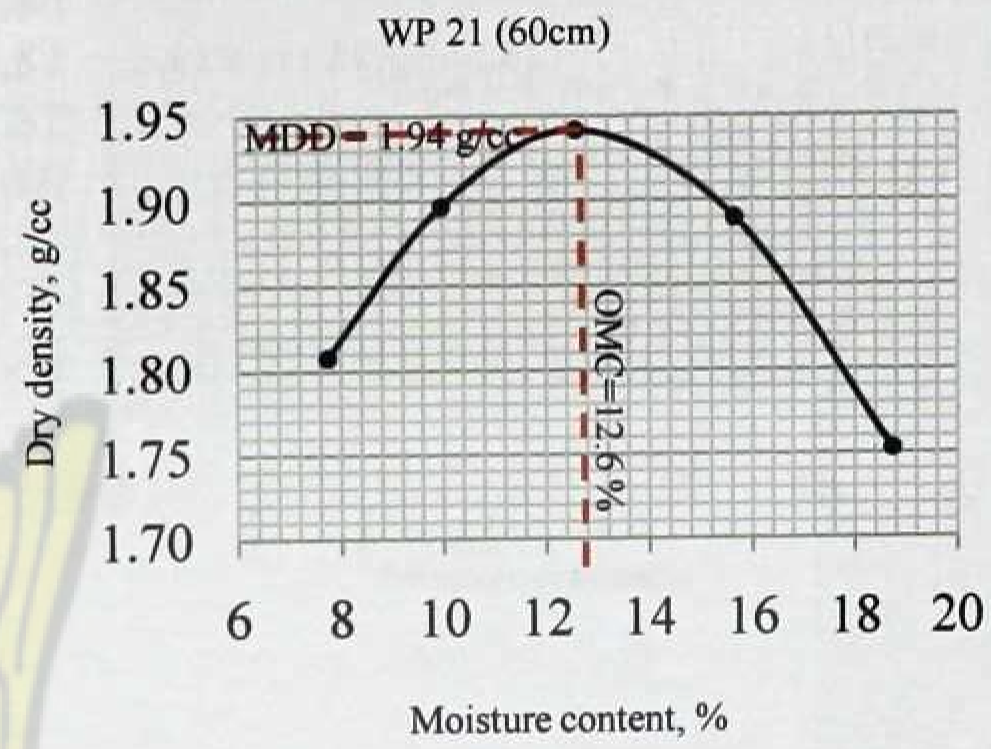


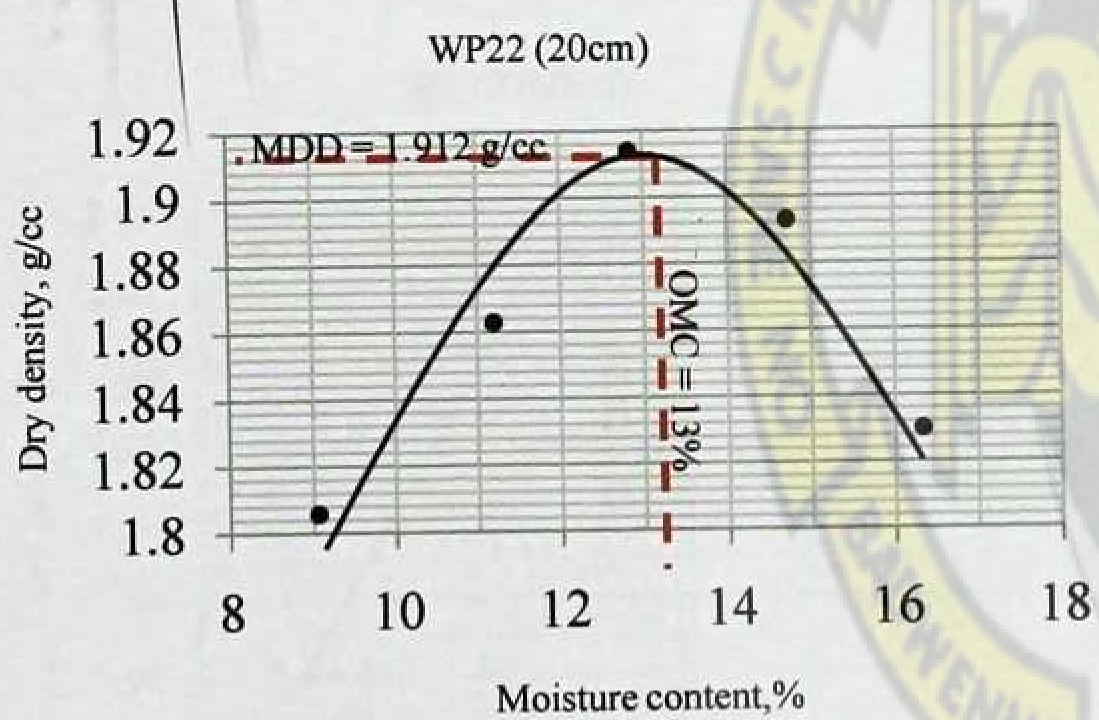


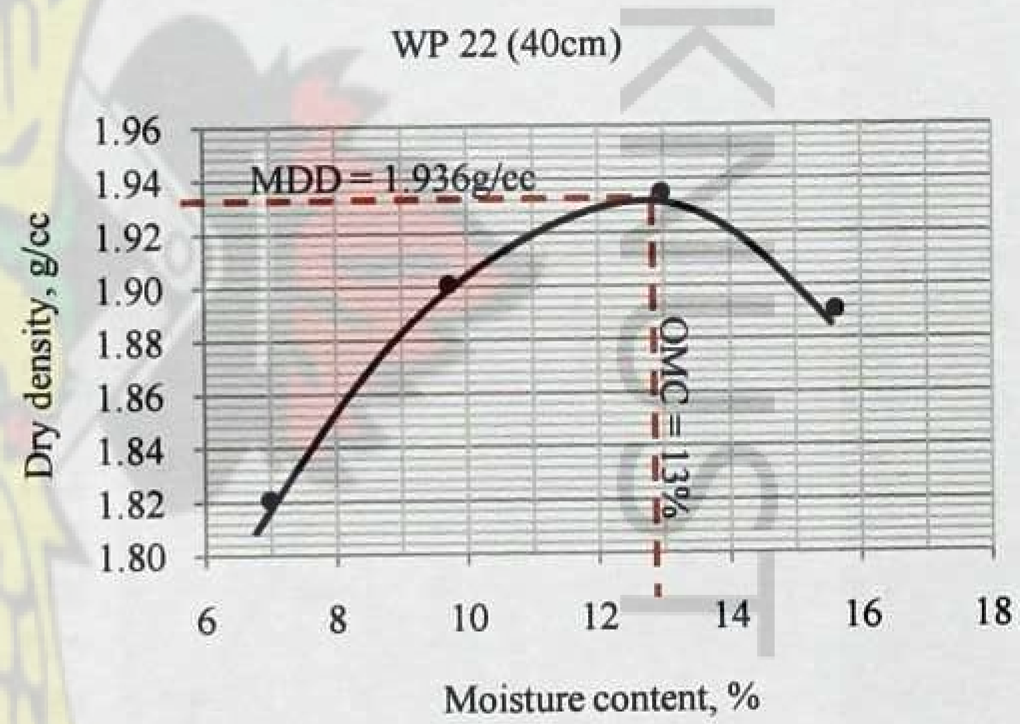


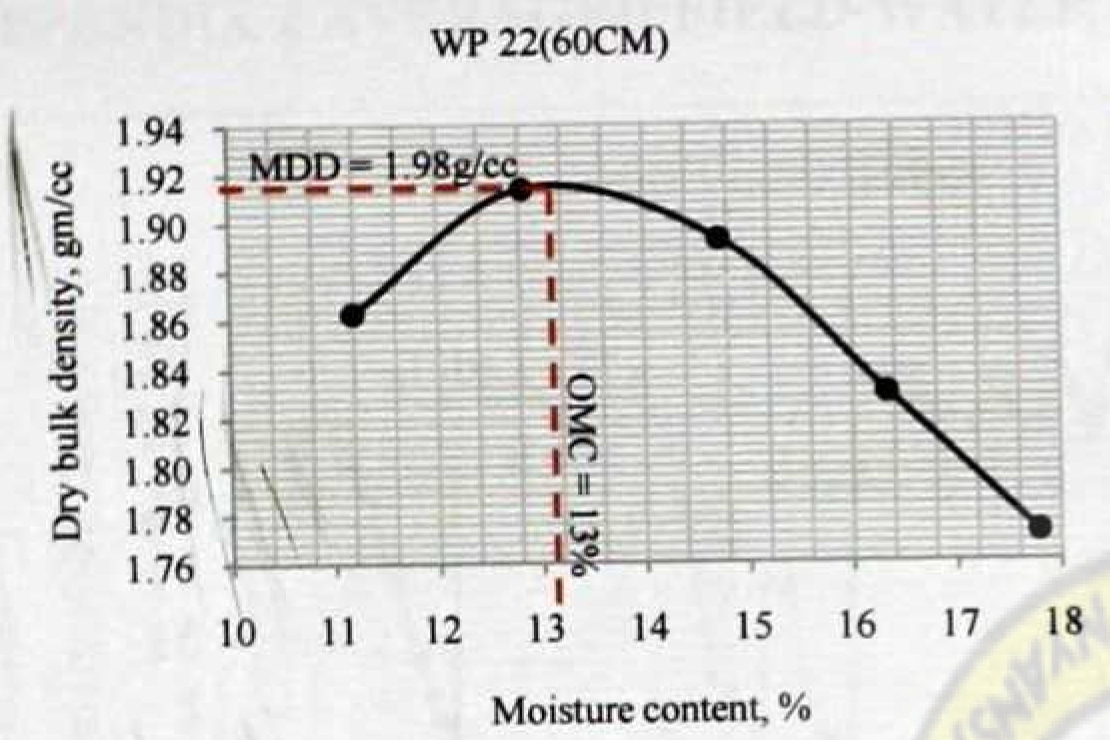


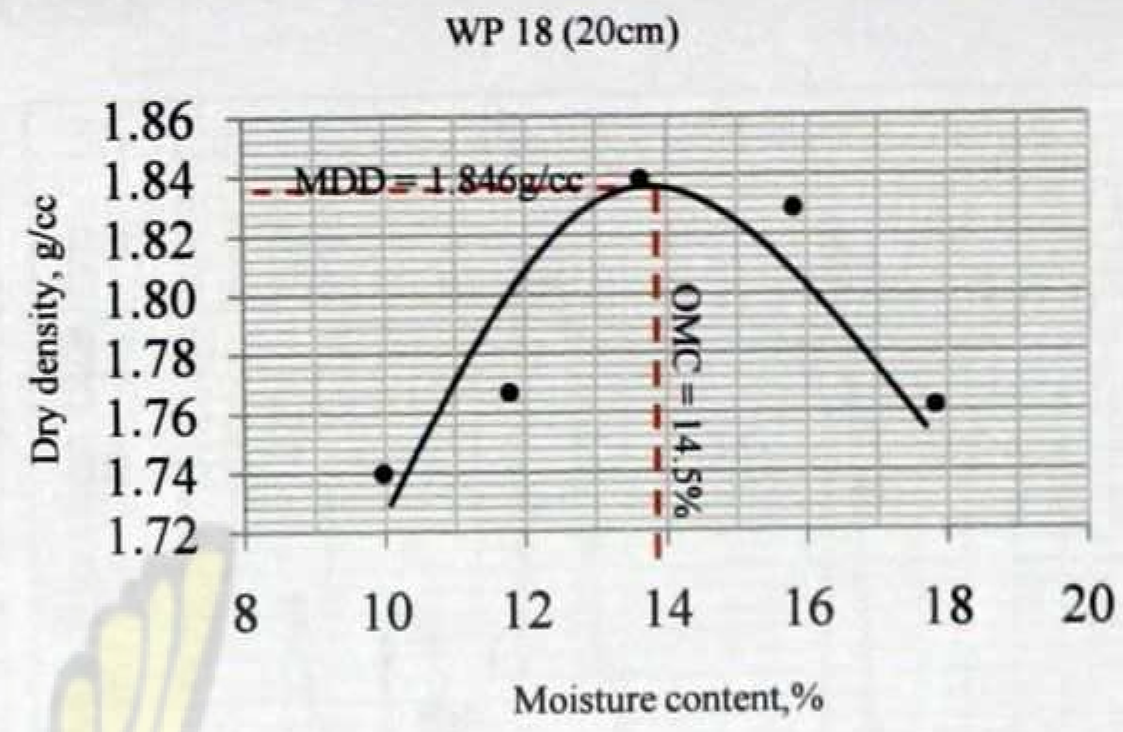

WP 21 (40cm)
MDD=1.91g/cc
OMC=13.8 %
Dry density,g/cc
1.95
1.9
1.85
1.8
1.75
1.7
6
8
10
12
14
16
18
20
Moisture content,%

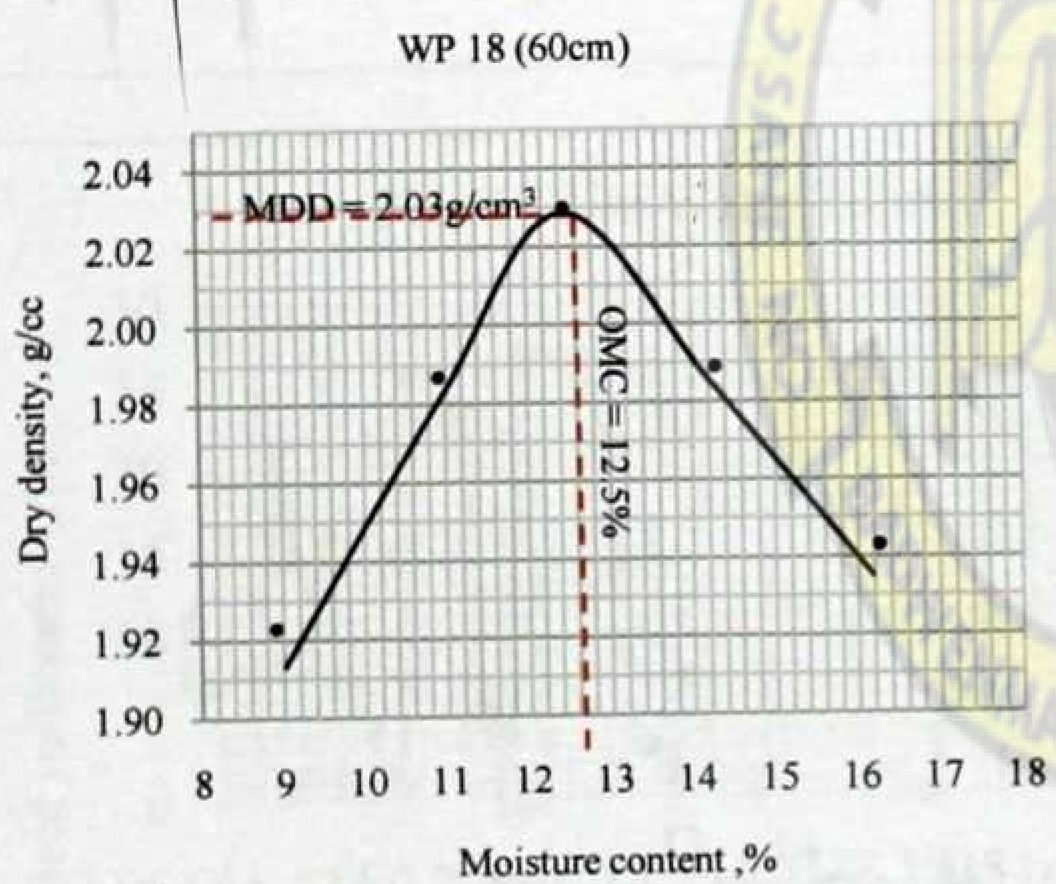

WP 21 (60cm)
MDD = 1.94 g/cc
