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SCHOOL OF ENGINEERING

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

EFFECT OF CHISEL PLOUGHING ON PHYSICAL AND MECHANICAL SOIL PROPERTIES: CASE OF A CLAY SOIL.

By

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December, 2018

DECLARATION

I, Mwangi Simon Thuku, hereby declare that this Thesis is my original work, and to the best of my knowledge, this work has not been submitted for a degree programme in any University.

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DEDICATION

I dedicate this work to my family, friends and mentors for their invaluable support throughout the study. May God bless you immensely.

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To all those who contributed, my deepest gratitude

ABSTRACT

This study aimed at determining the effect of Chisel Ploughing(CP) on physical and mechanical soil properties on maize cropped field. The study incorporated a control tillage method (Disc Ploughing, DP) for the analysis of the data obtained. During the study, soil moisture content, penetration resistance, hydraulic conductivity, shear strength, operational depth and speed and soil bulk density were identified as parameters that influence draft requirement.

Field experiments were conducted at the University of Nairobi – Upper Kabete Campus to collect soil resistance datasets. Draft data was measured using the MSI 7300 digital dynamometer logging data directly to a laptop through the serial port MSI 8000RF Remote Display. A three tine CP was attached to the three-point hitch of the towed tractor (i.e. gear lever in neutral position); the dynamometer was attached between the rear towed tractor and the front towing tractor via steel shackles. The same was repeated for the DP and datasets obtained. The effect of different tillage implements (CP and DP) at three depth levels (0 -15, 15 -30 and 30 – 45 cm) on soil moisture, soil shear strength, hydraulic conductivity, soil penetration resistance and soil bulk density were established. A 2 by 3 factorial experiment in a Completely Randomized Block Design was used to investigated the effect of operating speed (3 and 5kph) and tillage depth (0 -15, 15 -30 and 30 – 45 cm) of each tillage method. Four replications were used to give a total of 16 treatments for each tillage method.

An exponential relationship of the form $y = Ae^{x}$ was obtained between moisture content and depth with an R^2 values of between 0.8 to 1.0. In DP plots, a high of 32.1mm/m for depth of 30 – 45cm were recorded and a low of 30mm/m for depths of 0 – 15cm while for CP a high 37.53mm/m and a low of 24mm/m was recorded for similar depths respectively. Penetration resistance increased with increase in depth and a plough pan was observed below depths of 20cm and the values for both treatments were found to be within the range 0f 2 – 3MPa. Hydraulic conductivity(Ksat) was found to decrease exponential with increase in depth with a mathematical model of the form $y = Ae\text{-}^{x}$.

ANOVA indicated that operating speed and ripping depth significantly influenced the value of the draft force at the 95% level of confidence. The draft force was found to increase as the tillage depth and operating speed increased suggesting that they are directly proportional with a mathematical model of the form $y = ax^2 - bx + c$. Draft force increase was also reported with increase in forward speed. However, higher forces were recorded for CP in comparison to DP for speeds of 3kph and 5kph. It was found out that ripping has significant effect on soil moisture regime, soil penetration resistance and hydraulic conductivity on depths greater than 20 cm below the soil surface. However, for shallow depths, the DP experimental plots had high moisture content as compared to CP experimental plots (i.e.29.95% and 24.07% respectively). Furthermore, cohesive and frictional soil properties were found to have no correlation with percent moisture content within moisture content of 18 to 34% range. ANOVA indicated that moisture content, penetration resistance, shear strength, hydraulic conductivity for DP and CP were significantly different at 95% confidence interval.

From the study, there is a significant difference on the effects of tillage implements on mechanical and physical soil properties as well as the variation of these properties with depth of tillage. Therefore, proper implement selection and depth optimization are pertinent for optimum energy consumption and favorable for plant growth.

Keywords: *Soil Compaction, Conservation Tillage, Conventional Tillage, Kenya, Subsoiling, Soil Properties Soil resistance, Ripping depth; Operational speed*

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ACRONYM

Acronym	**Meaning**
ANOVA	Analysis of Variance
ASALs	Arid and Semi-Arid Lands
FAO	Food and Agriculture Organization
SSA	Sub Saharan Africa
KRA	Kenya Revenue Authority
USDA	United States Department of Agriculture
FEM	Finite Element method
CDF	Computational Fluid Dynamics
DP	Disc Plough
CP	Chisel Plough
ALOI	Atleast One Inequality
DP	Disc Plough
CP	Chisel Plough
MoAl&F	Ministry of Agriculture, Livestock and Fisheries
DEM	Discrete Element Method
NRCS	Natural Resources Conservation Service
MC	Moisture Content

CHAPTER ONE: INTRODUCTION

1.1 Background

The threat posed by soil compaction is perhaps the most severe problem soils around the world face today. It worsens their long-term sustainable productivity, not only with regard to food production, but also as relates to climate change processes. It is also one of the main reasons for the increase of surface runoff and water erosion; this occurs through mechanical stress-induced reduction of vertical water infiltration because of the heterogeneity in both pore size distribution and pore continuity (Amanullah *et al.*, 2017).

Reduction in size of landholdings, climate change and escalation of agricultural input prices lead researcher to develop conservational tillage. Conservation tillage is core in mitigating the negative effects of conventional tillage (Linde, 2007). However, Raper (2005) noted that yields in conservation farming may be unsustainable because of the negative impacts of soil compaction. Accordingly, even in such a framework, deep tillage is critical in improving compacted soils although it may cause disruption on valuable surface residue and consequently reducing the returns associated with conservation tillage.

The following changes may take place in the soil mechanical properties as the soil becomes more compact:

a) Increase in soil strength leading to a proportionate increase in its ability to resist penetration by both roots and tillage tools.
b) Increased bulk density leading to reduced pore sizes hence decreasing the hydraulic conductivity.

The intensity of these changes is dependent on the type of soil. However, increased compaction not only leads to significant increment in tillage energy requirement, but it also hinders plant roots development, especially at low soil moisture levels (Linde. 2007). Appropriate crop development requires soil to have tolerable void spaces for holding enough water-air blend, thus decrease in soil pore sizes debases plants of water and nutrients.

In an effort to rehabilitate compacted fields, the use of chisel plough to break and burst subsoil layers have expanded extensively. In most cases, interest in subsoiling is directed towards increasing water infiltration rate, hence facilitating root growth. An increased water infiltration rate reduces run-off, reducing soil erosion significantly and increasing soil moisture holding capacity, normally resulting in increased crop yields, especially in areas subjected to water stress and shortage (Barber *et al.*, 2016).

Busscher *et al*. (2009) attributed improved maize and soybean yields to sub-soiling. However, for whatever the benefits might be, ripping is an intensive-energy demanding operation and needs to be carried out after thorough consideration of all available management options (Moeenifar *et al*., 2013). According to Kassam *et al*. (2009), a substantial amount of energy is used to manipulate soil during tillage and planting, accounting for almost 50% of the total energy consumed in crop production systems. Large amounts of energy are consumed because of the required high draft forces. These excessive draft forces result in frictional and wear losses of the soil engaging tools. Draft forces are primarily subject to soils physical and mechanical properties, tillage tool geometry, operating depth and speed of the implement.

Kasisira *et al*. (2006) reported that draft forces for tillage implements, increases at a rate higher than a proportionate increment in working depth, this limit deep tillage as it turns out to be to a great degree hard to recuperate the working expenses. This problem is aggravated by unstable prices of petroleum products on the international market, normally resulting in high-energy costs on the farm. Prior knowledge of the costs implication is therefore vital to farmers and farm managers (Moeenifar *et al*., 2013).

Considering the benefits associated with chisel ploughing, it is crucial to clearly investigate these merits in comparison to benefits associated with disc ploughing as a control.

1.2 Problem Statement

Kenya is predominantly a dry country with approximately 80% (467,200 km^2) of the total land mass falling under the Arid and Semi-Arid Lands (ASALs). Rainfall events are ordinarily intense and in most instance produces runoff and consequently soil erosion.

According to Fageria *et al*. (2010) seed quality, nutrition, spacing and protection, timeliness of field operations (e.g. weeding and planting), and soil conditions are some of the factors that affect maize yield. However, in spite of substantial research efforts on seed improvement, plant nutrition, plant spacing and plant protection the impact on the farm level yield has been minimal. The main challenge has been farmer’s inability to achieve timeliness requirements in performing farm operations. The other equally crucial cause of low agricultural yield is soil compaction in form of sub surface plough pan (Soane *et al.*, 2013).

Plough pan inhibits root development and therefore the plant does not benefit from water and nutrients in the lower soil horizon. Moreover, the hard pan itself reduces water permeation and thus increasing overflow and associated soil loss.

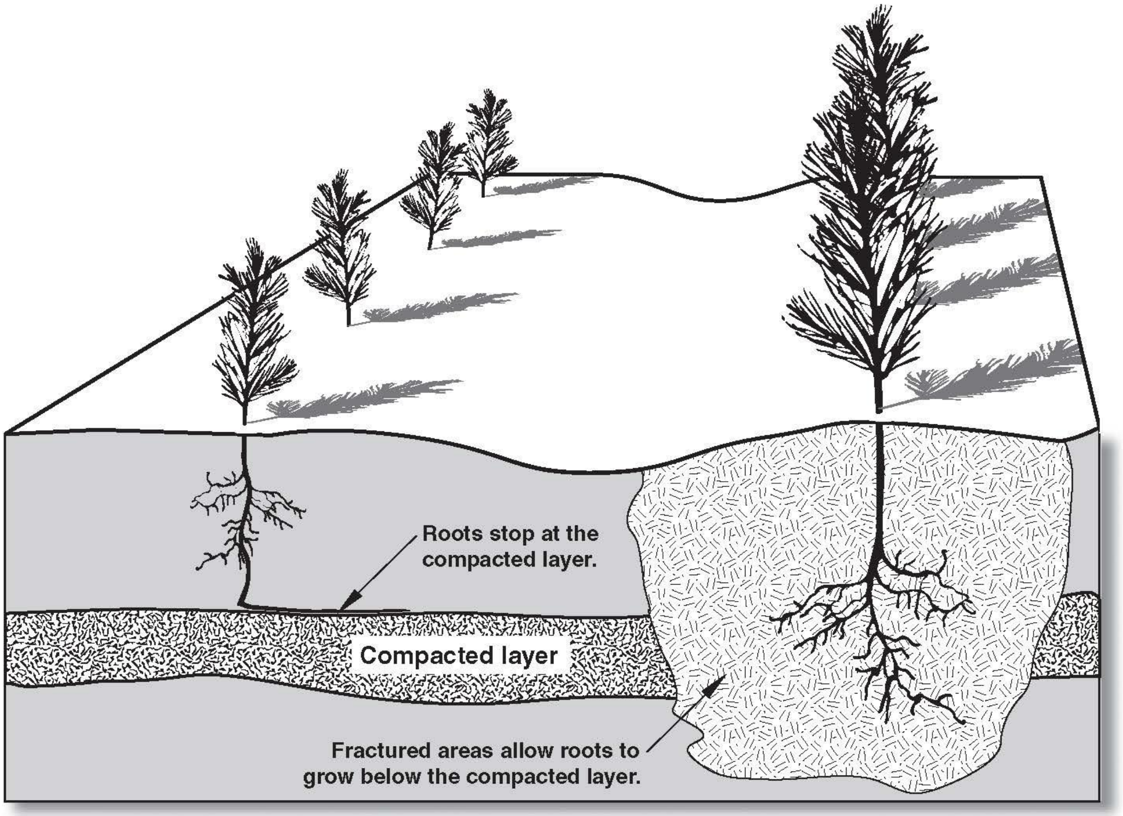


Figure 1-1 Illustration of how deep tillage promotes root development (USDA, 2008)

In an effort toward averting the hostile effects of soil compaction on crop yields, deep tilling (subsoiling) once every 3 years with conventional ripper is recommended (Raper et al,. 2004). The justification of the proposed trials is to substantiate the effect of chisel ploughing in comparison to conventional disc ploughing on physical and mechanical soil properties in a maize cropped field.

1.3 Objectives

1.3.1 Overall Objective

The overall objective of the study was to evaluate effects of chisel ploughing on physical and mechanical soil properties on a clay soil.

1.3.2 Specific Objectives

The specific objectives of the study were to;

a) Identify pertinent soil parameter that influence ripping.
b) Evaluate the effect of chisel ploughing compared to disc plough on parameters identified in (a) above and
c) Model the relationship between the parameters evaluated in (b) above.

1.4 Scope of work

This research was limited to effect of chisel ploughing on physical and mechanical soil properties on a maize cropped field in a clay soil. A three-tine Chisel was subjected to field tests under varying operating speed and tillage depths.

The soil tests conducted were those necessary and sufficient in investigating the effect of the two tillage methods on soil properties; they included soil bulk density, angle of internal friction, cohesion, adhesion, soil textural analysis, moisture content and penetration resistance.

The model developed was limited to capturing the forward horizontal forces (i.e. draft forces). The vertical and side forces were therefore not predicted.

CHAPTER TWO: LITERATURE REVIEW

This chapter provides a review of past research efforts linked to this study. It includes a brief background on soil compaction, ripping and the impacts of soil parameters and operating factors on soil failure. Further, the various effects of subsoiling on soil properties are also reviewed.

2.1 Agricultural Mechanization

The world population is forecast to grow to 9 billion by 2050 from the current population of 7.31 billion. Currently, the 500 million smallholder farmers account for about 80 percent of the world food production. Primarily, these smallholder farms will have to respond to the need of over 60 percent food production increase (compared to 2007) by 2050 (FAO, 2011a). However, smallholder farmers have limited access to farm inputs, particularly mechanization; consequently, attaining low productivity levels and more than often contributes to increased negative environmental impacts on already tapering natural resources.

In developing countries, agriculture is powered through human muscles, draught animals and engine engines. Inadequate access to energy for agriculture can be attributed to high dependence on human muscle as the major source of power in smallholder agriculture (Sims and Kienzle, 2015). Use of different farm power sources varies across regions (Table 2.1). In sub-Saharan Africa, large and emerging agricultural farms (20–50 ha) do not ordinarily have a problem with access to farm power, but smallholder farms (< 2 ha) experience extreme difficulty in accessing farm power.

Table 2-1 Sources Of Power For Land Preparation (% of Total)

	Human power	Animal power	Engine power
Sub-Saharan Africa	65	25	10
East Asia	40	40	20
South Asia	30	30	40
Latin America and the Caribbean	25	25	50

Source: FAO, 2006.

Generally, as more engine power is being used, the number of draught animals used is decreasing. This move from human power to engines has been more pronounced in Latin America and Asia as compared to the Sub-Saharan Africa. In India and China, a drastic decrease in the number of draught animal has been reported from a peak of over 100 million and in their places more 4-wheel tractors are introduced. In Bangladesh, 2-wheel tractors have replaced draught animals and are current performing more than 80 percent of land preparation operations.

In Asia, green revolution is credited with kick-starting the shift to profitable commercial farming, saving fragile land from conversion to extensive farming, avoid potential hunger threats in the face of a growing world population and alleviating rural poverty (FAO, 2009b). The enormous gains in farm productivity is often accompanied by adverse impacts on the natural resource, threatening productive potential of agriculture and impacting negatively on agrifood value chains. At the production level, considerable impacts are easily observable: land degradation through soil compaction and soil erosion, over-extraction of groundwater pest resistance build-up, salinization of irrigated lands and reduction in biodiversity. The vulnerability and variability of crop yields and quality of the produce, coupled with degraded lands and overexploited water resources, have made smallholder value addition and processing a far less secure business.

Mechanization, intensification, adoption of modern technologies and use of fertilizers have remained at low level across the African continent. In addition, degraded farms are widely spread across the continent for a variety of reasons including continuous shallow tillage using the plough resulting in degraded soils, formation of plough pan and loss of fertile soils through erosion (Kienzle and Sims, 2015).

In Kenya, draught animal technology was introduced by the European settlers in 1910. Small holder farmers in Ukambani were the first to adopt the technology. By the year 1930, the technology had spread widely in the region. According to Bymolt and Zaal (2015), Sub Saharan Africa (SSA) has the gloomiest uptake of mechanization globally and is highly dependent on manual labour. For instance, Nationally Kenya has a 30% use of motorized power, 50% hand and 20% animal draught (FAO, 2006; MoAL&F, 2015).

Kenya Revenue Authority (KRA) records reveal that the sale of 4-wheel tractor has risen slowly from 6422 units in 1961 to 12844 units in 2002 (Wawire, *et. al.,* 2016). However, most of these tractors are owned by large commercial farms. Among small scale farmers, tractor ownership stands at 5% and is highly dependent on human and animal power (Bymolt and Zaal, 2015).

2.2 Soil Compaction

Soil compaction is an adverse condition in agricultural land as it decreases soil infiltration capability leading to an increase in surface runoff and subsequently excessive top soil wash away. Soil compaction affects soil biological, physical and chemical parameters as well as impeding plant root development. Reduced root development affects efficiency in water and nutrients uptake (Gitau, 2008 and Payne 2008). Inappropriate tillage methods, farm traffic and untimeliness in performing field operation are the primary causes of soil compaction in China (Zhang et al. 2006). According to Hamza and Anderson (2005) and Mosaddeghi *et al.* (2009) compacted soils results in unfavorable soil properties in the subsurface which in turn hinders root development and crop yield.

Soil compaction alters the soil structure, restricts plant root development, inhibits water and air infiltration and this often results to reduction in crop yield. (Petersen *et al*., 2004). There are several soil parameters that determine degree of soil compatibility. However, soil moisture is one of the short-term property that can be managed through reduced soil compaction.

Tillage cannot be used to alleviate deep soil compaction and this may have long lasting implications for crops production (Hamza *et al*., 2005), (Raper, 2005), (Wells, *et al*., 2005), Subsoiling is the commonly used method to alleviated deep compacted soil conditions (Mullins *et al*., 1992), (Vepraskas, *et al*., 1995).

According to Mosaddeghi *et al*. (2009), physical soil properties and crop growth are greatly influenced by tillage systems employed. Nevertheless, the impacts on root development between varying tillage systems have not been consistent. Laddha and Totawat (1997) reported that deep tillage reduces soil penetration resistance and bulk density, improves soil water storage capacity, improves root development (Holloway and Dexter 1991), which resulting in improved crop production. (Ghosh *et al*. 2006). Also, Mosaddeghi *et al.* (2009) found that in arid and semi-arid environments, soil properties under a conservation system were superior compared to those under conventional system.

