THE EFFECT OF TILLAGE ON MOISTURE RETENTION IN SOILS: A CASE OF VOLCANIC SOILS OF EASTERN MAU, KENYA

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DECLARATION and RECOMMENDATION

DECLARATION

I declare that this thesis is my original work and that it has not been submitted to any other University for an award of Degree.

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ABSTRACT

Only 20% of Kenya's land mass is suitable for rain fed agriculture. In the past few years this has been adversely affected by the temporal and spatial variability of rainfall. There is evident deficit of moisture at critical stages of crop growth. This has occasionally led to poor yields and every so often crop failure. The soils in the study are mainly loamy sand (*mollic andosols*). These are volcanic ash soils which are associated with *pyrocrastic* parent materials. They are well drained, an attribute that augments the moisture stress problem. Different tillage systems in these soils appear to have varying effects on soil moisture retention as evidenced by early wilting of crops on some fields. The aim of the study was to determine soil moisture retention characteristics under different tillage systems. The results were achieved by studying changes of soil moisture characteristics in the profile under different tillage systems and evaluating temporal moisture variations in the root zone. A Randomized Complete Block Design with four tillage treatments (i.e. Conventional Tillage-CT, Minimum Tillage-MT, Zonal Tillage-ZT, NoTillage-NT), replicated three times was set up at the Kenya Agricultural Research Institute - Njoro located in Eastern Mau. Samples for soil moisture determination were taken on a weekly basis at 6 depth levels of 10cm interval down the profile to a depth of 60cm. A Neutron probe, pressure plate moisture meter, permeameter and double ring infiltrometer were used in determination of moisture retained, matric potential, hydraulic conductivity and infiltration rate respectively. Soil physical characteristics were determined before and after the treatments. Data was analysed using SAS. Moisture retention levels due to tillage treatment were found to decrease in the order CT>ZT>NT>MT with values of 30.6, 21.6, 14.1 and 10.8 respectively. Soil textural analysis revealed a rich gradation. Soil texture was found to be sandy loam with an infiltration rate of 10-30mmh^{-1} classified as moderate to fast. Results of this study are applicable to farmers under similar environment in selection of suitable tillage equipment for desired soil moisture conservation.

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LIST OF SYMBOLS AND ABBREVIATIONS

amsl	-	Above Mean Sea Level
AP	-	Troxler Sentry 200-Ap
AQ	-	Aquaterr Probe
ASTM	-	American Society for Testing Materials
AWC	-	Available Water Capacity
CHP	-	Chisel Ploughing
cpm	-	Counts per minute
CT	-	Conventional Tillage
CU	-	Cultivator
CV	-	Coefficient of Variability
DAS	-	Days after Sowing
DP	-	Disk Plough
DPH	-	Disk Plough Followed By Harrow
DPHR	-	Disk Ploughing Followed By Harrowing and Ridging
FWC	-	Field Water Capacity
GB	-	Gypsum Block
GLM	-	Generalized Linear Model
GS	-	Gravimetric Sampling
IR	-	Infiltration rate
KMS	-	Kenya Meteorological Station
K_s	-	Saturated Hydraulic Conductivity
MT	-	Minimum Tillage
NARL	-	National Agricultural Research Laboratories
NP	-	Neutron Probe
NPBRC	-	National Plant Breeding Research Centre
NT	-	No Tillage
NWP	-	Numerical Weather Prediction
OTC	-	Official Testing Centre
P	-	Exceedence Probability
PAW	-	Plant Available Water

PH	-	Plough Harrow
PP	-	Plough-Plough tillage
PSM	-	Profile Soil Moisture
SAMs	-	Super absorbent materials
SAS	-	Statistical Analysis Software
SCS	-	Soil Conservation Service (SCS)
SIRMOD	-	Surface Irrigation Modelling
SWCC	-	Soil Water Characteristic Curve
SWR	-	Soil Water Retention
TDR	-	Time Domain Reflectometry
TM	-	Tensiometer
USCS	-	Unified Soil Classification System
USDA	-	United States Department of Agriculture
WB	-	Watermark Block
WSA	-	Water Stable Aggregation
Z	-	Reflectivity
ZT	-	Zone Tillage
ε	-	Porosity
ρb	-	Bulk Density

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CHAPTER ONE
INTRODUCTION

1.0 Background

Plant growth is seriously affected by abiotic stresses such as drought, salinity or temperature. Drought is one of the most important limiting factors for agricultural crops and vegetable production in particular, all around the world (Pervez *et al.*, 2009). Drought stress during vegetative or early reproductive growth usually reduces yield by reducing the number of seeds, seed size and seed quality. During the last decade or so, it has been observed that areas which previously had sufficient rainfall for crop production are now experiencing shortages due to unreliable rainfall amounts and distribution (Rowntree, K.M. 1989). Informed adoption of tillage methods may be among measures to cope with the decreases in soil moisture within soil profiles under rain fed agriculture.

In Eastern Mau, it has been observed that there is a consistent nature of little or no rain in the month of June every year (Meteorological Department of Kenya 1929-2011). But, the shortfall has increased in recent times. The main planting period in the area lasts from late March to early May. The June drought always poses a danger of yield loss it occurs when most annual crops are at their critical growth stage. Drought during this period can reduce maize yields by 10 to 50 percent (Heininger, *et. al.,* 2002). The amount of yield loss that occurs during dry weather depends on the growth stage of the crop and the magnitude of the dry conditions. The severity of moisture deficit in loamy sand soils (*mollic andosols*) is worsened by the inherent high drainage rate. This calls for the understanding of target soil properties and how they affect moisture retention, in order to allow manipulation for improved moisture retention. One way of increasing rainwater penetration and decreasing the risk of crop production failure is through conservation tillage (Smolikowski *et al.*, 2001).

According to Payne *et al.*, (1990) the proportion of moisture retained in the root zone could even be more crucial to increased productivity than the total rainfall. Poor moisture retention in these soils stems more from the ensuing unfavourable pore size distribution which results in high infiltration rate and hydraulic conductivity. The key to successful rain fed agriculture is the enhancement of moisture in the soil profile (Laddha *et al.*, 1997). One of the key conditions for achieving this in the sub-Sahara Africa is to ensure effective infiltration of rainwater into the soil (Lal *et al.*, 1997). Tillage systems modify soil structure, temperature and water distribution (Waddell and Weil, 1996). Thus, tillage operations normally have tremendous influence on soil

moisture (Agriculture and Rural Development (JICA), 2004). On the other hand, the Conventional Tillage (CT) conserves soil moisture through some complementary processes (Ali and Talukder, 2008). The implication of these peculiarities is that future crop production by the resource-poor farmers in Eastern Mau may remain water-constrained if no viable soil and water conservation practices are devised. These points to the need for a study with respect to moisture conservation in loamy sand soils to determine the most suitable tillage system amongst the CT, MT, ZT, and NT. So far present, no work has been done to evaluate the effect of these tillage systems on soil moisture status during the growing season without a crop. Therefore, the temporal variations in soil moisture status and depletion pattern under rain fed condition were monitored at KARI-Njoro Station. This was done with the objective of establishing the relative impact of CT, MT, ZT and NT on moisture retention in the soil profile. The adaptation and adoption of conservation tillage techniques can reduce and reverse current trends, but these options need to be identified and communicated to resource-poor farmers (Fowler and Rockstrom, 2000).

Eastern Mau is dominated by loamy sand soils (Mainuri, 2004). These soils are deep, fertile, easily drained, and worked. These attributes enable the soils to be tilled using most tractor tillage attachments (SUMAWA 2003-2004). This explains why there are multiple tillage operations employed by farmers in the region. Conventional tillage (CT) in the study area is composed of a combination of one disc plough; two disc harrows followed by one light tine pass (Mwangi, *et al.*, 2008). The commonly used tractors have an axle load ranging from 1.5 to 10Mg. The use of heavy machinery for tillage tends to emphasize a fine consolidated seedbed, which impedes soil water infiltration and accelerates soil erosion (Rahman *et al.*, 2004). In Zimbabwe, there was a trend of increasing ploughing depth to 30cm or more, but field results did not justify this increase (Gill *et al.*, 1960).

1.1 Statement of the Problem

Small scale farmers in Eastern Mau prepare their land using various tillage systems and customarily depend on rainfall as the main source of moisture for crop production. At the end of the long rains occurring from March – May, crops invariably suffer from moisture stress yet this corresponds to the critical growth period for annual food crops (i.e. booting, tussling and flowering) when moisture demand is highest. Insufficient moisture in the soil at this critical stage results in poor development, pollination and filling consequently to crop growth or complete

failure. There is limited information on soil moisture retention trends as influenced by tillage. This makes it difficult for farmers to adopt a specific tillage system that maximizes moisture retention.

1.2 Objectives

The broad objective of this study was to investigate the influence of tillage systems on moisture retention in soils as exhibited by loamy sand soils of Eastern Mau

The specific objectives of the study were:

(i) To characterize the physical properties of loamy sand soils of Eastern Mau

(ii) To evaluate changes in moisture retention in varying soil profiles under different tillage systems.

1.3 Hypotheses

The hypothesis for the study were;

Tillage systems have no effect on the amount of moisture retained in loamy sand soil profiles.

$H_{o1}: \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$

$H_{a1}: \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4$

Depth has no effect on the amount of moisture retained in the soil profiles.

$H_{o2}: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$

$H_{a2}: \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6$

1.4 Justification

While numerous papers have been written on tillage and soil moisture conservation practices, little specific research has been done successfully about tillage effects on moisture retention in soils of Eastern Mau. Most of the research into the tillage area has explored crop relations with soil and water applications and none has addressed water dynamics and tillage influence on moisture retention within the root zone. Drought during tussle/silking/booting to maturity period lowers kernel weight. Severe drought can reduce maize yields by 20 to 30 percent (Heiniger, 2000). Kenya has recently experienced periodic food shortages partly attributable to intermittent but severe droughts (FAO, 1997). Consequently, there is need to develop tillage systems that retain moisture for efficient utilization of limited and unpredictable rain water. An appropriate tillage practice consistent with the principles of water conservation and sustainability will reduce the severity of drought. The findings from the study will be useful to farmers in selecting a tillage

system within volcanic ash dominated soils of Eastern Mau covering Naivasha, Gilgil, Menengai, Rongai, Elburgon and upper Narok areas for increased crop yields. These areas are among the major wheat, barley and potato producers in the country (DAO Njoro. 2011). The study will contribute to bridging the academic gap on the choice of tillage systems for higher moisture retention in loamy sand soils.

1.5 Scope of the Study

The study focused on determination of moisture retained in volcanic soils through employing field and laboratory methods in characterizing soil physical properties that influence infiltration rate, moisture retention and monitoring the effect of different tillage systems on soil physical properties.

CHAPTER TWO
LITERATURE REVIEW

2.0 Introduction to the literature review

Moisture is the single most limiting factor to crop yields. Soil moisture content and retention depends on a number of factors, some soil based, others external. Among the soil based factors influencing soil water content and retention are a number of soil physical characteristics of which the following are the most important; soil profile, texture, structure, water, porosity, bulk density, particle density, soil water potential, soil salinity and chemical composition, pH, infiltration characteristics, hydraulic conductivity, particle size distribution and mineralogical properties. Soil physical characterization is the classification of soil material to discover its properties.

2.1 Characterization of soil physical properties

2.1.1 Topography

Topography or relief affects organic matter content through its influence on rainfall runoff/retention. Local variations in topography, such as knolls, slopes, and depressions, have profound effect on moisture retention in the upper portion of the soil, and thus organic matter content. Soils occurring in depressions, particularly those with restricted drainage; usually have high organic matter contents because the anaerobic conditions that prevail during wet periods which lead to the preservation of organic matter (Stevenson, 1986).

In field watershed and regional scale projects, soil water retention is often estimated from soil textural classes shown in soil maps. The textural classes are relatively broad, often only dominating textural classes are shown. Cartographers routinely use error-prone field judgments of soil texture yet soil texture is known to vary along slopes and to depend on the land surface shape (Rawls and Pachepsky, 2002). While monitoring moisture retained in a specific location, the inherent slope should be well defined since it will explain differences in soil moisture reading. The difference may not vary significantly on a small plot but becomes evident on a large field that may span several slopes.

2.1.2 Profile

Soil profile is the vertical section of soil from the ground surface to the parent rock showing different layers known as horizons. Three different horizons have been identified in soil study as A, B, and C horizons respectively. The three soil horizons have some distinct characteristics e.g.,

colour, texture, structure, consistence, and porosity and soil reaction. Different horizons may be several centimetres thick or as thin as a fraction of a centimetres. The horizons generally merge with one another and may or may not show sharp boundaries. Horizons in a soil profile are like the parts of a layered cake without the clear bonds between them.

Patterns of water replenishment and use, give rise to large spatial variations in soil moisture over the depth of the soil profile. Accurate measurements of profile water content are therefore the basis of any water budget study. When monitored accurately, profile measurements show the rates of water use, amounts of deep percolation, and amounts of water stored within.

In calorimetry, the Munsell colour system is a colour space that specifies colours based on three colour dimensions: hue, value (lightness), and chroma (colour purity). It was created by Professor Albert H. Munsell in the first decade of the 20th century and adopted by the USDA as the official colour system for soil research in the 1930s (Kuehni, 2002), this is the most common method used in soil profile identification.

Sources of soil profile guidelines are; from USDA Soil Survey Manual; Revised Legend of the Soil Map of the World; Keys to Soil Taxonomy; Australian Soil and Land Survey Field Handbook; World Reference Base for Soil Resources; USDA Field Book for Describing and Sampling Soils (1999); Soil Taxonomy and (2003) Keys to ST. AG-Boden (2004). KA5: Bodenkundliche Kartieranleitung -5. Auflage.

2.1.3 Root Zone Depth

Effective rooting depth is generally estimated as one half of the maximum rooting depth in unrestricted soil profile. It is where the majority of crop roots active in water and nutrient uptake are found. Maximum rooting depth is defined as the extreme depth attained by a crop for any specific soil situation. Effective rooting depths vary with crop and soils. Soil depth forms the third dimension of the overall soil water reservoir determination. It is therefore an important consideration in the determination of soil water content and retention. It forms the lower boundary of crop production related activities e.g. tillage. It also forms the lower limit of bio-activities for the improvement of soil plant environment. Root zone depth could be determined through an observation pit by measuring the extent of root penetration in unimpeded soil profile.

In most landscapes, soil is the major water storage site for plants. Once water has entered the soil profiles through precipitation, irrigation, run-off, or seepage, water penetrates the soil surface through infiltration. Water infiltrates into sandy soils much more quickly than into clayey soils.

To prevent water waste via runoff, gardeners should take the soil's infiltration rate into account when scheduling landscape irrigation. Once water infiltrates the soil surface, it percolates downward and sideways through the soil profile. Water moves rapidly through large soil pores, and slowly through small pores. Therefore, sandy soils with primarily large pores will accept and release water readily. On the other hand, clayey soils with primarily small pores will wet and dry slowly. After water percolates through the soil profile, some of the water will be stored in small pores, and a water films surrounding soil particles. Plants can use some of the stored water (called plant-available water) by extracting it with their roots.

However, some of the water is held so tightly by small pores or particle surfaces that plant roots cannot extract it. This water is unavailable to plants. When plants need more water than is available in the soil, they experience water stress. Because water is a component of photosynthetic, photosynthesis stops and growth stops. Furthermore, water stress compromises plant defence systems, making them more susceptible to abiotic stress factors as well as insect and disease problems. Some soils store more water than others. The amount of water held in the soil and available to plant depends on the following factors: Clay content (the amount of small pore space) to hold water, Soil organic content (Organic matter holds ten times more water than sand) and Rooting depth (Plants with deeper roots reach a larger water supply).

2.1.4 Soil Volume, Mass Properties

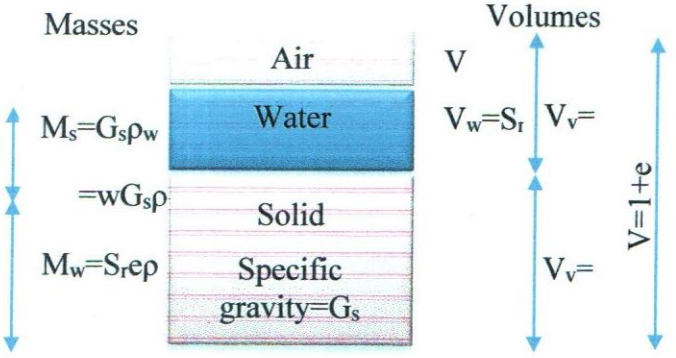


Figure 2:1 Soil Air, Solid,Water Volume ratio

The volume-weight properties of a soil define its state. Soil comprises three constituent phases: Solid, Liquid and Gases. In natural soils the three phases are intermixed. The three phases of the soil system have definite roles to play. The solid phase provides mechanical support and nutrients to the plants, the liquid phase supplies water along with it, dissolved nutrients to plant

roots. To aid analysis it is convenient to consider a soil model in which the three phases are seen as separate in their correct proportions (Figure: 2.1) above.

2.1.5 Soil Solid Phase

The solid phase of soils consists of both inorganic and organic components. Inorganic components range in size from tiny colloids (< 2μm) to large gravels (>2mm) and rocks, and include many soil minerals, both primary and secondary. Inorganic components usually control soil properties and its suitability as a plant growth medium. Organic components include plant and animal residues at various steps of decomposition, cells and tissues of soil organisms (0.5 – 5% of the solid phase). Yet, they can significantly alter soil properties even though their quantities may be small relative to the inorganic component.

2.1.6 Soil liquid Phase

About 50% of the bulk volume of the soil body is generally occupied by voids or soil pores which may be completely or partially filled with water. A considerable part of the rain which falls on soil is absorbed by the soil and stored in it to be returned to the atmosphere by direct evaporation or by transpiration through plants. The soil acts as the reservoir for supplying water to plants for their growth. The soil water keeps salts in solution which act as plant nutrients. Thus, the liquid phase is an aqueous solution of salts, when water drains from soil pores are filled with air.

2.1.7 Soil Gaseous Phase

The air filled pores in a soil constitutes the gaseous phase of soil system and dependent on that of the liquid phase. The nitrogen, (N) and oxygen, (O_2) contents of soil air are almost the atmospheric air but the concentration of carbon dioxide (CO_2) is much higher (8 – 10 times more) which may be toxic to plant roots. This phase supplies O_2 and thereby prevents CO_2 toxicity.

2.1.8 Soil Texture

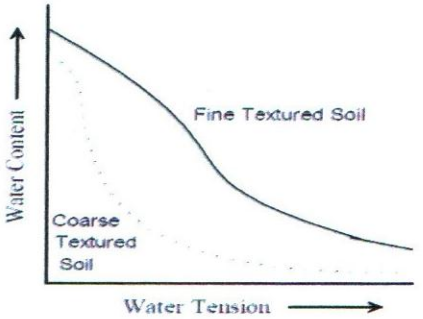


Figure 2:2 Comparing the effect of tension on moisture content in different soil texture

Soil is a three phase system comprising of soil solids, liquid, and gaseous phase or soil air. The solid phase of the soil comprises of on one part mineral particles, and on the other, the soil organic matter. The soil particles are derived from the parent material forming the soil. The solid phase is made up of three major classes in relative proportions termed sand, silt and clay. Soil texture refers to the relative proportions of particles of sand, silt and clay in the soil.

Texture influences the ease with which soil can be worked, the amount of water and air it holds and the rate at which water can enter and move through soil (FAO, 2008). Clayey soils retain more water (Figure 2.1), and tend to retain it longer than sandy soils (NRCS, 2012). Separates are illustrated in Table 1, showing the international system (SI) and the United States Department of Agriculture (USDA) standards.

Table 2: 1 Classification of Soil Separates

	Diameter Range Separates (mm)	
Separates	USDA	International System
Sand	2.00 - 0.05	2.00 - 0.02
Silt	0.05 - 0.002	0.02 - .002
Clay	< 0.002	< 0.002

2.1.8.1 Soil Textural Analysis

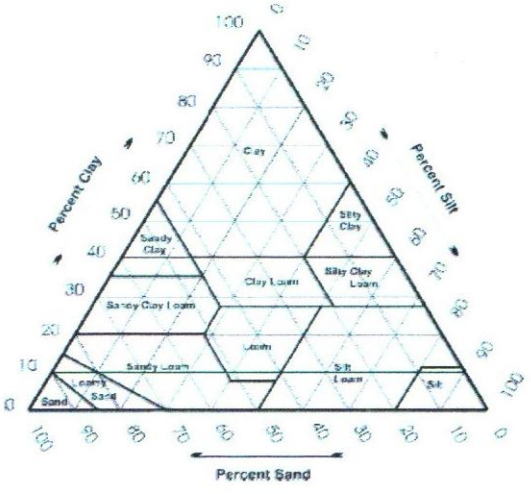


Figure 2:3 Textural Triangle

According to the United States Department of Agriculture (USDA) system of classification, there are 12 textural classes (as shown on the textural triangle in Figure 2.2). Commonly used methods to determine soil texture include:

a. Feel soil texture estimation method which is qualitative, but with experience many people can easily discern the different textural classes.
b. Separation by sieving which is mostly used for sand fractionation only (or between 0.05 and 2 mm diameter particles) using American Society for Testing & Materials (ASTM) sieve numbers between 270 or 300 and 10 (openings/inch), respectively. One limitation is that the probability of a particle passing through a sieve in a given time of shaking depends on the nature of the particle, the number of particles of that size, and the properties of the sieve (e.g., particle shape and sieve-opening shape affect probability of passage) (Gee & Bauer 1986). Sieving may be accomplished using either a wet (washing type) or dry method.
c. Separation by sedimentation is type of analysis depends fundamentally upon Stokes' Law. One form of this equation is:

$$v = g\frac{(\rho_2 - \rho_1)\chi^2}{(18\eta)}\pi r^2 \qquad \text{eqn (2.1)}$$

Where;

g = acceleration due to gravity,
v= particle velocity of fall,
g = acceleration due to gravity,
ρ_2= particle density,
ρ_1= liquid density

d. The pipette method is often used as the standard to which other methods are compared. It depends upon the fact that sedimentation eliminates from the depth, h, in a time, t, all particles having settling velocities greater than h/t, while retaining at that depth the original concentration of particles having settling velocities less than h/t (Sheldrick & Wang 1993; Gee & Bauder 1986).
e. The Bouyoucos hydrometer method is somewhat less accurate than the pipette method, but is easier to perform. The theory of the hydrometer method is similar to that of the pipette method except for the manner of determining the concentration of solids in

suspension. The large size of hydrometer bulb necessary to give adequate sensitivity reduces the depth discrimination of the instrument, but this limitation can be overcome by a simple correction (Day, 1965).

Depending on the degree of accuracy of separation required and the particle sizes of interest, the hydrometer method is well adapted for fast determinations of general categories of sizes present and is used in analyses.

2.1.9 Pedo-transfer Function

In soil science, pedotransfer functions (PTF) are predictive functions of certain soil properties using data from soil surveys. The term pedotransfer function was coined by Bouma, (1989), as translating data we have into what we need. The most readily available data come from soil survey, such as field morphology, soil texture, structure and pH. Pedotransfer functions add value to this basic information by translating them into estimates of other more laborious and expensively determined soil properties.

These functions fill the gap between the available soil data and the properties which are more useful or required for a particular model or quality assessment. Pedotransfer functions utilize various regression analysis and data mining techniques to extract rules associating basic soil properties with more difficult to measure properties. Although not formally recognized and named until 1989, the concept of the pedotransfer function has long been applied to estimate soil properties that are difficult to determine. Many soil science agencies have their own (unofficial) rule of thumb for estimating difficult-to-measure soil properties. Probably because of the particular difficulty, cost of measurement, and availability of large databases, the most comprehensive research in developing PTFs has been for the estimation of water retention curve and hydraulic conductivity.

2.1.10 Soil Structure

Soil structure is defined by the way individual particles of sand, silt, and clay are assembled. Single particles when assembled appear as larger particles that are called aggregates. By definition, class of structure describes the average size of individual aggregates. Usually, five distinct classes may be recognized in relation to the type of soil structure from which they come (FAO, 2007). They are: very fine or very thin; fine or thin; medium; coarse or thick; and very

coarse or very thick. Soil structure plays an important role in root development, water retention, infiltration capacity and soil porosity (Guber et al., 2005).

