EFFECTS OF TILLAGE AND MULCHING ON MAIZE YIELD, SOIL WATER CONTENT AND ORGANIC CARBON IN KIREGE, THARAKA-NITHI COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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This work is dedicated to my family for the support, encouragement and sacrifice towards my education.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

ANOVA	Analysis Of Variance
AWC	Available Water Capacity
C	Carbon
CT	Conventional Tillage
Gt	Gigatonnes
H 516	Hybrid 516
ISFM	Integrated Soil Fertility Management
KPa	Kilo Pascal
LSD	Least Significant Difference
MT	Minimum Tillage
N	Nitrogen
NT	No-Tillage
P	Phosphorous
RCBD	Randomized Complete Block Design
SIC	Soil Inorganic Carbon
SOM	Soil Organic Matter
SR	Sub soiling-Ripping
Tg	Teragrams
$t\ ha^{-1}$	Tonnes per hectare
TR	Tied Ridges
UM	Upper Midland

ABSTRACT

Sustainable agricultural production in Kenya requires improvement of yields per unit of land while still conserving soil resources. Besides poor soil nutrient status, water is a limiting factor to crop production in the rain-fed farming systems of central highlands of Kenya. Hence, there is need to address soil water scarcity challenges in order to increase crop production. The objective of the study was to determine the effects of tillage and mulching on maize (*Zea Mays. L*) yield, soil water content and organic carbon of Humic nitisols in the central highlands of Kenya. The study was conducted in Tharaka-Nithi County, Meru South Sub-County at Kirege for two seasons (long rains 2014 and short rains 2014). Two mulch levels; removal (W) and retention (R) of crop residue were applied randomly to plots measuring 7 m by 7 m under two tillage methods; conventional tillage (CT) and minimum tillage (MT). The treatments arrangement was a split-plot laid down in a randomized complete block design. Data on soil organic carbon, soil moisture, grain and biomass yield was subjected to Analysis of variance (ANOVA) using the mixed model in SAS 9.3. The soil organic carbon content data at the beginning and end of the experiment was subjected to student t-test for pair wise comparisons using the mixed model in SAS 9.3. Difference between treatment means was tested using least significant difference at 5% level of significance. The results showed significant tillage (p=0.0042) and mulching (p=0.0255) singular effect on maize yield. Combining tillage and mulching significantly (p=0.039) increased maize stover and grain yields. Overall, conventional tillage with residue treatment gave the highest increase in stover yield by 72%. Minimum tillage with residue and without residue, increased grain yield by over 50% compared to conventional tillage with and without residue. In the short term, soil water was not significantly influenced singly by tillage and mulching but it was positively influenced by tillage and mulch combination. On average, minimum tillage with residue and without residue increased soil moisture content by 10 and 7%, respectively compared to control, while Conventional tillage with residue and without residue increased moisture by 4 and 3% respectively. Tillage alone significantly (p=0.01) affected soil organic carbon content while mulching alone did not. There was significant (p=0.01) increase in soil organic carbon under minimum tillage as opposed to the reduction under conventional tillage at the 0–0.2 m soil depth. Combining tillage and mulching resulted to higher soil organic carbon content. Minimum tillage with residue, increased soil organic carbon by 0.33% more than minimum tillage alone. Short-term implementation of minimum tillage and mulching under the soil and climate conditions prevailing in Kirege Tharaka-Nithi County enhances maize production while improving soil conditions in terms of soil moisture and organic carbon content.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Global agricultural land is about 80% under rain-fed production systems and produces approximately 60% and 90% of the world's and Sub-Saharan Africa's staple food, respectively (Alam, Toriman, Siwar, and Talib, 2011). Despite the low yields of about 1 t ha^{-1}, rain-fed agriculture will continue being the main source of food worldwide for the foreseeable future (Rockström, Barron and Fox, 2003). In the past, increase in agricultural production was through expansion of agricultural land, but since estimates indicate that there is limited new land for agriculture, the focus now is to raise agricultural production by increasing yields per unit of soil and water (Erenstein, 2003; Rockström *et al.,* 2003).