Johnson, *et al.,* (1990) observed no soybean yield reduction due to surface and subsurface compaction while maize yields were consistently reduced. This was in agreement with Tardieu (1988) who had earlier reported that different crops and even different varieties show different sensitivity to soil compaction. Cowpea, for example, is capable of rooting well at a level of compactness that inhibits more sensitive crops like maize. He therefore concluded that crop rotation could alleviate moderate levels of soil compaction.

Soil compaction reduces soil void ratio; pore frameworks, which were at first similarly organized, experience three-dimensional changes, shifting to completely horizontal anisotropic conditions in platy structured soil stratus. This procedure has serious outcomes for hydraulic, gas, and heat transport processes, and also for nutrient storage and accessibility. However, if during trampling, wheeling or tillage tool operation a shear induced reorganization of soil particles occur, the configuration of soil particles per volume can become less dense leading to weak soil structure with reduced pore continuity and gas exchange (Hartge and Horn, 2016). According to Muchiri (2012), subsurface soil compaction or the plough pan developed over years affects farmers' timeliness during land preparation.

2.3 Subsoiling

Subsoiling is a high-energy demanding operation. It involves breaking compacted soil layers at depths of 15-50 cm. Therefore, to achieve a cost-effective operation, the equipment has to be properly adjusted and matched with the proper prime mover. Subsoiling loosens compacted soil profiles consequently improving water infiltration into the soil and enables plants roots to proliferate downward to access moisture content and adequate nutrients and in turns improves crop yield (Raper, 2005b; Wells *et al.,* 2005). The effectiveness with which compacted soil are shuttered depends on soil moisture, composition, texture, structure, porosity, type, density and its clay content. The success of the operation is dependent on equipment choice, configuration and speed with which it is operated (Kees, 2008).

Godwin (2007) during his study on effect of implement speed on forces and soil disintegration in clay loam and compact loam soils, found that speed has highly significant linear effects on the vertical force and highly significant quadratic effects on the horizontal force, total force, moment and specific resistance. Onwualu and Watts (1998) in a study on the relationship between tillage tool forces and speed which is important in evolving management strategies for optimum performance found the tool force to be a function of the speed and the square of speed. Mouazen and Nemenyi (1999) showed that a well-coordinated angle combination of the two parts of the subsoiler made a large reduction in the draught and vertical forces of the subsoiler with a shaft angle of 75° and a chisel angle of 15°.

2.4 Critical Depth and Rake Angle

According to Spoor and Godwin (1978), critical depth is function of the width, inclination and lift height of the tine foot and of the moisture and density status of the soil. They stated that the tine depth is pertinent because at shallow working depths the soil is displaced forwards, sideways and upwards (crescent failure), failing along well defined rupture planes which radiate from just above the tine tip to the surface at angles of approximately 45^0 to the horizontal. Crescent failure continues with increasing working depth until, at a certain depth, the critical depth, the soil at the tine base begins to flow forwards and sideways only (lateral failure) creating compaction at depth. They found that below the critical depth, compaction occurs rather than effective soil loosening. They concluded that the moist and plastic the soil is the shallower the critical depth.

McKyes and Maswaure (1997) demonstrated that designing a tillage tool for minimum draft requirement and high soil cutting efficiency called for a shallow operating depth and rake angle of 30^0.

2.5 Subsoilers

Due to significant draft force requirement for subsoiling, numerous ripper designs have been developed and tested. The shape of the shank has a significant influence on the draft required as well as the extent of soil disturbance. Raper (2005a) reported that bent leg shanks had the lowest surface soil disturbance when compared to several straight shanks for non-inversion in-row subsoiling. Smith *et al.,* (1988) observed that a parabolic ripper required less draft when compared to conventional and triplex rippers.

Ripper's point configuration has a substantial effect on soil disintegration and draft requirement. Some producers have reported that their draft force and their soil disturbance have been reduced by using a 'splitter point' on their subsoiler. It is important to note that no single implement or implement configuration works best for all prevailing soil conditions. It is therefore hard to set exact specifications for all ripping implements and operations.

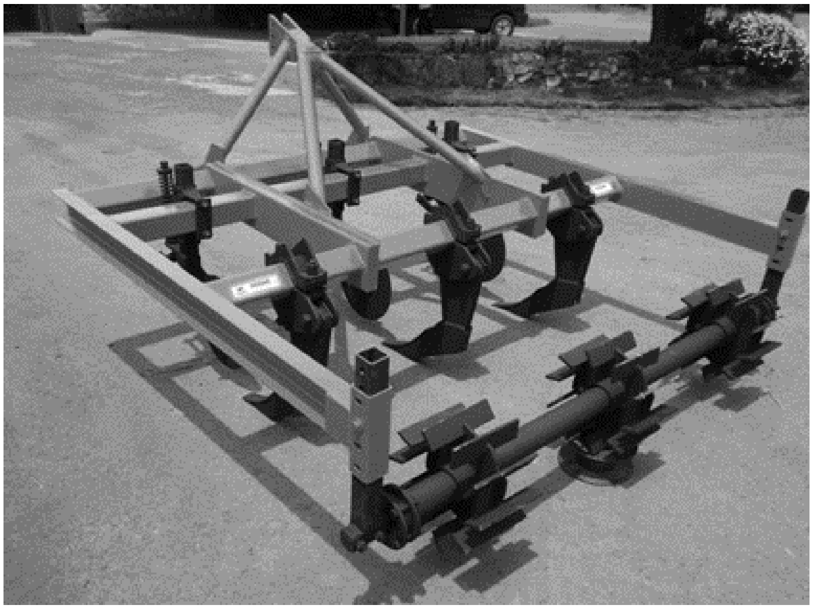


Plate 2-1 A Typical Chisel Plough

2.6 Specific Power Requirement

Power requirements and specific draft are crucial parameters in evaluating the performance of tillage implement and are therefore conceived as fundamental data when endeavoring to correctly match a prime mover to a tillage implement(Sahu and Raheman, 2008). Al-Suhaibani & Ghaly (2010) conducted studies to determine draft and power demands of tillage equipment under varying levels of soil conditions. Equipment operating width, depth and speed were parameters found to influence draft demand of tillage equipments.

Soil conditions and tillage implement geometry are also factors that affect draft demand according to Tong and Moayad, (2006). Soil type and shape of the implement influences the impacts of speed on draft requirment (Al-Suhaibani & Ghaly, 2010). Sub-soiling should be done when the soils are dry and friable. In instances where the soils are excessively wet, the implement shafts slides through the ground without shuttering the hard pan . On the other hand, in extremely dry soil, getting the implement into the ground can be difficult, requiring larger and more powerful prime-movers to pull the shafts through compacted areas. Soils with high clay content, can break into large clods or slabs if conditions are too dry. In most ares, the ideal subsoiling soil conditions are before the soils are completely dry.

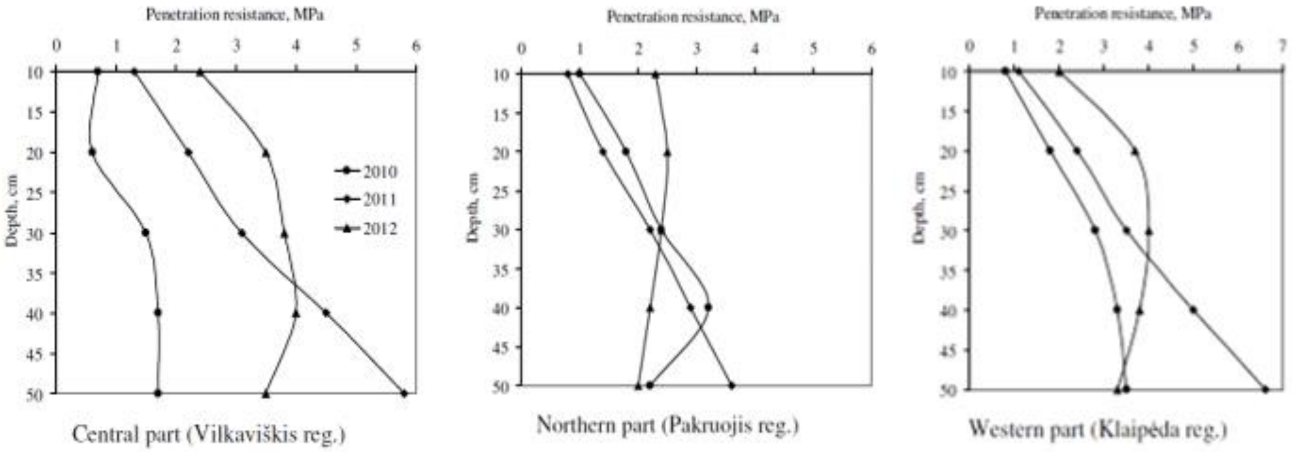
2.7 Effect of Soil Compaction on Soil Properties

The main consequence of soil compaction is reduction in soil void volume. Other soil properties and processes affected greatly or to a less extent include but not limited to; soil air volume and gaseous exchange capability, hydraulic conductivity, water holding capacity, soil strength and soil mechanical resistance to root penetration (Hillel, 2013 and Hadas, 1997). Sever effects of soil compaction on water infiltration results into heightened risks of surface overflow and soil destruction and/or moisture shortage in the plant root zone (Shaxson, *et al.*, 2016).

2.7.1 Penetration Resistance

According to Romaneckas *et al.*, (2016) in Vilkaviškis region, penetration resistance did not exceed 1MPa for depths below 20cm. however, they reported a continuous increase in the value of penetration resistance to depth of 30cm below which there was no further increase in penetration resistance with increase in depth as shown in Figure. 2-3. In spring, an even variation in penetration resistance within the entire sampling depth Figure. 2-3 was reported. For depth between 25 -30cm, they reported soil penetration resistance of 3MPa (i.e. existence of a plough pan). Below 30cm, soil penetration resistance increased more drastically indicating that the soils were getting harder and harder down the profile.

In Pakruojis region, penetration resistance above 10 cm was up to 1MPa while below 10cm to 30cm, the soil penetration resistance values recorded were 2 MPa. In Klaipeda region, soil penetration resistance increased evenly to depths of 50 cm (Romaneckas *et al.*, 2016).



Central part (Vilkaviškis reg.)

Northern part (Pakruojis reg.)

Western part (Klaipėda reg.)

Figure 2-1 Soil penetration resistance at the renewal of crop during three years after subsoiling (Romaneckas *et al.*, (2016)

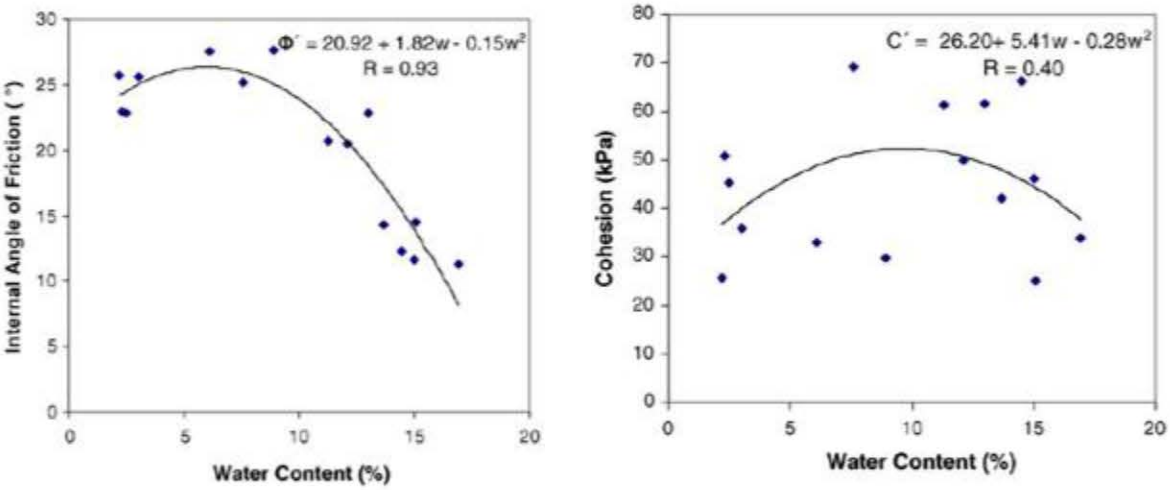
2.7.2 Soil Shear Strength

Several factors have been found to influence the strength of the soil. (Davies, 1985) studied effects of soil organic matter on shear strength. Organic matter content was found to increase the shear strength of soil by as much as 10kPa. This was explained by (Patto, *et al.*, 1978) to be due to increase in binding of soil mineral components together by organic matter. However high organic matter values result in a decrease in shear strength.

Moisture content has been found to be an influencing factor in soil strength values. Low shear strength was reported in areas with high soil water content (Veneman, *et al.*, 1976). Drainage in agriculture increases the bearing capacity of the soil. Davies, (1985) reported a significant correlation between mean shear strength and volumetric water content. McKyes, *et al.*, (1977) reported that the highest soil cohesive angle values were achieved at moderate moisture content for cohesive soils. Wells & Treesuwan (1978) observed a linear relation between friction angle and moisture content independent of density for a silty loam soil. Increase in soil density has also been shown to increase the shear strength parameter of the soil (Ayers P.D, 1987).

2.7.2.1 Strength Parameters

According to Gitau *et al.* (2006), soil cohesion and internal angle of friction increases with increasing water content to a point of inflection and the decrease with any further increase in water content. They reported that cohesive and frictional properties of the soils (for the range of water content of 9–17%) decreased with increase in soil water implying that higher water content reduced the bonding and frictional resistance between the soil particles.



(a) (b)

Figure 2-2 Effects of water content on soil (a) internal angle of friction (b) cohesion (Gitau et al , 2006)

2.7 Soil Moisture

Heidarpur *et al.,* (2011) reported that significant difference of moisture content was observed for the different tillage depths and tillage method at 95% confidence interval ($P < 0.05$), as well as for year and tillage depth and tillage method interaction ($P < 0.01$) at the flowering stage of the crop. Quincke *et al.* (2007) also reported that water permeability into the soil increased with depth for moldboard tillage implement.

Azim Zadeh *et al.*, (2002); Halvorson *et al.*, (2000); and Mohammadi *et al.*, (2009) reported increased soil moisture loss with moldboard use. Asghari-Meidani (2006), in a three-year study using different tillage implements under dry soil conditions reported that high soil moisture content was recorded for the chisel plough. Shamsabadi & Rafiee, (2007) and Mohammadi *et al.* (2009), reported significant improvement in physical soil properties and an increased soil moisture holding capability for chisel plough.

Soil moisture deficit as well as soil nutrient deficit due to low organic matter in the soil and relatively shallow rooting system has greatly affected crop yield over the years. (Muchiri, 2012)

2.8 Hydraulic Conductivity of Saturated Soils

According to Karuma *et al*. (2015), hydraulic conductivity(Ksat) of soil is used in studies of soil water movement for various drainage purposed. It is also used in giving an indirect indication of the soil structural instability. Due to the rapid draining capability of larger pores, there is a rapid decrease in hydraulic conductivity with decline in water content in unsaturated soils. In practice, Ksat is measured for two main purposes:

(a) Comparison of Ksat rates of different soil horizons, particularly as a guide to water movement and possible drainage problems within the soil profile.
(b) As a basis for in-field design. However, for this purpose, measurements may often be required to about 2m depth and regional studies may even call for deeper measurements

Pali *et al.,* (2014) during a study on unsteady subsurface drainage equation incorporating variability of soil drainage properties reported a polynomial relationship between hydraulic conductivity and depth as shown in Figure 3-1

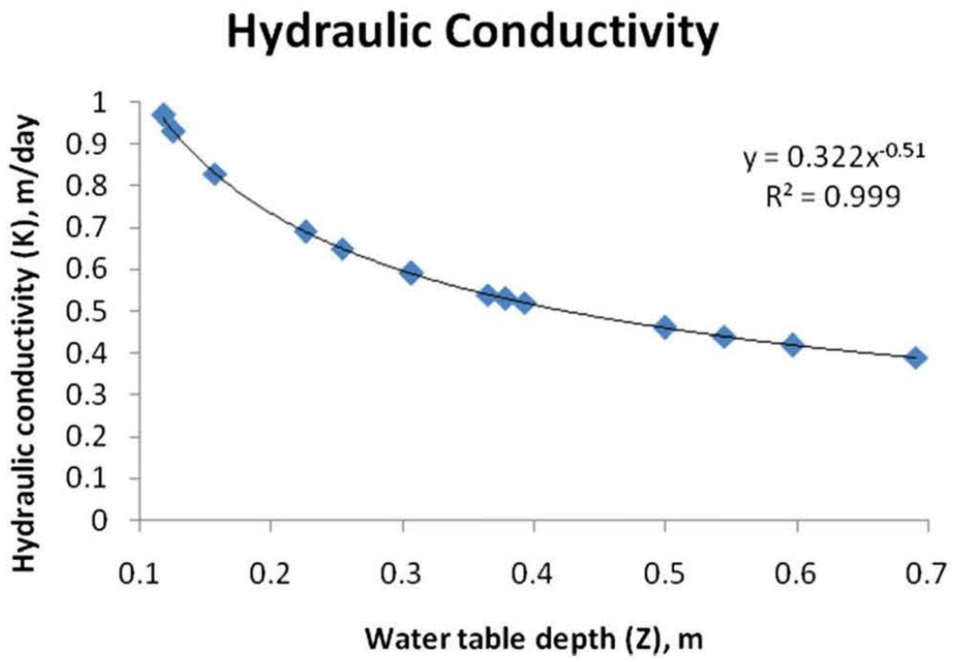


Figure 2-3 Variation of hydraulic conductivity with water table depth

2.9 Effect of Soil compaction on crop yield

Scholars have investigated the impacts of soil compaction on crop yield. Raghavan *et al*. (1979) found out that yield reduced by 40 – 50 % in highly compacted clay soil. Gameda *et al*. (1994) concluded that when axle load of 10 and 18 Mg is applied, the bulk density of soil at depths of 2 – 30cm increased up to 1.79Mg/m^3. They reported reduction in grain yield of 18 – 27 % on optimal weather condition and 55 – 86% during adverse conditions. Gaultney *et al.* (1982) reported 50% corn yield reductions in severe compaction and yield reduction of 25% in moderate compaction with severe compaction and 25% yield reductions with moderate compaction.