Numerous methods proposed for characterizing soil structure are indirect methods and designed to measure soil attributes depending on soil structure, rather than the structure per se (Hillel, 1998). Although soil structural units resulting from fragmentation through the application of mechanical energy are widely referred to as aggregates, Diaz-Zorita et al. (2002) believed that the term aggregate should be confined to units formed by "building-up" soil processes such as cohesion, organic bonding, inorganic cementation and influence of roots and fungal hyphae. Soil structure is influenced by its physical, chemical and biological characteristics. Good soil structure is vital, as it can affect the availability of air, water and nutrients for plant growth.

The type of structure refers to the shape of the peds.

i. Granular structure is spherical shaped aggregates bounded by curved or very irregular surfaces which have slight or no accommodation to the faces of the adjoining ped faces. Particles are arranged around a point.

ii. Sub angular blocky structure is block like aggregation. The blocks are polyhedrons bounded by flattened or rounded faces and have rounded the faces of the corners. The faces are casts or molds formed by adjoining peds. Particles are arranged around a point.

iii. Angular blocky structure is similar to sub-angular blocky, but the polyhedrons are bound by flattened faces and have sharp edges or corners.

iv. Platy structure is plate-like aggregates with horizontal dimensions considerably greater than the vertical dimension. Particles are arranged about a horizontal plane.

v. Prismatic structure is prism-like aggregates with vertical dimension considerably greater than horizontal dimension. Particles are arranged about a vertical line. Peds are bounded by planer vertical faces which are casts or the molds formed by the faces of adjoining peds and have flat caps.

vi. Columnar structure is similar to a prismatic structure except that it has rounded caps.

vii. Single grained structure has no observable aggregation. Individual particles are non-coherent and easily distinguishable.

viii. Massive structure has no observable aggregation. Individual particles are coherent, but the mass lacks planes of weaknesses.

Soil structure determines the pore geometry which is decisive for water retention of the soil. Soil aggregation leads to another pore system referred to as macropores. These pores are larger

than the matrix pores and therefore control the water retention at low tensions. Usually at field capacity most of the inter-aggregate pores already lost their water. In a well-aggregated soil, the inter-aggregate macropores drain very quickly, while the intra-aggregate micropores tend to retain their moisture. Therefore dispersed or compacted soil with few macropores drains very slowly. Air entry and oxygen diffusion are thereby also affected. The soil structure and its influence on water retention cannot be easily described. Soil structure is not an easily a measurable soil parameter. While it is possible to describe the aggregation of a soil qualitatively it is not possible to relate aggregation to a metric scale or at least to an ordinal scale. A quantitative description is not possible. Soil structure is therefore, despite its influence on water retention never a direct input variable in pedo-transfer function (PTF), but other input parameters are considered because they are affected by soil structure. An example is soil bulk density, which is a common input variable of PTF, because of its dependence on the structure.

Soil structure refers to the aggregation of individual soil particles into compound groups or clusters of particles, Brady *et al.*,2008. These are separated by natural lines, zones or surfaces of weakness. Individual aggregates are referred to as peds. The grade, class and type of structure is usually described for each sample. If a sample lacks structural arrangement, it is considered to be structure less.

2.1.11 Soil Water Potential

Water potential is the 'measure of the ability of water molecules to move freely in solution'. All this means is that is a solution of pure water where there is no solute, all of the water molecules are free to move, so the water potential is high. If a solute is added to the solution, it is attracted to the water molecules, so those water molecules can no longer move freely and the water potential is lower. The highest possible water potential is in pure water (0% solute concentration), with a water potential of 0 kPa (kilo-Pascals). As solute is added this decreases, so a weak solution might have a water potential of -10 kPa, and a strong solution might have a potential of -300 kPa. In osmosis, water molecules move down the water potential gradient, from a high water potential (0 kPa) to a lower water potential (<0 kPa).

Direct measurement of soil water potential involves determining water pressure or water surface elevation relative to a datum (e.g., pressure transducer, standpipe water level, etc.), while indirect measurement involves measuring some surrogate property that correlates with water potential (e.g., electrical resistance or conductivity, water vapour pressure, water content, plant

xylem potential, etc.). For example, a direct determination of positive pore water potential is obtained from the elevation of the water surface in a piezometer pipe, while an indirect determination of negative water potential can be obtained from electrical resistance or relative humidity.

A variety of automated sensors are available, most being pressure-sensing devices based on piezoresistive, strain gauge, or vibrating wire diaphragms, or non-pressure sensing devices based on sonic, radar, or time-domain reflectometry (TDR) technologies. Young (2002) gives a detailed discussion of the setup and use of automated water level sensors. The main advantages of manual water level devices are that they are simple, inexpensive, rugged, and easily portable so that many piezometers can be measured using a single device. Important advantages of automated water level devices include greatly improved temporal resolution and acquisition of data in a format that can be directly downloaded into a computer spreadsheet.

2.1.12 Soil Porosity

Porosity is a measure of how much of a rock is open space. This space can be between grains or within cracks or cavities of the rock and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0 and 100%. There are many ways to test porosity in a substance or part, such as industrial CT scanning. The term porosity is used in multiple fields including pharmaceutics, ceramics, metallurgy, materials, manufacturing, earth sciences, soil mechanics and engineering. In geology, hydrogeology, soil science, and building science, the porosity of a porous medium (such as rock or sediment) describes the fraction of void space in the material, where the void may contain, for example, air or water. It is defined by a ratio of pore to solid. When the soil pore space is completely water-filled (relative saturation = 1), the soil volumetric water content is equal to the soil porosity, n (porosity is defined as the total volume of soil pore space per unit bulk volume of soil). Relative saturation is frequently expressed as an "effective saturation," S_e, which includes the residual soil water content, S_r, that is the "immobile" water remaining in air dry soil and retained in small isolated pores.

2.1.13 Soil Particle Density

Usually, particle density is expressed in units of grams per cubic centimetre (g/cm^{-3}). An average value for particle density is 2.66 g/cm^{-3}. This means that a soil particle that is 1 cubic centimetre in volume has a mass of 2.66 g. Soil bulk density, r_b, is defined as the ratio of dry soil

mass to bulk soil volume (including pore spaces). The SI unit for density is mega grams per cubic meter (Mg m^{-3}), which is numerically equivalent to grams per cubic centimetre. Particle density measurements provide information about the kinds of material present in a soil. If the particle density is high, we know that the parent material of the soil consists of minerals that have a high density.

2.1.14 Soil bulk density

Soil bulk density is the ratio of the oven-dried mass of soil to its volume either at time of sampling or at a specified moisture content. It is usually expressed in terms of grams per cubic centimetre (g/cm) or SI units of mega gram per cubic meter (Mgm^{-3}). Measurement of bulk density generally require cores or clods in their natural structure.

Bulk density measurements can be done to account for variability, it is useful to take several measurements at the same location over time and at different depths in the soil, for example at 10, 30 and 50 cm depths to look at both the surface soil and subsoil. It is also useful to measure the bulk density of when comparing management practices (e.g. cultivated vs. non-cultivated) as physical soil properties are often altered (Hunt and Gilkes, 1992).The most common method of measuring soil BD is by collecting a known volume of soil using a metal ring pressed into the soil (intact core), and determining the weight after drying (McKenzie et al., 2004).

Since bulk density is an index of packing of soil separates, and bulk density in conjunction with aggregates size decides the pore geometry in a soil a soil system, the changes in this two properties as brought about by various tillage and management practices, have far reaching consequences with respect to; (a) soil compaction, (b) soil pore space distribution and (c) the soil moisture status (retention and conduction)

2.1.15 Soil Compaction

It has frequently been recognized that compaction reduces total porosity and increases bulk density while also reducing the proportion of larger pores that play an important role in water movement and solute transport, nutrient availability, aeration, and crop productivity, owing to the limitation in root growth (e.g., Domz˙ et al., 1991;Mapfumo et al., 1998; Arocena, 2000). Agricultural field operations employed at various levels of mechanization depend heavily on wheeled tractors as a source of traction power. It is common practice to use the same tractor for different operational requirements. Hence soils with different load-bearing capacities are exposed

to repeated compressive stress of the same magnitude. This results in the formation of a dense soil layer which has low hydraulic conductivity and aeration (e.g., Lipiec and Hatano, 2003).

2.1.16 Soil pH

As the amount of hydrogen ions in the soil increases the soil pH decreases thus becoming more acidic. Soil pH refers to a soil's acidity or alkalinity and is the measure of hydrogen ions (H+) in the soil. A high amount of H+ corresponds to a low pH value and vice versa. The pH scale ranges from approximately 0 to 14 with 7 being neutral, below 7 acidic, and above 7 alkaline (basic). Soil pH can affect cation exchange capacity, CEC and anion exchange capacity, AEC by altering the surface charge of colloids. A higher concentration of H+ (lower pH) will neutralize the negative charge on colloids, thereby decreasing CEC and increasing AEC. The opposite occurs when pH increases.

The measurement of pH in an aqueous solution can be made in a variety of ways. The most common way involves the use of a pH sensitive glass electrode, a reference electrode and a pH meter. Alternative methods for determining the pH of a solution are: indicator, colorimeter and pH meter. Indicators are materials that are specifically designed to change colour when exposed to different pH values. The colour of a wetted sample paper is matched to a colour on a colour chart to infer a pH value. pH paper is available for narrow pH ranges (for example, 3.0 to 5.5 pH, 4.5 to 7.5 pH and 6.0 to 8.0 pH), and fairly wide pH ranges of 1.0 to 11.0 pH. The colorimeter can be used for grab sample measuring, but not continuous on-line measuring. It is typically used to determine the pH value of water in swimming pools, spas, cooling towers, and boilers, as well as lake and river waters. A pH meter is always recommended for precise and continuous measuring. Most laboratories use a pH meter connected to a strip chart recorder or some other data acquisition device so that the reading can be recorded or stored electronically over a user-defined time range.

2.1.17 Chemical influence on Moisture Retention

There are several approaches to prepare hydrogel nano-composite structures. Several clays such as kaolin, bentonite, montmorillonite, potassium humate, sodium humate, attapulgite, and smectite and cellulose nanowhiskers have so far been used in the synthesis of superabsorbent composites (SHCs). Use of humic compounds in soil improves absorption of microelements and soil structure. Currently most of the research in the area of development of polymers for soil water conservation involves the use of natural clays as nanocomposite materials to enhance moisture

retention. Only the physical properties of the superabsorbent hydrogels without considering the actual crop nutrient requirements.

Soil is an important resource that is vital for the sustainability of life in ecosystems, and acts as a buffer to global climatic change (Sparling et. al., 2006). Water absorbing materials have been reported to be effective tools in increasing water holding capacity. With regard to problems associated with water resources in the Semi-arid areas, laboratory and greenhouse studies were conducted in 2009-2010 to evaluate the absorption of water by pumice and to study the effect of its application on moisture content and growth properties of maize. Super absorbent materials (SAMs) are hydrophilic polymer complexes that have potential to absorb large volumes of aqueous fluids within a short time and under stress conditions can hold the absorbed water. Pumice is one of the super absorbents, being a type of extrusive volcanic rock, produced when lava with a very high content of water and gases is extruded from a volcano and serves to open up the mix and reduce the moisture retention properties of the soil (Akbal, 2004). The application of super absorbent polymer has a significant impact in reducing drought stress effects and to improve plant yield and stability in agriculture production (Khadem *et al.*, 2010). Woodhouse and Johnson (1991) reported that hydro-absorbents can play a crucial role in germination rates because of improving water accessibility. Johnson and Piper (1997) found that fruit quality was better using polymers in the growing media as water stress reduced during the growth cycle. Application of hydro gel at the rate of 2 g/kg increased the water holding potential of sand from 171% to 402% (Johnson, 1984). Different elements in the soil have a bearing on water holding capacity. Some of the most used elements in manufacturing water absorbent polymers are potassium, magnesium, sodium, phosphorous and inherent ph. Use of superabsorbent can increase yields through improved water use efficiency (Lal et al., 2005).

2.1.18 Soil Water

Soil water content is basically defined by its gravimetric basis (mass of water per unit mass of dry soil) or on a volumetric basis (volume of water per unit bulk volume of dry soil), and it is expressed either as a dimensionless ratio or as a percentage. Bulk volume of dry soil refers to the dimensions of the soil sample just before the water volume determination and before any soil disturbance. Gravimetric water content (i.e., mass water/mass dry soil) is related to volumetric water content.

Soil water analyses can be organized into two main groups: (i) analysis of storage properties and (ii) analysis of hydraulic properties. Storage properties refer to the soil's ability to absorb and hold water, and these properties include water content, water potential, and water desorption and imbibition characteristics. Hydraulic properties, on the other hand, refer to the soil's ability to transmit or conduct water and these include saturated hydraulic conductivity, unsaturated hydraulic conductivity and various associated capillarity parameters such as sorptivity, flux potential, sorptive number and flow-weighted mean (FWM) pore diameter.

Water in soil is a vital link in the hydrological cycle that controls exchange with the atmosphere above and with the groundwater below. Water in soil acts both as a lubricant and as a binding agent among the soil particulate materials, thereby influencing the structural stability and strength of soil and geologic materials. The high heat capacity of water causes a moderation of diurnal and seasonal temperature cycles at the soil surface. Chemically, water serves as the transport agent for the dissolved inorganic chemicals and suspended biological components that are involved in the processes of soil development and degradation. Biological production from soil, either as forest products or agricultural crops, is influenced primarily by water availability.

The measurement of soil water content then is important directly for quantifying water balance, for estimates of plant water status and for characterizing most soil physical, chemical, and biological processes.

2.1.19 Measurement of Soil Water

The volumetric water content is often expressed as "relative saturation" (also known as saturation ratio or degree of saturation), which gives the ratio of the measured volumetric water content to the corresponding volumetric water content at full or complete saturation. Consequently, relative saturation gives the fraction of the soil pore space that is water-filled and therefore ranges from a minimum value of (no water in pore space) to a maximum value of 1 (pore space completely water-filled). The measurement of soil water content has undergone revolutionary advancements in the last 20 years. They can broadly be categorized into two major areas, direct and indirect measurements.

2.1.19.1 Direct soil moisture measurement

In direct measurements, soil moisture determinations measure soil water potential or soil water content. Soil water content is an expression of the mass or volume of water in the soil, while the soil water potential is an expression of the soil water energy status. The relation between content

and potential is not universal and depends on the characteristics of the local soil, such as soil density and soil texture. Soil water content on the basis of mass is expressed in the gravimetric soil moisture content, θg, defined by:

$$\theta g = \frac{M_{Water}}{M_{Soil}} \qquad \text{eqn (2.2)}$$

Where M_{water} is the mass of the water in the soil sample and M_{soil} is the mass of dry soil that is contained in the sample. Values of θg in meteorology are usually expressed in per cent. Because precipitation, evapotranspiration and solute transport variables are commonly expressed in terms of flux, volumetric expressions for water content are often more useful. The volumetric soil moisture content of a soil sample, θv, is defined as:

$$\theta v = \frac{V_{Water}}{V_{Soil}} \qquad \text{eqn (2.3)}$$

V_{water} is the volume of water in the soil sample and V_{soil} is the total volume of dry soil + air + water in the sample. Again, the ratio is usually expressed in per cent. However, recently, the standard to express soil moisture many research communities are adopting now is volumetric water content (m^3/m^3) which when simplified can be coverted to equivalent depth or cm of water per meter depth of soil. This is a more convenient way of expressing soil water because it enables soil water to be compared to rainfall amount or amount of irrigation water. The relationship between gravimetric and volumetric moisture contents is:

$$\theta_V = \theta g \frac{\rho b}{\rho w} \qquad \text{eqn (2.4)}$$

Where ρb is the dry soil bulk density and ρw is the soil water density. When root depth has been specified, the equivalent depth can then be expressed in terms of cm. The overall equation then becomes:

$$\theta_V = \theta g \frac{\rho b}{\rho w} D_{RZ} \qquad \text{eqn (2.5)}$$

Where D_{RZ} is depth of the root zone

Direct soil moisture measurement is used as a calibrating datum for all other methods for standardization.

2.1.19.2 Indirect soil moisture measurement

From having gravimetric sampling and neutron moderation as the methods in the early 1980s to now available numerous options, such as time-domain reflectometry (TDR), capacitance (and impedance) devices, ground penetrating radar (GPR), airborne/satellite active radar and passive microwave methods (Gardner et al. 2001; Topp and Ferre 2002). These five newer methods are all

based on electromagnetic (EM) measurements. All of the EM methods make use of the high relative permittivity (dielectric constant) of the water (80) in soil compared with the permittivities of the other soil components, which range from one for air to 3-5 for typical soil solids. Due to this contrast, methods that measure the bulk dielectric permittivity of soil are effective for the measurement of volumetric water content. A selection of EM methods offer a variety of sample geometries and spatial coverage that are minimally site disruptive, collect data digitally allowing real or near real-time information and measure on volumetric basis directly. The basic water content parameters and expressions for water content are defined as volumetric, gravimetric and degree of saturation. Indirect moisture content measurements are classified in Radiological, Dielectrics, Soil water potential instrumentation and emerging technologies as:

i. Radiological methods
    a. Neutron attenuation
    b. Gamma absorption
ii. Emerging technologies
    a. Pulsed nuclear magnetic resonance
    b. Remote sensing
iii. Soil water potential instrumentation
    a. Tensiometers
    b. Pressure plate apparatus
iv. Others are resistance blocks under electrical and psychrometers under temperature based metering equipmentss

Like hydrogen ion in the case of neutron probe equipment which contain a radioactive source emitting high-energy (fast) neutrons and a counter of slow neutrons is lowered into the ground. The hydrogen nuclei, having about the same mass as neutrons, are at least 10 times as effective for slowing down neutrons upon collision as most other nuclei in the soil. Because in any soil most hydrogen is in water molecules, the density of slow "thermalized" neutrons in the vicinity of the neutron probe is nearly proportional to the volumetric soil water content. Some fraction of the slowed neutrons, after a number of collisions, will again reach the probe and its counter. When the soil water content is large, not many neutrons are able to travel far before being thermalized and ineffective, and then 95 per cent of the counted returning neutrons come from a relatively small soil volume. In wet soil, the "radius of influence" may be only 15 cm, while in dry soil that radius may increase to 50 cm. Therefore, the measured soil volume varies with water content and thin

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layers cannot be resolved. This method is hence less suitable to localize water-content discontinuities, and it cannot be used effectively in the top 20 cm of soil on account of the soil air discontinuity. Several source and detector arrangements are possible in a neutron probe, but it is best to have a probe with a double detector and a central source, typically in a cylindrical container.

Such an arrangement allows for a nearly spherical zone of influence and leads to a more linear relation of neutron count to soil water content. A cable is used to attach a neutron probe to the main instrument electronics, so that the probe can be lowered into a previously installed access tube. The access tube should be seamless and thick enough (at least 1.25 mm) to be rigid, but not so thick that the access tube itself slows neutrons down significantly. The access tube must be made of non-corrosive material, such as stainless steel, aluminium or plastic, although polyvinylchloride should be avoided as it absorbs slow neutrons. Usually, a straight tube with a diameter of 5 cm is sufficient for the probe to be lowered into the tube without a risk of jamming.

Care should be taken in installing the access tube to ensure that no air voids exist between the tube and the soil matrix. At least 10 cm of the tube should extend above the soil surface, in order to allow the box containing the electronics to be mounted on top of the access tube. All access tubes should be fitted with a removable cap to keep rainwater from entering the tubes. In order to enhance experimental reproducibility, the soil water content is not derived directly from the number of slow neutrons detected, but rather from a count ratio (CR), given by:

$$CR = \frac{C_{Soil}}{C_{Background}} \qquad \text{eqn (2.6)}$$

Where C_{soil} is the count of thermalized neutrons detected in the soil and $C_{background}$ is the count of thermalized neutrons in a reference medium.

To determine the percentage moisture by volume using a Neutron Probe; the bulk density (Db) is calculated from:

$$Db = \frac{Mass\ of\ Dry\ Sample(g)}{Volume\ of\ Sample\ (cm^3)} \qquad eqn(2.7)$$

The percentage moisture by dry weight (Pd) Calculated using;

$$Pd = \frac{Wt.wet\ sample - Wt.dry\ sample}{Wt.dry\ sample - Wt.Pan} \times 100 \qquad eqn(2.8)$$

Where:

Wt. wet sample = weight of sample and Container before drying

Wt. dry sample = weight of sample and Container after drying

Wt. pan = weight of empty container

Then, the percentage moisture by volume (Pv) is:

$$Pv = Pd \times Db \qquad eqn(2.9)$$

Where:

Pd = Percent moisture by dry weight

Db = Bulk density (gcm^{-3})

All neutron probe instruments now come with a reference standard for these background calibrations, usually against water. The standard in which the probe is placed should be at least 0.5 m in diameter so as to represent an "infinite" medium. Calibration to determine $C_{background}$ can be done by a series of ten 1 minute readings, to be averaged, or by a single 1 h reading. C_{soil} is determined from averaging several soil readings at a particular depth/location. For calibration purposes, it is best to take three samples around the access tube and to average the water contents corresponding to the average CR calculated for that depth. A minimum of five different water contents should be evaluated for each depth. Although some calibration curves may be similar, a separate calibration for each depth should be conducted. The lifetime of most probes is more than 10 years.

2.1.20 Soil Water Characteristics Curve

The graph giving the relationship between soil moisture tension and soil moisture content is referred to as moisture retention curve or soil moisture characteristic. The method of determination is detailed by (Klute, 1986). If the tension is expressed as the logarithmic value of cm of water, the graph is referred to as a Soil water Characteristic-curve. Moisture retention curves are used to:

a. Determine an index of the available moisture in soil (the portion of water that can be readily absorbed by plant roots) and to classify soils accordingly, e.g. for irrigation purposes. To determine the drainable pore space (effective pore space, effective porosity, specific yield) for drainage design.
b. check changes in the structure of a soil, e.g. caused by tillage, mixing of soil layers etc.,
c. Ascertain the relation between soil moisture tension and other physical properties of a soil (e.g. capillary conductivity, thermal conductivity, clay and organic matter content).

To construct the moisture retention curve of a soil sample, the moisture content of that sample must be documented. This is done by equilibrating the moist soil sample at a succession of known Matric Potential values and each time determining the amount of moisture that is retained. If the

equilibrium moisture content expressed as volume percentage is plotted against the corresponding tension (SWC), the soil moisture retention curve (SWCC) can be drawn. There is no single method of inducing the whole range of tensions from kpa = - ∞ (total saturation) to kpa = -1,000,000 (oven dry). The ceramic plate equipment is suitable for determination of SWC-curves in the matric potential range of -10 to -1584 kpa. Soil moisture is removed from the soil samples by raising air pressure in an extractor. A porous ceramic plate serves as a hydraulic link for water to move from the soil to the exterior of the extractor. The high-pressure air will not flow through the pores in the plate since the pores are filled with water. The smaller the pore size, the higher the pressure that can be exerted before air passes through. During an experimental run, at any set pressure in the extractor, soil moisture will flow around each of the soil particles and out through the ceramic plate and outflow tube. Equilibrium is reached when water flow from the outflow tube ceases. At equilibrium, there is an exact relationship between the air pressure in the extractor and the soil suction (and hence the moisture content) in the samples. Accuracy of equilibrium values will be no more accurate than the regulation of air supply; therefore the pressure control panel has independent double regulators. For each soil type, the characteristic SWC-curve may be developed. These curves relate the soil suction to its moisture content. This relationship is important in studies of soil moisture movement and quantity and availability of soil moisture for plant growth. These "moisture characteristic" curves for each soil are extremely important in soils research and development of practical, effective irrigation practices.

The shape of water retention curve can be characterized by several models, one of them known as the Mualem-van Genuchten:

$$(\psi) = \theta_r + \frac{\theta_s - \theta_r}{[1 + \alpha|\psi|^n]^{1-1/n}} \qquad eqn(2.10)$$

Where;

θ (ψ) is the water retention curve [L^3L^{-3}], | ψ | is suction pressure ([L^{-1}] or cm of water), θ_s saturated water content [L^3L^{-3}], θ_r residual water content [L^3L^{-3}], α is related to the inverse of the air entry suction, $\alpha > 0$ ([L^{-1}], or cm^{-1}); and n is a measure of the pore-size distribution, $n > 1$ (dimensionless).