The anticipation to achieve the Sustainable Development Goals (SDGs) of eliminating hunger and extreme poverty, requires support of the smallholder farmers and other poor households in overcoming financial constraints and in better managing risks (Food and Agriculture of the United Nations, 2016). However, success of the targeted small holder farmers in Sub-Saharan Africa, accounting for over 80% of the rain-fed production systems, has been afflicted by numerous constraints among which are water scarcity and declining soil fertility (Johansen, Haque, Bell, Thierfelder and Esdaile, 2012).

Potential crop yields in the tropics are partly limited by the highly variable rainfall that characterizes the region (Mupangwa, Twomlow, and Walker, 2012). In Kenya, rainfall variability combined with the relatively low asset base and technological capacity of most rural households limits overall crop production (Miriti, Kironchi, Esilaba, Gachene, Heng and Mwangi, 2013). These small holder farmers, practice rain-fed subsistence agriculture characterized by minimal application of organic and inorganic fertilizers, deteriorating soil conditions and uncertain weather conditions especially the low erratic rains, hence run a risk of crop failure (Masvaya, Mupangwa, and Twomlow, 2008; Johansen *et al.*, 2012).

Over time, soil fertility decline has been attributed to factors such as, limited application of organic matter to the soils, minimal and unbalanced addition of fertilizer and the perceived need for regular tillage (Johansen *et al.*, 2012; Okeyo, Mucheru-Muna, Mugwe, Ngetich, Mugendi, Diels, and Shisanya, 2014). In view of this, the farmers' ability to realize yields that would ensure household food security requires that the current trend of soil fertility decline and soil desiccation be reversed (Rockström, Kaumbutho, Mwalley, Nzabi, Temesgen, Mawenya, and Damgaard-Larsen, 2009). This can be achieved through tillage and crop residue management practices that ensure effective infiltration of rainwater into the soil as well as address the problem of declining soil fertility ((Obalum, Igwe, and Obi, 2012; Thierfelder Mwia and Rusnamhdzi, 2013).

1.2 Justification and Problem statement

In the past, agricultural yield increase was realized through expansion of agricultural land. However, estimates show that there is limited new land for agriculture hence the focus towards raising agricultural production by increasing yields per unit of soil and water. Small holder farmers in Sub-Saharan Africa, account for over 80% of the rain-fed production systems, yet they are faced with numerous constraints among which are water scarcity and declining soil fertility. In the tropical region, the highly variable rainfall that characterizes the region limits production of potential crop yields. Continuous cultivation of land without nutrients replenishment through addition of organic and inorganic fertilizers has resulted to declining soil fertility. Achievement of food security amidst such constraints in Kenya as a developing country requires improvement in yields per unit of land while conserving soil resources. Majority of smallholder farmers in central highlands of Kenya depend on rain-fed agriculture. Besides poor soil nutrient status, water is also a limiting factor to food production under rain-fed conditions. Thus water and nutrients are key factors that limit crop production. Soil organic matter is known to play a strategic role in the maintenance and improvement of soil fertility, yet low soil organic matter has been observed in most household farms in Meru South Sub-County. Therefore, solving the problem of low crop productivity requires that, besides the poor soil nutrient status and water deficit, low organic matter content be addressed through selected approaches such as tillage and mulching. Thus, there is need to evaluate the effects of the selected tillage and mulching on soil condition and crop yield under the prevailing agro-climatic conditions.

1.3 Research questions

The study sought to answer the following questions;

i. How does conventional tillage, minimum tillage and mulching affect maize yield at Kirege, Tharaka-Nithi County?
ii. How does conventional tillage, minimum tillage and mulching influence soil water content at Kirege, Tharaka-Nithi County?
iii. How does conventional tillage, minimum tillage and mulching affect soil organic carbon at Kirege, Tharaka-Nithi County?

1.4 Research hypotheses

The study was guided by the following hypotheses:

i. Conventional tillage, minimum tillage and mulching do not have significant effect on maize yield, at Kirege, Tharaka-Nithi County.
ii. Soil water content is not significantly influenced by conventional tillage, minimum tillage and mulching at Kirege, Tharaka-Nithi County.
iii. Conventional tillage, minimum tillage and mulching do not significantly affect soil organic carbon, at Kirege, Tharaka-Nithi County.

1.5 Objectives

The study had the following broad and specific objective(s).

1.5.1 Broad objective

To determine the effects of tillage and mulching on maize yield, soil water content and soil organic carbon of Humic Nitisols in Kirege, Tharaka-Nithi County.