However, crop yield is not always decreased due to compaction. Voorhees, (1991) reported that yields can slightly improve with moderated compaction depending on the prevailing climatic conditions. Bicki *et al.* (1991) reported that in dry seasons, corn yields in compacted plots were grater compared to plots with no compaction. However, with favorable moistures levels, soil compaction was found to have an adverse effect on yield.

2.10 Models Used in Soil-Implement interactions

Precise modelling of the soil-implement interaction allows for the implement design optimization which has a direct effect on tillage cost as well as time used (Zadeh 2006). Due to the changes dynamic nature of soil, the interaction between soil and the implement is a complex process. Different models have been developed and used over time in predicting the soil – implement interaction.

According to Ucgul *et al* (2014), the models have been classified into three broad categories;

(i) Analytical methods- they examine the soil failure by studying the quasi-static or dynamic conditions. These methods are not commonly used because they do not consider the soil movement.

(ii) Empirical methods- Involve rigorous measurements, calculations and extrapolation of field conditions which is not easy to achieve.

(iii) Numerical methods – are classified into two groups; continuum and dis-continuum methods. Finite element method (FEM) and computational fluid dynamics (CDF) are continuum methods while discrete element method falls under the later method. These methods are used to solve bottlenecks of methods (i) and (ii).

Continuum methods assume continuity which is not always valid. Discrete element method (DEM) considers among many things in its modelling: soil failure, soil deformation and translocation. These considerations make DEM the most preferred method for soil –implement interaction study. Dexter (2004) stated that models used in soil tillage need to consider the crumbliness and workability effects during tillage.

2.11 Summary of the Literature Review

Soil shear strength and draft force requirements of a tillage tool are functions of soil deformation rate. It therefore follows that, during the execution of the field tests; operating speed should be kept constant so that a uniform speed influence on the collected data is maintained.

Soil water content has been reported to be an influential factor of the soil characteristics and draft force requirements of the tillage tools thus influencing the size of the soil cross-section area tilled. At the same time, it affects the soil-failure type. It was therefore important to determine the variation in soil water content during the field tests for the different test plots.

The rake angle, geometry of the tool and operating speed have been proven to influence both the soil-failure types and rupture planes. To have the same type of soil-failure and rupture planes, the rake angles and the geometry of the blades for subsoilers should be maintained for each test.

The reviewed literature has shown that the draft force requirements of a tillage tool increased when operated below its critical depth. It was therefore hypothesized that when the subsoiler is operated above the critical depth, energy utilization would be optimized. During the field test, different depths were used in determining it effect on draft requirement.

It is also reported from literature that different tillage methods affect soil properties differently and therefore, to investigate the effect of chisel plough (CP) a control must be used in order to quantity the difference in the affected properties. In this research, a Chisel plough (CP) and a Disc Plough (DP) were used.

CHAPTER THREE: THEORETICAL FRAME WORK

This chapter entails models formulated by scientists and other researchers to predict, explain and understand pertinent parameters affecting draft requirement for ripping. It describes models used in computing parameters important to the study.

3.1 Soil Classification

The following equations will be used to compute the percentage composition of each constituent component in the soil sample (Bouyoucos, 1962). The values obtained will be used on the soil texture trial Figure 3-1 to determine the soil classification.

$$\%\text{Sand} = 100 - 2((H_1 - B_1) + 0.36(T_1 - 20)) \tag{3.1a}$$

$$\%\text{Clay} = 2((H_2 - B_2) + 0.36(T_2 - 20)) \tag{3.1b}$$

$$\%\text{Silt} = 100 - (Sand + Clay) \tag{3.1c}$$

Where;

H_1 = hydrometer reading at 40 seconds after stirring

H_2 = hydrometer reading 3 hours after stirring

B_1= hydrometer reading 40 seconds after stirring for the blank

B_2 = hydrometer reading 3 hours after stirring for the blank

T_1 = Temperature reading 40 seconds after stirring

T_2 = Temperature reading 3 hours after stirring

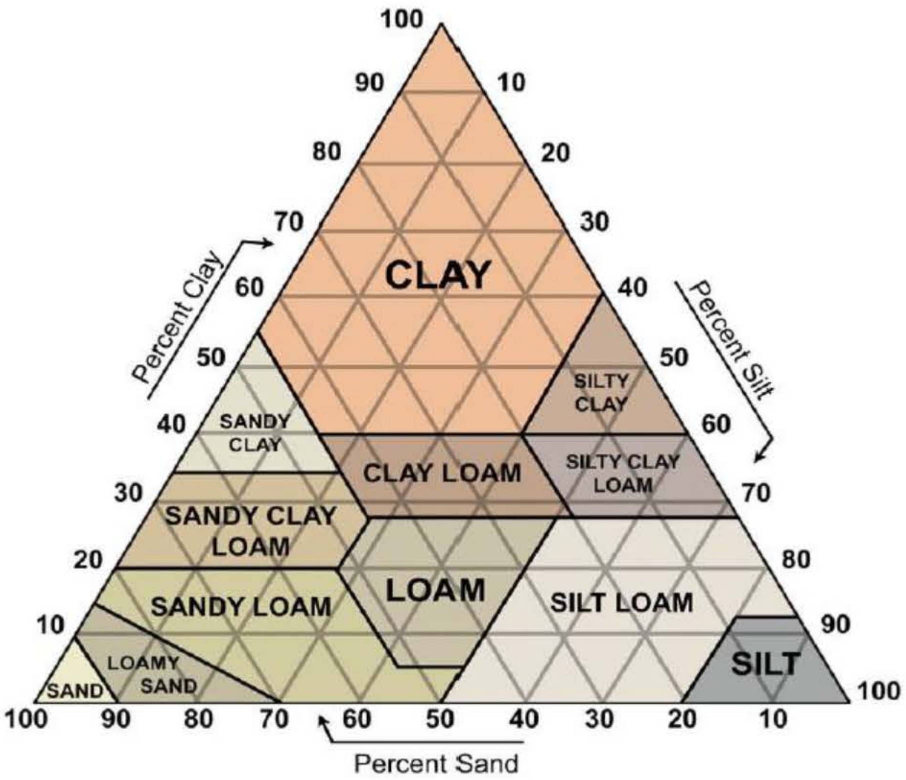


Figure 3-1 Soil texture triangle (Source: USDA-NRCS: http//soils.usda.gov)

3.2 Draft Power

Palmer and Kruger (1982) stated that energy required to till a given area is a function of tillage depth and implement operation speed. Upadhyaya., *et al* (1984) developed the following equation for draft requirement of a subsoiler:

$$D = B_o(CI \, x \, W)d + B_1(\rho_w)d \, x \, W \, x \, S^2 \tag{3.2}$$

Where;

D = Draft (F)

CI = Cone Index (FL-2)

W = Width of subsoiler cutting edge (L)

d = depth of operation (L)

ρ_w = wet bulk density (ML-3)

S = travel speed (LT-1)

Bo, B1 = constants

Draft power is a measure of the rate of work accomplished according to the equation

$$D_p = \frac{F \times D}{T} \tag{3.3}$$

Where;

D_p = draft power (watts)

F = force (Newtons)

D = distance (meters) and

T =time (seconds)

Draft power is directly proportional to draft force and speed which reduces the time required to complete a task. Draft refers to the force necessary in moving an implement in the travel direction. For most implements, draft required is mainly influenced by soil resistance and crop residue. (Hamlett *et al.*, 1990).

Compacted dry soil has relatively large resistance to the tillage implements compared to unconsolidated wet soil. Surface contact also has a great influence on the draft. Loose soil results in increased tractor wheels' slippage with in turn affect the draft required. Also, the slope affects draft requirement. For instance, draft is increased when the tractor is moving upslope. Another factor that affect draft is the depth of tillage (Kees, 2008).

3.3 Soil Shear Strength

Soil shear strength refers to the maximum shear stress a given soil structure can support without any further compression. This is of agricultural and engineering importance in conserving the soil against compaction by farm machinery and animals. It is also important in informing the design of tillage implements used in alleviation of soil compaction. Soil strength is defined by the extent of cohesion and internal friction existing between soil particles. The strength of the soil has a bearing on root penetration and seedling emergence.

Soil shearing strength comprises of cohesive component and frictional component (McKyes, 1985). Empirically, soil shear strength is described by the Mohr – Coulomb equation below as cited in (McKyes, 1985) and (Davies, 1985)

$$\tau = C + \sigma \tan \Phi \tag{3.4}$$

Where

τ = Soil Strength

C = Soil Cohesion

σ = Normal Stress

$\tan \Phi$ = Coefficient of friction

3.4 Penetration Resistance

The following equation will be used in the determination of penetration resistance (in situ testing penetrometers); (in situ testing penetrometer

$$CR = I \text{ x } \frac{CS}{AC} \tag{3.5}$$

Where;

CR = Cone resistance (N/cm^2)

I = Impression on the scale (cm)

Cs = Spring Constant (N/cm)

AC = Area of cone (cm^2)

3.5 Soil Moisture Content

Refers to the quantity of water in a given volume or mass of soil. Soil moisture (M.C) can be expressed in different form;

i. Gravimetric – Dry-weight Basis

The range is usually from zero to infinity. It is the commonly used method of expressing moisture content.

$$\mathrm{W_d} = \frac{\text{grams of water}}{\text{grams of dry soil}} \tag{3.6a}$$

ii. Gravimetric – Wet-weight Basis

This ranges from 0 to 1 or from 0% to 100%

$$\mathrm{W_m} = \frac{\text{grams of water}}{\text{grams of most soil}} \tag{3.6b}$$

$$= \frac{\text{grams of water}}{\text{grams of water+grams of dry soil}} \tag{3.6c}$$

3.6 Bulk Density of Soil

The bulk density of soil refers to the ratio of weight of dry soil (Ms) to the total volume of soil V Total soil volume represent the volume of solids and the volume of voids which may contain air or water or both. Soil bulk density and soil porosity are important indicators of soil suitability for root growth and water permeability and vitally important for the soil-plant system (Hamilton, *et al.,* 2002).

$$\text{Bulk Density} \left(\frac{\mathrm{g}}{\mathrm{cm^3}}\right) = \frac{\text{Dry soil weight (g)}}{\text{Soil Volume (cm}^3\text{)}} \tag{3.7}$$

3.7 Hydraulic Conductivity (Ksat)

Estimations of saturated soils Ksat is based on direct application of Darcy's equation to saturated soil column of uniform cross-sectional area. Hydraulic head difference is imposed on the soil column and the resulting flux of water is measured

Ksat is given by:

$$K_{sat} = \frac{Q}{AT} x \frac{L}{H} \tag{3.8}$$

Where;

Q = amount of water collected

T = time taken to collect

A = cross-sectional area of the sample

L = length of sample

H = length of sample + depth of constant water (Δh)

CHAPTER FOUR: MATERIALS AND METHODS

This Chapter outlines the procedure used in meeting the set objectives. Also, it outlines the field and laboratory procedures used in obtaining various datasets and the analysis done.

4.1 Experimental Site

The study was carried out at Kanyariri Vet Farm, Upper Kabete Campus -University of Nairobi. The experimental plots were located at Kanyariri within coordinates A_1(1.242693°S, 36.702490°E), A_2(1.243784°S, 36.704519°E), A_3(1.242278°S,36.704329°E) and A_4 (1.241718°S, 36.703675°E) 1910m above sea level off Kepenguria road on Fort Smith Road which is 2 km to the west of Upper Kabete Campus and 15km from Nairobi City. The farm has a land size of 152 hectares (370 acres) and there are 4 main enterprises: dairy unit, poultry unit, pig unit and the small ruminant unit.

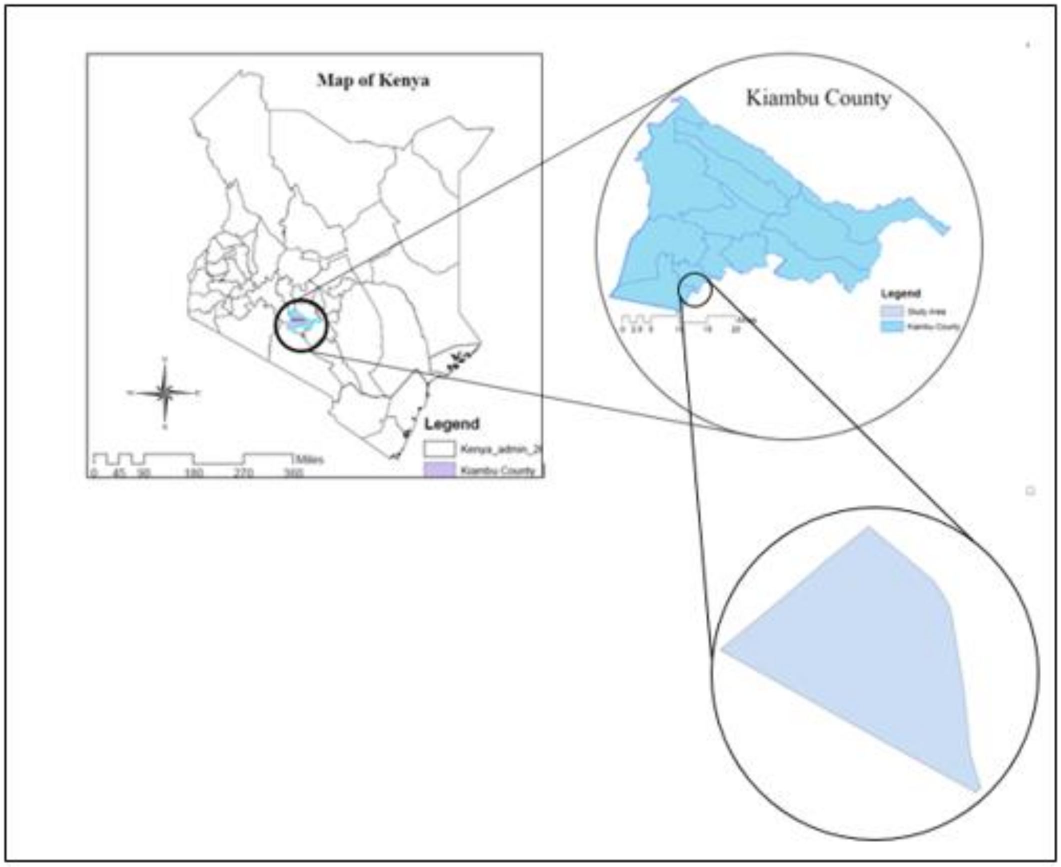


Figure 4-1 Map of the Study Area

Figures 4.1 and 4.2 show the average temperature and rainfall data respectively.

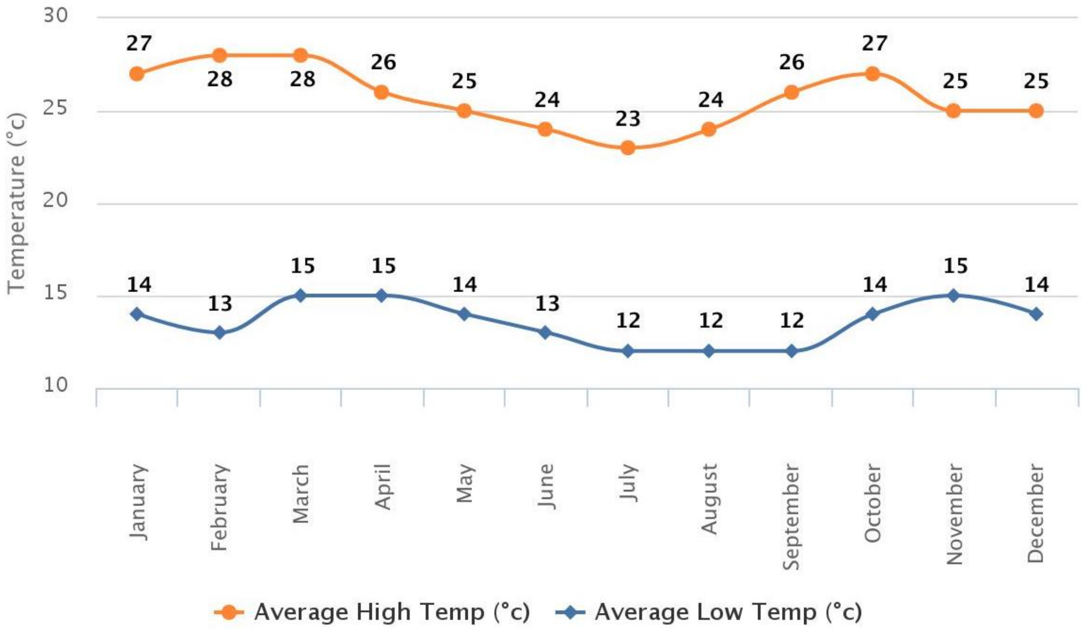


Figure 4-2 Average temperature for Kabete (World Weather Online, 2012)

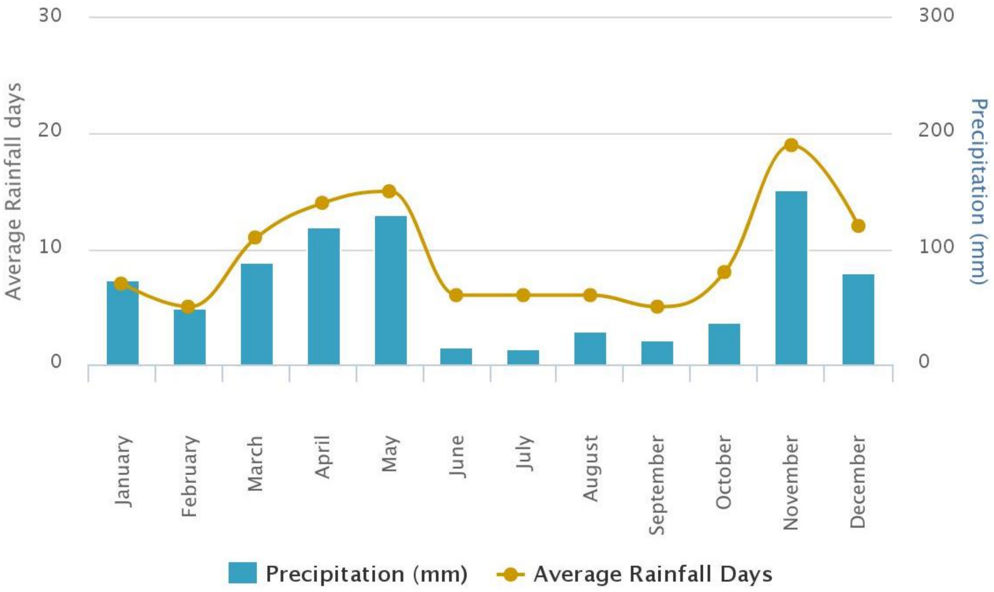


Figure 4-3 Average rainfall for Kabete (World Weather Online, 2012)

4.2 Data Collection Approach

4.2.1 Literature Review

In order to determine the soil parameters that influence draft requirement for tillage, literature review was conducted. Once these physical and mechanical soil parameters pertinent to tillage were identified, the experimental study was conducted to identify their values.