OMC=12.6 %
Dry density, g/cc
1.95
1.90
1.85
1.80
1.75
1.70
6
8
10
12
14
16
18
20
Moisture content, %

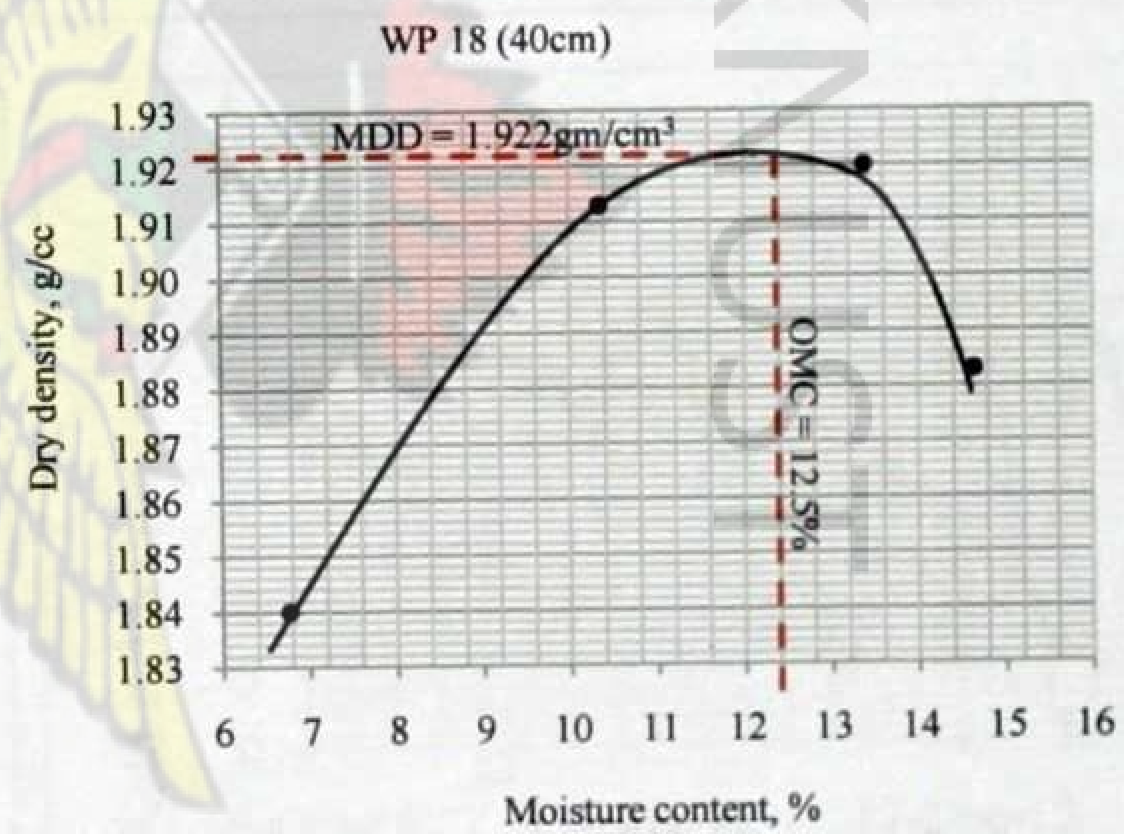

WP22 (20cm)
MDD = 1.912 g/cc
OMC = 13%
Dry density, g/cc
1.92
1.9
1.88
1.86
1.84
1.82
1.8
8
10
12
14
16
18
Moisture content,%


WP 22 (40cm)
MDD = 1.936g/cc
OMC = 13%
Dry density, g/cc
1.96
1.94
1.92
1.90
1.88
1.86
1.84
1.82
1.80
6
8
10
12
14
16
18
Moisture content, %