1.5.2 Specific objectives

The specific objectives were to:

i. Evaluate the effects of tillage and mulching on maize yield, at Kirege, Tharaka-Nithi County.
ii. Assess the effects of tillage and mulching on soil water content, at Kirege, Tharaka-Nithi County.
iii. Determine the effects of tillage and mulching on soil organic carbon, at Kirege, Tharaka-Nithi County.

1.6 Significance of the study

The findings from this study will contribute scientific knowledge on how mulch retention affects maize performance, soil water content and carbon sequestration, with or without tillage in the central highlands of Kenya. Additionally, it will provide more insight with respect to tillage and crop residue management to researchers and other stakeholders. This will be useful when recommending suitable and sustainable practice for improved maize production, soil fertility and environmental quality. Such information will enable the extension service providers to advise farmers on the best tillage and mulching practices and in turn, farmers will be able to make informed decisions on the most appropriate tillage-mulch management to increase yields.

1.7 Conceptual framework

In most of the Kenyan smallholder farms, continuous conventional farming based on extensive tillage, especially when combined with removal or *in-situ* burning of crop residues has been the common practice. As illustrated in the conceptual framework, this has greatly contributed to loss of soil organic matter and consequently reduced soil water (Figure 1.1). The situation has been aggravated by the erratic rainfall received. Hence, the smallholder farmers are faced with the challenge of low maize (staple food) production.

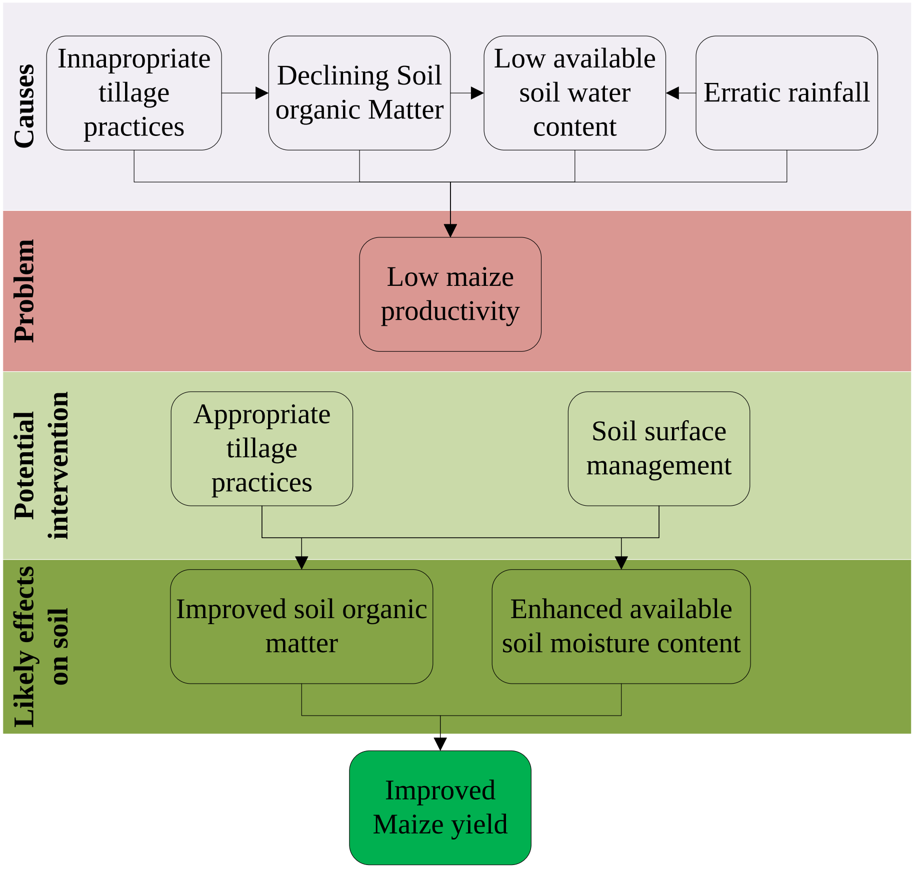

Figure 1. 1: Conceptual framework (Source: Author)

There are a number of appropriate tillage and mulching practices that the farmers can adopt as intervention strategies to reverse the low crop productivity, improve soil organic matter and moisture content as well as maintain desired soil nutrients status. This calls for a proper understanding of the specific contribution of tillage and mulching in improving the soil characteristics (soil organic carbon, water content) and ultimately crop yields to ensure informed choices on the best soil management practices with respect to tillage-mulching options.