4.2.2 Experimental Set-up

Field experiments were conducted to collect numerical values of pertinent soil parameters before and after the two tillage treatments (chisel plough and disc plough). Draft data was recorded using the MSI 7300 Dynalink2 and transmitted remotely to a computer setup trough MSI-8000MF data logger. The set-up arrangement was as shown in Figure 4.4. the tillage implements was attached to the three-point hitch of the towed tractor. The dynalink2 was attached between the towing and the towed tractor via steel shackles.

In order to determine the rolling resistance, the set-up was run without the tillage implement engaged. The obtained draft values were subtracted from the values obtained when the implement is engaged so as to establish the draft requirement of the implement alone.

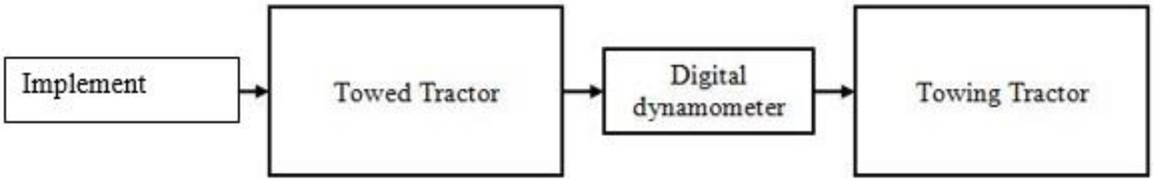
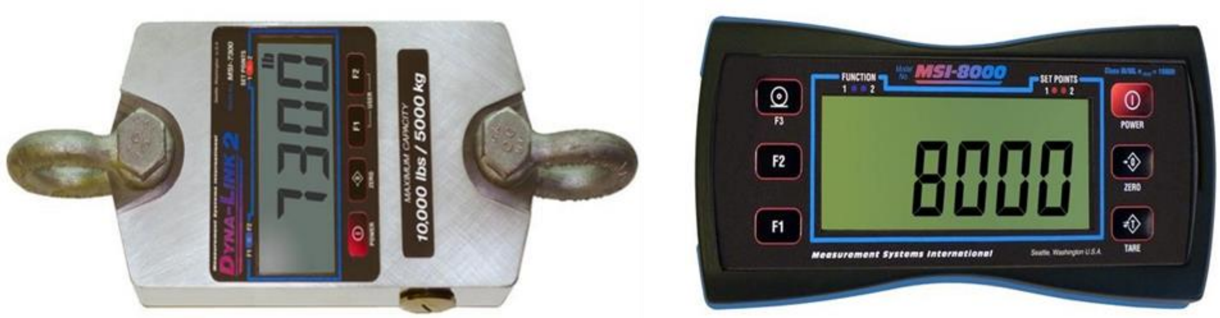


Figure 4-4 The experimental set – up

Plate 4.1 show close-up images of the dynamometer and the remote display;



MSI 7300 Dynalink 2 MSI 8000 Remote Display

Plate 4-1 Digital Dynamometer Components

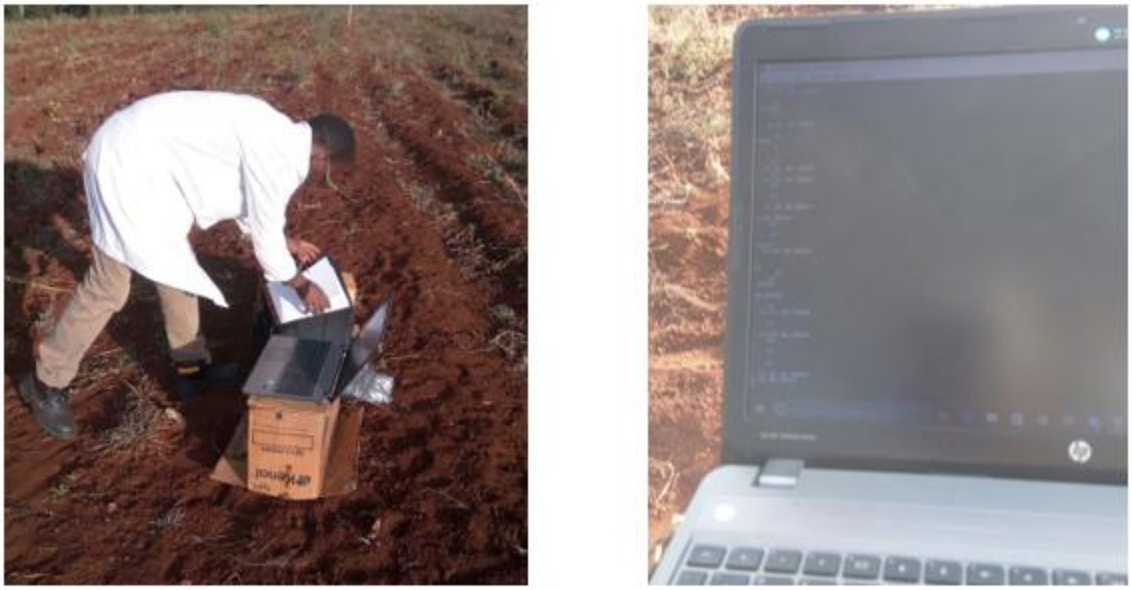


Plate 4-2 Field Data logging station Setup

4.2.3 Experimental Design and treatments

The trial field were arranged out in a randomized complete block design with a factorial arrangement consisting of 3 tillage levels and 2 different levels operating speed replicated in 2 blocks. The plot sizes were 16 m by 50m. the plots were separated by a buffer of 1m width. The separation between blocks was 5m which acted as the tractor turning area (Figure 4 -5). Three different depths (i.e.0 - 15cm, 15 - 30cm, and 30 - 45cm for chisel plough and to a limit of 25cm for disc plough) were used. All the runs were conducted at constant engine speed and transmission ratio while continuously recording the draft forces through the dynamometer.

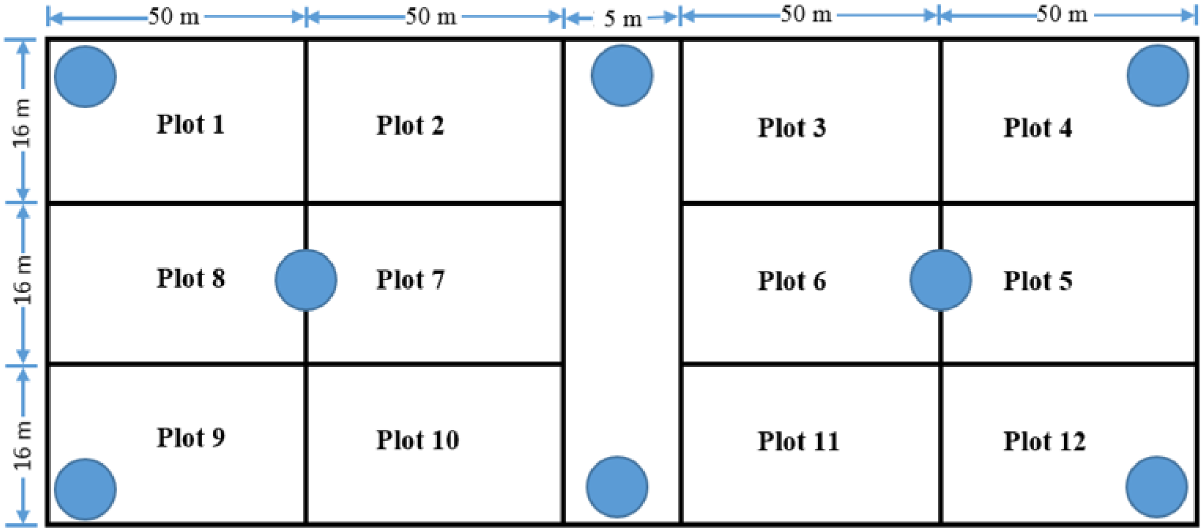


Figure 4-5 Experimental field lay-out.


Chisel ploughing

Disc Plough

Plate 4-3 Tillage exercise using chisel plough and disc plough

Soil samples were collected for determining soil moisture content, bulk density and hydraulic conductivity. In-situ soil tests were also conducted to determine cone resistance index and soil strength. These soil tests were replicated at two other times after the tillage i.e. in December of 2016 and February of 2017 (during the short rains and after the short rains respectively).

4.2.4 Soil physical properties

Physical soil properties (soil moisture, Infiltration rate, soil texture, bulk density, shear stress and penetration resistance) was measured before tillage operations were carried out. The soil texture was determined through the Buoyocos method. To determine soil moisture content, soil samples were collected randomly from the field and weighed. The samples were oven dried at 110°C for 48 hours and reweighed. The moisture content was calculated on a dry weight basis by computing the difference between wet mass and dry mass of the samples as per Standards Association of Australia. AS 1289 B1.1-1977 procedure.

A soil penetrometer was used in determining the initial soil penetration resistance. The penetrometer was pushed into the soil and the values of resistance read. For each test, six (6) values were obtained and used in computing mean of penetration resistance.

To determine initial soil bulk density, core rings were used in collected soil samples at different depths (0-15 cm, 15 -30cm and 30 – 45cm). Each sample in the core rings was oven dried at 105° C for 24 hours and bulk density computed using equation 3.7.

Triaxial machine was used in determine the soil cohesion and internal angle of friction. Soil infiltration rate was determined using the hydraulic conductivity experiment set-up. These soil tests were replicated two others times (during the short rains and after the short rains) for both chisel ploughed and disc ploughed plots.

Soil physical and mechanical properties (soil moisture, texture, structure, bulk density, shear stress and penetration resistance) were measured during the experiments. Soil samples were collected randomly to depths of 45cm with each test block having at least three soil samples. Soil samples were collected using polythene bags clearly labelled with reference numbers indicating the block from which the sample was collected.

4.2.4.1 Soil Classification

Soil classification was done using the texture analysis method. Samples collected from the field before tillage were subjected to Texture Analysis Procedure (Appendix E) and using equations 3.1a, b and c, to compute the percentage of Sand, Clay and Silt in the sample respectively. The percentages obtained were used to classify the study field soils using soil texture triangle Figure 3-1.

4.2.4.2 Shear Strength

Soil shear strength was determined using the BS 1377-8 procedure. The soil to be tested was placed on a tray and pre-moistened. All the uneven particles of the soil were removed and the resulting mixture moulded by putting soil into the mould then the soil compacted with a rod until the specimen mould is full. The excess soil was then removed using a scalpel and the mould removed by sliding it outwards on both sides that hold the specimen together. The mould was first oiled before putting the soil sample. This was to ease the removal of the moulded samples.

The moulded soil sample were shaped until the height of 76mm and then placed on the base of the triaxial chamber. It was then put inside a rubber membrane. The soil sample was also placed in between two porous stones at the top and at the bottom. The soil sample were then enclosed by glass housing and placed in position of axial loading device. Pressure was readjusted to the desired chamber level. After this the pressure valve was opened. The pressures used in this practical ranged between 100 kPa to 400 kPa. Lateral /all- around pressure was applied by means of air. With the application of the chamber pressure an axial load was applied so as to produce an axial strain at a given rate of 0.5mm/min. At this point, time recording was started.

The data sheet was filled with data of, initial height and weight, final height and weight after deformation, diameter of the sample, the proving ring readings, time taken to apply an axial load until the soil sample failed. Failure was demonstrated by the decline of the proving ring reading.

The soil sample was then removed after failure and its final weight and height measured and recorded. This process was repeated for all the soil samples of the same soil constituent at different chamber pressures. Mohr circles were then plotted for each data set and the values of internal angle of friction and cohesion determined.

4.2.4.3 Bulk Density

Bulk density tests were conducted to determine the degree of soil compaction. Undisturbed soil samples collected using core rings were weighed and the weight recorded. The samples were then placed in the oven for drying. Weight of dried samples was determined and recorded appropriately. Dried soil sample was removed and the weight of the ring measured. The difference between the two weights was computed and the weight of moisture in the soil samples. The height and diameter of each core ring were determined and recorded and the respective volume calculated. This was repeated for all samples and bulk density computed.

4.2.4.4 Penetration Resistance

In-situ soil penetration resistance was determined using a penetrometer with a cone angle of 30^{o} and cone diameter of 12.83mm. The penetrometer was pushed into the soil to a pre-determined depth and penetrometer resistance of each 15cm depth interval was drawn. The values obtained over the depth were used as the mean of penetration resistance.

4.2.4.5 Moisture Content

The moisture content of the soil was established using the gravimetric method. Soil sampled for moisture content analysis was taken just before a run and kept in moisture bags to prevent drying. The soil was weighed, oven dried at $105^{o}C$ for 72hrs and then re-weighed. The moisture content was obtained as the ratio of the difference in weight between the original and the oven dried soil to the original weight using equation 3.6.

4.2.4.6 Soil Hydraulic Conductivity

An undisturbed soil sample was collected from the field using core rings and using a rubber band, a piece of muslin cloth was tied on one end of the sample. The samples were then moistened by placing it on a shallow tray of water with the muslin cloth-covered end downwards.

The samples were allowed to soak overnight for it to be completely saturated. Identical empty sample core-ring was carefully secured in place with waterproof tape so that there was no leak at the joint. The sample was transferred to the conductivity rack and water was carefully added into the upper core ring until it was almost full. One of the siphons with the tip under water was opened to maintain a constant head on the sample. The furthest siphon on the rack from the water reservoir was opened first.

The time when the water level on the sample became constant was noted and the percolate collected at convenient time intervals. Volume of water(Q) that passes through the sample in a given time (T) was recorded in hours. The hydraulic head difference was noted (Δh) and the hydraulic conductivity (Ksat) was computed using equation 3.8.

4.3 Mathematical Models Development

This involved establishment of relationships between pertinent parameters (i.e. soil moisture content, penetration resistance, hydraulic conductivity, shear strength) identified with depth. Graphs of each of these parameters against depth of tillage were developed and equation of best fit established. These equations formed the mathematical relationship between the individual parameter with depth.

Furthermore, graphs of draft against operation depth of tillage at operation speeds of 3kph and 5kph were developed and equations of best fit identified as the mathematical relationship between draft and depth at these particular speed levels.

4.4 Statistical Analysis

Two different tillage mechanisms were used to investigate their effects on soil physical properties. Data obtained was subjected to regression analysis by determining the Pearson product moment correlation coefficient, R, between two variables according to Bluman (1998). Moreover, a single-way analysis of variance (ANOVA) was used to test any significant difference in the physical soil parameters for the two different tillage methods and for the three different depths, at the 95% confidence level.

The ANOVA table was represented as in Table 4-1 (Triola, 2013)

Table 4-1 ANOVA Table

Source of Variation	SS	df	MS	F	P-Value	F- crit
Blocks						
Treatment						

Where;

SS = Sum of Squares

df = degrees of freedom (n-1)

MS = Mean Sum of Squares = $\frac{SS}{df}$

F = Variance Ratio =$\frac{MS(blocks)}{MS(treatments)}$

To compute parameters in the table, the following equation will be used

$$SS_{error} = SS_{total} - SS_{treatment} \tag{4.1a}$$

$$SS_{total} = \sum x^2 - \frac{(\sum x)^2}{n} \tag{4.1b}$$

$$SS_{tretament} = \frac{(\sum T_i)^2}{r_i} - C.F \tag{4.1c}$$

Where C.F = correction factor = $\frac{(\sum x)^2}{n}$ (4.1d)

x = value of the outcome

n = number of outcomes

Sources of the expected research errors included data collection, soil sample collection, testing methods and experimental errors. The errors were minimized through making several runs and sampling at different points in the experiment field and computing the mean values.

CHAPTER FIVE: RESULTS AND DISCUSSIONS

This chapter presents the findings and interpretation of the various datasets obtained during the research. The soil characteristics of the study site are presented herein; the draft data from experiments are also provided. Statistical analysis and comparison of various measured datasets for the two implements are also presented; an evaluation effect of chisel ploughing on physical and mechanical soil properties on a maize cropped field at different depths and operating speed was conducted and has been presented. The detailed field data are provided in Appendix B

5.1 Pertinent Parameters Influencing Disc and Chisel Ploughing

Table 5-1: **Pertinent Parameters Affecting Draft Requirements**

Soil Property	Author of study
Moisture content	Muchiri G. (1982), Edward S.M (2006),.Sahu R.K (2006)
Cohesion and internal angle of friction	Ijioma (1995), Tong J. (2006). Gitau A.N.*et al.*, (2006)
Bulk Density	Tong J. (2006), Sahu R.K. (2008) , Muchiri G. (2012)
Speed of ploughing	Sahu R.K (2006), Mulliah *et al.*, (2006), Godwin *et al.*, (2007)
Depth of ploughing	Sahu R.K. (2006), Edward S.M. (2006), Chris Saunders(2007)
Angle of repose	Chris Saunders (2007) Asaf Z. (2007), Rubinstein D. (2007), Mustafa Ugul (2014),
Width of cut	Godwin R.J. (2007), O'Dogherty M.J (2007)
Shear Strength	Gitau A.N. *et al*., (2006)

5.2 Soil Characteristics

The overall soil texture across the three depths as deduced from the texture triangle was clay soils (Table 5.2).

Table 5-2: **Soil Texture Analysis**

Depth (cm)	Proportions of soil Separates in (%)			
	Sand	**Clay**	**Loam**	**Soil Texture Class**
0 - 15	44.837	43.54	11.623	Clay
15 - 30	43.837	44.04	12.123	Clay
30 - 45	42.904	48.94	6.797	Clay

Note: Each value is a mean of six replications

5.3 Site Soil Characteristics

5.3.1 Moisture Content

Figure 5.1 represent variations of moisture content at different time during the growth period for different tillage method. The figure shows an exponential relationship of the form $y = Ae^{bx}$ with R^2 values of 0.809, 0.944 and 0.998 for Chisel plough (CP), Disc Plough (DP) plots and during tillage respectively.