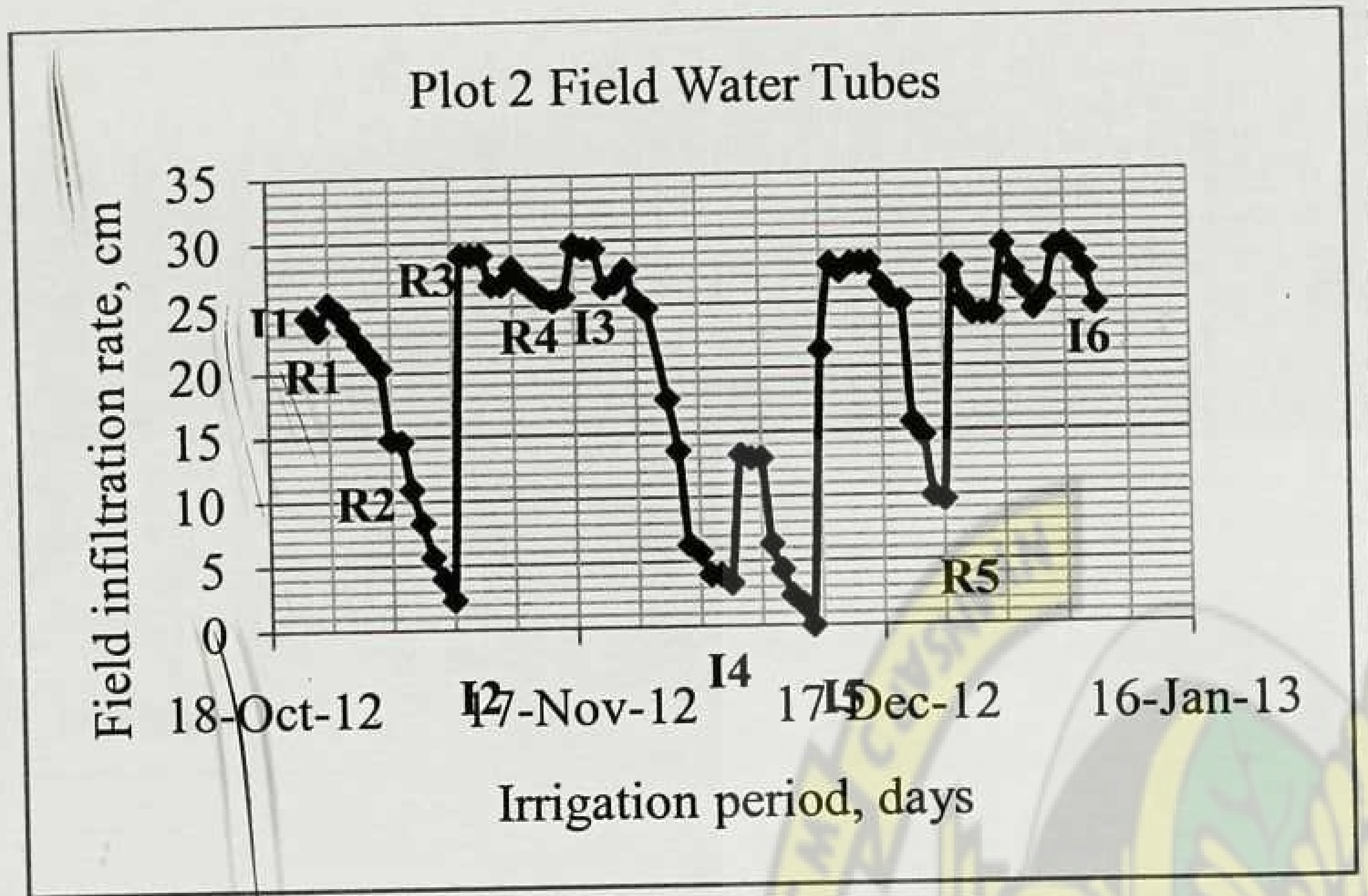

WP 22(60CM)
MDD = 1.98g/cc
OMC = 13%
Dry bulk density, gm/cc
Moisture content, %

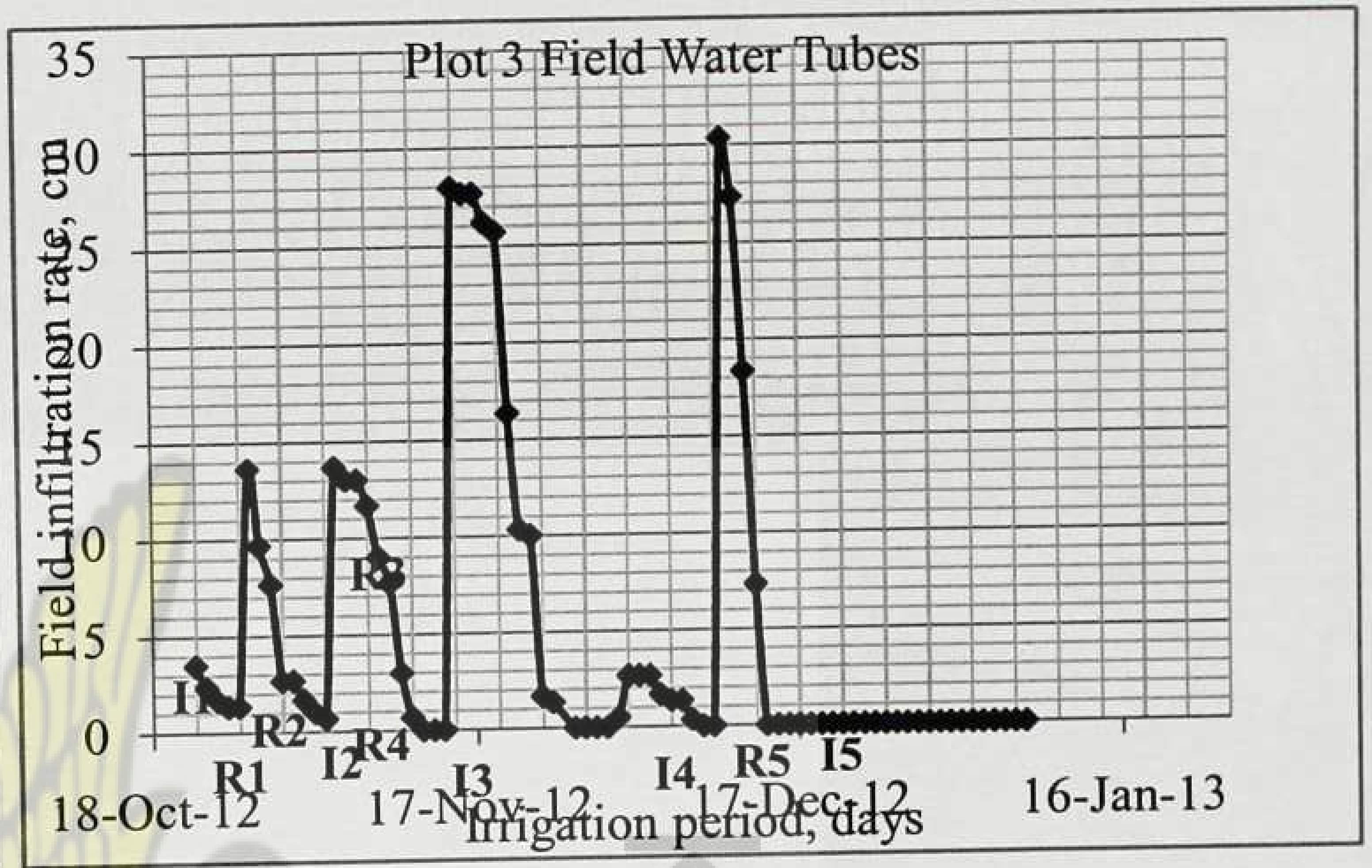

WP 18 (20cm)
MDD = 1.846g/cc
OMC = 14.5%
Dry density, g/cc
Moisture content,%

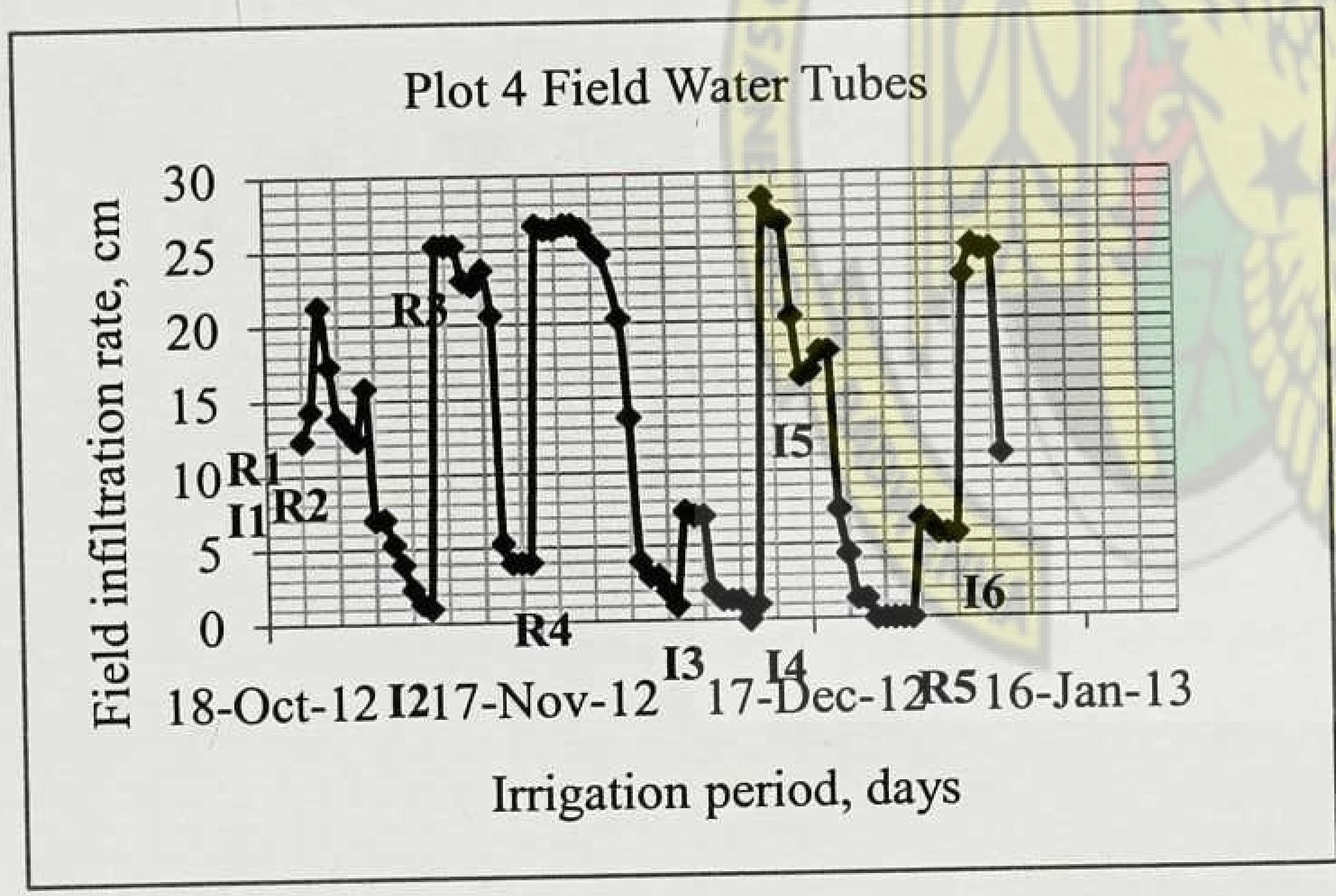

WP 18 (60cm)
MDD = 2.03g/cm³
OMC = 12.5%
Dry density, g/cc
Moisture content ,%

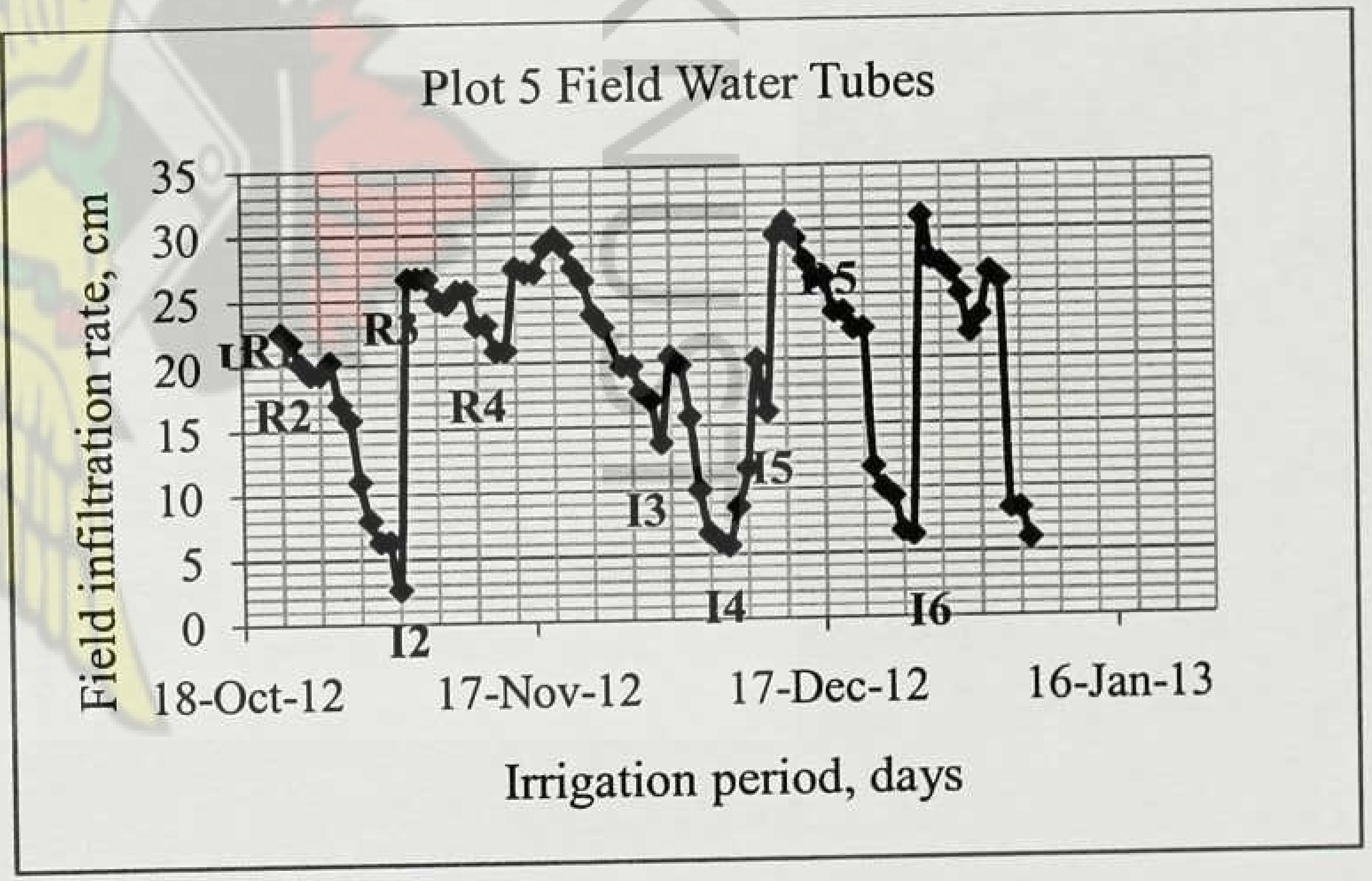

WP 18 (40cm)
MDD = 1.922gm/cm³
OMC = 12.5%
Dry density, g/cc
Moisture content, %

APPENDIX 2 AVERAGED FIELD-WATER TUBES FIGURES

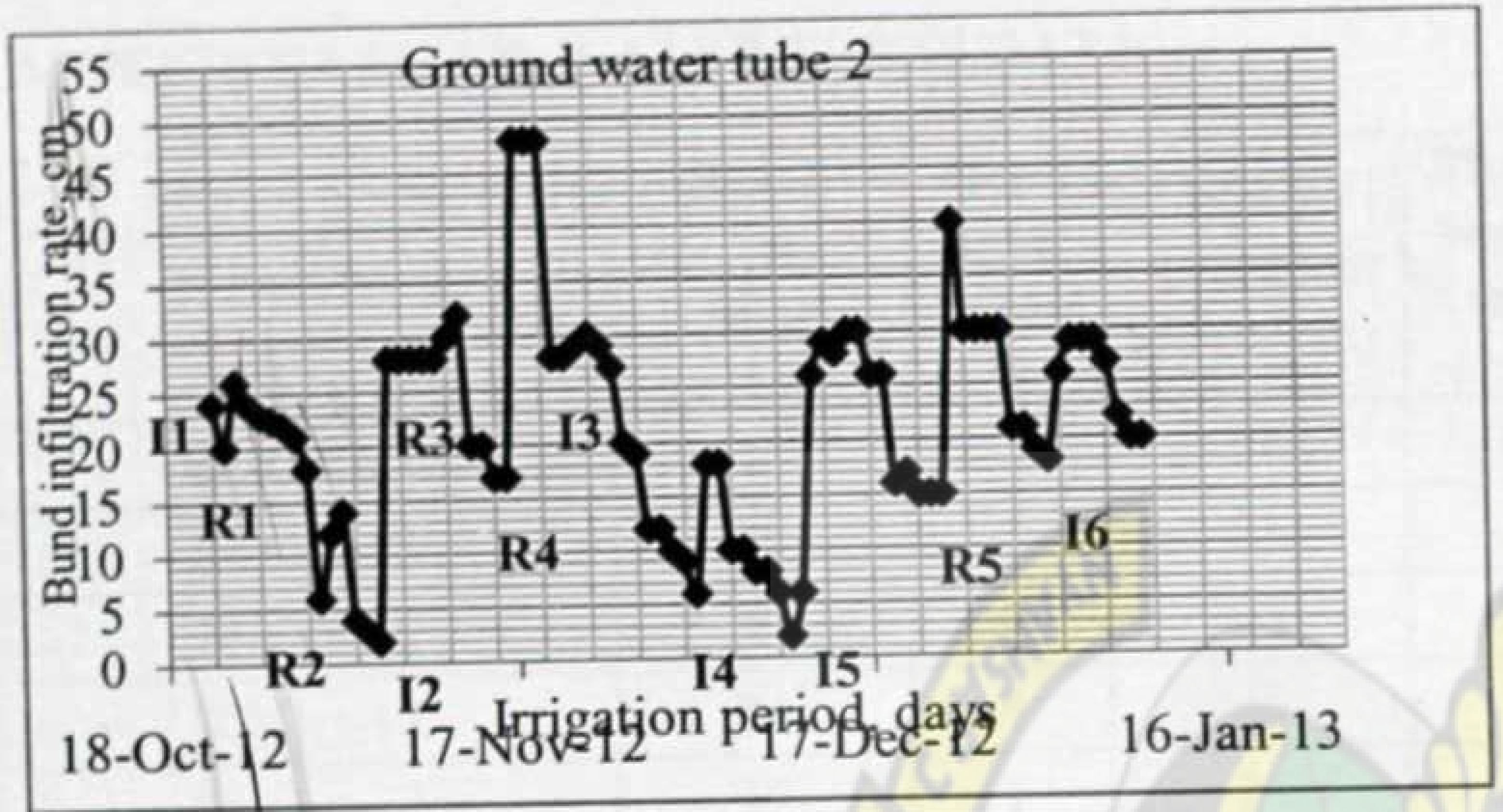


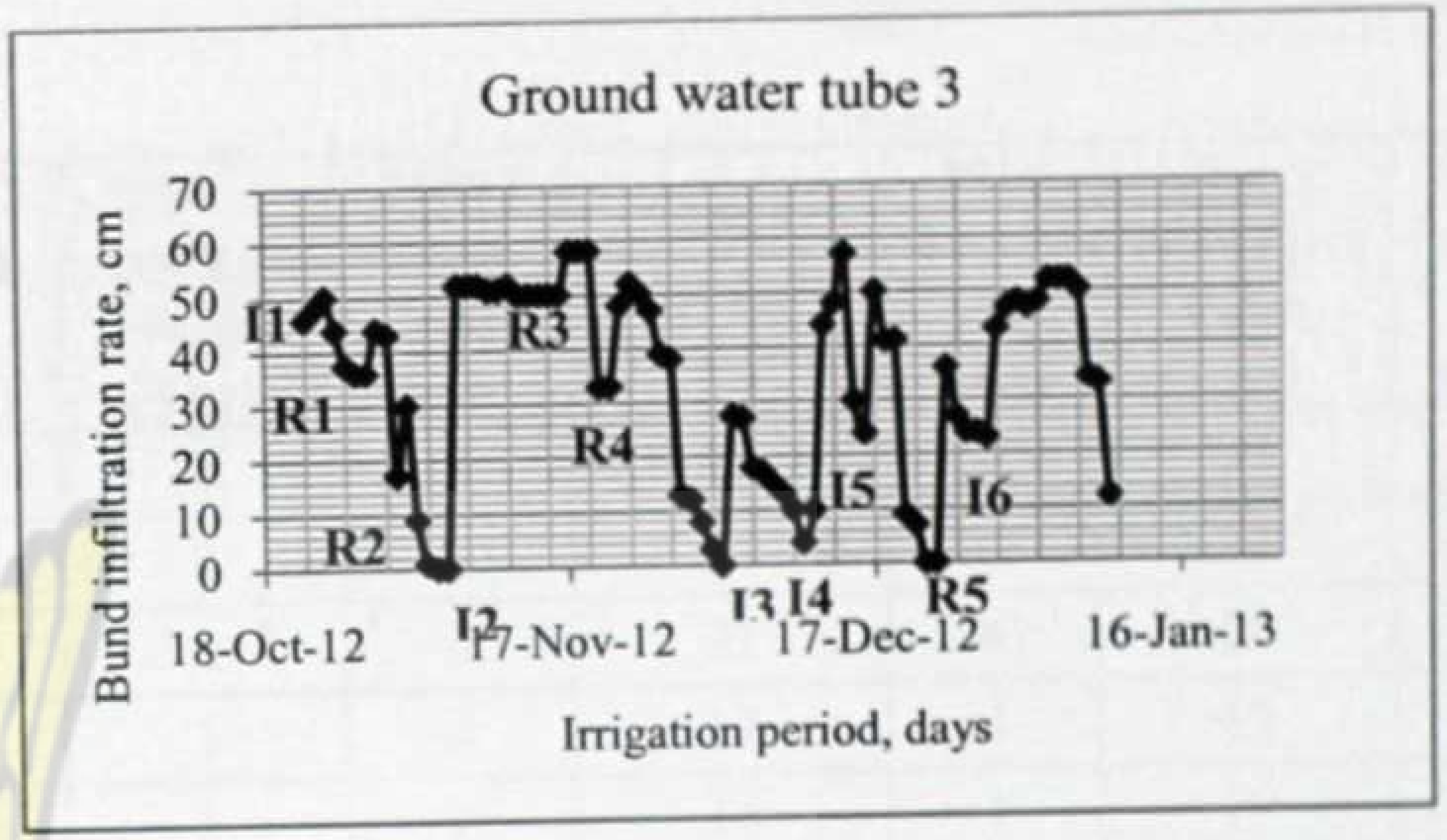


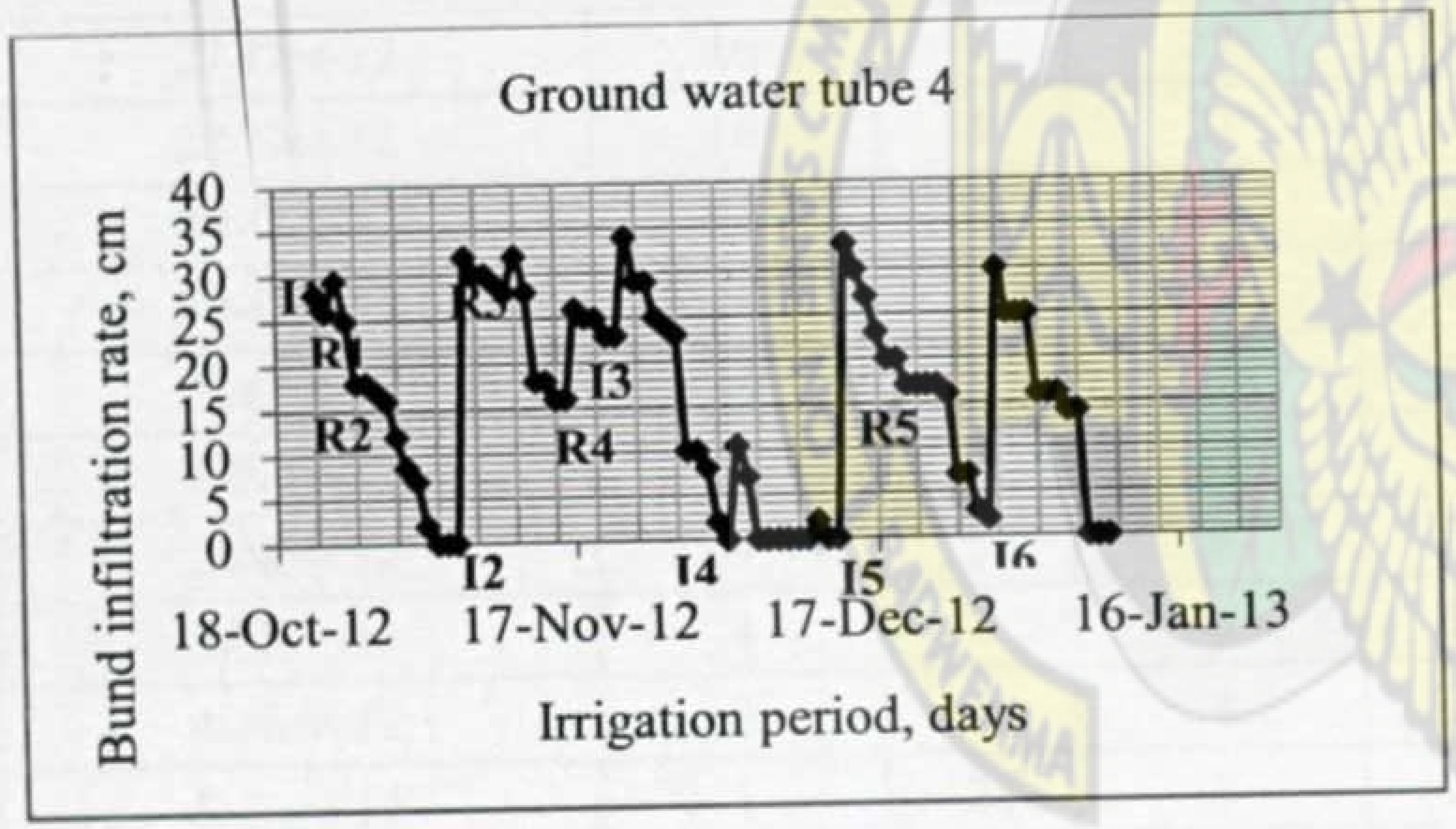


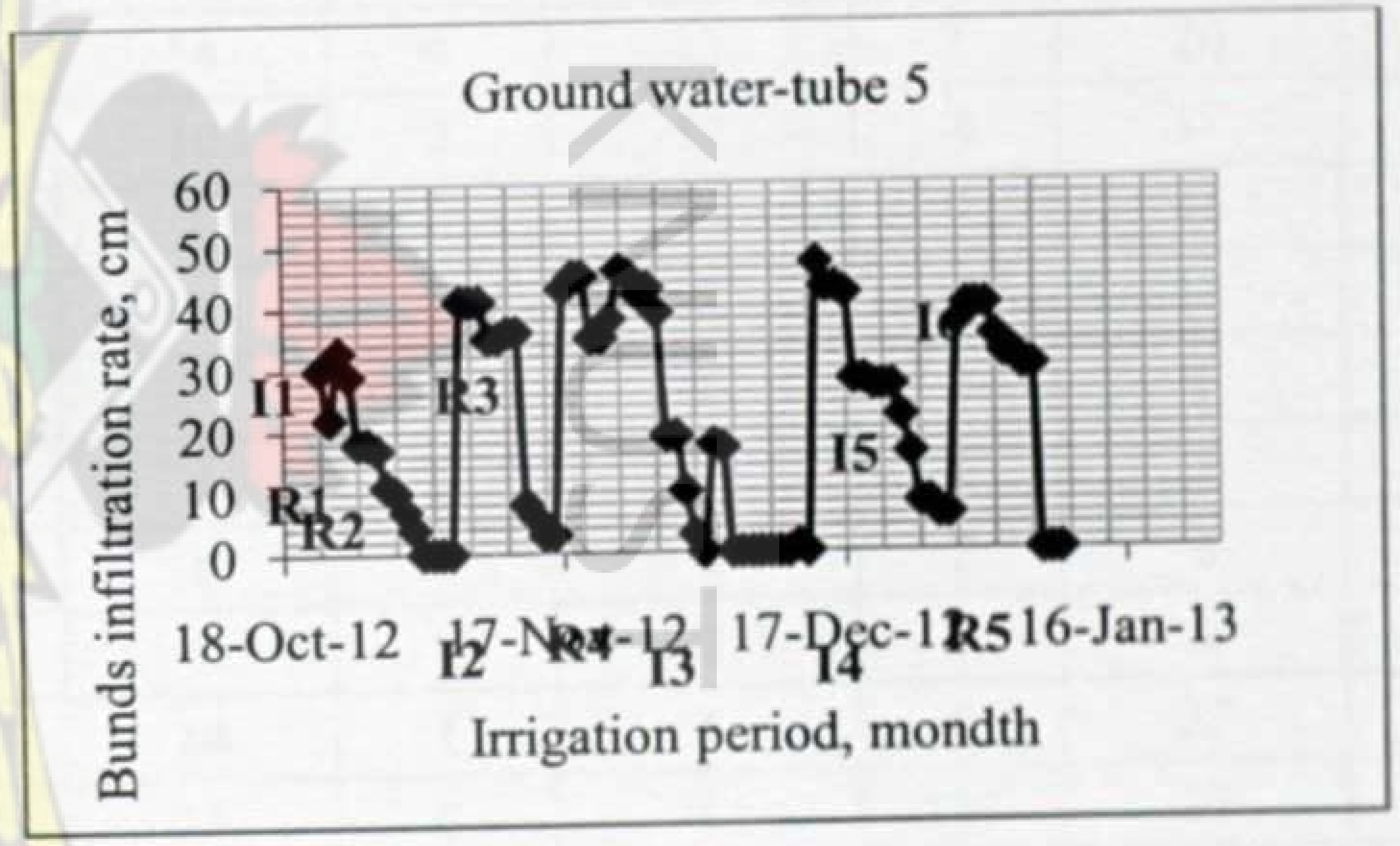


APPENDIX 3 GROUND-WATER TUBES FIGURES









APPENDIX 4 FIELD-WATER TUBES DATA

DATE	Plot 1 Averaged value (cm)	Plot 1 water use (cm)	Plot 2 Averaged value (cm)	Plot 2 water use (cm)	Plot 3 Averaged value (cm)	Plot 3 water use (cm)	Plot 4 Averaged value (cm)	Plot 4water use (cm)	Plot 5 Averaged value (cm)	Plot 5 water use (cm)
22-Oct-12	21	2	24	1	4	1	12	-2	23	1