This model can be used to check conformity of the retention curve from the pressure plate extraction machine.

2.1.21 Infiltration

There are many factors that contribute to the infiltration rate including time from onset of rain or irrigation, initial water content of the soil, hydraulic conductivity, surface conditions, and profile depth and layering (Hillel, 1998). All the infiltration equations make use of some of these factors in characterizing infiltration. However the more physically based equations rely more heavily on the soil hydraulic and physical properties occurring within the profile, such as saturated hydraulic conductivity, soil moisture gradient, and suction at the wetting front.

Empirical models rely more on parameters that are determined by curve fitting or estimated by other means and thus may better reflect the effect of differences in surface conditions than the physical models, as long as parameters are calibrated separately for those different conditions. Additionally, sometimes approximate physically based models are used as empirical models with parameters determined in a similar manner. The assumptions, form and intent of each equation need to be considered in deciding which equation to use for a particular application.

Infiltration is the process by which water on the ground surface sources such as rainfall, snow melt or irrigation enters the soil. The infiltration process is a component in the overall unsaturated redistribution process that results in soil moisture availability for use by vegetation transpiration exfiltration or process, chemical transport and ground water recharge. Soil moisture in turn controls the partitioning of available energy between sensible and latent heat flux.

Because of the importance of soil moisture on multiple processes, its definition can be elusive, however it is most often described as moisture in the unsaturated surface layers (first 1-2m) of soil that can interact with the atmosphere through evaporation and precipitation.

Infiltration rate may be limited by two factors; rainfall intensity and hydraulic conductivity of the soil. There are three processes of water movement within the soil which are the passage of water through the soil surface, movement of water through the soil mass (percolation) and depletion of soil moisture storage. Infiltration rate usually shows a sharp decline with time from the start of the application of water. The constant rate approached after a sufficiently large time is referred to as the steady infiltration rate. This process is described by several equations showing a decreasing infiltration rate as a function of time. Methods commonly used to measure infiltration include; Kostiakov's equation, Ring infiltrometer, Spinkler infiltrometer, Tensionmeters, Furrow infiltrometer among many others.

i. Ring infiltrometer

This simple method is most appropriate for flood irrigation or pond seepage infiltration. A cylindrical metal ring is sealed at the surface and flooded. Intake measurement are recorded until steady-state conditions are reached. If the effects of lateral flow are significant, then a double – ring infiltrometer can be used. Due to ponding conditions within the ring observed infiltration rates are often higher than under natural conditions.

ii. Sprinkler infiltrometer

This method is appropriate for qualifying infiltration from rainfall artificial rainfall simulators are used to deliver a specified rainfall rate to a well-defined plot. Run-off from the plot is measured, allowing computation of the infiltration rate.

iii. Tensionmeter

The tension or disk infiltrometer employs a soil contact plate and a water column that is used to control the matric potential of the infiltrating water. By varying the tension, the effect of different size macropores can be determined.

iv. Furrow infltrometer

This method is useful if information on infiltration of flowing water in irrigation furrows is desired. Either the water added to a small section of blocked off furrow to maintain a constant depth or the inflow-outflow of a furrow segment can be monitored to determine the infiltration characteristics of the system.

2.1.22 Kostiakov's Method for analyzing infiltration data.

The double-ring infiltrometer measuring 15cm and 50cm diameter for the inner and outer rings respectively were used to measure infiltration rates (dry run tests). In the field, the infiltration rate were measured in 12 tillage treatment plots. The cylinder will be hammered 10cm deep into the soil. Uniform and vertical penetration of the cylinder will be ensured in all cases during the time of driving them into the soil. During water pouring in, disturbance of the soil surface in the inner cylinder will be protected by placing a sack before pouring water. The cylinders will be filled with water to a depth of about 15cm starting with the outer ring then the inner one. Readings of infiltration versus time were taken and recorded for the inner cylinder for at least two hours. After this the rate of infiltration will be calculated using Kostiakov's (1932) equation as follows:

$$I_r = kT^2 \qquad eqn(2.11)$$

where: I_r = Infiltration rate mm/min

T = Time interval (minutes)

k, n are Kostiakov's constants

For ease of evaluating the Kostiakov's constants n and k, the above equation is normally expressed in cumulative form as follows:

$$I_c = k(T_c)^B \qquad eqn(2.12)$$

Where: I_c = cumulative infiltration (mm)

T_c = Cumulative time (minutes)

$$A = \frac{k}{n+1} \qquad eqn(2.13)$$

$$B = n + 1 \qquad eqn(2.14)$$

The Kostiakov's constants k and n are evaluated by plotting log T_c versus log I_c on double-log paper where A becomes the intercept and B the gradient of the resulting straight line. Basic or steady infiltration rate is the near constant value obtained after many hours of infiltration say 24 hours. The concentric rings are installed at a selected site. The inner cylinder is placed about 10cm deep in the soil using a hummer and wooden plank. A sack is placed on the floor of the inner cylinder to prevent puddling. Water is poured quickly in the buffer pond and in the inner cylinder till 15cm in depth. The sack is removed carefully not to disturb the water surface and is timed by a stop watch as it infiltrates. Before pouring additional water back to initial level, the depth reading at new depths is taken each time using a point gauge. Depth readings are made after 5, 5, 5, 10, 20, 15, 15, 20 and 20 minutes, elapse. The results obtained are recorded and analysed, Table 2:1.

Table 2: 2 Infiltration data

Elapsed time	Depth before filling	Depth after filling	Infiltrated Depth	Accumulated infiltration	Average infiltration rate

2.1.23 Soil Permeability

Permeability is the measure of the soil's ability to permit water to flow through its pores or voids. Due to the existence of the inter-connected voids, soils are permeable. The permeable soils will allow water flow from points of high energy to points of low energy. Permeability is the parameter to characterize the ability of soil to transport water. Permeability influences the rate of

settlement of a saturated soil under load. The stability of slopes and retaining structures can be greatly affected by the permeability of the soils involved.

The coefficient of permeability, or hydraulic conductivity, k, is a product of Darcy's Law. In 1856, Darcy established an empirical relationship for the flow of water through porous media known as Darcy's Law, which states:

$$v = -ki \; or \; q = -kiA \qquad \text{eqn (2.13)}$$

q = flow rate (cm^3/s)

k = coefficient of permeability (cm/s)

A = cross-sectional Area (cm^2)

i = hydraulic gradient

2.1.23.1 Hydraulic Conductivity

The coefficient or permeability is also known as hydraulic conductivity; Hydraulic Conductivity, k, is a measure of soil permeability; k is determined in the lab using two methods: Constant-Head Test and Falling-Head Test. Hydraulic conductivity of soils depends on several factors: Fluid viscosity, pore size distribution, grain size distribution, void ratio and degree of soil saturation The constant head test is used primarily for coarse-grained soils; This test is based on the assumption of laminar flow where k is independent of i (low values of i); ASTM D 2434; This test applies a constant head of water to each end of a soil in a "permeameter".

The Falling Head Test is used both for coarse-grained soils as well as fine grained soils; same procedure as in constant head test except for the height measurements: For analytical studies on soil moisture regime, critical review and accurate assessment of the different controlling factors is necessary. The controlling factors of soil moisture may be classified under two main groups' viz. climatic factors and soil factors. Climatic factors include rainfall intensity, storm duration, inter-storm period, and temperature of soil surface, relative humidity, radiation, evaporation, and evapotranspiration. The soil factors include soil matric potential and water content relationship, hydraulic conductivity and water content relationship of the soil, saturated hydraulic conductivity and effective porosity. Besides these factors, the information about depth to water table is also required.

Saturated and unsaturated hydraulic conductivity are related to the degree of resistance from soil particles when water flows through soil pores. In addition, unsaturated hydraulic conductivity is affected markedly by the volumetric water content of soil. The relation between matric potential

and volumetric water content in a soil is termed as the soil moisture characteristic curve. The differences among soil moisture characteristic curves are attributed primarily to the differences in pore size distribution among soils. These curves are sensitive to the changes in bulk densities and disturbances of soil structures. In addition, the curves generally show hysteresis according to the degree of wetting or drying of soils.

In the present study, laboratory investigations have been carried out to determine the soil moisture characteristics (unsaturated hydraulic conductivity and soil moisture retention curve).

2.2 Rainfall

Rain is liquid water in the form of droplets that have condensed from atmospheric water vapour and then precipitated that is, become heavy enough to fall under gravity. Rain is a major component of the water cycle and is responsible for depositing most of the fresh water on the Earth. It provides suitable conditions for many types of ecosystems, as well as water for hydroelectric power plants and crop irrigation. The major cause of rain production is moisture moving along three dimensional zones of temperature and moisture contrasts known as weather fronts.

The preliminary results by Njoku *et al.*, (2004) revealed some insights into the relationship between precipitation and soil moisture. Precipitation intensity is the greatest factor controlling infiltration in amount and characteristics. Precipitation that infiltrates into the ground often seeps into streambeds over an extended period of time, thus a stream will often continue to flow when it has not rained for a long time and where there is no direct runoff from recent precipitation. Some infiltrated water (precipitation) is retained near the land surface and by the process of evaporation it is moved back into the atmosphere.

Design rainfall is defined as the total amount of rain during the cropping season at which or above which a catchment area will provide moisture to satisfy crop water requirements (FAO, 1991). If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress in the plants; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may result in damage to conservation structures, soil surface and soil aggregation. Several methods have been used to analyse rainfall data with varying results. These include; Annual Exceedance Probabilities, (Nandakumar *et al*, 1997), graphical fitting, least square principle, Madsen, *et al.*,(2002),, annual maxima, Manikandan *et al.*, 2011, among many others. Water falling on steeply-sloped land runs off quickly and infiltrates less than water falling on flat

land. Surface conditions of land influence rate of infiltration depending on the tillage type applied. For better understanding of the impact of rainfall on infiltration, many limitations of the current soil moisture and land rainfall algorithms need to be resolved as well as further comparative analyses done to compare current rain screening methods for amount and probability of occurrence to guide tillage timing.

i. Radar

Meteorological radar is a remote-sensing system that sends an electromagnetic pulse and receives the back-scattered radiation from raindrops in the atmosphere (Krajewski and Smith, 2010). This method is used for predicting real time rainfall probabilities. Availability of the Radar reflectivity equipment limits its use in most research work in the developing world.

ii. Plotting Position Formulae

Ke-Sheng, (2008) reported that methods of plotting positions can be used to determine design storm depths. Most of these methods are empirical. If n is the total number of storm event to be plotted and m is the rank of a storm event in a list ordered by descending magnitude, the probability exceedence of the m^{th} largest depth, x_m, is , for large n, shown below.

The general form of exceedence probability $P(\chi \geq \chi_m) = \frac{m-b}{n+1-2b}$ the California's formula.

$$P(\chi \geq \chi_m) = \frac{m-1}{n} \quad \text{the California's formula} \qquad \text{eqn (2.14)}$$

$$P(\chi \geq \chi_m) = \frac{m-0.5}{n} \quad \text{Hazen formula b} = 0.5 \qquad \text{eqn (2.15)}$$

$$P(\chi_m) = \frac{m-0.3}{n+0.4} \quad \text{Chegodatev formula b} = 0.3 \qquad \text{eqn (2.16)}$$

$$P(\chi \geq \chi_m) = \frac{m-0.375}{n+0..25} \quad \text{Blom formula b} = 0.375 \text{ for normal distribution} \qquad \text{eqn (2.17)}$$

$$P(\chi \geq \chi_m) = \frac{m-0.44}{n+0.12} \quad \text{Gringorten formula b} = 0.44 \text{extreme value type 1} \qquad \text{eqn (2.18)}$$

Where; m is rank of annual totals, n is total number of observations and b is a constant.

Typical values for the Soil Conservation Services (SCS) Curve Number, (CN) as a function of soil type, land use and degree of saturation were conducted by; Kibler, (1982).

$$S = \frac{25400}{CN} - 254\ (millimeters)$$ eqn (2.19)

The value of S is defined by the empirical expression in millimetres.

iii. Graphical Method

The probability of drought occurrence during the crop growing period can be determined by a graphical method (FAO, 2008). The probability of rainfall occurrence P (%) for each of the ranked observations is calculated using the equation:

$$P(\%) = \frac{m - 0.375}{N + 0.25} \times 100$$ eqn (2.20)

Where; m is rank of annual totals, N is total number of observations and P is the probability in % The above equation is recommended for N = 10 to 100 (Reining *et al.*, 1992). There are several other, but similar, equations known to compute experimental probabilities. According to Roy *et al.*, (2001)

$$T = \frac{100}{P}(Years)$$ eqn (2.21)

Where; T is the return period and P the probability of occurrence or exceedence. Each of these datasets has advantages and disadvantages. Rain gauge gives relatively accurate point measurement of rainfall but observations are not available over most remote land areas and over oceanic areas.

According to Roy *et al.*, (2001), other graphical methods such as; semi average method, moving average, conventional approach and window based approaches are some of the methods used in evaluating precipitation. A problem with the land rain gauge observations is the sampling error if the network is not adequately dense and the varying natural tendencies of data readers. Though there has been rapid progress in numerical weather prediction, rainfall prediction skill over tropics has remained wanting. However, this continues being the only easily accessible tool of analyzing rainfall data in sub-Saharan Africa.

2.3 Effect of Tillage on Soil Physical Properties

Tillage is the physical manipulation of the soil for the purposes of management of previous crop residues, control of competing vegetation, incorporation of amendments and preparation of a seedbed Kay (1990). Soil physical properties affected by tillage are soil test measurements, structure and aggregate stability, soil water relationships, temperature and Strength.

Wolkoski (2003) reported that tillage of a continuous no-till system reduced bulk density and penetration resistance to that where tillage was continuous, removed much of the soil test stratification in the surface layers, enhanced early-season K uptake, and tended to increase yield. That the omission of tillage for one season resulted in higher soil bulk density and penetration resistance approaching those measured in continuous no-till, reduced early season K uptake, and tended to decrease yield. The responses are likely in part due to changes in the soil root zone condition, such as improved aeration and water relationships. This may explain some of the problems growers experience when converting to no-till from aggressive tillage systems.

Double-cropping systems were found to exhibit superior soil structure with up to 57% better visual soil structure scores and up to 16% smaller mean weight aggregate diameter (Hill, et al., 1985). Soil tillage is carried out with the objective of changing the soil physical properties and to enable the plants to show their full potential. Incorrect tillage is one of the causes of erosion and of physical degradation of the soil Diaz-Zorita *et al.,* 2004.

Soil physical degradation may be defined as the loss of the soil's structural quality. These structural degradation may be observed both on the surface where thin crusts may be formed. With this type of degradation, the infiltration rates of the water into the soil are reduced, whilst the rates of runoff and erosion increase Ra´tonyi (1998).

One of the major causes of structural degradation is excessive tillage or tillage undertaken when the soil moisture content is not appropriate which causes adverse effects. Excessive tillage on the surface breaks up the aggregates, favouring the formation of surface crusts, increased runoff and the erosive transport of the soil particles Singh et al., (1994). The reduction of the soil surface roughness leads to less infiltration and increased kinetic energy of the water running over the surface. Subsurface compacted layers, normally situated at depths of 10 to 30cm and with a thickness of 10 to 15cm, are also formed when poorly selected and excessively heavy equipment passes over the soil and when the soil consistency is plastic Badalı´kova´ et al., (2007). These layers offer strong resistence to root penetration and restrict the capacity for water infiltration and aeration. Inadequate management causes loss of soil organic matter. This leads to greater soil

density and lower moisture retention capacity and stability of the soil aggregates, which together contribute to an overall loss of quality and stability of the soil structure.

The loss of the physical quality of a soil can be evaluated through the changes that occur to some of its important quality of a soil can be evaluated through the changes that occur to some of its most important physical characteristics such as density, porosity, pore size distribution, structure and infiltration rate.

Soils naturally possess different densities owing to variations in their texture, porosity and organic matter content. Brandy (1984) quotes sandy soils as having a density of 1.2 to 1.8 MgM^{-3} and a porosity of 35-50 percent. However, the density in the range of 1.0 -1.6 MgM^{-3} and a porosity of 40 - 60%. However, the density and the porosity vary according to the type and intensity of tillage, thus they are very good indicators of the adequacy of various tillage systems, indicating the serious or minor compaction which the tillage operations may have caused.

Adequate values for soil density were defined by Lipiec et al., (2006) as those which provide maximum moisture availability and at least 10 percent air in the pore spaces with a suction of 50mb. According to the other authors, these optimum soil densities are in the neighbourhood of 1.75 MgM^{-3} for the loam, 1.5 MgM^{-3} for the sandy loams, 1.5 MgM^{-3} for silty loams and 1.21.5 MgM^{-3} for clay loams.

Modifications to the physical properties due to tillage systems can give rise to an increase in soil density, greater resistance to root penetration and a reduction in soil porosity characterized by a compacted layer below the cultivated horizon. This compacted layer affects the movement of the water and the development of the root system due to the mechanical impediment and the lack of air. The plough pan starts at the tilled layer and the depth at which this lies has a greater or lesser effect on crop development. This has negative effect on crop yields, more pronounced when the compacted layer is only 10cm deep than when it lies at a depth between 20 and 30cm Dexter (1986).

As a consequence of the increased density, there is a corresponding but much more significant increase in resistance of the soil to root penetration. It was observed by Voorhees et al., (1978), when working in a clay-silt loam under the same weight of vehicles that the soil density increased 20 per cent whilst the resistance to root penetration increased more than 400 per cent. The values of the resistance to plant root penetration that limit crop development vary from one crop to another the base of the tilled layer and the depth at which this lies has a greater or lesser effect. From the point of view of soil management, a good structural quality of the soil means a good quality of the

pore space or more specifically, a good porosity and a good distribution of the sizes of the pore spaces. It follows that the infiltration rate of water, together with the root distribution through the profile are the best indicators of structural quality of the soil Cabeda (1984).

The size and stability of the aggregates can be indicative of the effects of the tillage system and of the crop on the soil structure. Well aggregated soils provide better moisture retention, adequate aeration, easy penetration for the roots and good permeability. The distribution of the aggregate sizes is one of the important factors in crop development. according to Olaoye, J.O. (2002), the aggregates should be reduced to a size which approached that of the seeds and of the roots of the new plants with the objective of providing sufficient moisture and perfect contact between the soil, the seed and the roots. However, the aggregates should not be too small to the point of favouring the formation of compacted surface crusts and caps. For Kahnke (1968), the ideal size for the aggregates is between 0.50 and 2.00 mm in diameter. Larger aggregates restrict the soil volume explored by roots and smaller aggregates give rise to very small pores, which do not drain through the action of the forces of gravity. Break-up of the soil aggregates is caused through the intense disturbance of the soil during tillage operations, through a reduction in organic matter content and through the impact of rain droplets on an unprotected surface.

The soil moisture content at the time of tillage is a factor that determines the intensity of the breakup of the aggregates that will occur. The prejudicial effects of the weight of agricultural machinery and of excessive soil tillage under soil moisture conditions that are unfavourable and tend to be cumulative and to intensify with the sequence of annual tillage operations. Soil disintegration can be reduced by doing less tillage, through the use of crop rotations and through the protection of the soil surface with crop residues. In this way pastures better assist soil aggregation, followed by direct drilling and by conventional tillage.

The infiltration rate of water into the soil determines the rapidity of this process and thus, the volume of water that will remain to run off over the soil surface. When the infiltration rate is low, moisture availability in the root zone can be limiting. The infiltration rate is conditioned by the state of the soil surface, the rate of transmission of the water through the soil profile, the soil moisture storage capacity and flow characteristics of the water. Water infiltration in the soil reflects the soil physical properties. Cropping and tillage systems influence the eventual infiltration rate, both through modification to the roughness and the cover of the soil surface and through changes to the structure, density and porosity of the soil.

2.4 Tillage Systems

Tillage systems are sequences of operations that manipulate the soil in order to produce a crop. Operations include tilling, planting, fertilization, pesticide application, harvesting, and residue chopping or shredding.Soil management chosen to alleviate specific constraints within field boundaries is essential for maintaining and/or improving soil quality. Such decisions involve considerations of the complex interactions between soil physical, chemical properties and land use management. Karunatilake et al., (2002) reported that tillage practices influence structure and water transmission properties of soils.

Many tillage systems are employed to till land depending on the benefit they add to the farm. Tillage types vary from the type of equipment used to the sequence and frequency of carrying out the operation. Some type of tillage systems are selected based on soil type and agro climatic conditions. The commonly employed types of tillage systems include: Conventional tillage (CT), Zonal tillage (ZT), Minimum tillage (MT), No tillage (NT).

2.4.1 Conventional tillage (CT)

Traditionally, tillage has been practiced for the purpose of mixing surface residues deeper into the soil, loosening the soil prior to seedbed establishment and to aid in weed control. The primary tillage implement for many years was the mouldboard plough. The rough surface left by primary tillage was smoothed by secondary tillage implements, usually a disk harrow followed by one or more passes of another fine toothed harrow for final smoothing of the surface in preparation for seeding. These techniques have been described as conventional tillage. Another traditional application of secondary tillage has been the use of a myriad of cultivating tools to provide mechanical weed control and to break up surface crusts. However, the advent of widespread use of chemical weed control during the late 1950s greatly reduced the amount of secondary tillage used for weed control. The major disadvantages of these conventional tillage techniques were increased risk of soil erosion on sloping land and breakdown of soil structure. Largely due to massive nationwide loss of topsoil from conventional tillage, additional primary tillage techniques were developed to leave varying amounts of the residues from the previous crop lying on the soil surface for the purpose of lowering the erosion potential. Several implements, mostly a variation of the chisel plough, were developed to accomplish this. When followed by a shallow harrowing, these conservation tillage techniques provided a seedbed smooth enough for successful planting of corn but still left some residue cover.

2.2.1 Zonal tillage (ZT)

Zonal tillage is defined as tillage that keeps the area of land cultivated and the number of cultivations to a minimum. Usually the zone of cultivation is restricted to the row area. It is also referred to as strategic tillage. Zonal tillage follows the well-researched concept of only working the parts of a field that the crop uses to grow, rather than the whole field. Cultivating just the row area of the field reduces area costs and creates controlled traffic lane-ways that can be maintained. Zonal tillage improves soil structure as less passes are needed to prepare the bed for planting. Also, when combined with controlled traffic it reduces compaction, water absorption increases. This improvement in soil structure and reduction in compaction reduces the loss of soil and particulate nutrients from the field. Zonal tillage also saves time from less passes and lowers fuel costs as lower axle load machines can be used.

2.2.2 Minimum tillage (MT)

Minimum tillage is a soil conservation system like Strip-till with the goal of minimum soil manipulation necessary for a successful crop production. It is a tillage method that does not turn the soil over which involves the retention of stubble. Most of the weeds are controlled with herbicides during the fallow together with one mechanical cultivation. Reduced tillage systems are important for soil erosion control because they: reduce the effect of raindrop impact on the soil surface, reduce surface sealing of soils, increase infiltration of water into the soil, reduce runoff from the soil surface, reduce the rapid breakdown of soil structure, slow the breakdown of organic matter in the soil, reduce the formation of hard pan layers in soils, provide a better soil environment for crop growth, slow down overland flow of surface runoff and reduce wind erosion

2.2.3 No tillage (NT)

Developments in chemical weed control and planting equipment that could successfully plant through surface residues resulted in development of no-tillage seeding techniques. The only tillage involved in no-tillage seeding is the narrow, in-row disturbance made by the coulter and furrow-opener on the planter. No-tillage results in most prior crop residues remaining on the surface, which causes a dramatic reduction in soil erosion and increased water infiltration. No-tillage has a number of advantages, including less soil erosion as compared with clean-tilled systems and fuel, machinery, and time savings are all impressive. There is also a tendency toward better crop yields on soils that are moderately well drained to well drained, due to higher water availability.

Conversion to no-till, (NT) increases WSA, AWC, and infiltration rate while decreasing runoff and soil bulk density (ρb), Wright et al., (1999).