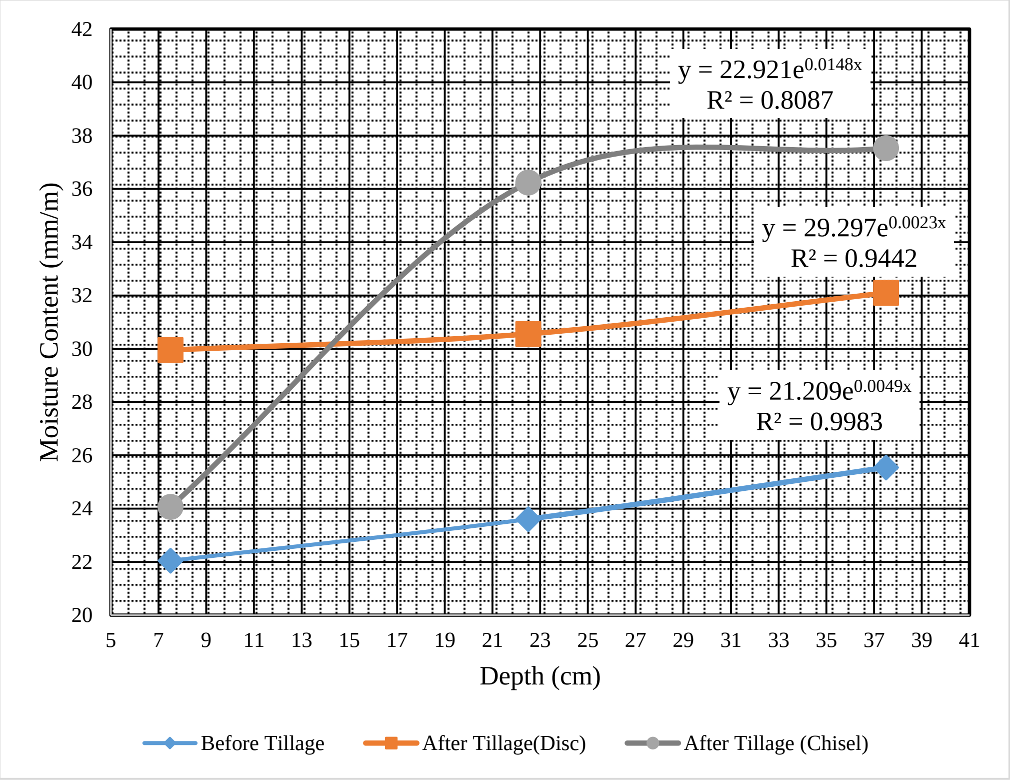
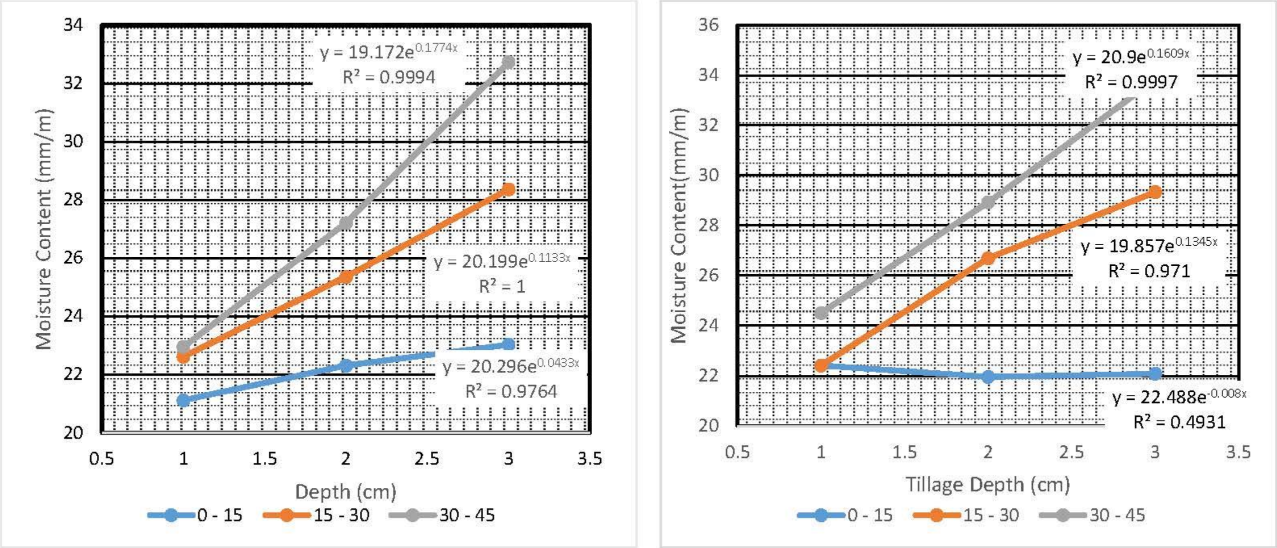


Figure 5-1: Moisture content versus depth at different periods during the growing period

At depths of 0-15 cm, moisture levels are relatively low compared to moisture levels at deeper depths. For CP, the moisture at 0-15cm is slightly higher compared to moisture content at the same depth before but it is slightly lower than that of DP. This might be due to larger surface area exposed to rainfall for DP as compared to CP. However, the trend changes with increase in depth. For depths 15 -30cm and depths 30 -45 cm, the moisture content in disc ploughed experiment plots was lower compared to that in chisel ploughed plots this may be due to water harvesting nature of chisel ploughed area. Shamsabadi, (2007) and Mohammadi *et al*. (2009), reported an increase in the stored moisture for CP due to the improvement of soil physical properties.

Figure 5 -2 represent the variations in moisture content at different sampling depths for different DP and CP depths.

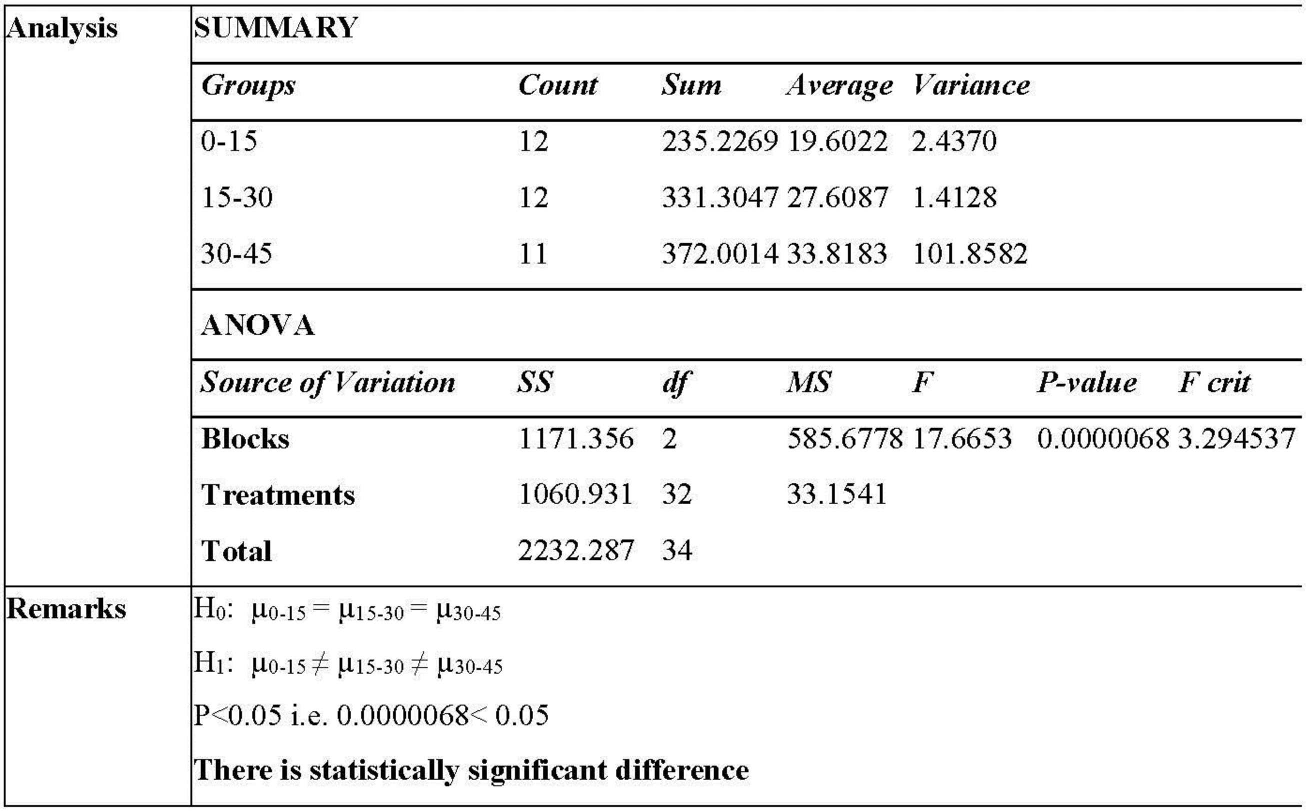


(a) (b)

Figure 5-2 Variation of moisture content at different sampling depths (a) disc Plough (b) Chisel Plough (13th March, 2017)

The moisture determined after maturity of the maize crop portrays that moisture content increases with depth for the three tillage depths used (0-15 ,15 -30 and 30 -45 am). However, there is a significant difference in the moisture content at each respective depth increasing from tillage depth 0 -15 and the highest being achieved at tillage depth 30 – 45 as indicated in Table 5-3.

Table 5-3: ANOVA of Moisture Content at Different Sampling Depths



Analysis	**SUMMARY**						
	Groups	*Count*	*Sum*	*Average*	*Variance*		
	0-15	12	235.2269	19.6022	2.4370		
	15-30	12	331.3047	27.6087	1.4128		
	30-45	11	372.0014	33.8183	101.8582		
	ANOVA						
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Blocks	1171.356	2	585.6778	17.6653	0.0000068	3.294537
	Treatments	1060.931	32	33.1541			
	Total	2232.287	34				
Remarks	H_0: $\mu_{0-15} = \mu_{15-30} = \mu_{30-45}$ H_1: $\mu_{0-15} \neq \mu_{15-30} \neq \mu_{30-45}$ $P<0.05$ i.e. $0.0000068 < 0.05$ **There is statistically significant difference**						

The p-value was all found to be less than 0.05 with 95% of confidence; the null hypothesis was thus rejected in favor of the alternative. It was thus concluded that moisture content varies significantly with tillage method and tillage depth.

5.3.1 Penetration Resistance

Penetration resistance as a function of tillage depth before and after primary tillage for DP and CP is shown in Figure 5-3. Plough method effects in relation to varying tillage depth on penetration resistance of soil were statistically significant among the tillage method at P>0.005 as shown in Table 5-4.

Table 5-4 ANOVA of Penetration Resistance at Different Sampling Depths for CP and DP

Analysis	**SUMMARY**						
	Groups	*Count*	*Sum*	*Average*	*Variance*		
	0-15	21	30.44098	1.44957	1.266878		
	15-30	21	78.49715	3.737959	4.18605		
	30-45	21	80.40025	3.828583	3.564851		
		ANOVA					
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Blocks	76.33247	2	38.16623	12.697	0.0000252	3.150411
	Treatments	180.3556	60	3.005926			
	Total	256.688	62				
Remarks		H_0: $\mu_{0-15} = \mu_{15-30} = \mu_{30-45}$ H_1: $\mu_{0-15} \neq \mu_{15-30} \neq \mu_{30-45}$ $P<0.05$ i.e. $0.0000252 < 0.05$ **The difference is statistically significant.**					

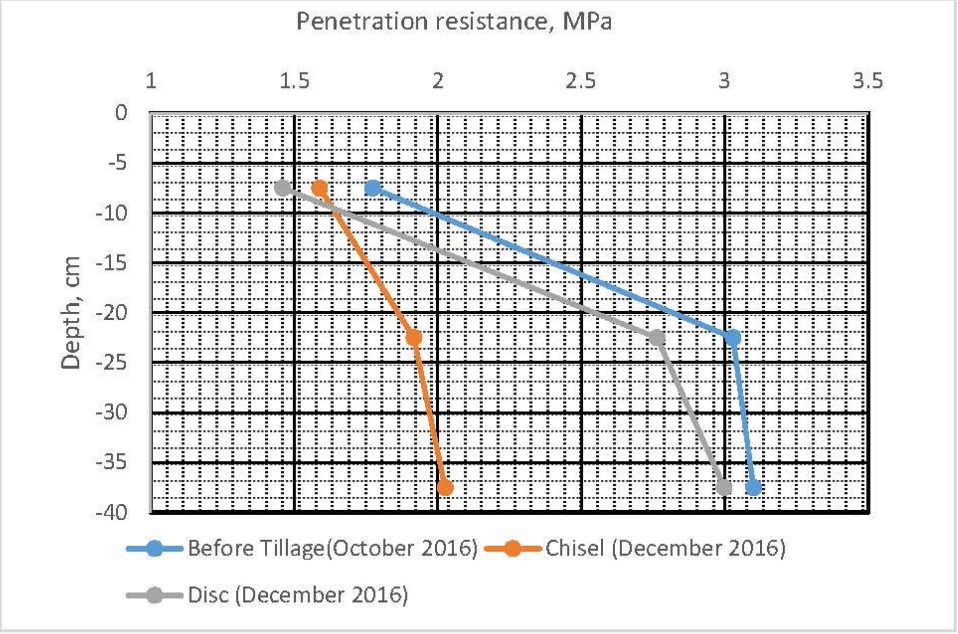


Figure 5-3 Soil penetration resistance at tillage and after the rains

Figure 5-3 illustrates that penetration resistance increased with tillage depth under all tillage methods. The highest penetration resistance was recorded before primary tillage. However, between DP and CP, the highest penetration resistance values were recorded for DP for depths beyond 10cm. The lowest penetration resistance values were recorded for CP expect for depths lower than 10cm due to the existence of a plough/hard pan. The penetration resistance values in both treatments at 0 – 35 cm were below the 2-3 MPa critical level. Above this level, root growth is considered slow (Vepraskas, 1994; Bengough and Mullins, 1990). Similar scenario was reported by Boydaş, & Turgut, . (2007) where they reported that penetration resistance increase with depth for different tillage implements.

5.3.2 Hydraulic Conductivity

Investigation on the hydraulic conductivity of soil at tillage and during/after the rains revealed a decline in the hydraulic conductivity with depth forming an exponential mathematical model of the form $y = Ae^{-x}$ with an R^2 value of 0.9997,0.9985 and 0.9788 for CP, DP and during tillage curves respectively. Pali *et al.*, (2014) reported a similar mathematical model for hydraulic conductivity against depth as shown in Figure 2-4. The highest hydraulic conductivity was achieved with DP for shallow depths, however, for depths greater than 20cm, DP achieved lower hydraulic conductivity as compared to chisel plough as shown in Figure 5-4.

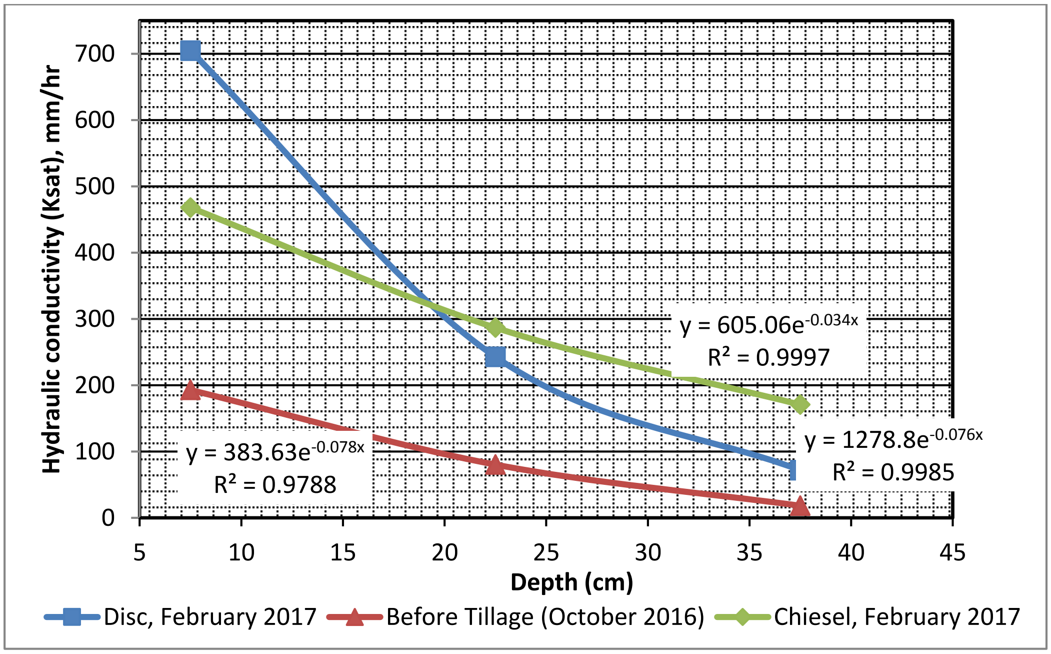


Figure 5-4 Hydraulic conductivity versus depth at different periods during the growing period

5.3.3 Shear Strength

The values indicated variation of soil shear strength from one sampling point to the other as well across the test depth Table 5-5. The highest value of 20.46kPa and lowest of 3.76Kpa was obtained for depths of 30 – 45 cm, a high value of 16.51kPa and a low value of 1.58kPa was obtained for depth 15 – 30 cm and for depths 0 -15 cm, a high of 11.32kPa and a low of 4.94kPa was obtained. However, depths of 30-45 cm showed the highest average value of shear strength (8.84kPa) while the lowest value was obtained for depths of 0-15 cm (8.39kPa). High shear strength indicates an increase in tillage tool resistance while low shear strength indicates ease with which the tillage tool penetrates the soil.