23-Oct-12	19	-2	23	-2	2	1	14	-7	22	2
24-Oct-12	21	0	25	1	2	0	21	4	20	1
25-Oct-12	21	4	25	1	1	0	17	4	19	0
26-Oct-12	17	1	24	1	1	-12	14	1	19	-1
27-Oct-12	16	1	22	1	14	4	13	1	20	3
28-Oct-12	16	-1	21	1	10	2	12	-4	17	1
29-Oct-12	17	3	20	6	8	5	16	9	16	5
30-Oct-12	14	0	15	0	3	0	7	0	11	3
31-Oct-12	14	3	15	4	3	1	7	2	8	2
1-Nov-12	11	2	11	3	2	1	5	1	6	0
2-Nov-12	9	5	8	3	1	0	4	2	6	4
3-Nov-12	4	2	6	2	1	-13	2	1	3	-24
4-Nov-12	3	2	4	2	14	1	1	0	27	0
5-Nov-12	1	-28	2	-27	13	0	1	-24	27	0
6-Nov-12	29	0	29	0	13	1	25	0	27	2
7-Nov-12	29	0	29	0	12	3	25	0	25	0
8-Nov-12	29	1	29	2	9	1	25	2	25	-1
9-Nov-12	28	0	27	0	8	5	23	0	26	0

10-Nov-12	28	-1	27	-1	3	2	23	-1	26	3
11-Nov-12	29	2	28	1	1	1	24	3	23	0
12-Nov-12	27	10	27	1	0	0	21	15	23	2
13-Nov-12	17	0	26	1	0	0	5	1	21	0
14-Nov-12	17	2	26	0	0	-28	4	0	21	-6
15-Nov-12	15	0	25	0	28	0	4	0	27	0
16-Nov-12	15	-16	26	-4	28	0	4	-23	27	0
17-Nov-12	31	0	30	0	28	2	27	0	27	-2
18-Nov-12	31	1	29	0	26	1	26	0	29	-1
19-Nov-12	31	3	29	3	26	9	26	0	30	1
20-Nov-12	28	0	26	0	16	6	27	0	29	2
21-Nov-12	28	0	27	-1	10	0	27	0	27	1
22-Nov-12	28	1	28	2	10	8	26	1	26	3
23-Nov-12	27	0	25	1	2	0	25	1	24	1