Zero or No-tillage, stubble management and increase of herbicide use are some of the possibilities that would maintain soil structure and organic matter content while reducing air and water pollution. Tillage and crop establishment option also facilitates crop diversification and intercropping. Where tillage for one crop results in an unfavourable condition, another type of tillage for a different crop may alleviate the problem.

Tillage increases the volume of macro pores over a short duration while decreasing the continuity of macro and micro pores (Hill, 1990; Shukla et al., 2003). However, over a longer duration, tillage generally increases bulk density (ρb), decreases water stable aggregation (WSA), reduces infiltration rate and plant available water capacity (AWC) (Shipitalo et al., 2000; Franzluebbers, 2002). Soils are more friable after tillage and increasing water content may decrease friability and increase clay dispersion (Kay, 1990).

Crop residue left on the soil surface after harvest enhances the earthworm population, moderates soil temperature, and preserves aggregates (Wuest, 2001). Wetting and drying cycles contribute to the development of macro pores (Messing et al., 1993). Although total porosity (ε) may be smaller with NT than with CT, macro pores and bio-pores remain undisturbed between peds (Unger et al., 1991). Transmission and storage pores for NT are generally high; however, tillage comparisons for periods of less than 10 years have not produced consistent results (Hill, 1990; Kay et al., 2002).

A study conducted by Hill et al., (1985) to determine the effects of conservation and conventional tillage on soil water retention and pore size distribution of two loamy sand soils in two locations revealed that; statistical differences in soil water retention due to tillage treatments appeared at site 1, with general means comparisons of reduced tillage > no tillage > conventional tillage in the amount of water retained at any matric potential. Reduced tilled soil generally retained a significantly ($P \leq 0.05$) larger quantity of water than conventionally tilled soil. No-tilled soil was not significantly different from reduced tilled or conventionally tilled soil in its water retention characteristics. Differences in water retention between tillage treatments were not significant at site 2, but trends in the means comparisons similar to those of site 1, were observed. Analysis of variance failed to show significant tillage effects for the pore size distribution regardless of pore radius interval partitioning. Trends indicated that soil under conventional tillage had a larger proportion of its pore volume in pores >15μm radii compared with soils under conservation tillage.

Conservation tilled soils appeared to have a larger portion of pores in the 15 to 0.1μm pore radius interval.

Implications are that conventionally tilled soils should drain more rapidly than conservation tilled soils and that conservation tilled soils should retain more plant available water (PAW) than conventionally tilled soils. The data indicated that bulk density increases occurred at the expense of larger pores (>150μm radii). Since conventionally tilled soils have the greater proportion of large pores, these soils seem to be more susceptible to densification than the soils under the conservation tillage systems. Comparing findings from the two sites, they agree with the finding by (Hangen et al., 2002) that results are site specific and since little work on moisture retention under specific agro-climatic conditions of eastern Mau has been undertaken to reveal the missing information about the inherent loamy sandy soils. Wakindiki, et al., (2006) reported that soil use and management activities that increased the soil bulk density significantly lowered hydraulic conductivity in a study conducted within River Njoro Watershed in Kenya.

2.5 Factors Affecting the Choice of Tillage Practices

Tillage is the agricultural preparation of soil by mechanical agitation of various types, such as digging, stirring, and overturning. Examples of human-powered tilling methods using hand tools include shovelling, picking, mattock work, hoeing, and raking For any given location, the choice of a tillage practice depends on one or more of the following factors: relief (slope), length rainfall period, amount and distribution, erodibility, water balance erosivity, length of growing season, rooting depth, temperature (ambient and soil), texture, structure and organic-matter content mineralogy.

In theory and practice, subdividing factors affecting tillage systems according to their influence on the final results and the nature of effect on soil and crops is paramount. There are positive, negative or conditional, depending on the circumstances A basic group of factors of positive effect are as follows: appropriate selection of crop rotation and techniques; properly selected agricultural equipment with a view to the method of operation as well as the basic parameters; the respectively utilized power system which should also be of high technical and technological indexes conformable to the trends for soil non-compacting, low power consumption, etc. Conditions such as: relatively flat terrain; weed-free areas; favourable rainfall and temperature for particular periods, have a positive effect too. Proper shape and sizing of the fields, appropriate

planning and infrastructure, adherence to proper timing and working conditions result in another positive effect on tillage systems.

If all of the above mentioned factors of positive effect are not observed, they can affect negatively the tillage systems. However, there are several factors which have negative effect and these call for additional measures for reducing and eliminating them. Unfavourable physical properties of the soil, are in the first place among the factors of negative effect. A group of factors of negative effect to the tillage systems is the one ensuing from water and wind erosions. According to Ruseva S. (2006) it results in lessening the depth of the root location layer, decrease in the quantity of the nutrient elements and soil moisture supplies; running low on the soil filtering and buffer capacity; depletion of soil organic matter content; loss in bio-development; deterioration of the soil structure, formation of soil crust, etc. For limiting or avoiding adverse conditions, it is necessary to apply special tillage systems as well as technological combinations of equipment for carrying it out (Dimitrov et al., 2003, Dimitrov et al., 2006, Dimitrov et al., 2007).

Overdamping or drying of the arable land has a significant direct and indirect negative effect on the rest of the factors of negative effect such as deterioration of the physical and chemical properties of the soil. Overpacking of the soil is typical with power tillage carried out in inappropriate moisture conditions. This negative factor has a significant effect on all of the rest factors of negative effect. Without examining its origin it should be mentioned that loosening through tillage which brings about additional rough impact is not the most appropriate way of avoiding the noxious effect of the packing. It is more appropriate to eliminate the reasons for this soil deterioration factor through utilization of various technical and technological solutions (Dimitrov et al., 2007). As a factor of negative effect soil humus decrease and respectively the clotting ability of the organic colloids results in deterioration of the soil structure and all negatives ensuing from that. Using chemicals in agricultural production and especially the mass application of fertilizers might turn not only into a factor of negative effect affecting the different tillage systems but affect the entire eco-system. According to Dimov et al., (2005) this calls for utilization of alternative techniques which will regenerate and enhance soil fertility through Lumbricus compost. All factors related to the agricultural intensification can be assigned to this group of factors. They are as follows: establishing production of high-yield crop varieties, pre- and catch-crops, melioration and mainly hydro-melioration,

Any tillage operation that changes soil bulk density in turn modifies pore size distribution, water holding capacity, infiltration rate penetration resistance and soil aeration. Since each soil

type and cropping system responds differently to tillage, tillage system desirable in one location may be a complete failure in another location. Different farming systems exist. These practices include conventional and conservation tillage. The way they improve the aforesaid physical properties is critical in selection of a certain tillage practice for a specific location. However, a tillage system having better impact on the soil physical properties conducive for crop growth and economic return would be ideal for the site.

2.6 Conceptual Framework

The main concept for this study was derived from the fact that the Eastern Mau experiences a tri-modal rainfall pattern and most sowing is undertaken late during the long rains. Between the first and the second rains there is a dry spell that extends beyond 3 weeks the time most crops are at their critical growth stage of maximum moisture demand. This adversely affects the quantity and quality of the yield. The reduced yield may be attributed to among other factors, the tillage equipment for seedbed preparation. It is hypothesized that in order to have more water infiltrating and retained longer in the soil profiles there must be one tillage system that can mitigate the problem. To test the hypothesis, work done by other researchers was examined. It was found that the effect of tillage systems on crop performance and yield have been extensively investigated under different crops (Dugas et al., 1990; Moreno et al., 1997; Benjamin, 1993; et al., 2001). Hill, et al., (1990); Kay and Van den (2002) reported that transmission and storage pores for NT are generally high; however, tillage comparisons for periods of less than 10 years have not produced consistent results in moisture retention. Hill et al., (1985) reported that soil water retention due to tillage treatments appeared at site 1, with general means comparisons of reduced tillage > no tillage > conventional tillage in the amount of water retained at any matric potential but no significance at site 2 though the trend was the same. Lal et al., (1991) showed that data on saturated hydraulic conductivity (Ks) were highly variable and tillage treatments had no effect. Moisture retention characteristics differed significantly among depths but not among treatments.

Shukla, et al., (2003), reported that even under similar ecological conditions, the uniform, "over standardized" adaptation of tillage methods for soil moisture conservation is rather risky, their application needs special care and the future is for site-specific precision technologies. In all the above sited research work, moisture retention was investigated under a crop and crops may have influenced the results in either way. There is limited information about tillage influence on soil moisture retention and other physical characteristics of volcanic soils of Eastern Mau.

Developing moisture retention curves is important for a site in that, future estimation of moisture retention potential in the soil can be obtained from a pedo-transfer function without the need for conducting the whole exercise again which is time consuming. The curves can be used for determining available moisture in the tested systems.

CHAPTER THREE
MATERIALS AND METHODS

3.0 Study Area

The experimental site, Njoro, is located in the Kenya's southwestern Rift Valley 0°34'00'' South, 35°, 94'28'' East and about 20 km from Nakuru as shown in Figure 3.1, below. The site lies within Eastern Mau which is mainly covered by the Quaternary and the Tertiary volcanic deposits (Kinyanjui, 1979). (Somroek, 1980) and Mainuri, (2005) reported that volcanic soil types in the region are majorly loamy sand soils (*mollic andosols*). It is elevated at 2170 m above mean sea level (amsl) and has a general slope of 1.65% to the east. Rainfall in the area is characterized by a tri-modal precipitation pattern with main season lasting from April – May, short rains from November – December, and an additional small peak in August (Migwi, 2006). Mean annual rainfall measured at Kari-Njoro, Kenya Meteorological Station Identification Number 9031021 from 1960 to 2010 was found to be 939.3 mm. The average annual temperature of the site ranged from 9° to 24°C.

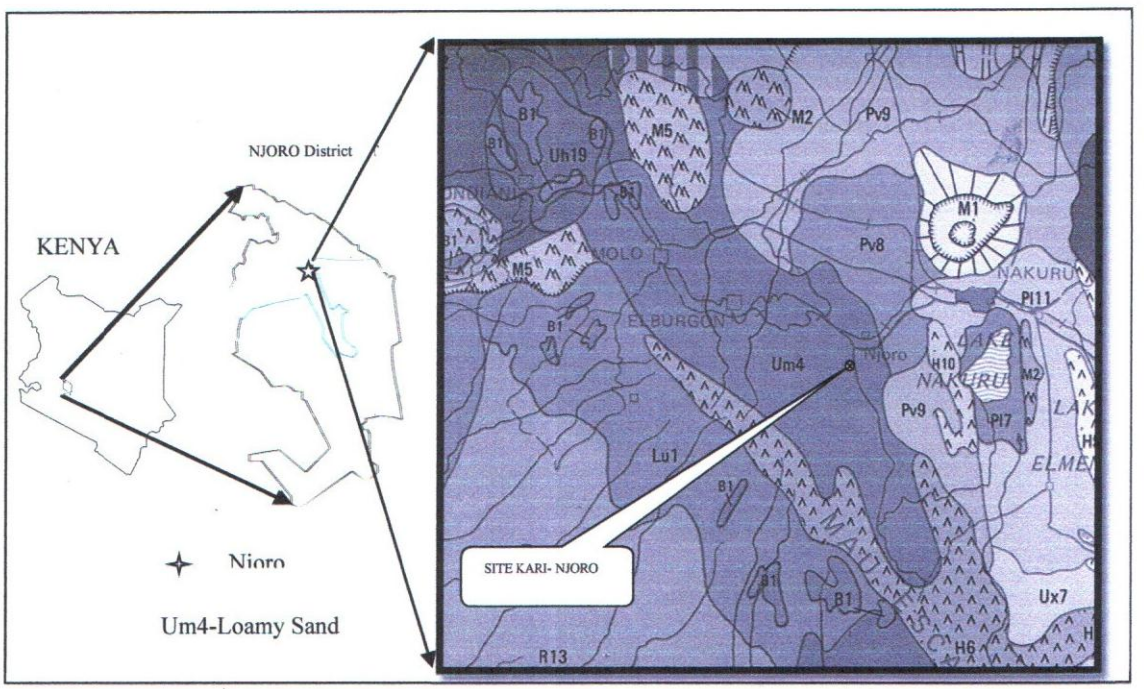


Figure 3:1 Experimental Site (Soil Map Source; ISRC, Wageningen-Netherlands)

3.1 Experimental Design

In this study, a split plot experimental design was adopted where the plots were randomized in blocks replicated three times. The tillage method represented the main plot and depth as subplot.

Each block consisted of four plots (3 m by 36 m) under different tillage treatments, Figure 3.2. All plots received identical chemical weed control application (glyphosate *N*-phosphonomethyl glycine). The recommended glyphosate application at 2.5l/ha to control perennial weeds on stubble land (NPBRC, 1989) was used. Initial soil physical properties established before applying the tillage treatments were; bulk density porosity and infiltration rate. Tillage treatments applied were; Conventional tillage (CT) - 1, Minimum tillage (MT) - 2, No-tillage (NT) - 3 and Zone tillage (ZT) – 4. CT treatment was disking at 20cm depth followed by two harrow passes. The plough, first harrow and second harrow passes were spaced at two week interval to allow for weed seed bank depletion through germination. The rest of the tillage treatments were applied when CT was receiving the second harrow pass.

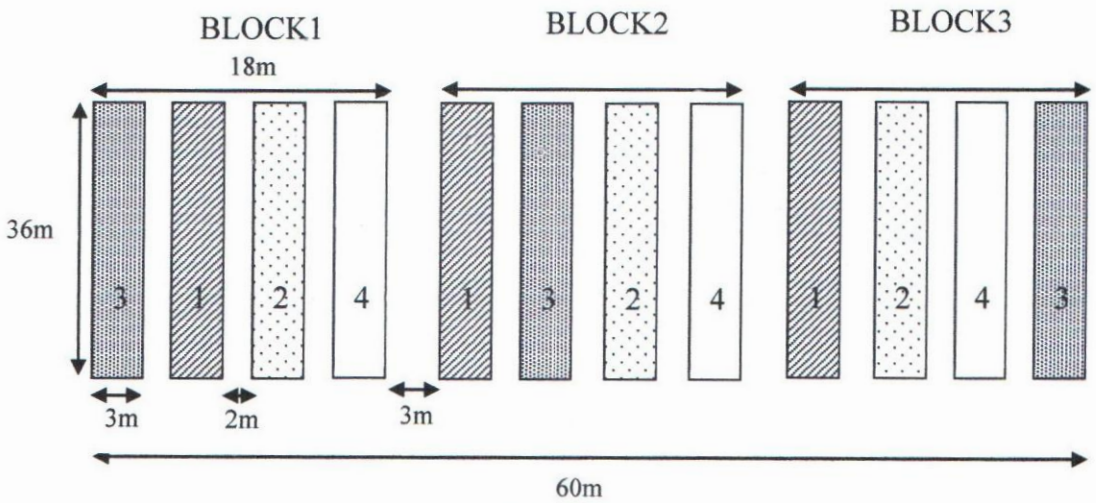


Figure 3:2 Field Layout; CT-1, MT-2, NT-3, ZT-4

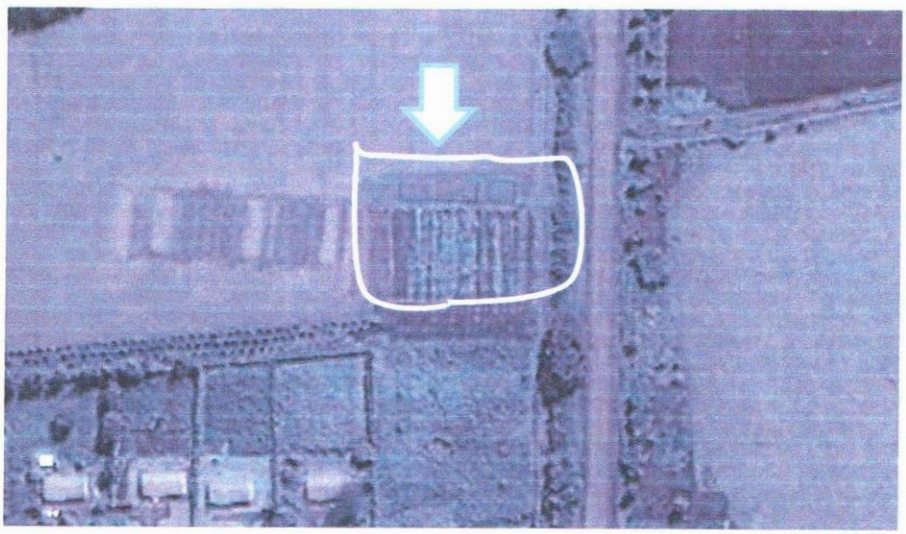


Figure 3:3 Aerial View of the Experimental Site at KALRO NJORO Field 1

One offset disk harrow pass was applied to minimum tillage (MT) treatment plots. In the ZT treatment plots, the chisel plough was set to operate at 30cm depth with tines spaced at 25cm while NT plots were left undisturbed after the previous crop harvest. Tillage treatments were undertaken by an 82-kW four-wheel-drive Massey Ferguson (MF 4270) tractor weighing 4.121Mg, with dual axle loads distributed in 1.700 Mg and 2.421 Mg on the front and rear axles respectively. The MF 4270 has a rear wheel base of 2095mm. The Figure 3.4 is part of the experimental field with access pipes that are covered with plastic caps to shield direct moisture from rain.



Figure 3:4 Access Pipes in experimental Plots

3.2 Characterization of soil physical properties

3.2.1 Topography determination

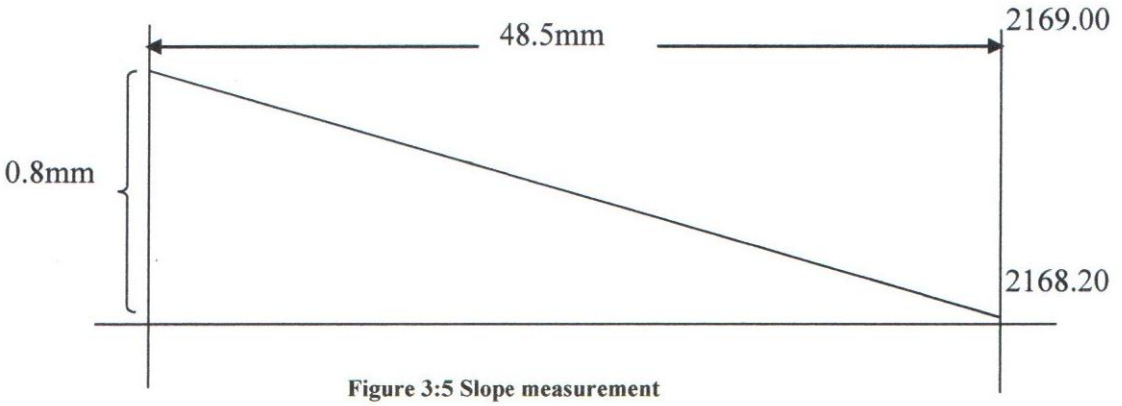


Figure 3:5 Slope measurement

To determine the site slope, extreme end reduced levels were, 2169.00 and 2168.20m respectively determined by a survey equipment (Figure 3:5). Ground distance measured was 48.5m towards the East from which slope was calculated as 1.65% Table 3:1. To plot the terrain, the site

was divided into 5x5m grids and stuff readings taken at every junction of the row, R1, R2, R3……Rn and column, C1, C2, C3……Cn respectively (Figure 3:6). The results for the whole site are represented in table (Table 3.1) for further processing.

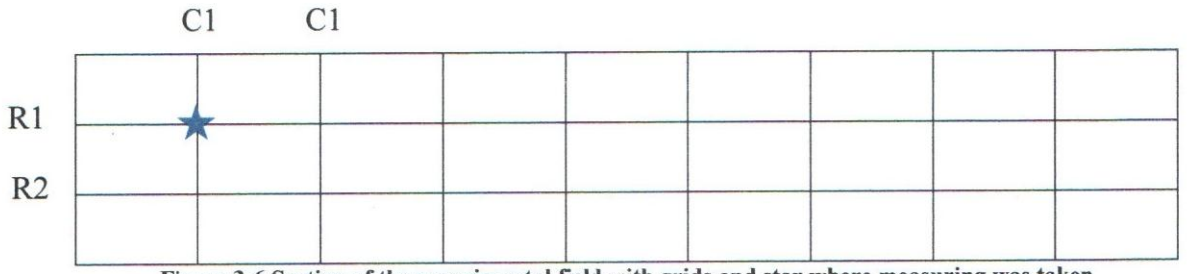


Figure 3:6 Section of the experimental field with grids and star where measuring was taken

Table 3:1 Reduced Levels

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
2168.3	2168.3	2168.5	2168.6	2168.9	2168.9	2168.8	2168.9	2169.2	2169.1	2169.1	2169.2
2168.3	2168.4	2168.7	2168.6	2168.9	2168.8	2168.8	2169.0	2169.2	2169.0	2169.1	2169.2
2168.2	2168.4	2168.7	2168.5	2168.9	2168.8	2168.8	2168.9	2169.2	2169.0	2169.1	2169.2
2168.2	2168.3	2168.5	2168.6	2168.9	2168.8	2168.8	2168.9	2169.0	2169.0	2169.1	2169.1
`	2168.3	2168.6	2168.5	2168.9	2168.8	2168.8	2168.9	2169.1	2169.0	2169.1	2169.1
2168.2	2168.3	2168.4	2168.5	2168.7	2168.8	2168.7	2168.8	2169.1	2169.0	2169.1	2169.2
2168.2	2168.3	2168.4	2168.6	2168.7	2168.8	2168.9	2168.9	2169.1	2169.1	2169.1	2169.1

Since all readings were more than 2160m, the value was subtracted from each reduced level and presented in table 3:2.

Table 3:2 Grid Reduced Levels for the experimental Plot

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
						+2160						
R1	8.3	8.3	8.5	8.6	8.9	8.9	8.8	8.9	9.2	9.1	9.1	9.2
R2	8.3	8.4	8.7	8.6	8.9	8.8	8.8	9.0	9.2	9.0	9.1	9.2
R3	8.2	8.4	8.7	8.5	8.9	8.8	8.8	8.9	9.2	9.0	9.1	9.2
R4	8.2	8.3	8.5	8.6	8.9	8.8	8.8	8.9	9.0	9.0	9.1	9.1
R5	8.2	8.3	8.6	8.5	8.9	8.8	8.8	8.9	9.1	9.0	9.1	9.1
R6	8.2	8.3	8.4	8.5	8.7	8.8	8.7	8.8	9.1	9.0	9.1	9.2
R7	8.2	8.3	8.4	8.6	8.7	8.8	8.9	8.9	9.1	9.1	9.1	9.1

3.3 Soil Profile

The materials and equipment used for studying soil profile at the study site were; shovels, measuring tape, core samplers and sample bags. A rectangular hole, 70cm deep measuring 2×2m was excavated. Core samples from each horizon were taken for soil physical properties analysis. This formed the baseline data that was not to be affected by tillage. The excavation was completely restored after profile observation. Some of the initial data can be seen in table (3.2)

Table 3:3 Pit hole soil properties before application of treatments

Property (units)	Value
amsl (m)	2170
Slope(%)	1.65
pH	5.02-5.96
Carbon%	1.7-3.4
Particle density	1.61 - 2.18
Bulk Density (Mgm^{-3})	104-137
Moisture content (%)	7.88-31.70
Root depth (cm)	0-27
Porosity	0.30-0.60
Bulk Density	1.04-1.37
Structure	Blocky
Texture	Loamy sand
Profile boundaries (0-70cm)	Ap_1, Ap_2, Bw_1 Bw_2

3.3 Soil Textural Analysis

To determine the soil textural curve, samples from the study site were analysed according to the Bouyoucos hydrometer method, Bouyoucos, (1962) and the weighted means of soil fractions as shown in Table 3:4 below.

Table 3:4 Sieve Analysis: Sandy Loam Depth 0-40cm

Sieve size (mm)	Mass retained (g)	% passing	Mass passing
3.3528	65.32	80.68	272.72
1.00076	95.71	52.36	177.01
0.50038	65.91	32.87	111.1
0.35306	46.4	19.14	64.7
0.29718	25.69	11.54	39.01
0.24892	11.13	8.25	27.88
End receiver	27.88	0	0
TOTAL	338.04		

3.4 Soil Bulk and Particle Densities, Porosity Before and After Tillage Treatments

Soil physical characteristics were monitored after tillage treatment application. The initial and final results of the findings were tabulated (Table 3.5). The analysed depth was up to 40cm to cover the depth directly influenced by the tillage implements. In the table measurements were done at every 10cm from the soil surface to determine bulk density and moisture content at the same time. Moisture content was later monitored within the treatments.