Table 5-5 Shear Strength Values at Different Depths for Different Sampling Points

	Shear Strength		
Depths	**0-15**	**15-30**	**30-45**
1	9.77	16.51	10.06
2	5.91	10.98	11.47
3	8.75	10.43	20.46
4	11.32	7.99	7.63
5	4.94	9.33	6.80
6	10.07	9.20	4.20
7	9.14	6.48	8.81
8	7.99	12.38	3.76
9	9.54	1.58	5.87
10	9.84	7.17	8.72
11	7.12	6.52	8.90
12	6.31	5.18	9.34
Average	**8.39**	**8.65**	**8.84**

Insitu shear strength data Obtained from twelve (12) sampling sites Table 5-5 were subjected to ANOVA analysis. The following hypothesis test was conducted;

$$H_o: \mu_{0-15} = \mu_{15-30} = \mu_{30-45}$$

$$H_1: Atleast\ One\ Inequality\ (ALOI)$$

Table 5-6 Shear Strength Data Summary

Analysis	*SUMMARY*						
	Groups	*Count*	*Sum*	*Average*	*Variance*		
	0-15	12	100.6954	8.391283	3.774894		
	15-30	12	103.7437	8.645308	14.4496		
	30-45	12	106.0271	8.835595	18.68206		
	ANOVA						
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Blocks	1.192605	2	0.596303	0.048471	0.952752	3.284918
	Treatments	405.9722	33	12.30219			
	Total	407.1648	35				
Remarks	H_0: $\mu_{0-15} = \mu_{15-30} = \mu_{30-45}$						
	H_1: ALOI						
	P > 0.05 i.e. 0.952752 > 0.05						
	The difference is NOT statistically significant.						

The p-values (0.952752) were all found to be greater than 0.05 with 95% of confidence; the null hypothesis was thus **NOT** rejected. It was thus concluded that there is no significant difference between the soil shear strength at different sampling points as well as at different depths from 0 – 45 cm.

However, Figure 5-5 indicated a proportional increase in soil shear strength with increase in depth from 0 – 45 cm soil layer. This indicated the existence of a hard pan

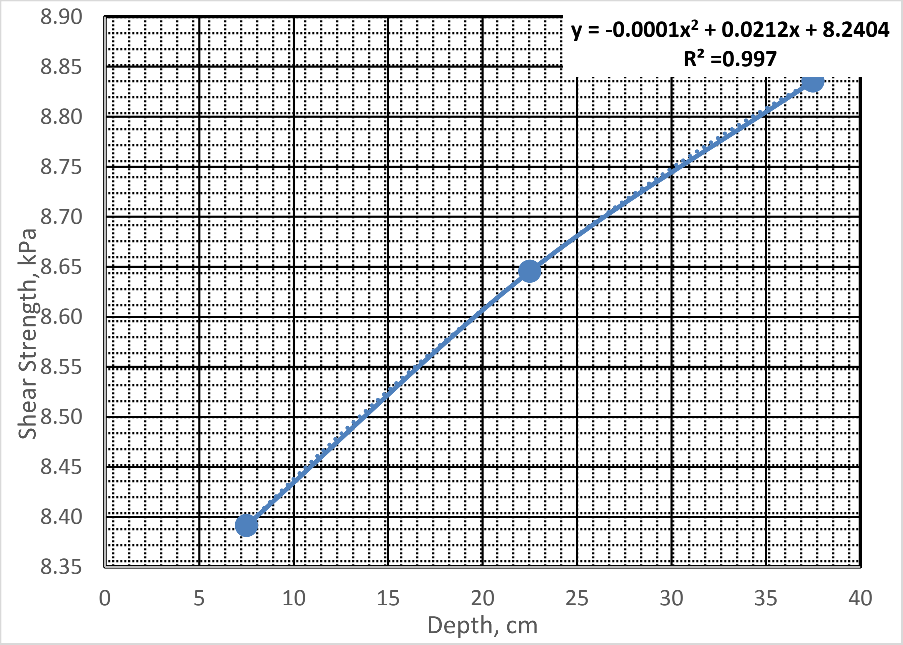


Figure 5-5 Soil shear strength versus depth at tillage

The regression equation indicates that soil shear strength and soil depth has quadratic equation of order 2 with a high correlation (r = 0.997).

Figure 5-7 and Figure 5-8 shows that cohesive and frictional properties of the soils for the range of water content 18- 34 % has no correlation with depth. The values represent a scattered distribution indicates that although cohesion and internal angle of friction are critical state parameters, they cannot be correlated with the moisture content of clay soil.

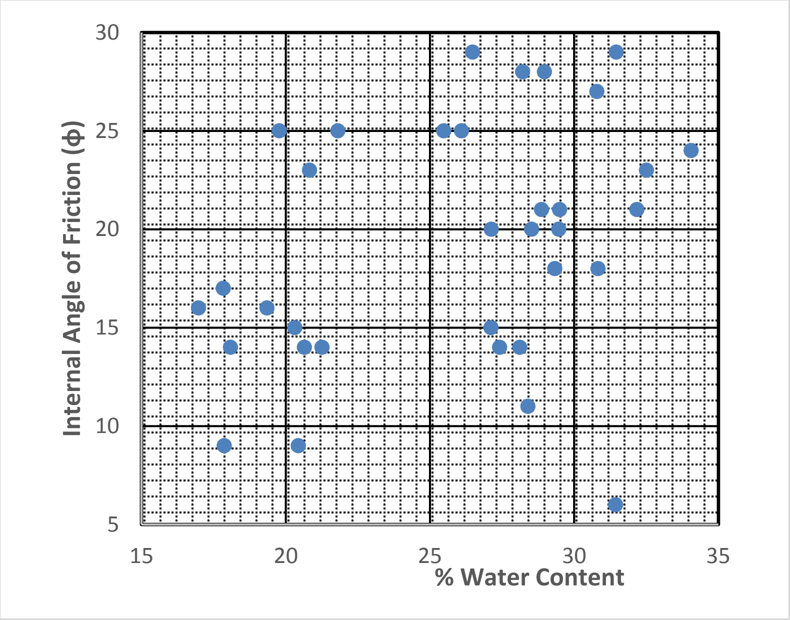


Figure 5-6 Effects of water content on soil internal angle of friction

However, Gitau *et al.*, (2006) found out that between moisture content 9-17 %, cohesive and frictional properties of soils decrease with increase in soil water. Within the same moisture limits, he found that a correlation cannot be established between cohesion and percent water content of sandy soils.

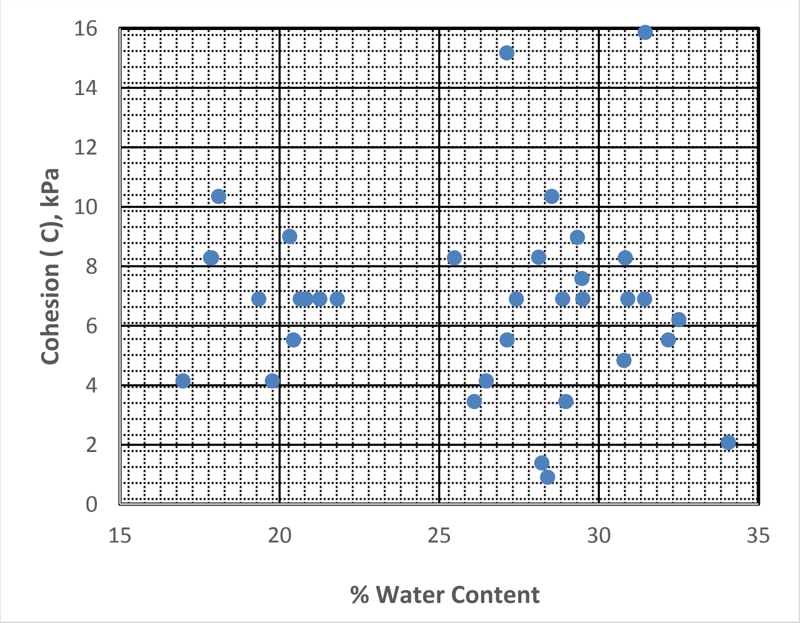


Figure 5-7 Effect of water content on soil cohesion

5.3.4 Specific Soil resistance

Figure 5-8 represent the relationship between soil resistance and tillage depth at different operating speeds. An increase in tillage depth leads to an increase in specific soil resistance. At lower tillage depths of between 0 – 15 cm, the specific soil resistance for both chisel plough and disc plough converges for each respective operating speed. However, at deeper depths, the draft requirements for chisel plough are higher compared to those for disc plough.

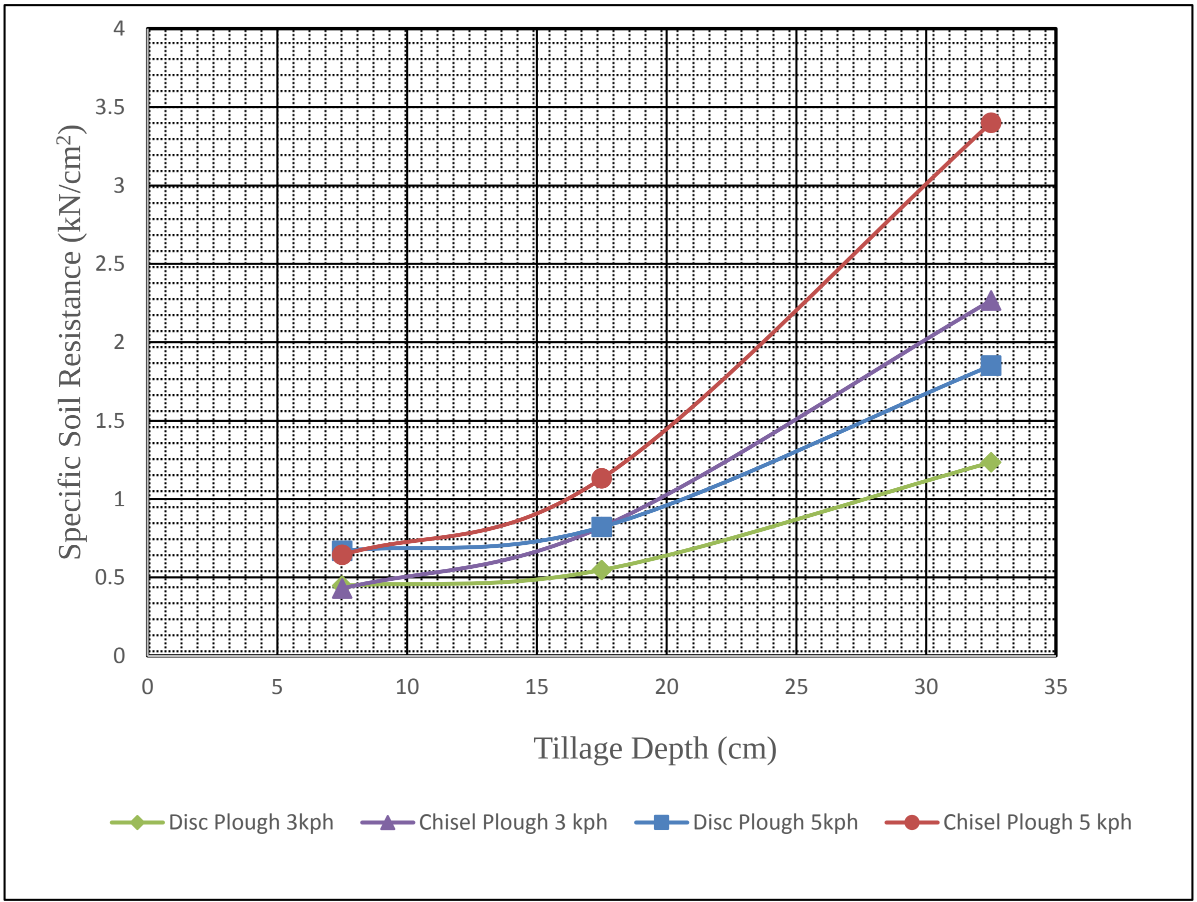


Figure 5-8 Specific Draft against tillage depth

Table 5 -8 gives the equations of best fit and the coefficients of determination to the plots in Figure 5 -8 at different speeds; the equations are polynomial of order two with a coefficient of determination (R^2) of 1.00 indicating an exact fit to the plots.

Table 5-7 Equations of Best Fit at different Operating Speed

Tillage Implement	**Speed (Kph)**	**Equation of Best Fit**	**Coefficient of Determination (R^2)**
Disc	3	$y = 0.0014x^2 - 0.0256x + 0.5582$	1.00
Chisel	3	$y = 0.0023x^2 - 0.018x + 0.4359$	1.00
Disc	5	$y = 0.0021x^2 - 0.0384x + 0.8373$	1.00
Chisel	5	$y = 0.0041x^2 - 0.0537x + 0.8164$	1.00

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Based on the soil physical properties measured in this study, there was significant advantage of chisel plough(CP) over disc plough(DP) as the soil physical properties improved significantly for CP as compared to DP.

Significant difference was identified in soil moisture content for the two tillage methods studied. Moisture regime in deeper soil strata was found to be higher for chisel plough due to breakage of the hardpan compared to that of disc plough whose tillage depth was only limited to about 25cm below the soil surface. CP therefore resulted in increased water storage space as well as drainable pore space.

Penetration resistance was found to increase with increase in tillage depth. The highest penetration resistance values were obtained with Disc plough (DP). However, these values were below the critical level (2 – 3 MPa) for root growth for both Chisel Plough (CP) and DP. Reduction in penetration resistance in CP plots is evidence of hardpan shuttering during chisel ploughing

Draft power is a function the operating speed and depth. It is significantly influenced by the operational speed and depth of tillage. Draft force increase with increase in operating speed and depth. Draft force requirement also varies depending on the tillage equipment used. CP had higher draft farce requirement in comparison the DP.

From the study, there is an indicated significant difference on the effects of tillage implements on mechanical and physical soil properties as well as the variation of these properties with depth of tillage. Therefore, proper implement selection and depth optimization are pertinent for optimal soil conditions and optimum energy consumption.

6.2. Recommendations

The following recommendations were made based on the findings of this research;

1. The study should be replicated with more tillage equipment (disc plough, Chisel plough, mouldboard plough and ripper) on different soil types. This will establish a wider range of application.
2. The study was conducted at 2 speed levels (3kph and 5kph). To optimize speed of operation, further studies are recommended at speed level within the above range to make observations on their effect on the draft force under different soil types.
3. During the experiment, three depth ranges were used and this gave an indication of a perfect fitting curve with R^2 values of 1.00. It follows therefore that the study should be conducted with 4-5 depth intervals of 10cm and to enable better formulation of the mathematical relationship
4. Based on the advantage identified for chisel ploughing over the disc plough, further studies should be carried out in ASALs areas to aid in adoption of chisel plough as a driver of the big four agenda on food security.

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APPENDIX

Appendix A: Soil Texture Data

Table 8-1 Soil Texture Analysis

Plot No.	**Depth (cm)**	**Proportions of soil Separates in (%)**			
		Sand	**Clay**	**Loam**	**Soil Texture Class**
PT 1	0 -15	42.504	48.54	8.956	Clay
	15 -30	44.504	44.54	10.956	Clay
	30 - 45	40.504	52.54	6.956	Clay
PT 3	0 -15	44.504	44.54	10.956	Clay
	15 -30	42.504	50.54	6.956	Clay
	30 - 45	40.504	54.54	4.956	Clay
PT 5	0 -15	48.504	38.54	12.956	Sandy Clay
	15 -30	44.504	40.54	14.956	Clay
	30 - 45	48.504	40.54	10.956	Sandy Clay
PT 7	0 -15	46.504	42.54	10.956	Sandy Clay
	15 -30	46.504	40.54	12.956	Sandy Clay
	30 - 45	42.504	48.54	8.956	Clay
PT 9	0 -15	42.504	46.54	10.956	Clay
	15 -30	42.504	45.54	11.956	Clay
PT 11	0 -15	44.504	40.54	14.956	Clay
	15 -30	42.504	42.54	14.956	Clay
	30 - 45	42.504	48.54	8.956	Clay