24-Nov-12	27	4	25	7	1	1	25	4	23	3
26-Nov-12	23	5	18	4	0	0	20	7	20	0
27-Nov-12	18	10	14	7	0	0	14	10	20	2
28-Nov-12	8	0	6	1	0	0	4	1	18	1
29-Nov-12	8	1	6	2	0	-1	3	0	17	3
30-Nov-12	7	1	4	0	1	-2	3	1	14	-7
1-Dec-12	6	2	4	1	3	0	2	1	20	1
2-Dec-12	4	-9	3	-10	3	0	1	-6	20	4
3-Dec-12	13	1	13	0	3	1	7	0	16	6

4-Dec-12	12	0	13	0	2	0	7	0	10	3
5-Dec-12	12	6	13	7	1	0	7	5	7	1
6-Dec-12	7	3	6	2	1	1	2	1	6	0
7-Dec-12	4	0	4	2	0	0	1	0	6	-3
8-Dec-12	4	1	2	1	0	0	1	0	9	-3
9-Dec-12	3	2	2	2	0	-30	1	1	12	-8
10-Dec-12	2	-30	0	-21	30	3	0	-1	20	4
11-Dec-12	32	0	21	-7	27	9	1	-27	16	-14
12-Dec-12	32	2	28	1	18	11	28	1	30	-1
13-Dec-12	31	-1	27	-1	7	7	27	0	31	1
14-Dec-12	31	3	28	0	0	0	27	6	29	2
15-Dec-12	28	1	28	0	0	0	20	4	28	1
16-Dec-12	27	0	28	2	0	0	16	0	26	0
17-Dec-12	27	6	26	1	0	0	17	-1	26	3
18-Dec-12	21	0	25	0	0	0	18	0	24	0
19-Dec-12	21	6	25	9	0	0	18	11	24	1
20-Dec-12	15	2	16	1	0	0	7	3	22	0
21-Dec-12	13	4	15	5	0	0	4	3	22	11
22-Dec-12	9	0	10	0	0	0	1	0	12	2
23-Dec-12	9	-22	10	-18	0	0	1	1	10	1
24-Dec-12	31	2	28	3	0	0	0	0	9	3
25-Dec-12	29	1	25	1	0	0	0	0	7	0
26-Dec-12	29	1	24	0	0	0	0	0	6	-25