Table 3:5 Bulk Density and Porosity Before and After Application of Treatment

Depth (cm)	%MC	Before treatment	After treatment				Before treatment	After treatment			
		Bulk Density(gcm^{-3})					Porosity				
		ALL	CT	MT	ZT	NT	ALL	CT	MT	ZT	NT
10	7.88	1.04	1.08	0.95	1.12	1.04	0.35	0.33	0.41	0.30	0.35
20	9.91	1.08	1.56	1.45	1.36	1.08	0.50	0.28	0.33	0.38	0.50
30	10.91	1.37	1.35	1.36	1.37	1.37	0.28	0.29	0.28	0.28	0.43
40	12.91	1.30	1.30	1.31	1.31	1.30	0.31	0.31	0.31	0.31	0.28
50	17.31	1.18	1.18	1.19	1.19	1.18	0.42	0.42	0.41	0.41	0.36
60	31.70	1.18	1.18	1.18	1.18	1.18	0.30	0.30	0.30	0.30	0.30

3.5 Spatial Variability of Soil chemical Elements Associated with Water Holding

The experimental site was subdivided into 5×5m grids to form sampling quadrants. Soil samples of 200g each were obtained from the center of each quadrant. Samples were subjected to soil primary macronutrient elements tests using relevant laboratory protocols to investigate any systematic variation of specific elements across plots so as it could be associated with soil moisture retention variation if any. The type of elements that were investigated and the equipment used were as follows;

i. pH- Mettler Toledo Seven-Multi pH meter with an InLab Routine Pro combination electrode
ii. P- Phosphorus is determined on the filtrate by the molybdate-blue method using ascorbic acid as a reluctant.
iii. Ca, K, Mg, Na Mn - Exchangeable by Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES)

The purpose was to detect any relationship between known water holding elements and their concentrations within the study area. Results obtained from the soil chemical analysis were tabulated Table 3:7.

Table 3:6 Grid Analysis for P, K, Zn Mn, Mg, Cu, Fe, Ca, and pH

K	Na	Zn	Mg	Mn	Cu	Fe	Ca	pH
329.2977	134.5239	10.7651	475.2852	710.9635	1.4752	66.5200	178.9780	5.3700
255.2378	91.9226	12.7476	275.9625	910.5121	1.0165	67.3800	225.4462	5.5300
352.3521	89.6403	12.8694	303.8855	1058.3650	1.0582	65.9000	215.3945	5.5000
291.4176	99.4031	14.5563	228.1369	1122.3600	1.0999	74.0500	363.2987	5.3100
383.7387	104.8551	11.9477	257.2481	1488.0450	0.8705	65.4700	132.1086	5.5700
314.2024	112.4625	12.0172	259.0304	1240.3760	1.2041	65.4400	205.3427	5.4500
213.6736	81.3990	12.8868	266.1597	1227.0790	1.1207	63.1700	113.4411	5.5000
367.8484	129.3255	12.7824	271.5067	1515.4720	1.3501	85.4300	123.4928	5.4500
346.4426	101.8122	13.9128	297.9444	1306.0340	1.0999	65.6300	221.1383	5.4200
293.7158	113.4768	12.6259	265.5656	1074.1560	1.1833	67.0800	259.9093	5.5400
353.6654	113.8572	12.1737	269.4273	1178.8750	1.0373	62.6700	232.6260	5.6500
368.8990	112.8429	10.8694	260.5157	1037.5870	0.9331	62.8100	232.6260	5.6700
377.9604	137.1865	11.1651	262.8921	603.7511	0.9748	59.8400	29032.88	5.6200
290.5640	115.7590	11.6868	268.5361	1297.7230	0.8705	61.4400	208.2147	5.4000
327.4005	92.3029	11.3042	252.7923	1086.6220	1.0165	65.8800	221.1383	5.0400
419.0649	104.4747	12.1911	276.8536	1365.8730	1.0373	65.0100	216.8304	5.7200
415.9132	124.0004	12.0694	275.3683	1074.9870	1.1416	63.8300	160.8279	5.7600
380.6526	97.2477	12.1390	277.4477	1394.1310	1.1416	65.4000	254.1655	5.7500
398.9723	85.4563	13.0433	277.1507	1077.4800	1.0790	63.6700	267.0891	5.6100
360.1003	103.5872	12.1563	286.3593	1152.2800	1.1416	59.8500	170.8796	5.6900
339.5480	95.4727	12.8346	292.6637	1366.7040	1.0373	61.4900	259.9093	5.8300
386.6278	141.8777	14.3302	296.1792	1237.0520	1.1833	59.5000	305.8602	5.7600
399.1693	84.6955	12.2955	299.6946	1266.1410	1.3292	59.2100	271.3970	5.6200
335.6740	112.7161	10.5564	279.4806	1519.6270	1.2250	76.7600	216.8304	5.6000
327.0065	84.8223	11.2172	289.7341	1404.1040	0.9122	60.5000	280.0128	5.7300
342.8968	127.5505	12.7824	275.0863	1351.7440	1.2667	59.0300	191.9016	5.5600
345.1293	90.9082	11.8259	253.9934	1302.7090	1.0165	61.0000	241.2418	5.5900
362.7924	104.6015	14.5563	257.5089	998.6810	1.1624	70.2300	211.0866	5.4400
381.8345	82.4133	15.1302	290.0271	1399.1170	1.3292	59.4100	173.7515	5.6200
323.6578	130.0863	12.1216	238.1738	1206.3010	1.0999	70.1300	195.2910	5.7200
372.3791	111.1946	13.2346	229.3851	1400.7790	1.2875	64.5100	238.3699	5.5200
410.8572	98.7692	13.4955	238.4667	1320.1620	1.0373	59.9800	228.3181	5.5100
403.8313	90.6547	14.4172	299.6946	937.0236	1.1833	54.6500	150.7761	5.7300
400.8108	90.6547	13.2694	307.0186	1027.6140	1.0999	58.3000	198.1629	5.7700
383.0164	85.2027	14.2954	307.6045	1118.2040	1.1624	64.0100	168.0077	5.6600
376.6472	139.9759	15.0085	290.6130	393.7856	1.3918	70.4700	248.4216	5.4200
383.6074	82.4133	14.3998	321.0805	291.2562	1.1207	62.1400	146.4682	5.5500
379.2080	134.2703	15.0780	306.4326	932.0370	1.2667	66.7900	169.4437	5.9500
460.7604	77.7221	13.7042	290.9059	1136.4890	1.1833	74.2100	156.5200	5.2300
363.3177	85.9634	13.8781	290.9059	1153.1110	1.2667	67.2900	176.6235	5.5800
494.0512	98.2620	19.1302	256.9230	1109.8930	1.2250	65.4400	104.8253	5.4800
373.9550	93.4440	14.6780	323.7171	1174.7190	1.2458	67.6800	176.6235	5.5000
343.8055	137.6936	11.8607	296.7651	1150.6170	1.3292	62.8500	134.4631	5.5700
397.0024	75.9470	11.9129	335.4354	952.7295	1.3501	58.0500	238.3699	5.5600

3.6 Soil Water

3.6.1 Soil Water Characteristic Curve Determination

Soil samples were collected in 2 cores from 7.5 and 22.5cm depths of each tillage treatment in steps of 10cm from top to 30cm deep. A total of 24 soil cores obtained from the plots were analysed in a laboratory for soil water characteristic curve. Sampling was done before, immediately after six, seven and eight weeks after treatment application using methods as described in the ASTM 2008D-09 and ASTM 2008D 1452-09. The volumetric water content each soil sample was computed gravimetrically for each suction level and determined using the core method at the end of SWR measurements. Plant available water was computed as the difference between volumetric water content at -10 and -1584.8 (Table 3.7).

Table 3:7 Matric Potential analysis for loamy sand soils from 10 to 60cm Depths

				Kpa					
4.0									
Depth(cm)	-0.1	-0.25	-1.25	-3.16	-6.31	-10	-19.95	-50.12	-1584.89
	Moisture Content(cm/m)								
10	52	51	50	49	50	48	48	46	45
20	59	56	49	34	35	38	32	28	23
30	43	42	41	40	39	38	36	32	23
40	65	63	61	58	57	56	45	35	22
50	59	58	56	55	56	55	45	35	22
60	36	35	34	32	31	28	26	24	14

3.6.2 Saturated Hydraulic Conductivity Determination

A constant-head permeameter (Cote's infiltrometer), with a special head that can be moved directly onto a pot surface (Banton et al. 1991) was used In measurement of the hydraulic conductivityand the results were found as in Table 3:8 below.

Table 3:8 Hydraulic Conductivity (10^{-6}×m s^{-1})

0-10cm	12.50
10-20cm	0.07
20-30cm	1.31
30-40cm	8.05
40-50cm	11.80
50-60cm	9.29

3.6.1 Infiltration determined using Kostiakov's method

The Kostiakov's method was used to determine base infiltration rate in each tillage treatment immediately after application. The mean results obatained were as in table 3:10 below.

Table 3:9 Basic Intake Rates in Loamy Sand Soils of Eastern Mau

Tillage	Base infiltration rate mm/hr
MT	30.6
CT	21.6
NT(control)	14.1
ZT	10.8

3.6.2 Permeability

To determine permeability, undisturbed chrome ring samples were saturated and put in the permeameter. The volume of the water passing through the samples and the time taken was determined. Infiltration was calculated from discharge passing and time. . Permeability was determined directly from Water permeability meter (Table 3:11). Soil cores were saturated with distilled water for sandy loam, loamy sand soils at a constant flow rate of 5 mmh^{-1} for the determination of Ks. Air-dried bulk samples were ground, passed through 2mm sieve, and tightly packed in rubber rings for determination of SWR at -1585kpa using California Test 219 procedure.

Table 3:10 Hydraulic conductivity analysis by constant head (California Test 219)

Soil Depth (cm)	Hydraulic Gradient
10	6.6
10	6.4
20	6.5
20	6.6
30	6.4
30	6.3
40	6.4
40	6.4
50	6.3
50	6.5
60	6.4
60	6.4

3.6.3 Monitoring Soil Moisture Retention by the Neutron Probe

Prior to performing moisture tests and calibration of radiological attenuation instrument is done. During calibration, the gauge automatically compares the new standard count with the average of the last four standard counts. Calibration is done to take care of the sphere of influence

radius of the radioactive source for top and deep measurements. Standard counts are plotted against actual obtained using a gravimetric method as explained by (Kramer *et al.*, 1992).

Two pairs of data were developed for;

(i) Top soil curve (10-20cm)

(ii) Subsoil curve (20-40cm)

The probe counts were converted into volume of moisture retained for a given probe reading (Table 3.12).

Table 3:11 Neutron Probe calibration values for top and subsoil

Surface(10-20cm)		Subsurface (20-40cm)	
Count ratio	m^3	Count ratio	m^3
0.361	0.043	0.56	0.04
0.360	0.044	0.57	0.04
0.365	0.044	0.59	0.04
0.371	0.044	0.63	0.05
0.360	0.044	0.64	0.04
0.360	0.044	0.67	0.04
0.360	0.043	0.76	0.05
0.360	0.043	0.78	0.06
0.370	0.043	0.72	0.05
0.368	0.044	0.79	0.06

Soil moisture was measured for different systems and the moistred was found to be as in table 3:13 below.

Table 3:12 Weekly Moisture Retained under Different Tillage Systems for Eight weeks

Week1	Average m^3/m^3			
	ZT	**NT**	**CT**	**MT**
10	0.39	0.39	0.39	0.39
20	0.56	0.56	0.60	0.58
30	0.69	0.68	0.74	0.72
40	0.76	0.76	0.78	0.78
50	0.79	0.79	0.82	0.80
60	0.84	0.85	0.87	0.84

Table 3.13 Weekly Moisture Retained under Different Tillage Systems for Eight weeks Continued

Week2	Average m^3/m^3			
	ZT	**NT**	**CT**	**MT**
10	0.37	0.39	0.37	0.38
20	0.52	0.51	0.51	0.55
30	0.66	0.62	0.65	0.69
40	0.73	0.68	0.75	0.76
50	0.76	0.75	0.80	0.80
60	0.83	0.78	0.86	0.83

Table 3.13 Weekly Moisture Retained under Different Tillage Systems for Eight weeks Continued

Week3	Average m^3/m^3			
	ZT	NT	CT	MT
10	0.38	0.40	0.37	0.38
20	0.54	0.54	0.52	0.56
30	0.66	0.63	0.66	0.69
40	0.72	0.69	0.74	0.76
50	0.76	0.74	0.80	0.79
60	0.81	0.78	0.85	0.83

Table 3.13 Weekly Moisture Retained under Different Tillage Systems for Eight weeks Continued

Week4	Average m^3/m^3			
	ZT	NT	CT	MT
10	0.41	0.43	0.40	0.44
20	0.63	0.61	0.60	0.65
30	0.71	0.70	0.70	0.73
40	0.73	0.72	0.75	0.76
50	0.77	0.75	0.79	0.79
60	0.82	0.78	0.83	0.82

Table 3.13 Weekly Moisture Retained under Different Tillage Systems for Eight weeks Continued

Week5	Average m^3/m^3			
	ZT	NT	CT	MT
10	0.43	0.46	0.42	0.46
20	0.72	0.72	0.65	0.75
30	0.83	0.82	0.80	0.84
40	0.86	0.85	0.87	0.85
50	0.88	0.88	0.88	0.86
60	0.92	0.90	0.92	0.89

Table 3.13 Weekly Moisture Retained under Different Tillage Systems for Eight weeks Continued

Week6	Average m^3/m^3			
	ZT	NT	CT	MT
10	0.42	0.44	0.39	0.43
20	0.67	0.66	0.60	0.63
30	0.80	0.78	0.73	0.79
40	0.83	0.83	0.82	0.84
50	0.86	0.85	0.85	0.85
60	0.94	0.89	0.90	0.90

Table 3.13 Weekly Moisture Retained under Different Tillage Systems for Eight weeks Continued

Week7	Average m^3/m^3			
	ZT	NT	CT	MT
10	0.40	0.42	0.37	0.39
20	0.61	0.61	0.55	0.62
30	0.75	0.72	0.70	0.76
40	0.81	0.79	0.78	0.83
50	0.85	0.84	0.83	0.85
60	0.91	0.87	0.87	0.89

Table 3.13 Weekly Moisture Retained under Different Tillage Systems for Eight weeks Continued

Week8	Average m^3/m^3			
	ZT	NT	CT	MT
10	0.43	0.46	0.41	0.42
20	0.72	0.70	0.63	0.70
30	0.82	0.80	0.76	0.81
40	0.84	0.83	0.81	0.84
50	0.87	0.85	0.84	0.85
60	0.93	0.89	0.86	0.89

3.6.4 Rainfall Data

Rainfall data was collected from KARI-Njoro weather station, KMS ID No. 9031021 near the experimental site during the probe reading period Table 3:14. Secondary data was used to establish the trends for the past 50 and last 3 years in order to compare trends. The probability of drought occurrence during a crop growing period was determined by a graphical method in which rainfall totals were ranked in a descending order from m=1 to m=50, Table 3:15 The probability of occurrence P (%) for each of the ranked observations was calculated with eqn. (2.20). The rainfall analysis was for determining the expected time of land preparation and planting time for the crop to escape the partial drought after the first rains.

Table 3:13 Mean Daily Rainfall Data; KMS ID No. 9031021, KARI, NJORO Jan-Aug 2010

Date	Jan	Feb	Mar	Apr	May	June	July	Aug
1	9.9	0	2	20.4	14.2	0.6	0.8	3.2
2	11.1	0	4	2.5	1.5	0.1	0	0.4
3	7.2	0	8	0.1	0	2.4	0.2	0
4	2.3	7.5	2.6	7.1	1.5	0.1	0.3	0
5	0.1	6.8	6.8	0	11.5	0.4	0	0.1
6	0	0	12.1	0	0	26	0	0
7	0	10.5	0	7.4	0	3.5	0	0
8	0.1	0	0	1.1	0	0.1	1	0.5
9	8.1	0	0.4	0	17.1	0	3.8	0.3
10	0.6	0	0	0.1	20.1	0	8.4	7.7
11	1.8	0	0	0	5.1	0	6.9	0
12	0	0	0	0.1	21	0	0	0
13	0	0.1	0	0	0.5	11.5	0	0.1
14	0	0	0	0.1	0	5.5	0	1
15	0	1.8	0	0	0	0	0	2.4
16	0	4.3	10.9	3.6	22	0.1	16.9	24.4
17	0	8.5	1.2	6.7	46.5	0.1	4.8	36.5
18	0	2.2	0	0.1	0.1	1.2	0.1	1.7
19	0	0	0	6.9	16.3	0	0	0.7
20	1.5	19.4	4.6	0	1.9	0	4.7	3
21	0.4	2.1	6.4	0	0	0	15.3	0

22	0	5.8	6.3	0.2	0	0	0	8
23	0	0.1	24.3	0	0.9	0.1	0	1.5
24	0	0	38.2	27	0.3	0	29	16.9
25	0	4.8	11.4	20	0	0	2.9	5.3
26	0	6.8	3.9	5	0	0	25.2	6.5
27	0	28.4	12.2	0	0	0.5	10	64.5
28	0	48.1	18.5	9.2	0	0	0.1	25
29	0	0	5.5	20.1	0.1	0	12.9	7.8
30	0	0	1	3.1	0	0	19.8	0.1
31	0	0	3.8	0	0	0	3.2	23.3
Total	43.1	157.2	184.1	140.8	180.6	52.2	166.3	240.9

Historical data obtained from KMS ID No. 9031021, KARI, NJORO 1960-2010 is shown in Table 3:15 from which analysis was undertaken to determine trends and probabilities in precipitation within the Eastern Mau region.

Table 3:14 Rainfall March to July; KMS ID No. 9031021, KARI, NJORO 1960-2010

Year	Rain (mm)	Year	Rain (mm)	Year	Rain (mm)	Year	Rain (mm)
1960	533.0	1973	726.7	1986	458.6	1999	511.6
1961	675.9	1974	379.5	1987	446.5	2000	436.8
1962	752.6	1975	542.9	1988	523.3	2001	604.4
1963	506.2	1976	574.3	1989	304.2	2002	422.9
1964	448.4	1977	409.4	1990	528.0	2003	556.9
1965	542.3	1978	504.6	1991	392.5	2004	282.9
1966	388.3	1979	458.7	1992	417.6	2005	520.8
1967	247.9	1980	403.6	1993	579.4	2006	399.5
1968	489.9	1981	721.7	1994	584.3	2007	412.1
1969	493.0	1982	509.7	1995	529.3	2008	484.9
1970	537.3	1983	625.5	1996	297.0	2009	574.8
1971	312.0	1984	665.9	1997	757.0	2010	624.8
1972	429.5	1985	523.3	1998	459.3	2011	438.5

3.6.5 Statistical Analysis Theory

The data sets were processed for analysis of variance as applicable to a split plot design, to test differences among the treatments, depths and their interactions using statistical program SAS 9.1, developed by, SAS Institute Inc., SAS Campus Drive, Cary, NC 27513, USA. Before the determination of soil physical characteristics, two factors influencing moisture retention in soil analysed were retained moisture, tillage method at specific depths. Rainfall was separately analysed using the graphical method since it was a nonparametric parameter, The characteristics of soil considered were; soil profile, texture, bulk density, particle density, porosity, void, void

ratio, saturation level at field capacity, moisture content, specific gravity, hydraulic conductivity, soil moisture characteristic curves, moisture retention and infiltration rate under different tillage systems. Differences among tillage treatments were tested for significant effects on moisture retention using analysis of variance (GLM). Separation of treatment means were achieved by the t-test procedure, Least Significant Difference (lsd). Probability level ($P \leq 0.05$) was used as the critical limit for distinguishing the degree of statistical differences between means since the research was agricultural.

Table 3: 15 Two Factor Experimental Model

Factor		*r* R i	*a* F j	*b* F k	1 R H	Expected Mean Square
Whole Plot	α_i	1	*a*	*b*	1	$\sigma^2 + \alpha\beta\sigma_\alpha^2$
	β_j	*r*	0	*b*	1	$\sigma^2 + \beta\sigma_{\alpha\beta}^2 + \frac{\alpha\beta\sum\beta_j^2}{a-1}$
	$(\alpha\beta)_{ij}$	1	0	*b*	1	$\sigma^2 + \alpha\beta\sigma_{\alpha\beta}^2$
Sub-plot	γ_k	*r*	*a*	0	1	$\sigma^2 + \alpha\sigma_{\alpha\gamma}^2 + \frac{r\alpha\sum\gamma_k^2}{b-1}$
	$(\alpha\gamma)_{ik}$	1	*a*	0	1	$\sigma^2 + \alpha\sigma_{\alpha\gamma}^2$
	$(\beta\gamma)_{ik}$	*r*	0	0	1	$\sigma^2 + \alpha\sigma_{\alpha\beta\gamma}^2 + \frac{\alpha\sum\sum(\beta\gamma)_{ij}^2}{(a-1)(b-1)}$
	$(\alpha\beta\gamma)_{ijk}$	1	0	0	1	$\sigma^2 + \sigma_{\alpha\beta\gamma}^2$
	$\epsilon_{(ijk)_h}$	1	1	1	1	$\sigma^2(not\ estimable)$

Model:

$$X_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma\kappa + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijk} \qquad Eqn\ (3.1)$$

Where, α_i , β_j and $(\alpha\beta)_{ij}$ represent the whole plot and γ_k, $(\alpha\gamma)_{ik}$, $(\beta\gamma)_{jk}$ and $(\alpha\beta\gamma)_{ijk}$ represent the split-plot. Here α_i, β_j, $\gamma\kappa$ are block effect, factor A effect and factor B effect, respectively. The sums of squares for the factors are computed as in the three-way analysis of variance without replication.

Where $(\alpha\beta\gamma)_{ijk}$ = the interaction effect of i^{th} tillage and j^{th} depth $\quad i = 1$ to a, $j = 1$ to b

Where ε_{ijk} = the error b

Assumptions

1. The model is additive
2. $\sum\alpha_i = \sum\beta_j = \sum\gamma_k = \sum\alpha\beta_{ij} = \sum\alpha\gamma_{ik} = \sum\beta\gamma_{jk} = \sum\alpha\beta\gamma_{ijk} = 0$

3. $\varepsilon_{ijkl} \cong IIN(0, \sigma^2)$ independent, identical, normally distributed with mean = 0, and variance, σ^2

CHAPTER FOUR

DATA ANALYSIS, RESULTS AND DISCUSSIONS

4.1 Overview of Results and Discussions

In this study, effect of different tillage methods on loamy sand soils'moisture retention was investigated. Plots were subjected to different tillage treatments in order to explore their effect on the amount of soil moisture retained during the study period. Data on rainfall, topography, soil chemical elements, soil profile, texture, particle density, soil bulk density, porosity, infiltration hydraulic conductivity, Soil Water Characteristic Curves, permeability and in situ soil moisture content were studied. The results of the study indicated that tillage system had a significant influence on moisture retention ($P \leq 0.05$) in loamy sand soil of Eastern Mau.

4.2 Topography

Relief of the experimental site represented on a 3D diagram, (Figure 4.1) below was found to lie between reduced levels 2169.19 and 2168.2 m amsl. with a slope of 1.65%. There were no visible signs of soil erosion, however, water was found to stagnate on the lower side (C1) of the field, Figure 4:1. Fine soil particles were expected to be carried along with draining water during infiltration and pack in the pore spaces. This would have reduced its porosity but this was not significant ($P>0.05$). Alternatively, leaching would have occurred but on the contrary, it had more organic matter percentage (3.4%) compared to 1.7% in the other parts of the field. Wet conditions provided an environment suitable for decomposition of biomass that accumulated in the lower area. However, soil moisture retention in the soil profile at the lower elevation was not found to be significantly different, ($P>0.05$).