Appendix B: Specific Draft Graph Output

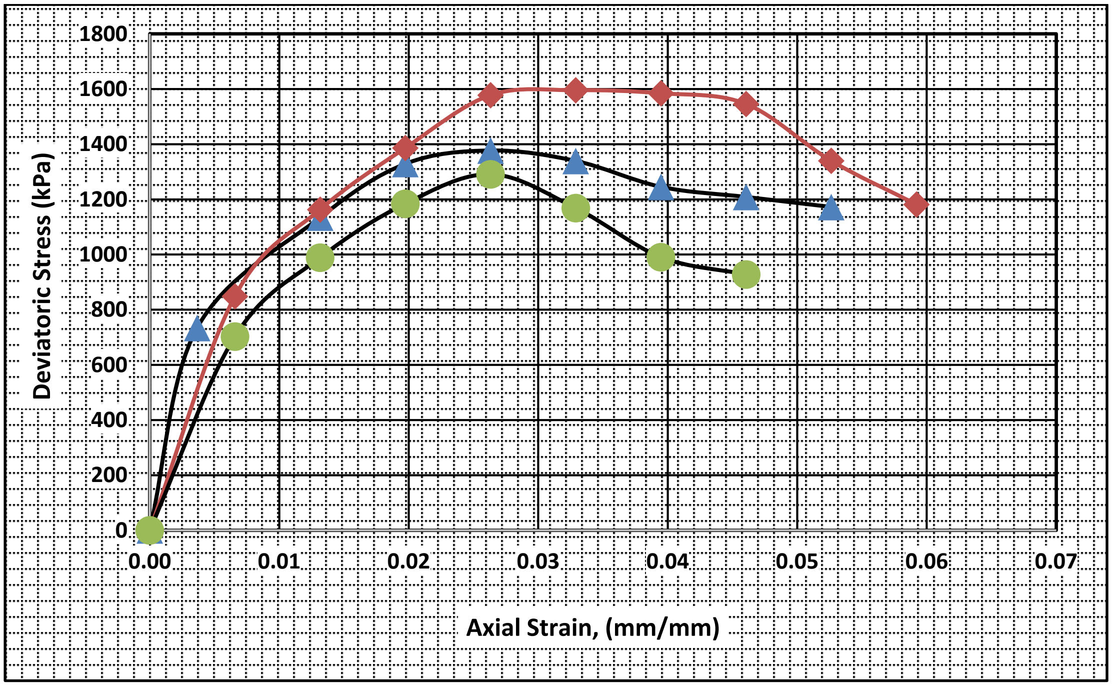


Figure 8-1 Triaxil output for depth of 0-15 cm

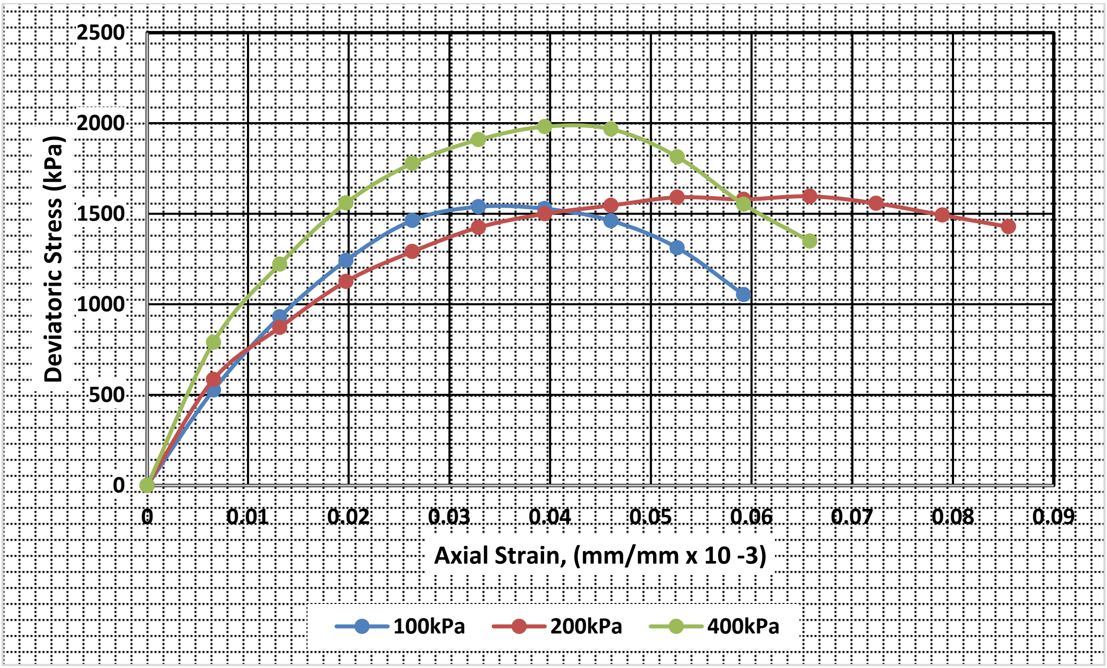


Figure 8-2 Triaxil output for depth of 0-15 cm

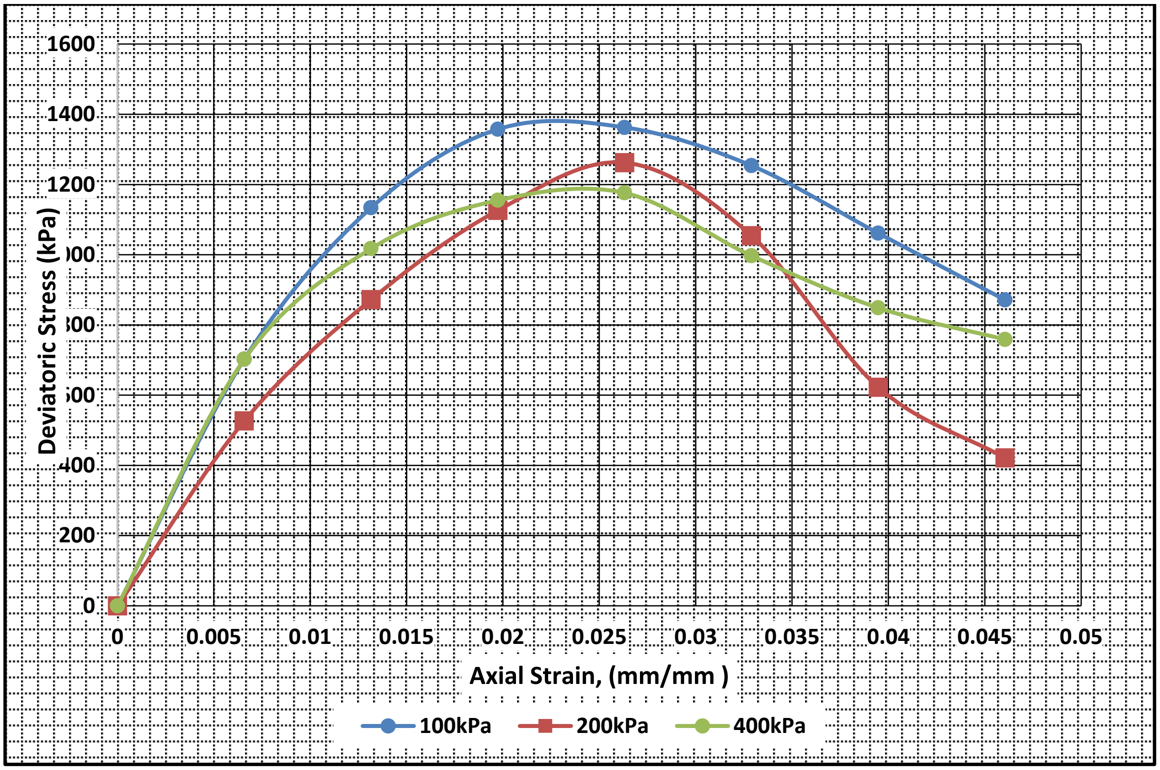


Figure 8-3 Triaxil output for depth of 15-30 cm

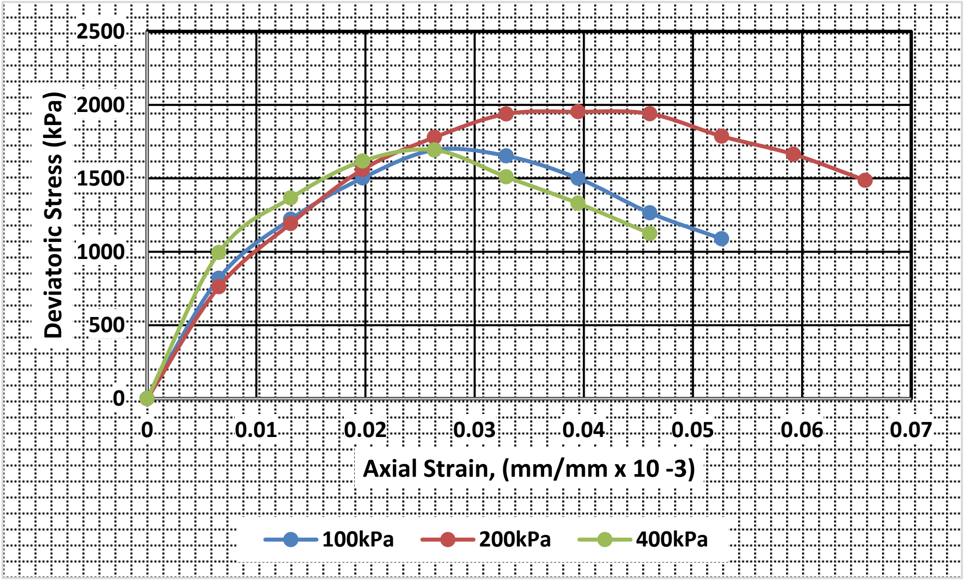


Figure 8-4 Triaxil output for depth of 30 -45 cm

Appendix C: Shear Strength Data

Table 8-2 Shear Stress Data

Plot No.	**Depth**	**Cohesion (C)**	**Phi (φ)**	**Sigma (σ)**	**Tan φ**	**Shear Strength (τf)**
Pt.1	0-15	8.274	17	4.9	0.306	**9.77**
	15-30	15.169	15	5	0.268	**16.51**
	30-45	8.274	18	5.5	0.325	**10.06**
Pt.2	0-15	5.516	**9**	2.5	0.158	**5.91**
	15-30	8.274	25	5.8	0.466	**10.98**
	30-45	6.895	36	6.3	0.727	**11.47**
Pt.3	0-15	8.274	9	3	0.158	**8.75**
	15-30	8.964	18	4.5	0.325	**10.43**
	30-45	15.859	29	8.3	0.554	**20.46**
Pt.4	0-15	10.343	14	3.9	0.249	**11.32**
	15-30	6.895	14	4.4	0.249	**7.99**
	30-45	4.827	27	5.5	0.510	**7.63**
Pt.5	0-15	4.137	16	2.8	0.287	**4.94**
	15-30	7.585	20	4.8	0.364	**9.33**
	30-45	4.137	29	4.8	0.554	**6.80**
Pt. 6	0-15	6.895	25	6.8	0.466	**10.07**
	15-30	6.895	21	6	0.384	**9.20**
	30-45	1.379	28	5.3	0.532	**4.20**
Pt. 7	0-15	6.895	23	5.3	0.424	**9.14**
	15-30	3.448	25	6.5	0.466	**6.48**
	30-45	6.895	21	5	0.384	**8.81**
Pt. 8	0-15	6.895	14	4.4	0.249	**7.99**
	15-30	10.343	20	5.6	0.364	**12.38**
	30-45	2.069	24	3.8	0.445	**3.76**
Pt. 9	0-15	9	15	2	0.268	**9.54**
	15-30	0.9	11	3.5	0.194	**1.58**

	30-45	4.137	24	3.9	0.445	**5.87**
Pt.10	0-15	8.3	25	3.3	0.466	**9.84**
	15-30	6.2	14	3.9	0.249	**7.17**
	30-45	6.895	23	4.3	0.424	**8.72**
Pt.11	0-15	6.895	6	2.1	0.105	**7.12**
	15-30	5.516	16	3.5	0.287	**6.52**
	30-45	6.895	20	5.5	0.364	**8.90**
Pt.12	0-15	5.516	14	3.2	0.249	**6.31**
	15-30	3.448	21	4.5	0.384	**5.18**
	30-45	5.516	28	7.2	0.532	**9.34**

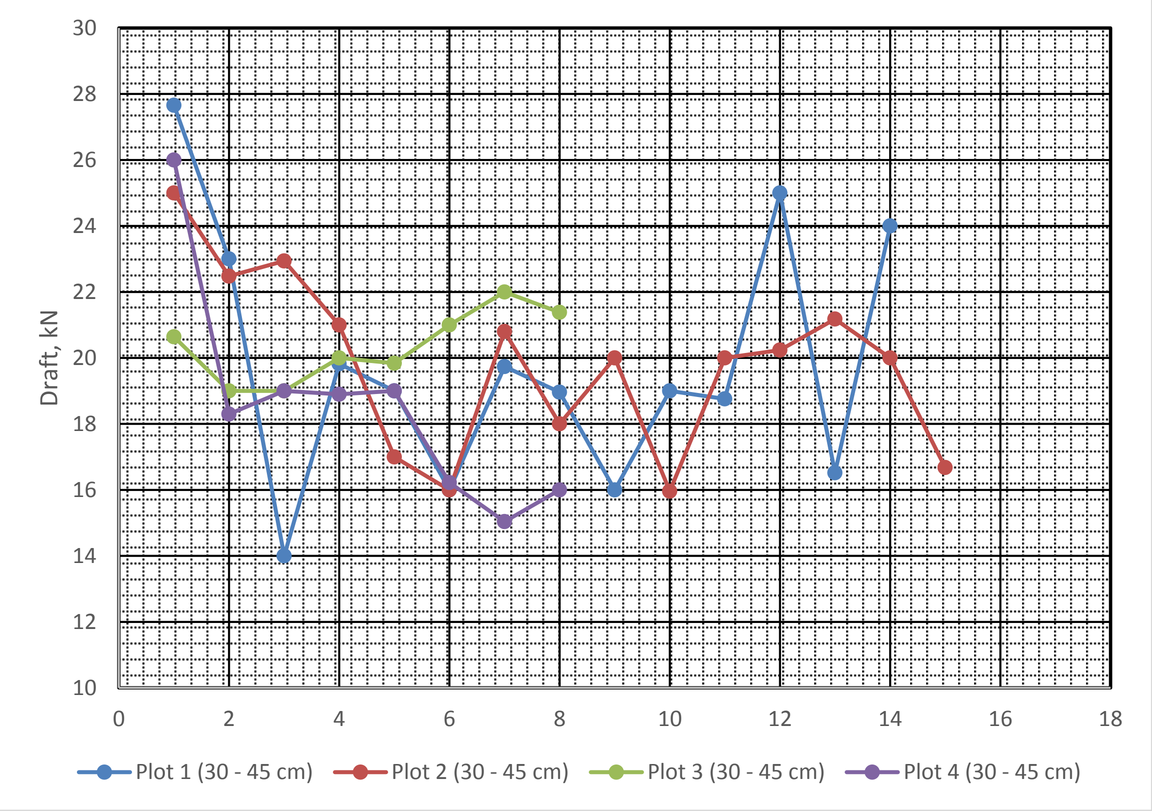
Appendix D Soil Resistance

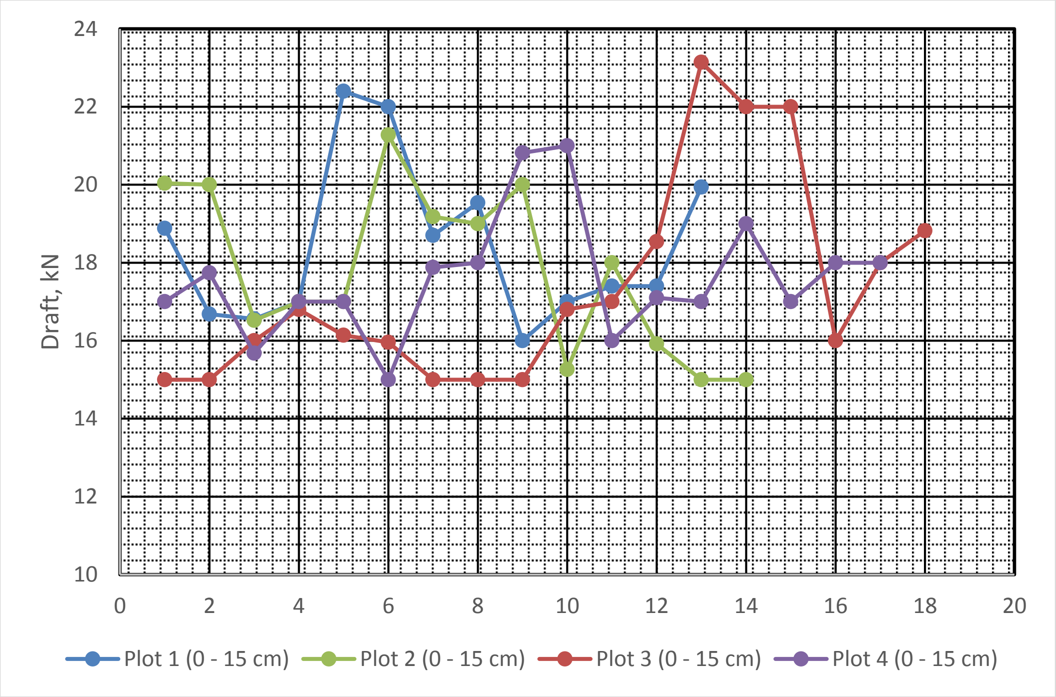
Table 8-3 Average Soil Resistance at Various Depths

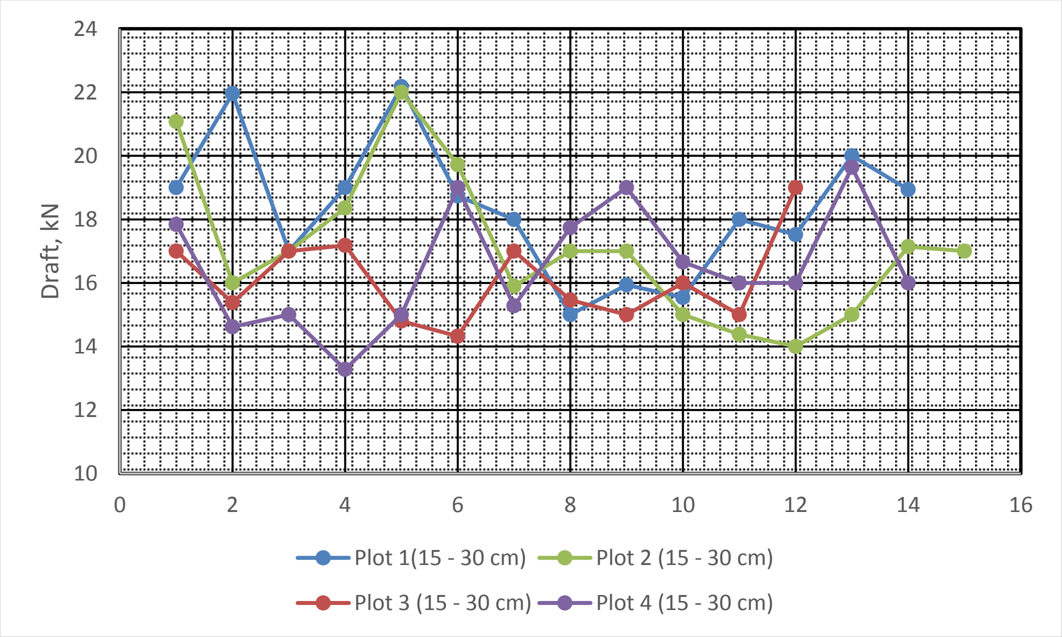
Average Resistance per Depth (5/10/2016)			
Plot No.	**0-15**	**15-30**	**30-45**
Pt1	6	55.95	53.55
Pt2	42.8	60	53.4
Pt3	8.3	53.3	50.5
Pt4	9.5	47.9	53.2
Pt5	8.2	32.7	47.4
Pt6	29.7	52.4	51.5
Pt7	9.77	46.29	48.26
Pt8	30.26	50.23	54.60
Pt9	23.03	51.68	52.95
Pt10	14.49	57.34	53.40
Pt11	8.40	52.03	56.49
Pt12	26.49	55.54	48.86
Average	18.08	51.28	52.01

Average Resistance per Depth (7/12/2016)			
Plot No.	**0-15**	**15-30**	**30-45**
Pt 1 Chisel	30.7	52.3	50.1
Pt3(Chisel)	11.14	28.46	22.89
Pt5(Chisel)	2.81	3.79	9.56
Average	14.89	28.18	27.51
Pt 2(Disc)	8.95	9.23	9.72
Pt4(Disc)	2.00	4.12	5.97
Pt. 6(Disc)	0.95	2.47	9.58
Average	3.97	5.27	8.42