27-Dec-12	28	0	24	0	0	0	0	0	31	3
28-Dec-12	28	11	24	-5	0	0	0	-7	28	0
29-Dec-12	16	1	29	2	0	0	7	0	27	1
30-Dec-12	15	3	27	1	0	0	6	1	27	2
31-Dec-12	12	0	26	2	0	0	6	0	25	3
1-Jan-13	12	4	24	-1	0	0	6	0	22	-1
2-Jan-13	8	-1	25	-4	0	0	6	-17	23	-3
3-Jan-13	10	0	29	0	0	0	23	-2	27	1
4-Jan-13	9	0	29	1	0	0	25	0	26	18
5-Jan-13	9	0	29	1	0	0	25	0	8	0
6-Jan-13	9	3	27	3	0	0	25	14	8	2
7-Jan-13	7	7	25	25	0	0	11	11	6	6
Inflow water (cm)		138		131		88		134		126
Outflow water (cm)		-111		-102		-86		-122		-100
Total averaged inflow water (mm)	1234									
Total averaged outflow water (mm)	-1042									
Total averaged ET (mm)	269.12									
Total averaged rain fall (mm)	241.42									

APPENDIX 5 GROUND-WATER TUBES DATA

	Ground water tubes data									
Date	G.W.T 1 (cm)	Water use (cm)	G.W.T 2 (cm)	Water use (cm)	G.W.T 3 (cm)	Water use (cm)	G.W.T 4 (cm)	Water use (cm)	G.W.T 5 (cm)	Water use (cm)
22-Oct-12	34	8	24	4	46	-2	28	2	30	8
23-Oct-12	26	-8	20	-6	48	-2	26	-4	22	-11
24-Oct-12	34	8	26	2	50	6	30	5	33	4
25-Oct-12	26	2	24	1	44	6.5	25	7	29	11
26-Oct-12	24	0	23	0.5	37.5	1.5	18	0	18	0
27-Oct-12	24	1	22.5	0.5	36	0	18	1	18	1
28-Oct-12	23	-7	22	1	36	-8	17	1	17	6
29-Oct-12	30	2	21	3	44	1	16	4	11	1
30-Oct-12	28	8	18	12	43	26	12	3	10	3
31-Oct-12	20	0	6	-6	17	-13	9	2	7	3
1-Nov-12	20	1	12	-2	30	21	7	5	4	4
2-Nov-12	19	8	14	10	9	8	2	2	0	0
3-Nov-12	11	0	4	1	1	1	0	0	0	0
4-Nov-12	11	8	3	1	0	0	0	0	0	0
5-Nov-12	3	-27	2	-26	0	-52	0	-32	0	-41
6-Nov-12	30	0	28	0	52	0	32	2	41	0
7-Nov-12	30	0	28	0	52	0	30	0	41	0
8-Nov-12	30	0	28	0	52	1	30	1	41	6
9-Nov-12	30	0	28	0	51	0	29	1	35	0
10-Nov-12	30	-4	28	-2	51	-1	28	-4	35	-1

11-Nov-12	34	-3	30	-2	52	2	32	4	36	0
12-Nov-12	37	12	32	12	50	0	28	10	36	28
13-Nov-12	25	1.5	20	0	50	0	18	0	8	2
14-Nov-12	23.5	0.5	20	3	50	0	18	2	6	3
15-Nov-12	23	0	17	0	50	0	16	0	3	0
16-Nov-12	23	-17	17	-31	50	-8	16	-10	3	-40
17-Nov-12	40	0	48	0	58	0	26	1	43	-2
18-Nov-12	40	0	48	0	58	0	25	0	45	0
19-Nov-12	40	11	48	20	58	25	25	2	45	10
20-Nov-12	29	3	28	0	33	0	23	0	35	0
21-Nov-12	26	-18	28	-1	33	-15	23	-11	35	-3
22-Nov-12	44	9	29	-1	48	-4	34	5	38	-8
23-Nov-12	35	0	30	1	52	2	29	0	46	1
24-Nov-12	35	-1	29	2	50	3	29	4	45	3
25-Nov-12	36	8	27	7	47	8	25	1	42	-1
26-Nov-12	28	4	20	1	39	1	24	1	43	4
27-Nov-12	24	4	19	7	38	25	23	13	39	20
28-Nov-12	20	3	12	0	13	1	10	0	19	0
29-Nov-12	17	7	12	2	12	4	10	2	19	9
30-Nov-12	10	1	10	1	8	5	8	6	10	7
1-Dec-12	9	2	9	3	3	3	2	2	3	3
2-Dec-12	7	-12	6	-12	0	-28	0	-11	0	-18
3-Dec-12	19	1	18	0	28	1	11	4	18	1
4-Dec-12	18	1	18	8	27	9	7	7	17	17

5-Dec-12	17	0	10	0	18	1	0	0	0	0
6-Dec-12	17	2	10	2	17	2	0	0	0	0
7-Dec-12	15	0	8	0	15	2	0	0	0	0
8-Dec-12	15	5	8	2	13	3	0	0	0	0
9-Dec-12	10	5	6	4	10	6	0	0	0	0
10-Dec-12	5	-9	2	-4	4	-6	0	-2	0	0
11-Dec-12	14	-12	6	-20	10	-34	2	2	0	-1
12-Dec-12	26	6	26	-3	44	-4	0	0	1	1
13-Dec-12	20	0	29	1	48	-9	0	-33	0	-47
14-Dec-12	20	0	28	-2	57	27	33	3	47	4
15-Dec-12	20	0	30	0	30	6	30	3	43	0
16-Dec-12	20	0	30	4	24	-26	27	4	43	1
17-Dec-12	20	0	26	0	50	9	23	3	42	14
18-Dec-12	20	-3	26	10	41	0	20	0	28	0
19-Dec-12	23	8	16	-1	41	32	20	3	28	1
20-Dec-12	15	0	17	2	9	2	17	0	27	0
21-Dec-12	15	0	15	0	7	7	17	0	27	0
22-Dec-12	15	0	15	0	0	0	17	0	27	5
23-Dec-12	15	-25	15	-25	0	-36	17	1	22	6
24-Dec-12	40	8	40	10	36	9	16	9	16	8
25-Dec-12	32	2	30	0	27	3	7	0	8	0
26-Dec-12	30	2	30	0	24	0	7	4	8	2
27-Dec-12	28	0	30	0	24	1	3	1	6	0
28-Dec-12	28	-1	30	9	23	-20	2	-28	6	-31

29-Dec-12	29	3	21	0	43	-4	30	5	37	-3
30-Dec-12	26	0	21	2	47	-1	25	0	40	0
31-Dec-12	26	0	19	1	48	1	25	0	40	0
1-Jan-13	26	2	18	-8	47	-1	25	9	40	5
2-Jan-13	24	4	26	-3	48	-4	16	0	35	3
3-Jan-13	20	0	29	0	52	0	16	0	32	0
4-Jan-13	20	0	29	0	52	0	16	2	32	2
5-Jan-13	20	0	29	2	52	2	14	0	30	0
6-Jan-13	20	0	27	5	50	16	14	14	30	30
7-Jan-13	20	0	22	2	34	1	0	0	0	0
8-Jan-13	20	10	20	0	33	21	0	0	0	0
9-Jan-13	10	10	20	20	12	12	0	0	0	0
Inflow water (cm)		181		177		323		163		237
Outflow water (cm)		-135		-155		-278		-131		-207
Total averaged inflow water (mm)	2162									
Total averaged outflow water (mm)	-1812									
Total ET (mm)	269.12									
Total rain fall (mm)	241.42									

APPENDIX 6 SOIL PHYSICAL PROPERTIES

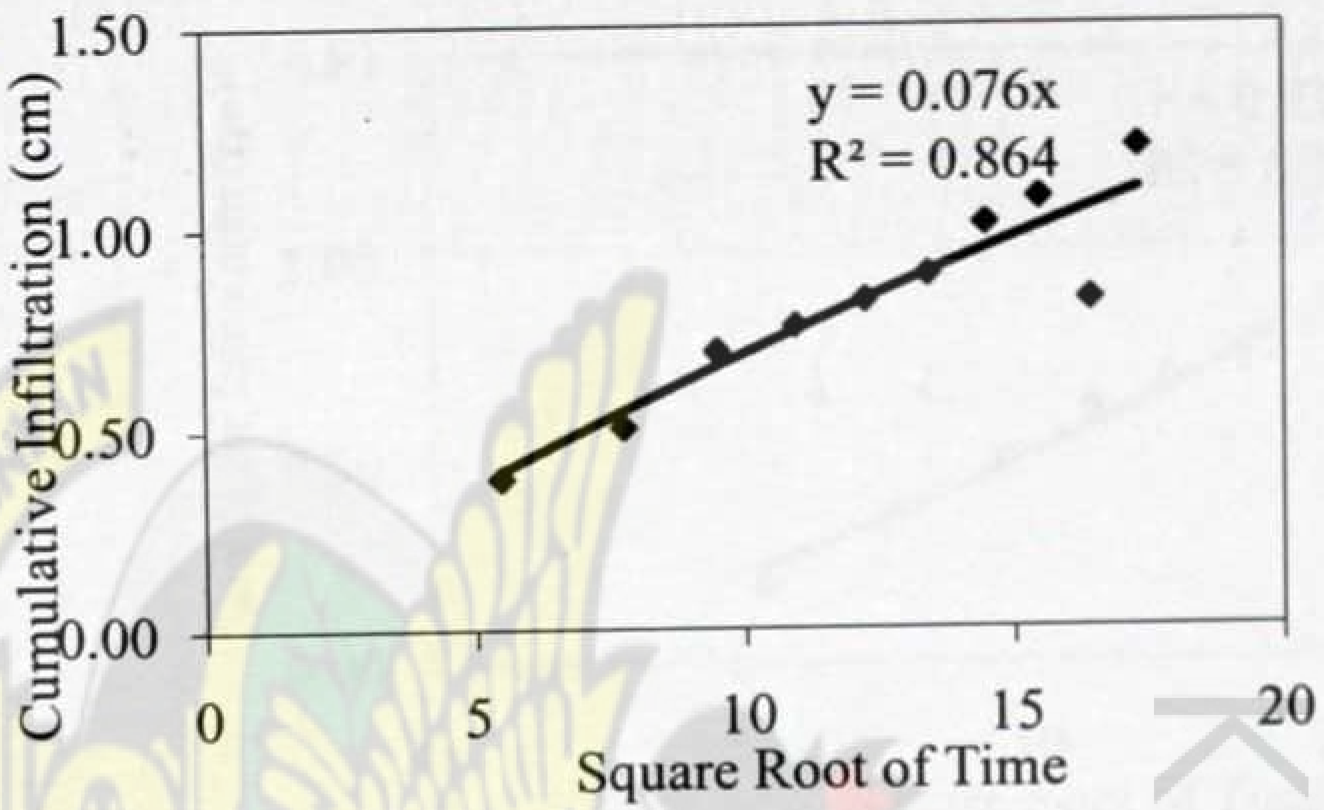
Soil Dry Bulk Density		Soil Wet Bulk Density		Moisture Content		Particle Density		Porosity		Air Filled Porosity	
5cm	10cm	5cm	10cm	5cm	10cm	5cm	10cm	5 cm	10 cm	5cm	10cm
1.3	1.2	1.5	1.4	15.4	12.5	1.5	1.4	0.509	0.547	-22.59	-16.95
1.4	1.5	1.7	1.7	15.4	14.1	1.7	1.7	0.472	0.434	-25.71	-23.54
1.4	1.4	1.6	1.6	14.8	13.1	1.6	1.6	0.472	0.472	-23.21	-20.49
1.4	1.5	1.7	1.9	22.2	21.9	1.7	1.9	0.472	0.434	-37.27	-41.18
1.4	1.4	1.6	1.6	14.6	12.1	1.6	1.6	0.472	0.472	-22.89	-18.89
1.4	1.4	1.6	1.6	13.4	10.7	1.6	1.6	0.472	0.472	-20.97	-16.65
1.5	1.7	1.8	2	23.6	17.6	1.8	2.0	0.434	0.358	-42.05	-34.84
1.5	1.6	1.9	1.9	24.2	20	1.9	1.9	0.434	0.396	-45.55	-37.60
1.3	1.6	1.8	1.9	32.5	23.6	1.8	1.9	0.509	0.396	-57.99	-44.44
1.3	1.5	1.5	1.7	11.5	14.2	1.5	1.7	0.509	0.434	-16.74	-23.71
1.3	1.3	1.5	1.5	10.5	12	1.5	1.5	0.509	0.509	-15.24	-17.49
1.3	1.3	1.5	1.5	9.7	10.9	1.5	1.5	0.509	0.509	-14.04	-15.84
1.3	1.4	1.4	1.5	10.5	10.5	1.4	1.5	0.509	0.472	-14.19	-15.28
1.3	1.5	1.5	1.7	12.7	12.1	1.5	1.7	0.509	0.434	-18.54	-20.14
1.3	1.5	1.4	1.6	11.3	11.6	1.4	1.6	0.509	0.434	-15.31	-18.13
1.5	1.6	1.7	1.9	18.4	18.3	1.7	1.9	0.434	0.396	-30.85	-34.37
1.4	1.5	1.8	1.9	29.7	23	1.8	1.9	0.472	0.434	-52.99	-43.27
1.5	1.6	1.8	1.9	17	19.9	1.8	1.9	0.434	0.396	-30.17	-37.41