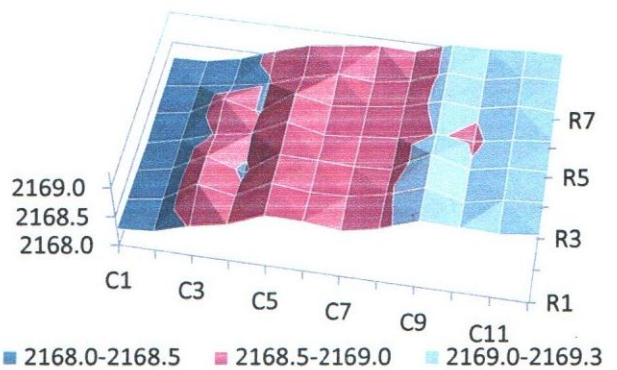


Figure 4:1 Contourson the Research Site

The soil elements known to affect moisture retention are; Nitrogen, Phosphorous, Potassium, calcium, manganese, and sulphur and none of the chemicals had significant effect on moisture retention. It is important to note that their spatial concentration variability was over 50% in all cases but did not attain critical masses to have any corresponding effect on the moisture retention.

4.3 Soil Profile

Well drained, moderately deep and with varied structure across profile pockets of soil were noticed in the weathered rocks. Root distribution was normal but was more concentrated in the top 40cm depth of the soil layer.

Ap_1 0-13cm Dark reddish brown (5 YR 2.5/2) moist, (7.5 YR 4/4) dry and (5YR 3/2) rubbed; clay loam, strong fine to coarse crumb and granular, slightly hard dry, friable moist, sticky and plastic wet; common micro, very fine and fine interstitial pores; many very fine and fine roots; pH 5.4; abrupt and smooth boundary to:

Ap_2 13-27cm Dark reddish brown (5 YR 2.5/2) moist, (7.5 YR 4/4) dry (5YR 3/2) rubbed; Clay loam, weak very coarse prismatic structure falling apart to weak fine to coarse angular blocky structure; very hard (dry) friable moist, sticky and plastic wet; common micro, very fine interstitial pores; common very fine and fine roots; pH 5.61; clear and smooth boundary to:

Bw_1 27-40cm Dark reddish brown (5 YR 3/2) moist, (5 YR 3/3) dry (5YR 3/3) rubbed; Clay; moderate fine to coarse sub angular blocky structure; slightly hard dry, friable moist, sticky and plastic wet; common micro, very fine, fine and medium interstitial pores; very few fine and fine roots; pH 5.02; gradual and smooth boundary to:

Bw_2 40-60cm Dark reddish brown Dark reddish brown (5YR 3/3) moist, (5YR 4/4) dry, (5YR 3/3) rubbed; clay; moderate fine to coarse sub-angular and angular blocky structure, slightly hard dry, friable moist, sticky and plastic wet; many micro, very fine, fine and medium interstitial pores; rare very fine roots; pH 5.96; abrupt irregular boundary to weathered vitric tuff, beyond 60cm falls outside the scope of this study.

The soil profile of the loamy sand soils was defined as well drained, moderately deep with varied structure across the profile as supported by the trend of moisture content analysis down the profile which revealed that the moisture content variation was a third order quadratic function that increased with depth. Though there were distinct abrupt and smooth soil profile boundaries, Ap_1, Ap_2, Bw_1 and Bw_2 this was not illustrated in a quadratic curve (Figure 4.14) of the moisture content

change which was entirely due to depth suggesting that the texture between profile boundaries was gradual.

4.4 Soil Textural Analysis

Soil from the study area belongs to volcanic soil series and has been classified as loamy sand soil. It is characterized by coarse texture, low organic matter status, deep and well-drained profiles. The sieve analysis revealed that it has a rich gradation which refers to a sample of aggregate with a high proportion of particles of small sizes. The weighted means of soil fractions were 82.1, 2.7 and 15.2% for sand, silt and clay respectively. The high quantity of sand is responsible for the low saturation time from 4 to 20 minutes, some clay soils take up to 72 hrs Kolay, (2008) to saturate. Sandy particles were found to be more concentrated in the topsoil which could be attributed to the previous land use. The grading curve (Figure 4.2) with Coefficient of gradation = 0.64. The soil textural analysis coefficients were D_{10} = 0.3mm, D_{30} = 0.48mm, D_{60} = 1.5mm, Coefficient of uniformity = 5. describes the test sample as poorly graded medium sand and fall under a soil classification of loamy sand according to USDA textural triangle classification.

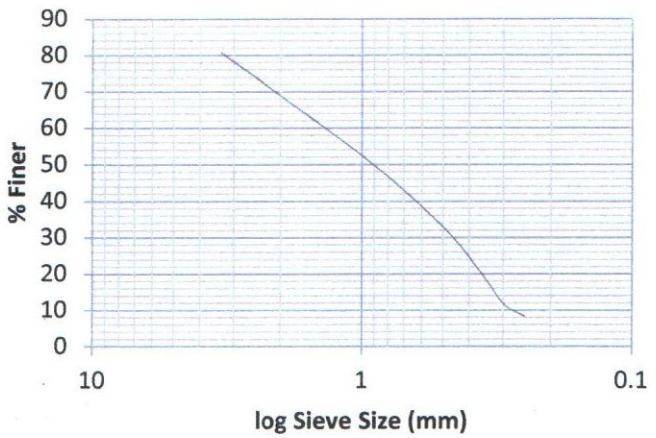


Figure 4:2 Grading Curve for the Loamy Sand Soils

Table 4: 1 Particle Size Distribution (%)

Sand	82.1
Silt	2.7
Clay	15.2
Textural Class	Sandy loam
Organic matter %	1.7-3.4

4.5 Bulk Density

Bulk density, BD, varied from 1.04-1.37 gcm^{-3} within the top soil. The highest BD in the study profiles was found to occur from 20 to 40cm depths, suggesting the existence of a plough pan. This can be accredited to previous land use practices where soil was frequently worked at 0-20cm deep, below which existed a plough pan. At that depth, porosity was lowest and the highest bulk density occurred here, Figure4.3. It was clear that tillage had an effect on bulk density but with weekly testing, it was discovered that the effect lasted for only 8 weeks and initial conditions were observed, Table 3.5.

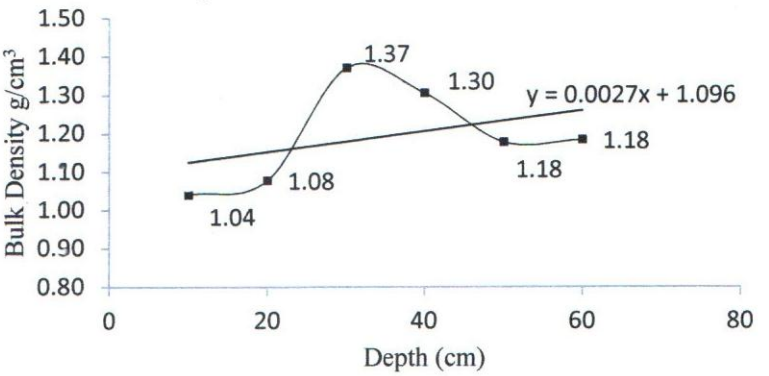


Figure 4:3 Variation of BD down the profile after Tillage Treatments

4.6 Particle Density

Particle density ranged from 1.61 - 2.18gcm^{-3}. The mean particle density was 2gcm^{-3} with particles of density, 2.18gcm^{-3} being dominant in the top 20cm. This could be attributed to particle segregation due to ploughing. This may have accumulated over time and increased in amount of dense particles. On the other hand, at 60cm depth, the particle density is low because of the type of rock found at the profile depth, (See Figure 4.4).

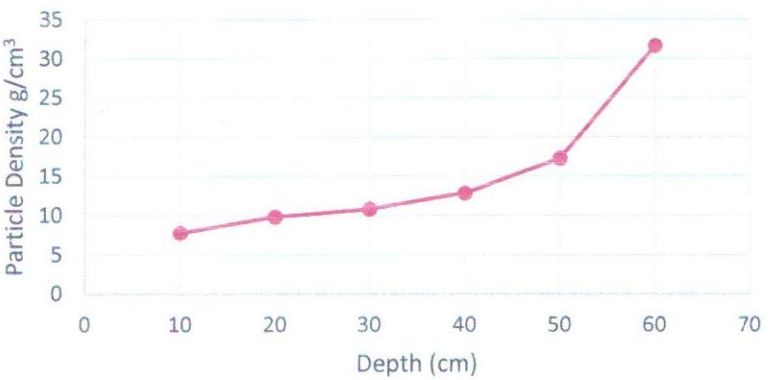


Figure 4:4 Particle Density down the profile

4.7 Porosity

A decrease in porosity (Figure 4.5), hydraulic conductivity (Table 4.5) and increase in bulk density between 25 and 40 cm (Figure 4.3), depth are accredited to the existence of a plough pan confirming an earlier stated case. Beyond 50cm, porosity was found to decrease as the depth approached the pumice rock which is semi permeable with a high bulk density.

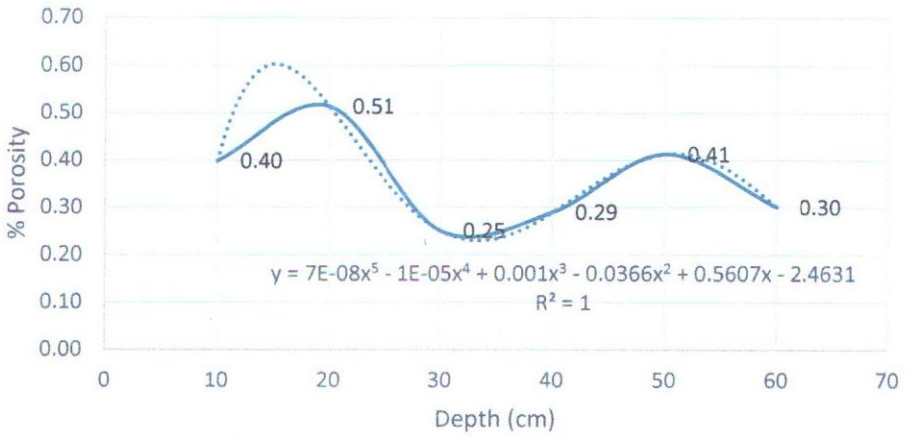


Figure 4:5 Porosity Variation down the Profile

4.8 Spatial Variability of Chemical Elements in Soil

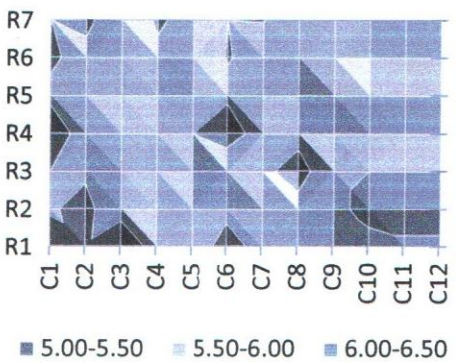


Figure 4:6 Phosphorous concentrations on the research site

The primary macronutrients, i.e., N.P.K secondary macronutrients, i.e., Ca, Mg, S and some micronutrients were analysed due to their known direct or indirect effect on soil moisture retention capabilities. Carbon was found to range from 1.7 to 3.4% and decreased down the profile. Nitrogen was found in quantities of 0.12 to 0.26%. Both Nitrogen and Carbon are used by bacteria during decomposition of organic matter which is responsible for moisture retention arising from its effect on soil aggregation and pore size distribution. The pH level was found to lie between 5.04 and 6.18, the range described as moderate to slightly acid soil. Potassium was 213.7 to 494.7ppm being concentrated more on elevated parts than the depressed ones (Figure 4.6-4.9). Potassium influences

soil stability due to increasing the soil's water retention properties, (Anna *et al.,* 2006). The precipitated potassium salts causes bridging between the soil and potassium salts, significantly increasing the soil's water retention properties. The precipitated potassium salts causes bridging between the soil particles, reducing the size of the macro pores and increasing the water retention capacity.

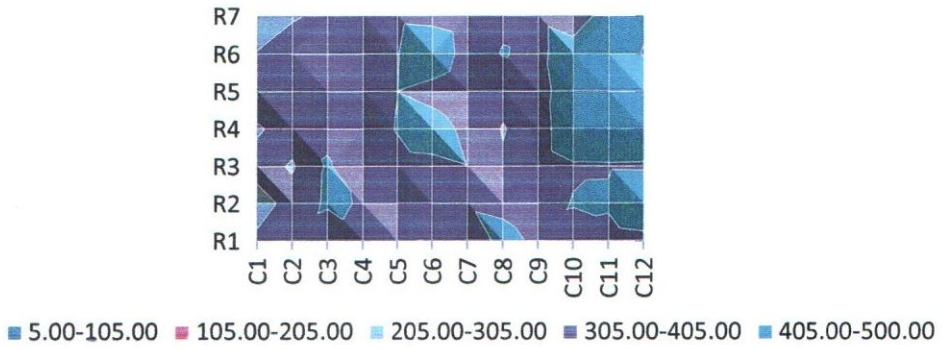


Figure 4:7 Potassium concentrations on the research site

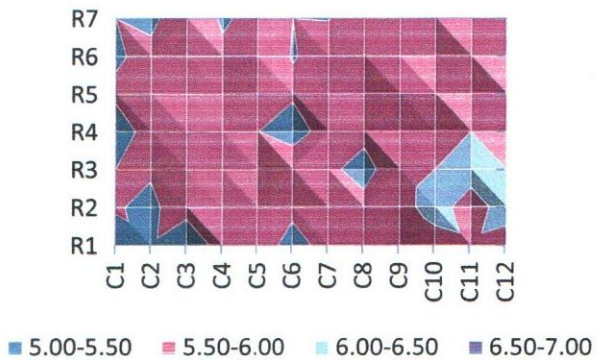


Figure 4:9 pH levels on the research site

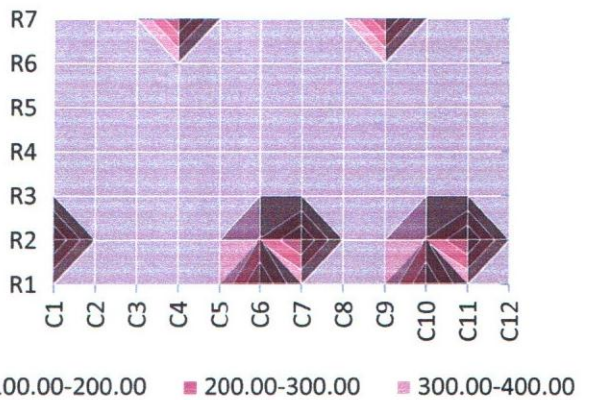


Figure 4:8 Manganese concentrations on the research site

4.9 Soil Water

4.9.1 Soil Water Characteristic Curves (SWCC) at Different Depths

The SWC curves for samples from soil depths; 10, 20, 30, 40, 50 and 60cm had unique SWCC though the soil texture was found to be similar in all sampled profiles. The upper moisture limit considered to be of field capacity Kpa = 300 and the lower soil moisture limit also called "wilting point", Kpa = 1500 were used to determine the amount of water retaining capacity in relation to crop requirement. Volumetric available moisture in the top 10cm soil was found to be 8% (Figure 4.10a). The low amount could be attributed to high hydraulic conductivity (Figure 4.20), low bulk density (Figure 4.3) and high organic matter content as compared to the results at 40cm depth with 34%.

The available moisture reduced from 15% to 13% at soil depths 20cm and 30cm respectively corresponding to the bulk density identified with the plough pan at the depth. The available moisture at 40 and 50cm depth did not exhibit a notable difference, 33, 34% respectively. At the 60cm depth, the hydraulic conductivity reduced because it is at this depth that the soil suddenly changes in structure as it approaches the underlying prominent distinct dark yellowish mottles (10YR 3/4) which occur from soil depth 56cm. Similar results were reported by (Kimotho, 1990). The storage coefficients (the slope of soil-water characteristic curve) of the six SWC curves from respective depths, do not exhibit significant difference after air entry point (Figure 4.10a-f). From the figure it can be observed that the low bulk density soil depth stored more water and dewater for a longer period in which, air entry value refers to the matrix suction value when water in the surface meniscus of soils body skeleton begins to move (Jin-yu Li, 2010). The absolute waterstorage capacity is 11.7cm, 19.5% by volume.

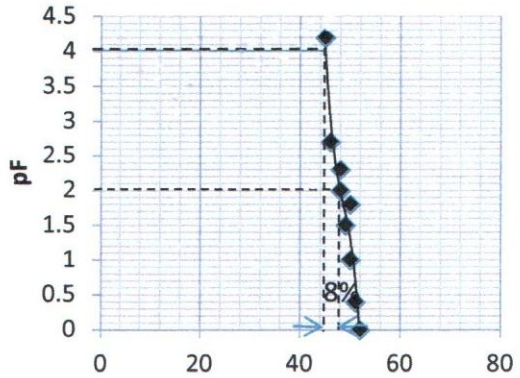


Figure: 4.10a Vol % Water(10cm)

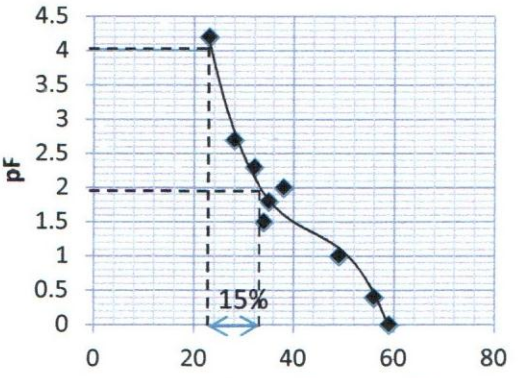


Figure: 4.10b Vol % Water (20cm)

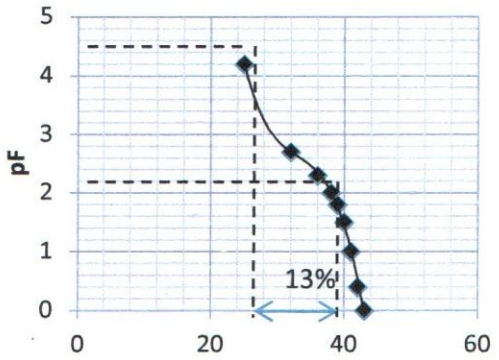


Figure: 4.10c Vol % Water (30cm)

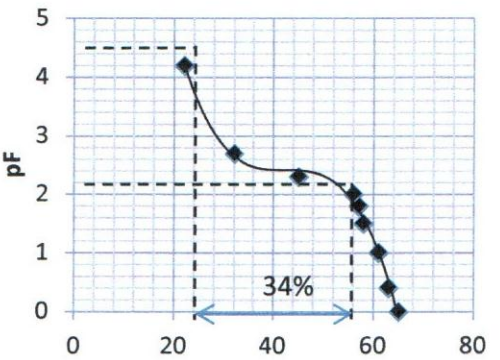


Figure: 4.10d Vol % Water (40cm)

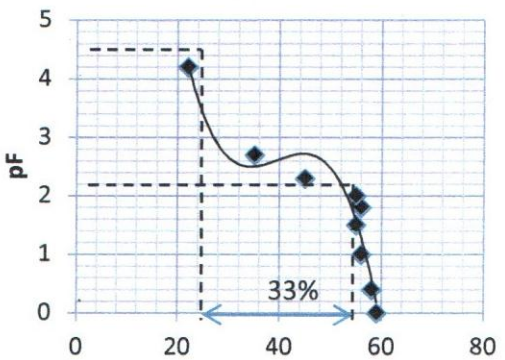


Figure :4.10e Vol % Water (50cm)

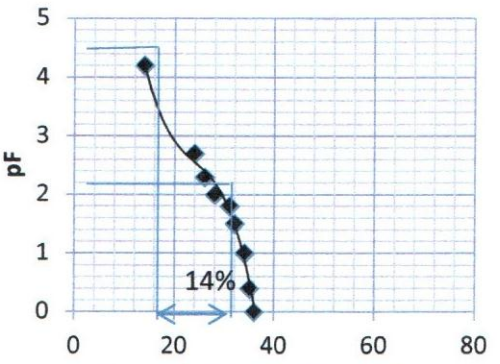


Figure: 4.10f Vol % Water (60cm)

Figure 4:10 SWC curves at 10, 20, 30, 40, 50 and 60cm

characteristic function, $R = 732.9e^{-0.008P}$. This function can be used by farmers to select the type of tillage to apply.

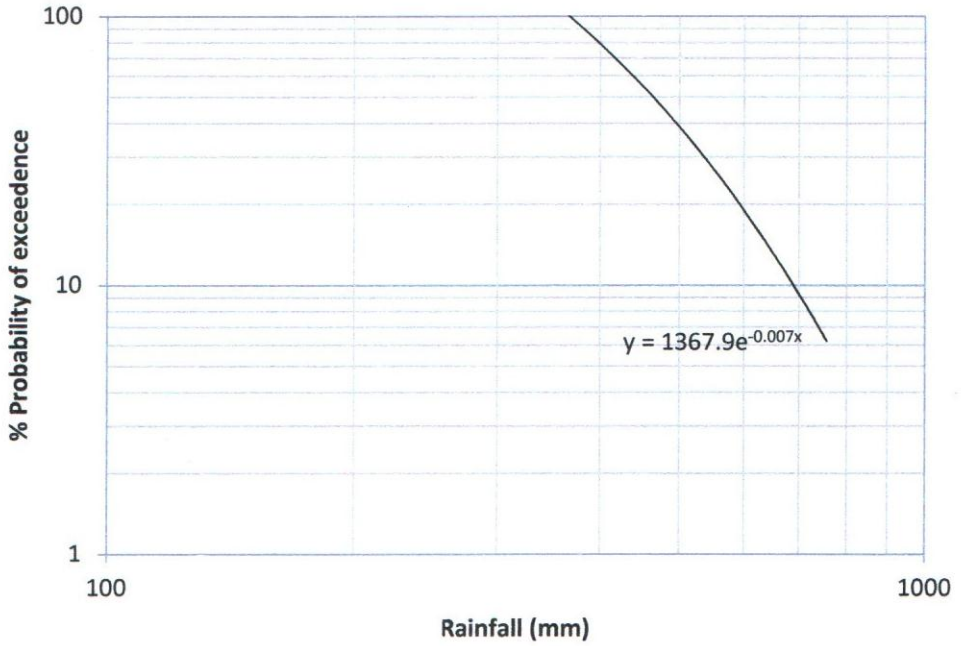


Figure 4:12 Rainfall Occurrence Probability Curve

Table 4: 2 Mean Annual Rainfall March-June, Ranked and Probability of Occurrence

Rain	Year	M	P (%)	Rain	Year	M	P (%)	Rain	Year	M	P (%)
757.0	2010	1	1.9	529.3	2008	19	36.5	436.8	1961	37	71.2
752.6	1975	2	3.8	528.0	2003	20	38.5	429.5	1985	38	73.1
726.7	1986	3	5.8	523.3	1998	21	40.4	422.9	1963	39	75.0
721.7	1994	4	7.7	523.3	2001	22	42.3	417.6	2005	40	76.9
675.9	1974	5	9.6	520.8	1966	23	44.2	412.1	1968	41	78.8
665.9	1997	6	11.5	511.6	1960	24	46.2	409.4	1990	42	80.8
625.5	1996	7	13.5	509.7	1995	25	48.1	403.6	1993	43	82.7
624.8	1971	8	15.4	506.2	1976	26	50.0	399.5	1967	44	84.6
604.4	1962	9	17.3	504.6	1991	27	51.9	392.5	2004	45	86.5
584.3	2007	10	19.2	493.0	1982	28	53.8	388.3	1979	46	88.5
579.4	2006	11	21.2	489.9	1981	29	55.8	379.5	1987	47	90.4
574.8	1970	12	23.1	484.9	1969	30	57.7	312.0	1984	48	92.3
574.3	1989	13	25.0	459.3	2011	31	59.6	304.2	2002	49	94.2
556.9	1964	14	26.9	458.7	1992	32	61.5	297.0	2009	50	96.2

542.9	1988	15	28.8	458.6	1999	33	63.5	282.9	1965	51	98.1
542.3	1978	16	30.8	448.4	1977	34	65.4	247.9	1980	52	100.0
537.3	1983	17	32.7	446.5	2000	35	67.3				
533.0	1973	18	34.6	438.5	1972	36	69.2				

4.9.4 Neutron Probe Calibration

The two neutron attenuation moisture meter calibration curves were generated before moisture variability monitoring in the profile began. The top 10cm (Figure 4.13) had a different curve gradient due to the radius of influence by the radioactive that detects moisture partly in the soil and the other part in the air. Below 10cm soil depth, (Figure 4.14), the radioactive radius of influence detection is all in the soil, hence the two different curves.