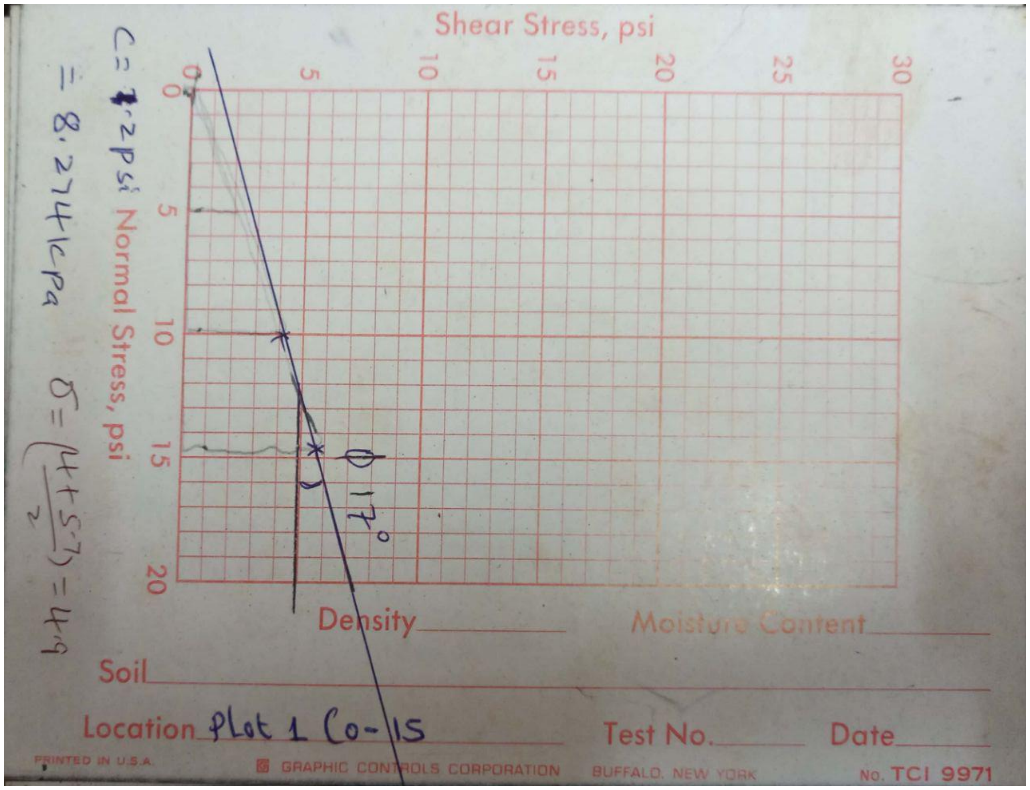
Appendix E Draft values from the digital dynamometer




Draft, kN
24
22
20
18
16
14
12
10
0
2
4
6
8
10
12
14
16
18
20
Plot 1 (0 - 15 cm)
Plot 2 (0 - 15 cm)
Plot 3 (0 - 15 cm)
Plot 4 (0 - 15 cm)


Draft, kN
24
22
20
18
16
14
12
10
0
2
4
6
8
10
12
14
16
Plot 1(15 - 30 cm)
Plot 2 (15 - 30 cm)
Plot 3 (15 - 30 cm)
Plot 4 (15 - 30 cm)

Appendix F: *In-situ* shear stress



Density

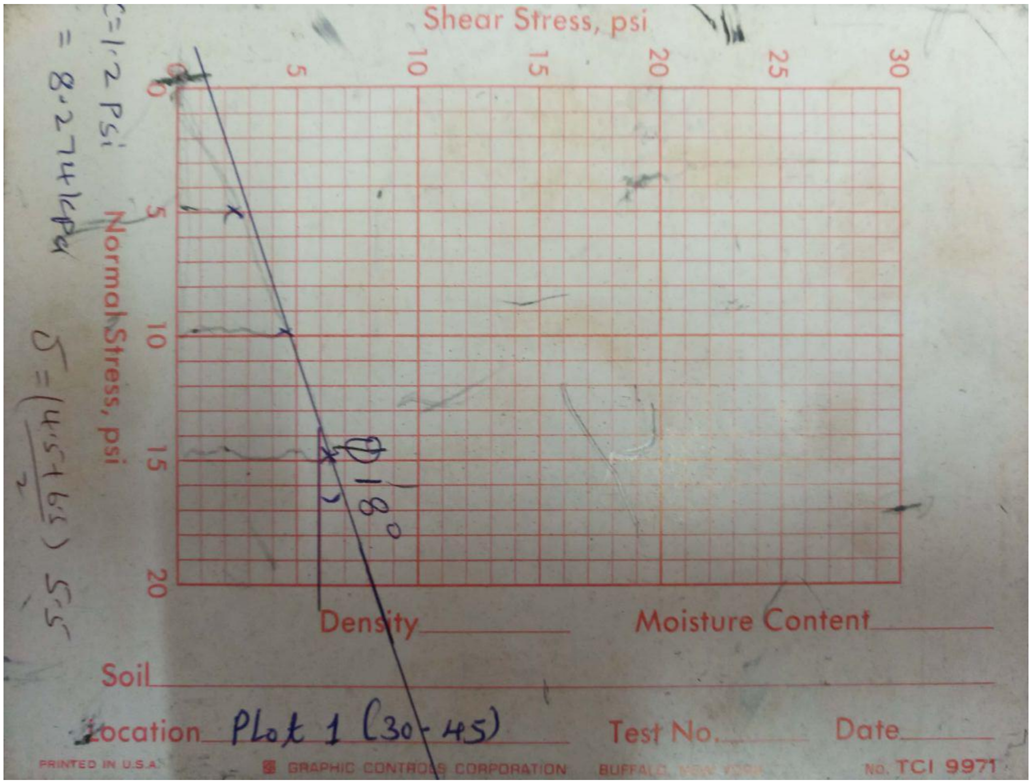
Moisture Content

Soil

Location Plot 1 (0-15

Test No.

Date



Density

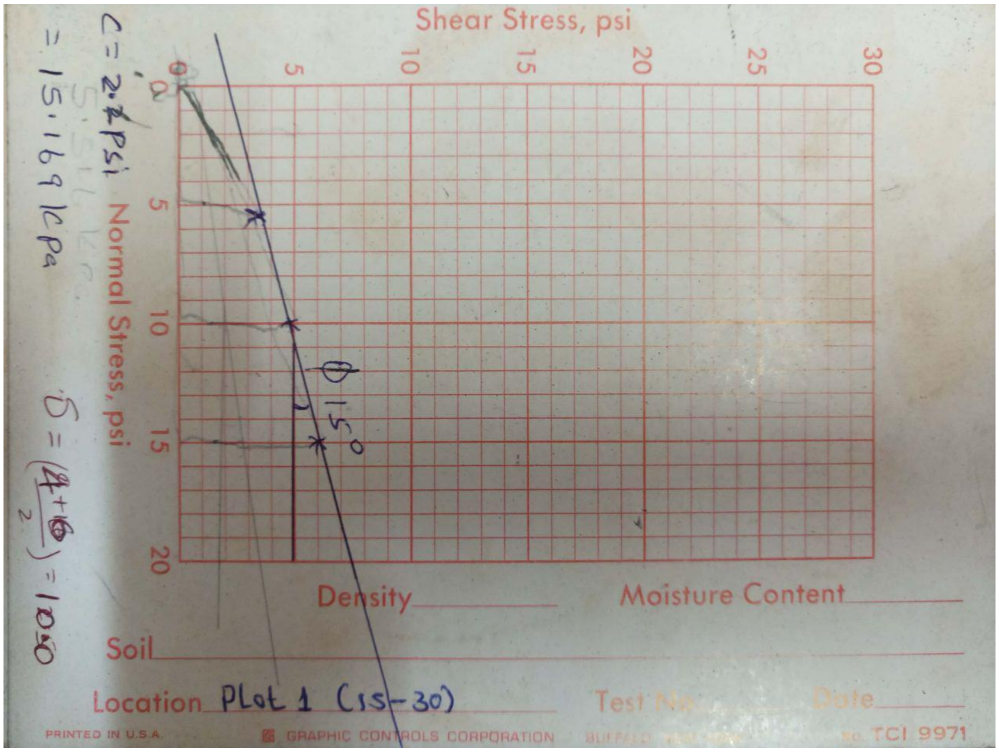
Moisture Content

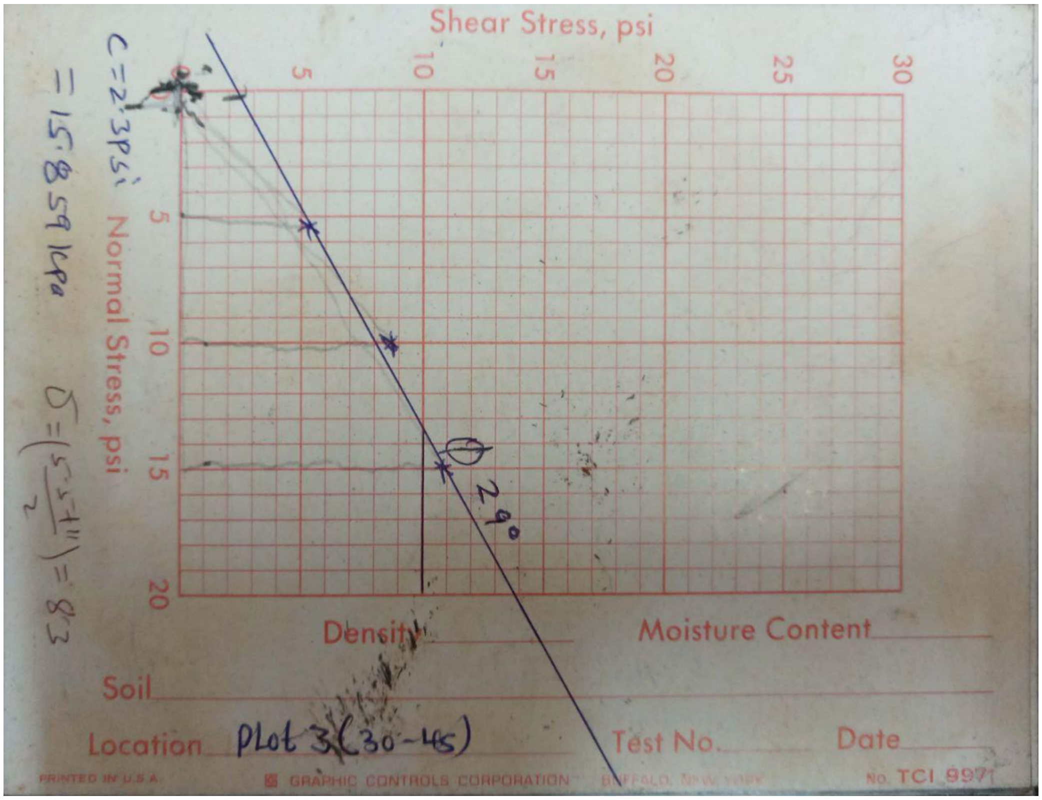
Soil

Location Plot 1 (30-45)

Test No.

Date


Shear Stress, psi
0
5
10
15
20
25
30
Normal Stress, psi
0
5
10
15
20
C = 2.2 psi
= 15.1691 kPa
δ = ((4+16)/2) = 10.0
ϕ 15°
Density
Moisture Content
Soil
Location Plot 1 (15-30)
Test No.
Date
PRINTED IN U.S.A.
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
No. TCI 9971


Shear Stress, psi
0
5
10
15
20
25
30
Normal Stress, psi
0
5
10
15
20
C = 2.3 psi
= 15.859 kPa
δ = ((5.5+11)/2) = 8.3
ϕ 29°
Density
Moisture Content
Soil
Location Plot 3 (30-45)
Test No.
Date
PRINTED IN U.S.A.
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
No. TCI 9971

Appendix G: Texture Analysis (Mechanical Analysis)

Method 1: Limited pretreatment of the soil; hydrometer readings.

Apparatus and other requirements:

Bouyoucos hydrometers or ASTM hydrometers No 152H.
Sedimentation cylinders, marked at 1000ml and length bottom to mark = 34 – 38cm
Special plunger or rubber stopper, that fits on the sedimentation cylinders, for mixing.
Conical flask, 1000ml.
Stopwatch or an accurate clock with seconds hand.
Thermometer with room temperature range.
Balance, accurate up to 0.01g
End-over-end mechanical shaker
500ml plastic bottles with screw cap.
Reagents: approx. 0.5 N Na:

Calgon solution; approx. 0.5N Na:

Dissolve 40.0g pre-of dried, powdered sodium hexametaphosphate (mainly $(Na\ PO_3)_6$) in 750ml. DW in a 1000ml conical flask, by slowly adding it to the water while stirring. Then add 10g of pre-dried anhydrous sodium carbonate (Na_2CO_3) and make up to 1litre with DW.

Deionised or distilled water(=DW).

Procedure:

Weigh 50.0g of soil in 500ml plastic shaking bottles, add 50ml of Calgon solution and leave overnight. Add about 400ml DW, tightly stopper the bottles and shake in an end-over-end shaker during 10minutes. Include a blank (No soil but with all other addition)

Transfer the soil suspension to the 1000ml sedimentation cylinders, rinse the plastic bottles well with DW make up to the mark with DW. Stir the suspension well with the plunger, or after the placement of the rubber stopper by hand shaking. Stop shaking when the seconds hand indicates 60seconds. Place the cylinder carefully on the table. Slowly immerse the hydrometer in the suspension and take a hydrometer – and a temperature reading of the suspension when the seconds hand indicates (for the first time) 40 seconds. Record the readings. Out of these readings the silt + clay content of the sample can be calculated.

Leave the cylinder, without touching, on the table.

Repeat the same readings (temperature and hydrometer) after 6-5 hours.

Out of these readings the clay content can be calculated.

Calculation

The hydrometer is calculated at 20^{o} c. For this reason, a correction has to be made when the temperature is higher or lower.

$$\%Sand = \frac{100 - ((R1 - B1) + 0.36(T1 - 20) * 100}{W}$$

For 50g of soil: $\%Sand = 100 - 2((R1 - B1) + 0.36(T1 - 20))$

$$\%Clay = \frac{((R2 - B2) + 0.36(T2 - 20) * 100}{W}$$

For 50g of soil: $\%Clay = 2((R2 - B2) + 0.36(T2 - 20))$

$$\%Silt = 100 - (\%Sand + \%Clay)$$

Where:

R1= first reading hydrometer sample.
B1 = first reading hydrometer blank.
R2= Second reading hydrometer sample
B2 = sec. reading hydrometer blank
T1= first temperature reading
T2= second temperature reading
0.36= temperature correction factor (in ^{o}C)
20= hydrometer calibration temperature (in ^{o}C)
W= weight of sample taken for analysis (50g or 51g)

Note:

Temperature differences between inside and outside the sedimentation cylinder causes turbulence in the cylinder. This will give errors. To overcome this, the cylinders should be left in a water bath of which the water has the same temperature as that in the cylinders or the whole analysis should be performed in a room with a constant temperature

Appendix H: Glossary

Tillage systems

Tillage systems refers to sequences of operations that manipulate the soil for crop production. Operations incorporating tilling, planting, fertilizer and pesticide application, harvesting and residue chopping or shredding. The mode used in the executing of these operations influences the chemical and physical soil properties consequently influencing plant development. The initial phase in making fertilizer administration verdicts is by comprehending the practices affiliated to each tillage system.

Convectional Tillage

This method of tillage is also called intensive tillage. In this farming system, only less than 15% if the crop residue is left on the ground. The moldboard plough is one of the implement that is used in convectional tillage. Convectional tillage is a very expensive process because of the high fuel requirements. It also results to compaction of soil which is a huge problem and consequently deterioration in the soil structure (*Chi, J et al,* 2016).

Deep Tillage

Deep tillage method aims at breaking the hard pan also called plough pan that forms after continuous traffic and ploughing. Hard pan is usually formed under the plough layer. The chisel plough is usually used to break the hard pan.

Minimum Tillage

This method of tillage is also called reduced tillage. It aims at reducing the soil compaction problems and soil erosion. With reference to soil and water conservation, reduced tillage extremely effective in comparison to conventional tillage method. Water conservation is achieved through improved infiltration and reduced evaporation.

Conservation Tillage

In this tillage method, more than 30% crop residue is left on the soil surface and it aims at crop residue management. Conservation tillage is not one method but a collection of tillage practices (*Karlen et al.,* 1994). This tillage practices lead to beneficial changes in soil physical properties; improve soil aggregate stability

Ridge Tillage

Ridge tillage refers to a tillage method in which there is zero soil disturbance from the planting to the harvesting season except during fertilizer application. Crops are planted on ridges created using disk openers or coulters while maintaining crop residues in between the ridges on the soil surface (*Hatfield et al.,* 1998).

Zero Tillage

This method of tillage is also called no tillage. No tillage is done and the soil is left undisturbed except only when planting the seed and during nutrient application. Zero tillage results to reduced evaporation, increased soil infiltration and greater water recharge in soil profile (Schwartz *et al.,* 2010). This method however results to heavy usage of pesticides this is because weeds are not removed.

Mulch-till

This tillage system incorporates all the conservation tillage systems practices except the no till and the ridge till. Zonal and strip tillage are the two tillage systems that fall in this category. These two tillage systems involve opening a strip where seeds and fertilizer are placed and leaving the other section of the land undisturbed. When the row disturbance is limited to 25% and below then the system is considered a no-till system. On the other hand, any system having anything above 25% row width disturbance is considered mulch-tillage or "other tillage system" depending on the quantity of crop residue left after planting (*Mitchell, J.P. et al.,* 2016).

Hydraulic Conductivity

Hydraulic conductivity of a soil, K, defines the volume of water, which will pass through a unit cross-sectional area of a soil in unit time, given a unit difference in water potential.

Saturated Hydraulic Conductivity

Saturated Hydraulic Conductivity is a constant referring to the flow of a fluid through a saturated conducting medium, derived from an empirical relationship established by Darcy (1956) between the rates of flow of water through saturated columns.