APPENDIX 7 MINI-DISC INFILTROMETER RESULTS

POINT 1

Time (s)	Square root (t)	Volume (mL)	Infiltration (cm)
0		90	0
30	5.48	89	0.06
60	7.75	80	0.63
90	9.49	77	0.82
120	10.95	75	0.94
150	12.25	73	1.07
180	13.42	70	1.26
210	14.49	68	1.38
240	15.49	66	1.51
270	16.43	60	1.89
300	17.32	53	2.33

POINT 1 cumulative infiltration gradient C_1

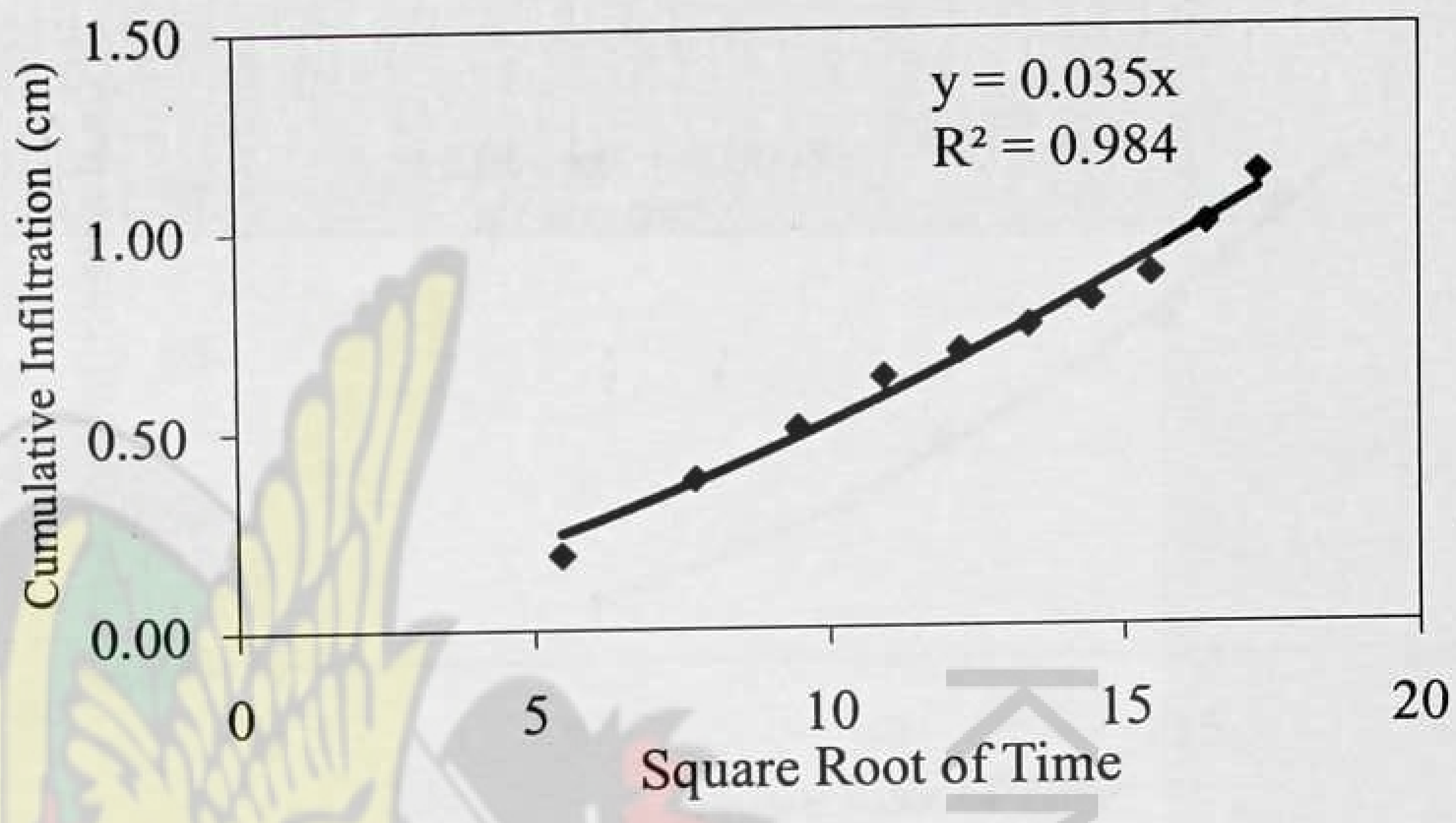


$$K = \frac{C_1}{A} = \frac{0.0008}{2.43} = 0.000329\ cm\ s^{-1}$$

POINT 2

Time (s)	Square root (t)	Volume (mL)	Infiltration (cm)
0		90	0
30	5.48	87	0.19
60	7.75	84	0.38
90	9.49	82	0.5
120	10.95	80	0.63
150	12.25	79	0.69
180	13.42	78	0.75
210	14.49	77	0.82
240	15.49	76	0.88
270	16.43	74	1.01
300	17.32	72	1.13

POINT 2 cumulative infiltration gradient C_1

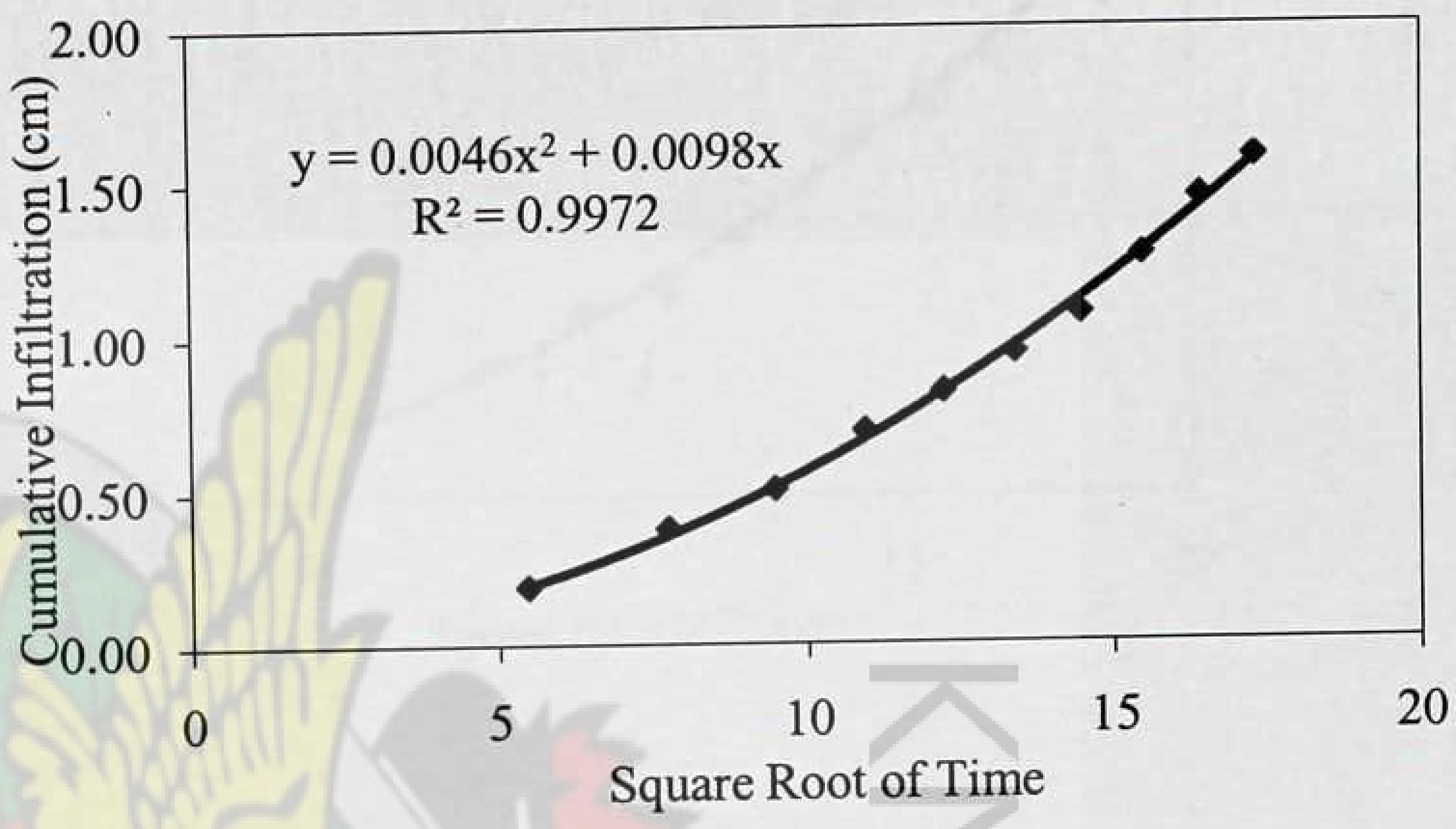


$$K = \frac{C_1}{A} = \frac{0.0016}{2.43} = 0.000658\ cm\ s^{-1}$$

POINT 3

Time (s)	Square root (t)	Volume (mL)	Infiltration (cm)
0		90	0
30	5.48	87	0.19
60	7.75	84	0.38
90	9.49	82	0.5
120	10.95	79	0.69
150	12.25	77	0.82
180	13.42	75	0.94
210	14.49	73	1.07
240	15.49	70	1.26
270	16.43	67	1.45
300	17.32	65	1.57