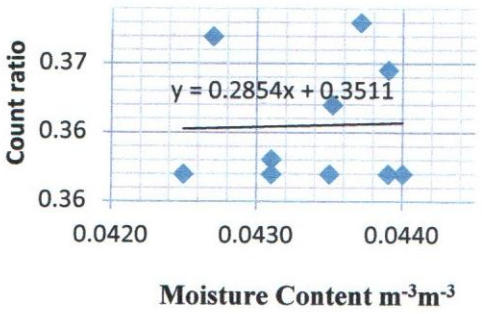


Figure 4:13 Sub Soil Neutron Probe Calibration

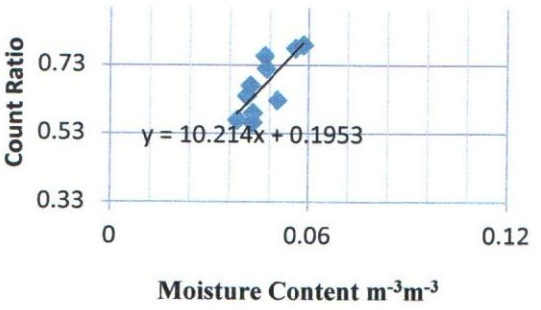


Figure 4:14 Top Soil Neutron Probe Calibration

4.9.5 Moisture Content

The soil moisture content in the top 10cm was 7.88%. It was found to geometrically increase with depth to 31.7% at 60cm, (Figure 4.14). The top soil looses water to 7.88% during the dry season which is ¼ of the wilting point as earlier observed from the SWC curves; available moisture at was 34%, within the top soil (0-30cm). After a long spell of drought, the soil develops deep cracks from the surface to a depth of 25-30cm. This enhances moisture loss through evaporation. At 60cm depth, there is a sudden change in the soil profile to pumice rock that has a low permeability that explains increasing moisture towards the 60cm depth. The relationship of depth and moisture content evaluated by regression revealed that the significant best fit occurs at the third order (quadratic) function, $y = 0.0005x^3 - 0.0442x^2 + 1.2075x - 0.4967$.

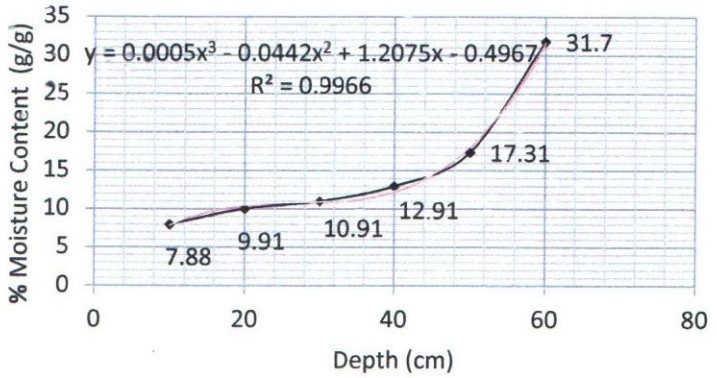


Figure 4:15 Variation of Moisture Content down the profile before onset of rains

4.9.6 Infiltration rate

Results showed how infiltration rates varied amongst the treatments due to different soil surface conditions. Infiltration rates under different tillage systems were in the order MT>CT>NT>ZT. The infiltration rate observed in the MT treatment was attributed to the shallow pulverization by the harrow that left a finer tilth compared to that in ZT treatment in which infiltration was hastened. Cracked sub-soil was left undisturbed following a dry spell, loamy sand soil develop cracks that stretch beyond 40 cm, (Figure 4.16).



Figure 4:16 Soil Profile 0-6cm

The tilled soil depth in CT is deeper than in MT. In CT soil receives more passes packing soil particles more closely than in MT. Thus, the voids are considerably reduced and the BD increased as established above, hence, accounting for a lower infiltration rate. The BD was found to be in the order of MT>CT>NT>ZT immediately after treatments which corresponds to the infiltration rates. The soil surface in NT had cracks that led to increased infiltration rate right from the surface hence higher than that in ZT. ZT had a lower infiltration rate because while chiselling, the chisel tool compressed the soil reducing crack sizes while being dragged through the soil. Soil surfaces in the chisel opening were found to have smeared reducing the water inflow and inhibiting infiltration but only for initially. If the wetting lasts long, the partcles fall easily.

The smear effect was caused by the higher soil moisture content that was found to increase with depth. Soil tillage can initially improve infiltration and sometimes benefit drainage over time.

Tillage favours degradation of the soil structure and a reduction of the infiltration rate due to the high soil water aggregation of the sandy loam.

Basic infiltration rates varied from 10.8, 14.1, and 21.6 to 30.6 mmh^{-1} for ZT, NT, CT and MT respectively, Figure 4.16. Infiltration rates for CT and MT ranged between 20 to 60mmh^{-1} and are distinguished as moderately rapid class according to ASTM D338-94

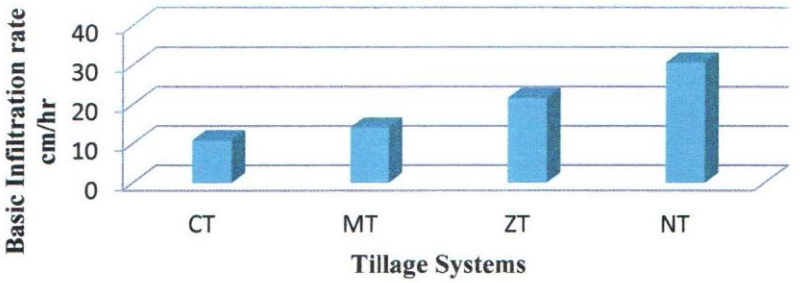


Figure 4:17 Basic Infiltration rates for loamy sand under different tillage systems

The high infiltration rate may be attributed to the high sand percentage, 82.1%. The curves Figure 4.17 can be used to estimate the amount of cumulated water in the soil for a given duration of wetting. The initial higher rate of infiltration observed in ZT over NT was due to the channel by the chisel in the sandy soil which tends to stabilize after 40 minutes when the effect of the treatment is overtaken by ponding.

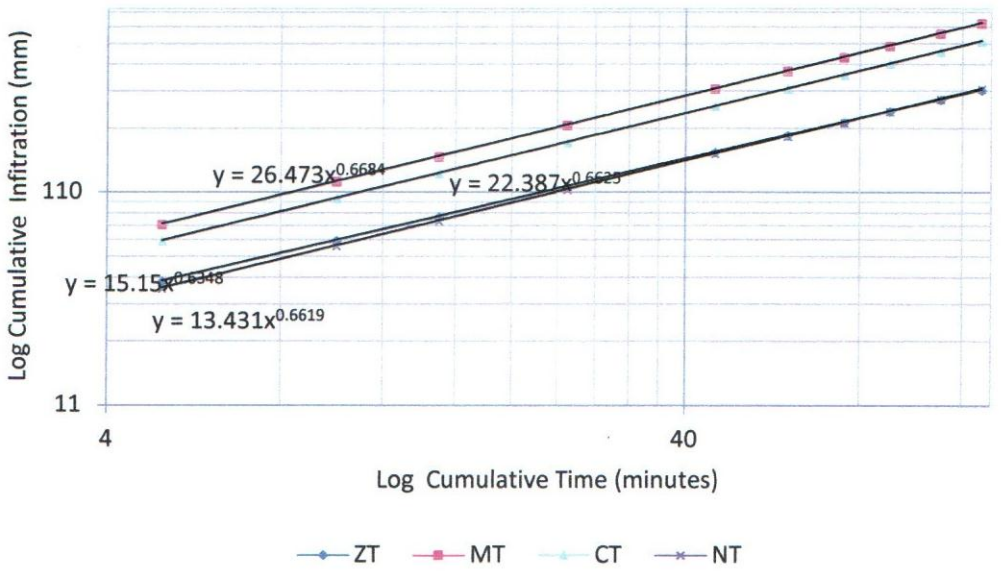


Figure 4: 18 Logarithmic plot of cumulative Infiltration for Tillage Systems

The gradients for the infiltration rate curves were similar (0.6684, 0.6684, 0.6348, and 0.6619) having coefficients of 1, 1, 0.99 and 0.95 for MT, CT, ZT and NT respectively.

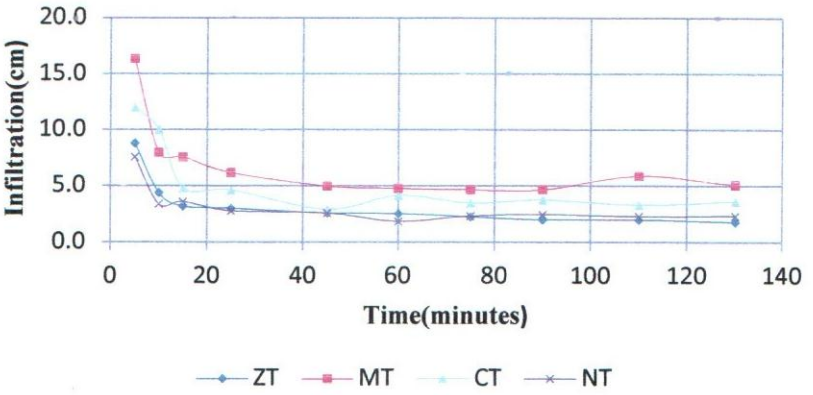


Figure 4:19 Actual Infiltration rate curves for CT, MT, ZT and NT

The phenomenon of coefficient similarity is credited to the identical soil type whose physical characteristics are varied only by tillage treatments.

Table 4:3 Infiltration depth after 40 minutes

Tillage Treatment	Time in Minutes	Accumulated Depth(cm)
MT	40	31.08
CT	40	25.37
ZT	40	16.50
NT	40	14.74

Table 4.1 is a summary of the amount of infiltrated water in the soil after 40 minutes under the four tillage systems and Figures 4.19a-4.19d are respective prediction curves.

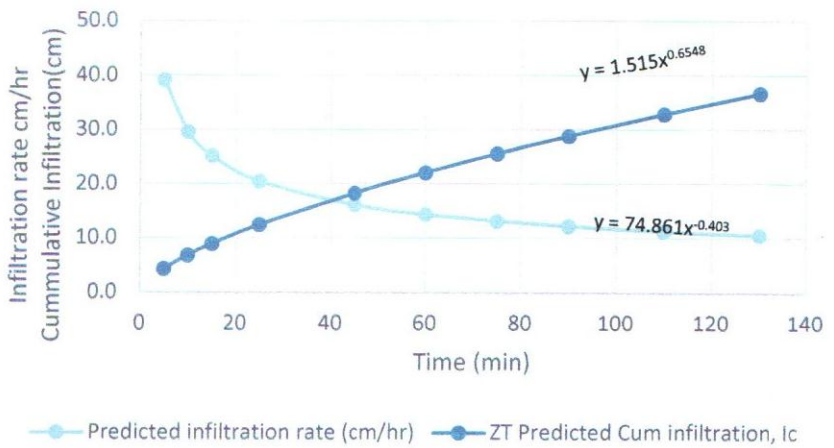


Figure 4:20a Predicted cumulative infiltration and depth for ZT (Met after 39.93 minutes)

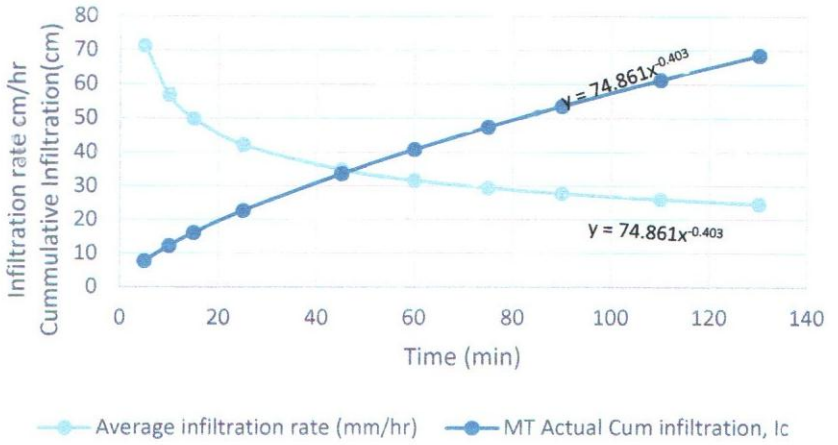


Figure 4:20b Predicted cumulative infiltration and depth for MT (Met after 46.53 minutes)

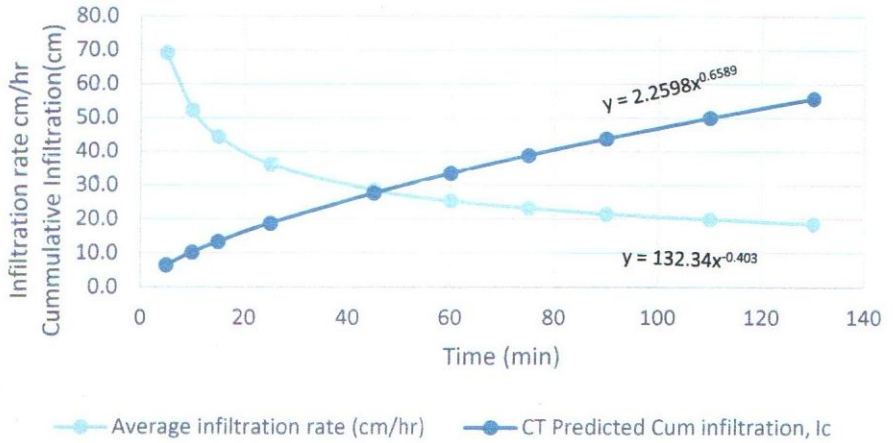


Figure 4:20b Predicted cumulative infiltration and depth for CT (Met after 46.19 minutes)

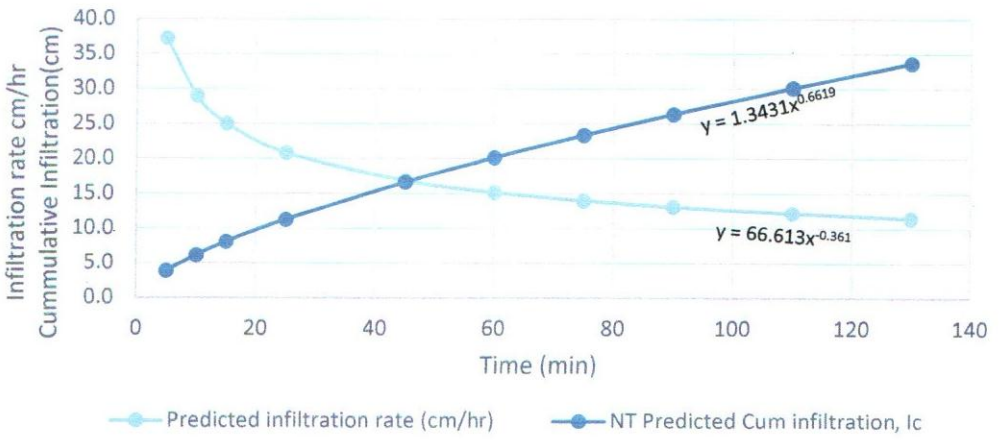


Figure 4:20d Predicted cumulative infiltration and cumulative depth for NT (Meet after 45.45 minutes)

Figure 4:20 Predicted cumulative infiltration and cumulative depth

The time taken for the two curves; Accumulated infiltration (cm) and average infiltration rate (cm/hr) to intercept among the treatments varied in the order of MT>CT>ZT>NT. The curves intercepted first in the MT treatment after 40 minutes when 31.2, 25.7, 17.6, and 17.0 mm depth for MT, CT, ZT and NT treatments had accumulated respectively. The differences were attributed to the surface conditions, type of tillage equipment and number of passes under the different tillage treatments within the plots. Tillage manipulations as observed in the results affected the physical properties of soil that are responsible for infiltration rate variability. When the ring infiltrometer test was repeated on the plots at the end of the experiment, the difference in IR was not significantly different ($P>0.05$).

Table 4:4 Hydraulic conductivity analysis by constant head (California Test 219)

Soil Depth (cm)	Permeability Coefficient (cm/day)
10	55.46
10	193.99
20	0.67
20	0.66
30	9.76
30	16.49
40	138.83
40	22.11
50	8.81
50	226.29
60	88.95
60	96.78

4.9.7 Hydraulic Conductivity (Double ring)

The K_s value determined from the infiltrometer method was 22.4mm/hr. The double ring infiltrometer method tends to exaggerate the IR. Hydraulic conductivity reduces with increasing bulk density as can be observed from (Table 4.2) and (Table 4.5). The variation in hydraulic conductivity may be due to the different bulk densities within the soil profile.

Table 4:5 Hydraulic conductivity by constant head (Laboratory Method)

Depth (cm)	Average $K(ms^{-1})\times10^{-6}$
10	12.50
20	0.07
30	1.31
40	8.05
50	11.8
60	9.29

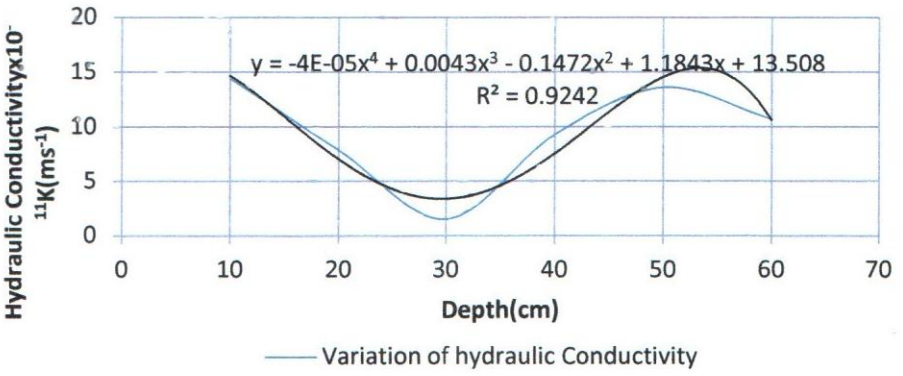


Figure 4:21 Hydraulic Conductivity down the Soil Profile

4.9.8 Mean Retained Moisture

CT maintained high moisture until the sixth week when it was overtaken by MT, Figure 4.22. By the time moisture in MT is superior, the difference in moisture retained among all treatments (CT, MT, NT, and ZT) is not significantly different ($P \leq 0.05$). Although NT retained more moisture than ZT, it was only for four weeks and the means were not significantly different.

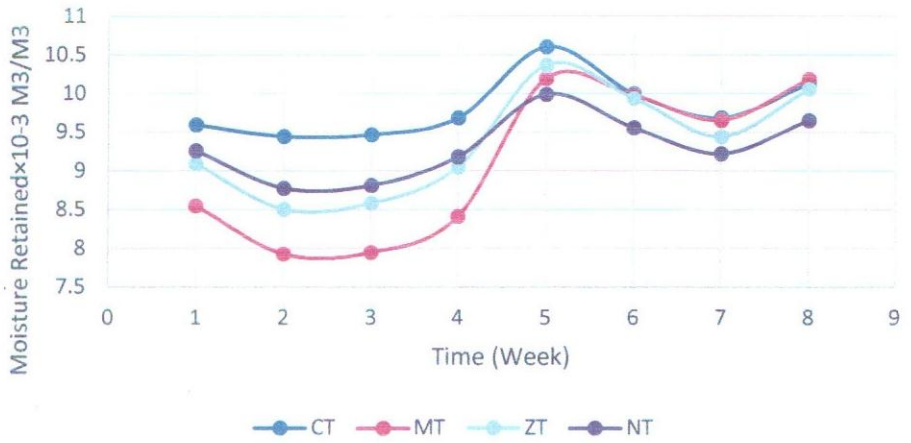


Figure 4:22 Mean Moisture retention over eight weeks

4.10 Statistical Analysis

Before statistical analysis, the assumption of normality was subjected to Shapiro–Wilk test. Analysis for homogeneity of variance was assessed with Levene's test. A two-way GLM was used separately to identify the differences in moisture retention between tillage systems, soil profile depths (0-10, 10-20, 20-30, 30-40, 40-50 and 50-60 cm) and their interaction effects on moisture retention due tillage and depth. Significant differences in moisture retention due to tillage and soil depths were analysed. All Post hoc mean separations were made with lsd ($P \leq 0.05$) since main

effects were found to significantly different. The retained moisture difference was significant within the 0-30cm of the ploughed depth. The top 10cm had the highest fluctuation in soil moisture content because of exposure to the atmosphere where heat and wind may have been responsible for the fluctuation in moisture content. Brocca *et al.,* (2007)

Analysis of variance was performed on the retained soil moisture data (Appendix A6) generated by use of a neutron probe. Variations in the results were considered as random effects. Tillage×Depth were found to have a significant effect on moisture retention ($P \leq 0.05$), Interactions within the main effects (Tillage × Depth) were significantly different following which the null hypotheses for tillage and depth factors were rejected.

While infiltration rate was in the order of MT>CT>ZT>NT, (Table 4.1), immediately after the treatments were applied, mean moisture retention over the test period was in the order of CT>ZT>NT>MT, (Table 4.3). Infiltration rate was high in MT but with the lowest moisture retention as there was excessive percolation due to the large undisturbed cracks that were observed below the tilled profile (see Figure 4.16). The rapid infiltration rate of the sandy loam (loamy sand soils) and evaporation at the surface led to moisture storage increasing with depth as the top soil served as an insulator.

Table 4:6 Analysis of Variance for Field Moisture Monitoring

Source	D	Sum of Squares	Mean Square	F Value	Pr > F
Model	199	4570.119256	22.965423	93.18	<.0001
Error	376	92.667231	0.246455		
Corre Total	575	4662.786487			
R-Square	Coeff Var	Root MSE	Retn Mean		
0.980126	5.288249	0.496443	9.387658		

Table 4:7 Analysis of Variance for Field Moisture Monitoring interactions

Source	DF	Anova SS	Mean Square	F Value	Pr > F
REP	3	49.714866	16.571622	20.28	<.0001
Tillage	3	52.629729	17.543243	21.47	<.0001
Depth	5	5238.986025	1047.797205	1282.37	<.0001
Tillage*Depth	15	26.509397	1.767293	2.16	0.0064

Examination of the Tillage × Depth interactions for the data of table 4.6 Lsd=0.2818

Table 4: 8 Separation of moisture retention means due to depth and tillage systems

Depth	Tillage				Mean retention (Depth cm)
	CT	MT	NT	ZT	
10	4.220**a**	3.833**b**	4.294**a**	3.665**b**	4.00**i**
20	9.196**a**	8.348**b**	8.319**b**	7.370**c**	8.31**h**
30	10.740**a**	9.732**bc**	9.999**b**	9.696**c**	10.04**g**
40	11.260**a**	10.320**c**	10.830**b**	10.840**b**	10.81**f**
50	11.660**a**	10.830**c**	11.350**ab**	11.290**b**	11.28**e**
60	12.300**a**	11.290**c**	12.030**b**	11.880**b**	11.87**d**
Mean Retention ($\times 10^{-2}$) (Tillage)	9.90**c**	9.06**b**	9.12**b**	9.47**a**	

$Lsd_{interraction}$ (5%)=0.254. Means with the same letter (a b c) in the row are not significantly different, means with the same letter (d e f g h i) in the column are not significantly different ($P>0.05$).

Tillage treatments had an effect on the amount of rain water that infiltrated and subsequently the soil. Various types of precipitation varying in intensity and duration were realized. In CT, soil particles were turned by the plough more times than in MT, NT and ZT, increasing bulk density while reducing the rate of infiltration. Moisture loses through evaporation was minimized because the soil surface is left flat reducing the surface area leading to a mean moisture retention of $0.094 m^3 m^{-3}$ (Figure 4.24). A similar effect was observed in all the six profile test levels. In ZT, the lowest amount of moisture was retained in the top 10cm since the surface had cracks (Figure 4.13) that lost water through evaporation and percolation. In the ZT, faster infiltration was enhanced by narrow trench openings formed by the chisel plough together with cracks that existed before the treatment enhanced infiltration. The infiltrated moisture started accumulating just below the chisel tool depth, 30cm, retaining more moisture than in MT and NT. There was no significant difference in the mean moisture retained between MT and NT since in MT the harrow gangs were operated at 10cm deep and so other than the surface conditions, the rest of the soil profile remained the same as in NT and yet top soil suffer surface moisture loss. Hydraulic conductivity varied from 0.0665 K (ms^{-1}) $\times 10^{-6}$ to 12.5K (ms^{-1}) $\times 10^{-6}$ so the limiting value of 0.0665K (ms^{-1}) $\times 10^{-6}$ in the profile represents the hydraulic conductivity for the study profile. It is noted that the lowest hydraulic conductivity occurred at the plough pan depth (20-40cm) where bulk density (Figure 4.9) was highest and lowest porosity (Figure 4.12) an illustrated that lower hydraulic conductivities are achieved at higher bulk densities.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The effect of these parameters and their interactions was evaluated through characterizing soil physical properties (bulk density, hydraulic conductivity, porosity, infiltration rate, sieve analysis, profile, macro and micro nutrients, topography, soil water characteristic curve and moisture retention) and by measuring changes in soil water content at various depths under the four tillage systems. Subsequently, the following conclusions were drawn;

a) Loamy sand soils of Eastern Mau are made of approximately 82 percent sand, 3 percent clay and 15 percent silt particles classified as loamy sand according USDA classification method. The loamy sand soils were found to be capable of quickly draining excess water. To maintain field capacity, this type of soil will require more frequent moisture replenishment. Soil physical characteristics were influenced by tillage systems and indirectly, moisture retention but only for eight weeks.
b) Tillage systems affect Soil physical properties differently by manipulating texture, structure, and porosity which influence the movement and retention of water. The soil class, loamy sand has a fast infiltration rate as compared to other loams. The available moisture is 34% by volume described as low when compared to clay loams which hold over 50%. Porosity was found be 38-41% compared to clay loams which are 44%
c) Physical properties that were modified by tillage tillage were Bulk density, Porosity and associated characteristics such as infiltration rate, moisture retention and resumed their initial characteristics after 8 weeks suggesting that tillage had a temporary effect on physical properties.
d) Limited amount of precipitation with a major moisture depression in June coupled with the high porosity of 41% was found to be responsible for low moisture before or during flowering in annual crops. Conventional tillage retained more moisture than the other tillage treatments in the order of CT>NT>ZT>MT in the loamy sandy soil.
e) Loamy sand soil profiles under conventional tillage treatment had higher bulk densities ($1.4gcm^{-3}$) and retained more moisture than lower bulk densities in other treatments.
f) Annual mean rainfall for over 50 year period was not found to be significantly different in magnitude and timeliness. However, reliability has remained a challenge, where for the

cropping period, on average an annual 240mm of rain or higher is expected in 2 out of 3 years and a seasonal annual rainfall of 487mm or more is expected in 1 out of 3 years during the main crop growing season (March to June).

g) The recent serious drought year, 2009 received 297mm of rainfall during the crop growing period and the probability of recurrence is 96.2% compared to 757mm for the year 2010 whose recurrence probability is 1.9%.

5.2 Recommendation

a) The recent serious drought year, 2009 received 297mm of rainfall during the crop growing period and the probability of recurrence is 96.2% compared to 757mm for the year 2010 whose recurrence probability is 1.9%.

b) For increased infiltration, conventional tillage was found to be superior to other methods.

c) Due to the limited amount of precipitation that occurs during the long rains, farmers in the study area and within the proximity of the study site, should prepare their fields just before the rains and plant on onset of rains in order to benefit from the duration it rains which would offer a longer opportunity time for crops to benefit.

d) It is important to emphasize that functional relationships have been developed for a specific site, geographical location and applicability of the average relationship for other regions need to be established.

e) The study should be repeated for a longer period to establish any changes that may occur due to extended time.

f) There is need to develop models that relate hydraulic conductivity, moisture retention characteristics and infiltration rates to parameters that are easy to determine e.g. BD, porosity, water content, particle size distribution and infiltration as this will hasten determination of this important physical property of soil for selecting a suitable tillage system.

g) Plough pan depth region retained more moisture in CT because of the low hydraulic conductivity developed by several implement runs. Compaction is encouraged so long as the bulk density is maintained at $Db \leq 1.61$ beyond which is known can inhibit root penetration.

REFERENCES

Agriculture and Rural Development (JICA), 2004

Akbal F 2004 Sorption of phenol and 4-chlorophenol onto Pumice treated with cationic surfactant. J Environ Manage. 74: 239–244.

Ali, M.H. and M.S.U Talukder, 2008. Increasing water productivity in crop production a synthesis. Agric. Water manage., 95; 1201-1213.

Atlantic Publishers.

Azevedo, P. A., C. Y. Cho, S. Leeson and D. P. Bureau, 1998. *Effects of feeding level and water temperature on growth, nutrient and energy utilization and waste outputs of rainbow trout* (Oncorhynchus mykiss). Aquat. Living Resour, 11(4): 227-238.

Badalı´kova´ B, Pokorny´ E (2007) Zmeˇny obsahu humusu prˇi ru˚zne´m zpracova´nı´ a utuzˇenosti pu˚dy k cukrovce. (The changes of humus content by different soil tillage and soil compaction in sugar beet). Agro 4:23–25

Banton O. P, Lafrance, R. Martel, and J.P. Villeneuve. 1992. Planning of soil-pore water sampling campains using pesticide ttransport modelling. Ground water Monitoring Review 12, no. 3: 195-202

Benjamin, J.G., 1993. *Tillage effects on near surface soil hydraulic properties*, Department of Agronomy, Iowa State University, Ames, IA 50011, USA

Bouma, Johan (1989). Using soil survey data for quantitative land evaluation. Advances in Soil Science 9: 177-213.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. Agron. J. 54:464-465.

Brocca L., Morbidelli R., Melone F., Moramarco T., 2007, "Soil moisture spatial variability in experimental areas of central Italy", Journal of Hydrology, 333, 356-373

Cabeda, m.s.v. Degradação física e erosão do solo. In: simpósio de manejo do solo e plantio direto no sul do brasil, 1., simpósio de conservação do solo do planalto, 3.,1984, passo fundo. Anais. Passo fundo, piucs e upf - faculdade de agronomia1984. P. 28-33.

Chang, C. and C.W. Lindwall. 1990. *Comparison of the Effect of Long Term Tillage and Crop Rotation on Physical Properties of a Soil.* Canadian Agriculture Engineering (32):53-55.

Derksen DA, Anderson RL, Blackshaw RE, Maxwell B (2002) *Weed dynamics and management strategies for cropping systems in the northern great plains.* Agron. J. 94:174-185.

Dexter A.R. (1986): Model experiments in the behaviour of roots at the interface between a tilled seed-bed and compacted sub-soil. Plant and Soil, 95: 123–133.

Diaz-Zorita M, Grove HJ, Murdock L, Herberck J, Perfect E (2004) Soil structural disturbance effects on crop yields and soil properties in a no-till production system. Agron J 96:1651–1659

Dugas W.A., Meyer, W.S. Barrs, H.D. and Fleetwood, R.J. 1990. *Effects of soil type on soyabeans crop water use in weighing lysimetersII. Root growth, soil water extraction and water table contributions.* Irrigation Science 11;77-81.

FAO , 2008, The State of Food Insecurity in the World, Food and Agriculture Organization of the United Nations Viale delle Terme di Caracalla, 00153 Rome, Italy

FAO 1991, *A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production.* Will Critchley - Conservation Agronomist Centre for Development Cooperation Services Free University, Amsterdam and Klaus Siegert - Water Resources Engineer Land and Water Development Division FAO, Rome with contributions from: C. Chapman, FAO Project Manager M. Finkel, Agricultural Engineer, Yoqneam, Israel

FAO,1997. Food and Agricultural Organization, Food Crops and Shortages, Information and Early Warning System on Food and Agriculture. December/1996/January 1997. Rome. Rome, Italy.

Fowler, R. and Rockstrom, J. 2000. Conservation tillage for sustainable agriculture: an agrarian revolution gathers momentum in Africa. Keynote address, ISTRO 2000, Fort Worth, USA.

Franzluebbers, A.J. 2002. *Water infiltration and soil structure related to organic matter and its stratification with depth*, USDA Agricultural Research Service, J.Phil Campell Sr. Natural Resources conservation centre, 1420 Experiment Station Road, Watkinsville, GA 30677-2373,USA.

Fravolini, A., K.R. Hultine, D.F. Koepke, and D.G. Williams. 2003. The role of soil texture on mesquite water relations and response to summer precipitation. In: Santa Rita Experimental Range: One Hundred Years (1903 to 2003) of accomplishments and contributions; conference proceedings; 2003 October 30 - November 1, Tucson, AZ. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Gameda, S., E. Raghavan, E. McKyes, and R. Theriault. 1987. Sub-soil compaction in a clay soil. II. Natural alleviation. Soil Tillage Res. 10:123–130.

Gee and Bauder, 1986. *Particle-size analysis.* p. 383–411. *In* A. Klute (ed.) *Methods of soil analysis.* Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Gill, W.R. and W.F. McCreery. 1960. Relation of size of cut to tillage tool efficiency.Agricultural Engineering, 41, 372-374.

Hangen, E., U Buckzo, O. Bens, J. Brunotte and R.F. Huttl, 2002. *Infiltration patterns into two soils under conventional and conservation tillage: Influence of the spartial distribution of plant root structures and soil animal activity.* Soil Tillage Res.,63: 181-186

Heiniger, R. W. (2000). NC Corn Production Guide - Chapter 4 - Irrigation and Drought Management. The North Carolina Corn Production Guide; Basic Corn Production Information for North Carolina Growers Retrieved April 13, 2011, from http://www.ces.ncsu.edu/plymouth/cropsci/cornguide/Chapter4.html

Hill R.L., Horton R., Cruse R.M.. 1985. *Tillage effects on soil water retention and pore size distribution of two Mollisols.* Soil Science Society of America Journal 49(5):1264-1270.

Hill, R. L. 1990. *Long - term conventional and no- tillage effects on selected soil physical properties.* Soil Science America Journal 54 (1), 161–166.

Hillel, D. 1998. Environmental soil physics. Academic Press, San Diego, CA. http://www.theodora.com/wfbcurrent/kenya/kenya_government.html Source: 2009 CIA World Factbook.

Jin-yu Li, 2010, Experimental Research on Soil-Water Characteristic Curve of Remolded desidual Soils. School of Civil and Hydraulic Engineering and the State Key Lab. of Coastal and Offshore Engineering, Dalian University of Technology, Dalian, Chinae-mail: lijinyu6@sina.com. Unpublished.

Johnson MS 1984. Effect of soluble salts on water absorption by gel forming soil conditioners. J Sci Food Agric. 35: 1063–1066.

Johnson MS, Piper CD 1997 Cross–linked water storing polymers as aids to drought tolerance of tomatoes in growing media. J Agron Crop Sci. 178: 2–27.

Karunatilake and van Es, 2002.Rainfall and Tillage Effects on soil structure after alfalfa conversion to maize on a clay loam soil in New York. Soil Till. Res. 67:135-146

Kay B.D. and Vanden Bygaart A.J.. *2002. Conservation tillage and depth stratification of porosity and soil organic matter.* Soil Tillage Research 66(2):107-118.

Kay, B.D., and A.R. Dexter. 1990. *Influence of aggregate diameter, surface area and antecedent water content on the dispersibility of clay.* Can. J. Soil Sci. 70:655–671.

Kemper, w.d. & Rosenau, R.C., 1986. Aggregate stability and size distribution. In: Klute, A., ed. Methods of soil analysis: Structure and mineralogical methods. Madison, America Society of America/Soil Science Society of America, P.635-660.

Ke-Sheng, C., 2008. Hydrology Rainfall Analysis, Department of Bioenvironmental Systems Engineering National Taiwan University. Unpublished.

Khadem SA, Galavi M, Ramrodi M, Mousavi SR, Rousta MJ, Rezvani-moghadam, P. 2010 Effect of animal manure and super absorbent polymer on maize leaf relative water content, cell membrane stability and leaf chlorophyll content under dry condition. Aust J Crop Sci. 4: 642-647.

Kibler, D. F. 1982 Urban Hydrology and the storm water problem. Washington DC, American Geophysical Union

Kimotho, P.W. 1990., Kenya Agricultural Research Institute,National Laboratories, Kenya Soil Survey Unpublished.

Kinyanjui, H.C.K. , 1979. Detailed Soil survey of Tatton farm, Egerton College, Njoro.Unpublished.

Klute, A., 1986. *Water retention: Laboratory methods. Methods of soil analysis*: Part 1, 2nd ed. Agronomy Vol. 9. ASA, SSSA, Madison, pp. 635–657.

Kolay AK (2008). Water and Crop Growth. New Delhi, India:

Krajewski, W.F., G. Villarini and J.A. Smith, 2010. Radar-rainfall uncertainties: where are we after thirty years of efforts? Bulletin of the American Meteorological Society, 91(1), 87-94.

Kramer, J.H., Cullen, S.J., Everett, L.G. 1992. *Vadose zone monitoring with the neutron moisture probe.* GWMR Summer, p177-187.

Kuehni, Rolf G., 2002. "The early development of the Munsell system". *Color Research and Application* **27** (1): 20–27.doi:10.1002/col.10002. A description of color systems leading up to Munsell's, and a biographical explanation of Munsell's changing ideas about color and development of his color solid, leading up to the publication of *A Color Notation* in 1905.

Laddha K.C., Totawat K.L. 1997. *Effects of deep tillage under rainfed agriculture on production of sorghum (Sorghum biocolor L. Moench) intercropped with green gram (Vigna radiata L. Wilczek) in western India.* Soil Tillage Research, Volume 43, Issues 3-4 10 November 1997, Pgs 241-250

Lal, R. 1997. Soil degradative effects of slope length and tillage methods on Alfisols in western Nigeria. I. Runoff, erosion and crop response. Land Degradation & Development 8: 201-219.

Lal, R. and Blanco-Canqui, H., 2005. *Regional assessment of soil compaction and structural properties under no-till farming*. Soil Sci. Soc. Am. J. 71:1770–1778.

Lal, Wasantha, A. M., 1991, *Mathematical Model for River Ice Processes*, Journal of Hydraulic Engineering, ASCE, 117(7), 851-867.

Lipiec, J., J. Kus, A. Nosalewicz, and M, Turski. 2006. Tillage system effects on stability and sorptivity of soil aggregates. Institute of Agrophysics, polish Academy of sciences.

Madsen, H., Mikkelsen, P.S., Rosbjerg, D. and Harremoes, P. (2002), *Regional estimation of rainfall intensity duration curves using generalised least squares regression of partial duration series statistics*. Water Resources Research, 38 (11), 1239

Mainuri, Z.G., 2004. Land use effects on the spatial distribution of soil aggregate stability within the River Njoro watershed, Kenya. Unpublished MSc Thesis submitted to Department of Geography, Egerton University, Kenya.

Manikandan, M., G. Thiyagarajan and G. Vijayakumar (2011). Probability Analysis for Estimating Annual One Day Maximum Rainfall in Tamil Nadu Agricultural University. *Madras Agricultural Journal*, 98(1-3) : 69-73.

Messing, I. & N.J. Jarvis. 1993. *Temporal variation in the hydraulic conductivity of a tilled clay soil as measured by tension infiltrometers*. Journal of Soil Science 44: 11-24.

Migwi P.K, Gamba, P.O., Onyango, T.A., 2006; Participatory on-farm technology transfer for increased livestock productivity in sub-Saharan Africa, A case study of Lare Division in Nakuru District, Kenya. Unpublished.

Mohanty , B. P., N. N. Das, R. B. Jana, and A. V. M. Ines., 1996 *Effective SoilHydraulic Parameter Estimation at Different Spatial Scales, Procs. of Water, Environment, Energy, and Society (WEES)*, January 12-17, New Delhi, India, pp. 188-196.

Moreno, F., Pelegerin, F., Fernandez, J.E. and Murrillo, J.M. 1997. *Soil physical properties, water depletion and crop development under traditional and conservation tillage in Southern Spain.* Soil Science 119:242-249.

Mwakalila & Hatibu, 1993; Rainwater harvesting technologies for agricultural production. A case for Dodoma , Tanzania.

Mwangi, H.G., Akuja, T.E., Kamwaga, J.N., Njuguna, M.N. and Nafuma, L.S., 2008. Soil Profile Based Tillage Practices for Wheat Production in the Central Rift Valley area of Kenya, *Journal of Applied Biosciences*, Vol. 11: 570-575

Nandakumar, N., Weinmann, P. E., Mein, R. G., Nathan, R. J. 1997, Estimation of Extreme Rainfalls for Victoria using the CRCFORGE Method, CRC for Catchment Hydrology.

Njoku, E., T. Chan, W. Crosson, and A. Limaye. 2004. Evaluation of the AMSR-E Data Calibration Over Land. *Italian Journal of Remote Sensing* 29 (4)): 19-37.

Olaoye, J.O. (2002). Influence of tillage on crop residue cover, soil properties and yield components of cowpea in derived savannah ectones of Nigeria, Soil & Tillage Research, 64 (3–4):179–187.

Onwualu A.P. and Ihaneka I.E, 2001. *Conservation and conventional tillage effects on soil properties and soybean production.* Agro-Science 2 (2): 15-20.

Payne, W.A.C.W, Wendtand, R.J. Lascano, 1990. Root zone winter balances of three low-input millet fields in Niger, West Africa. Agron J., 82:813-819

Pervez, M. A.; Ayub, C. M.; Khan, H. A.; Shahid, M. A.; Ashraf, I. 2009. *Effect of drought stress on growth, yield and seed quality of tomato (Lycopersicon esculentum L.).* Pakistan Journal of Agricultural Sciences 2009 Vol. 46 No. 3 pp. 174-178 http://www.pak-jas.com

Pervez, M. A.; Ayub, C. M.; Khan, H. A.; Shahid, M. A.; Ashraf, I. 2009. *Effect of drought stress on growth, yield and seed quality of tomato (Lycopersicon esculentum L.).* Pakistan Journal of Agricultural Sciences 2009 Vol. 46 No. 3 pp. 174-178 http://www.pak-jas.com

Ra´tonyi T (1998) Evaluation of tillage effects on penetration resistance of chernozem soil. In: Proceedings, Soil condition and crop production. Go¨do¨llo¨, Hungary, pp 100–103

Rawls, W.J., and Y.A. Pachepsky. 2002. Using field topographic descriptors to estimate soil water retention. *Soil Sci. 167:423–435.*

Reining, C., R.M. Heinzman, M.C. Madrid, S. Lopez, and A. Solorzano. 1992. Non-Timber Forest Products of the Maya Biosphere reserve, Peten, Guatemala. Conservation International,Washington, D.C.

Rockstrom Johan Biamah E. K.; George E. Okwach. 2000, Conservation Tillage for Dryland Farming: Technological Options and Experiences in Eastern and Southern Africa. 151 Seiten, Veröffentlicht 2000. ISBN-13: 978-9966-896-49-0, ISBN: 9966-896-49-X

Rowntree, K.M. 1989. Rainfall characteristics, rainfall reliability and the definition of drought : Baringo district, Kenya. *South African Geographical Journal, 71 (2). pp. 74-80. ISSN 0373-6245*

Roy B., Howmik S. K. and Prasad, K., 2001 Some characteristics of Limited Area Model Precipitation Forecast of Indian Monsoon and evaluation of associated flow features; Meteor. Atmos. Phys. 76 223–236.

Rydberg, T. 1990. *Effects of Ploughless Tillage and Straw Incorporation on Evaporation.* Soil & Tillage Research (17)1990:303-314. Elsevier Science Publishers B.V., Amsterdam.

Schafer-Landefeld, L., R. Brandhuber, S. Fenner, H.J. Koch, and N. Stockfisch. 2004. *Effects of agricultural machinery with high axle load on soil properties of normally managed fields.* Soil Tillage Res. 75:75–86.

Sheldrick BH and C Wang. 1993. Particle Size Distribution. p. 499-511. In MR Carter (ed.) Soil Sampling and Methods of Analysis. *Canadian Society of Soil Science*. Lewis Publishers. Ann Arbor.

Shipitalo, M. J.; Dick, W. A.; Edwards, W. M., 2000 Conservation tillage and macropore factons that affect water movement and the fate of chemicals. Soil and tillage research. Amsterdam, v. 53, n. 1, p.167-183.

Shukla, M. K.; Lal, R.; Owens, W. and Unkefer., 2003, Land use and management impacts on soil structure and infiltration characteristics of soil in the North Appalachian region of Ohio. *Soil Sci. 168:167-177.*

Sidhu, D. and S.W. Duiker. 2006. *Soil compaction in conservation tillage*: Crop impact. Agron. J. 98:1257-1264.

Singh B, Chanasyk D S, Mcgill WB, Nyborg MPK (1994) Residue and tillage management effects on soil properties of typic Cryoboroll under continuous barley. Soil and Tillage Res 32s:117–133

Smolikowski, B., H. Puig, and E. Roose. 2001. *Influence of soil protection techniques on runoff, erosion, and plant production on semi-arid hillsides of Cabo Verde.* Agric. Ecosyst. and Environ. 87:67-80.

Somroek, W.G., Brawn, H. and Van D. P. 1980. Exploratory soil map and Agro-climatic zone map of Kenya. Scale 1:1,000,000, Appendix Report by Kenya Soil Survey. Ministry of Agriculture. Nairobi, Kenya.

Sparling, G.P., Wheeler, D., Wesely, E.T., & Schipper, L.A. (2006). What is soil organic matter worth?. *Journalof Environment Quality*, 35,548–557.

Štekauerova V., Nagy V. & Kotorova D. 2006. *Soil water regime of agricultural field and forest ecosystem*, Biologia 61(Suppl.19): S300–S304.

Stevenson, F.J.1986. Carbon balance of the soil and the role of organic matter in soil fertility. In *Cycles of Soil- Carbon, Nitrogen, Phosphorous, Sulphur, Micronutrients*". Pp, 45-77, John Wiley and Sons, New York.

Sustainable Management of Watersheds. (SUMAWA) 2003 Annual Report 2003 - 2004), *The River Njoro, Kenya.the necessity for studying it from a dynamic point of view for purpose of amelioration*,Trans. Int. Congr. Soil Sci. 1932(A), 17-21.

Unger PW, Stewart BA, Parr JF and Shingh RP.,1991. *Crop residue management and tillage methods for conserving soil and water in semi-arid regions*. Soil and Tillage Research 20, 219-240.

Voorhees, W. B., C. G. Senst and W. W. Nelson. 1978. Compaction and soil structure modification by wheel traffic in the Northern Corn Belt. Soil Sci. Soc. Am. J. 42:344-349.

Waddell, J.T. and R.R. Weil, 1996. *Water distribution in soil under ridge-till and no-till corn*. Soil Sci. Soc. Am. J., 60; 230-237.

Wakindiki, I.C. Zachary G. Mainuri, and Maina Gichaba. 2006. Soil Use and Management Effects on Aggregate Stability and Hydraulic Conductivity Within River Njoro Watershed in Kenya. p149-22.

Wienhold, B.J., and D.L. Tanaka. 2000. *Haying, tillage, and nitrogen fertilization influences on infiltration rates at a conservation reserve program site*. Soil Sci. Soc. Am. J. 64:379–381.

Wolkowski, R.P. 2003. Wisconsin corn and soybean responses to fertilizer placement in conservation tillage systems. Proc. Wis. Fert., Aglime, and Pest Mgmt. Conf. 42:99-106.

Wright SF, Anderson RL. 2000 Aggregate stability and glomalin in alternative crop rotations for the central plains. Biol. Fertl. Soils 31:249-253.

Wuest, S.B., 2001.*Earthworm, infiltration and tillage relationships in a dry pea-wheat rotation* Applied Soil Ecology, 18:187-192.

Young PC. 2002. Advances in real time flood forecasting. Philosophical Transactions of the Royal Society A 360: 1433–1450.

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