POINT 3 cumulative infiltration gradient C_1

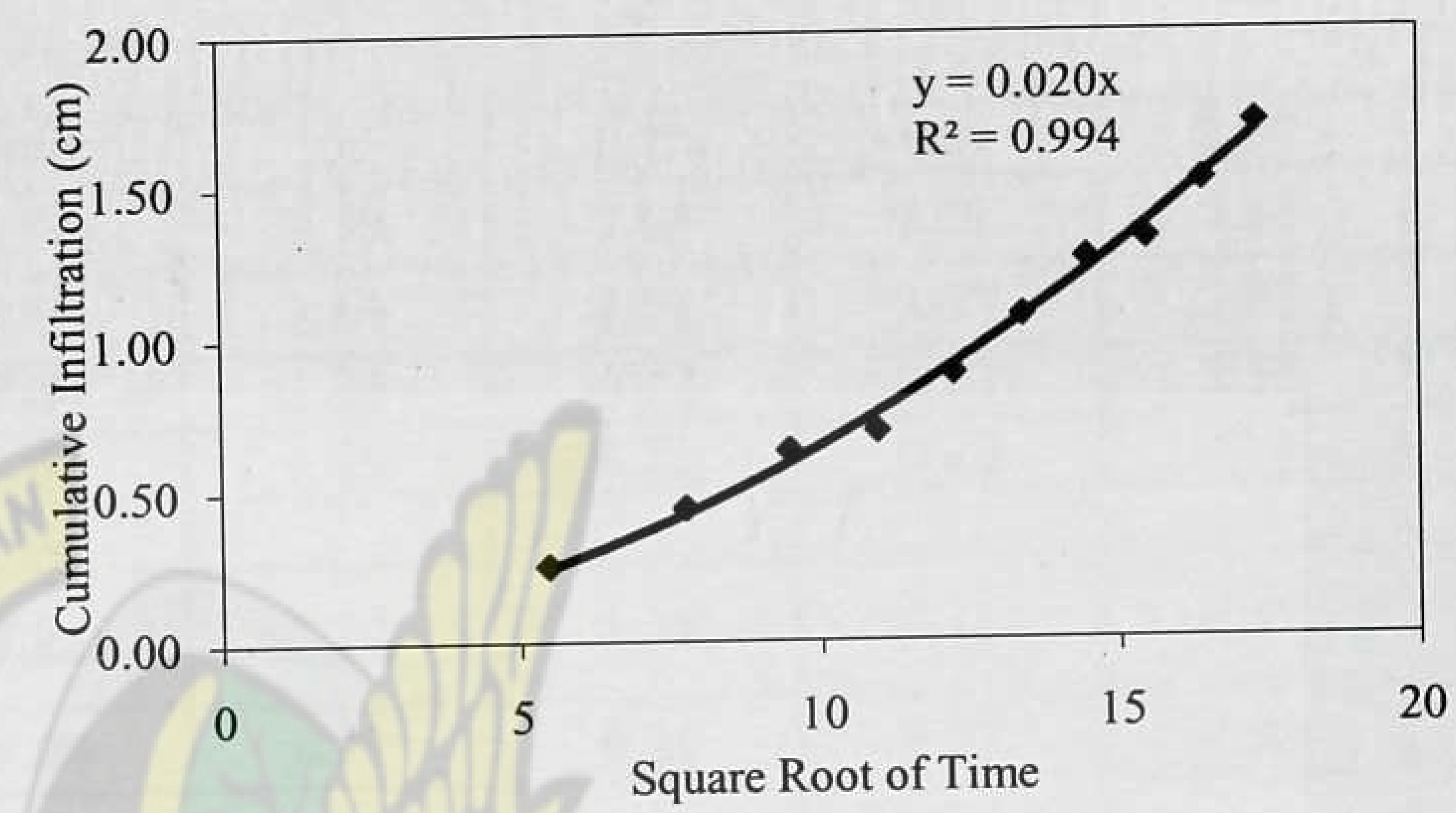


$$K = \frac{C_1}{A} = \frac{0.0046}{2.43} = 0.00189\ cm\ s^{-1}$$

POINT 3

Time (s)	Square root (t)	Volume (mL)	Infiltration (cm)
0		90	0
30	5.48	86	0.25
60	7.75	83	0.44
90	9.49	80	0.63
120	10.95	79	0.69
150	12.25	76	0.88
180	13.42	73	1.07
210	14.49	70	1.26
240	15.49	69	1.32
270	16.43	66	1.51
300	17.32	63	1.7

POINT 3 cumulative infiltration gradient C_1



$$K = \frac{C_1}{A} = \frac{0.0044}{2.43} = 0.00181\ cm\ s^{-1}$$

van Genuchten parameters for 12 soil texture classes and A values for a 2.25 cm disk radius and suction values from 0.5 to 6 cm

Texture			ho						
			-0.5	-1	-2	-3	-4	-5	-6
		n	A						
Sand	0.145	2.68	2.84	2.4	1.73	1.24	0.89	0.64	0.46
loamy sand	0.124	2.28	2.99	2.79	**2.43**	2.12	1.84	1.61	1.4
sandy loam	0.075	1.89	3.88	3.89	3.91	3.93	3.95	3.98	4
Loam	0.036	1.56	5.46	5.72	6.27	6.87	7.53	8.25	9.05
Silt	0.016	1.37	7.92	8.18	8.71	9.29	9.9	10.55	11.24
silt loam	0.02	1.41	7.1						
sandy clay loam	0.059	1.48	3.21	3.52	4.24	5.11	6.15	7.41	8.92
clay loam	0.019	1.31	5.86	6.11	6.64	7.23	7.86	8.55	9.3
silty clay loam	0.01	1.23	7.89	8.09	8.51	8.95	9.41	9.9	10.41
sandy clay	0.027	1.23	3.34	3.57	4.09	4.68	5.36	6.14	7.04
silty clay	0.005	1.09	6.08	6.17	6.36	6.56	6.76	6.97	7.18
Clay	0.008	1.09	4	4.1	4.3	4.51	4.74	4.98	5.22

APPENDIX 8 SOIL CLASSIFICATION, OC%, OM% MODEL PARAMETERS

Sampling points	Depth (cm)	Sand %	Silt	Clay %	O.C %	O.M %	Measured Ks (cm/s) X 10^{-4}	Bulk density (g/cm^3)	Simulated Ks (bulk density) (cm/s) $y = 0.0013X^{-1.469}$ X 10^{-4}	MDD (g/cm^3)	Simulated Ks (MDD) (cm/s) $y = 0.0013X^{-1.469}$ X 10^{-4}	Texture
WP 18	20	82.50	10.46	7.04	0.98	1.69	7	1.31	7.9	1.846	5.2	Loamy sand
	40	81.22	3.42	15.36	0.42	0.72	6	1.42	7.2	1.922	5	Sandy Loam
	60	82.26	2.38	15.36	0.34	0.58	5	1.42	7.2	2.030	4.6	Sandy Loam
WP 19	20	84.76	5.88	9.36	0.98	1.69	11	1.30	8	1.860	5.2	Loamy sand
	40	84.32	2.48	13.2	0.34	0.58	7	1.42	7.2	1.960	4.8	Loamy sand

	60	83.30	1.42	15.28	0.32	0.55	7	1.41	7.2	1.960	4.8	Sandy Loam
WP 21	20	83.30	7.34	9.36	0.98	1.69	14	1.36	7.6	1.836	5.2	Loamy sand
	40	79.34	5.38	15.28	0.76	1.31	7	1.37	7.5	1.910	5	Sandy Loam
	60	77.36	5.36	17.28	0.44	0.76	7	1.41	7.2	1.940	4.9	Sandy Loam
WP22	20	83.96	8.76	7.28	1.02	1.75	1.1	1.30	8	1.912	5	Loamy sand
	40	82.98	7.98	9.04	0.52	0.89	8	1.48	6.8	1.936	4.9	Loamy sand
	60	80.50	4.14	15.36	0.46	0.79	6	1.45	7	1.916	5	Sandy Loam

Appendix 9 soil dry and wet bulk densities, moisture content, particle density, porosity and air filled porosity

Soil Dry Bulk Density		Soil Wet Bulk Density		Moisture Content		Particle Density		Porosity		Air Filled Porosity	
5cm	10cm	5cm	10cm	5cm	10cm	5cm	10cm	5 cm	10 cm	5cm	10cm
1.3	1.2	1.5	1.4	15.4	12.5	1.5	1.4	0.509	0.547	-22.59	-16.95
1.4	1.5	1.7	1.7	15.4	14.1	1.7	1.7	0.472	0.434	-25.71	-23.54
1.4	1.4	1.6	1.6	14.8	13.1	1.6	1.6	0.472	0.472	-23.21	-20.49
1.4	1.5	1.7	1.9	22.2	21.9	1.7	1.9	0.472	0.434	-37.27	-41.18
1.4	1.4	1.6	1.6	14.6	12.1	1.6	1.6	0.472	0.472	-22.89	-18.89
1.4	1.4	1.6	1.6	13.4	10.7	1.6	1.6	0.472	0.472	-20.97	-16.65
1.5	1.7	1.8	2	23.6	17.6	1.8	2.0	0.434	0.358	-42.05	-34.84
1.5	1.6	1.9	1.9	24.2	20	1.9	1.9	0.434	0.396	-45.55	-37.60
1.3	1.6	1.8	1.9	32.5	23.6	1.8	1.9	0.509	0.396	-57.99	-44.44
1.3	1.5	1.5	1.7	11.5	14.2	1.5	1.7	0.509	0.434	-16.74	-23.71
1.3	1.3	1.5	1.5	10.5	12	1.5	1.5	0.509	0.509	-15.24	-17.49
1.3	1.3	1.5	1.5	9.7	10.9	1.5	1.5	0.509	0.509	-14.04	-15.84
1.3	1.4	1.4	1.5	10.5	10.5	1.4	1.5	0.509	0.472	-14.19	-15.28
1.3	1.5	1.5	1.7	12.7	12.1	1.5	1.7	0.509	0.434	-18.54	-20.14
1.3	1.5	1.4	1.6	11.3	11.6	1.4	1.6	0.509	0.434	-15.31	-18.13
1.5	1.6	1.7	1.9	18.4	18.3	1.7	1.9	0.434	0.396	-30.85	-34.37
1.4	1.5	1.8	1.9	29.7	23	1.8	1.9	0.472	0.434	-52.99	-43.27
1.5	1.6	1.8	1.9	17	19.9	1.8	1.9	0.434	0.396	-30.17	-37.41

In-situ bulk density and seepage loss potential of 20 and 40 cm

Bulk density	Seepage loss potential % (20 cm)	Seepage loss potential % (40 cm)
1.2	35.6	47.39
1.3	30.26	40.91
1.4	24.89	34.15
1.5	19.53	27.12
1.6	14.16	19.88
1.7	8.8	12.85
1.8	3.43	5.21