1.8 Definition of terms

Appropriate tillage practices: Tillage practices that avoid the degradation of soil properties but maintain crop yields as well as ecosystem stability.

Convention tillage: Extensive tillage, combined with removal or in situ burning of crop residues.

Conservation tillage: Soil management practices that result in at least 30% of the soil surface being covered with crop residues after seeding of the subsequent crop normally involving some degree of tillage reduction and the use of non-inversion tillage methods.

Minimum/Reduced tillage: A form of conservational tillage aimed at reducing tillage to the minimum necessary, ensuring good seed-beds, rapid seed germination, satisfactory crop stand and favourable growing conditions of crop and ultimately good and economic yields of crops

No-Till/Zero tillage: The most extreme form of minimum tillage where the physical manipulation of the soil is avoided completely and reduced to direct seeding, that is no cultivation prior to seeding.

Mulching: The artificial application of mulch (crop residues, stubble mulch), practiced to obtain beneficial changes in the soil environment.

Diviner2000: A portable soil moisture monitoring system, comprising of a data display unit and a portable probe

Conservation agriculture: A set of cropping principles aiming at sustaining high crop yields with minimum negative consequences for the resource base – i.e. water, soil, and surrounding natural environment

Meteorological drought: When cumulative rainfall for the growing season is below the amount required to produce a crop and occurs for a period above four weeks hence could result in complete crop failure

Dry spell: Absence of rainfall in periods ranging between 10-28 days during crop growing season.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Increase in agricultural production in the developing world to a larger extent depends on better use of the already available arable land. Therefore, there is need to overcome soil degradation which has greatly contributed to the reduction in productive capacity of most of the arable land (Erenstein, 2003). While it is clear that agricultural production needs to be doubled in the economies that rely mainly on the smallholder farming systems to feed their population, a major challenge of reversing the existing trends of declining soil fertility and soil desiccation exists (Rockstrom *et al.,* 2009). Declining soil fertility in Africa, has been the result of mainly continuous removal of nutrients from the soil through harvested products without sufficient addition of the same through application of either organic material or inorganic fertilizers (Mugwe, Mugendi, Mucheru-Muna, Merckx, Chianu, and Vanlauwe, 2009).

In Sub-Saharan Africa, deteriorating soil physical condition has with time resulted to lack of available water and this has been associated with the risk of drought that the farmers face especially those without management strategies to overcome the problem (Araya and Stroosnijder, 2010). Agriculture in Eastern Africa is mainly rain-fed and since the region is prone to extreme climate events, even in seasons when high rainfall is received the interval between consecutive rainfall events is too long often resulting to droughts and eventually crop failure (Guto, Ridder, Giller, Pypers, and Vanlauwe, 2012). Intensive soil preparation using hoe or plough in combination with removal or burning of crop residue has been identified as a major cause of soil degradation since it leaves soil exposed to climatic hazards such as rain, wind and sun (Rockstrom *et al.,* 2009). Achieving a significant net increase in nutrient levels while improving other soil and production conditions such as soil water, has been the long-term objective of agricultural research (Gachene and Kimaru, 2003)

Conservation agriculture which is based on the principles of minimum soil disturbance, soil cover retention and crop rotation has been advocated for, due to its potential to conserve soil and water, reduce soil organic matter decline, soil structure breakdown and soil erosion (Erenstein, Sayre, Wall, Hellin, and Dixon, 2012). Minimum tillage and crop residue management (mulching) as pillars of conservation agriculture, are actively promoted by research and extension programmes supported by major international initiatives (Giller, Witter, Corbeels, and Tittonell, 2009). According to Singh and Malhi (2005) the effects of a particular tillage-mulch management vary with soil type and agro-ecological condition and needs to be established for clear understanding.

2.2 Tillage

Soil tillage involves the mechanical manipulation of the soil and may take several forms, such as; conventional tillage, conservational tillage, minimum or no tillage (Carter, 2005; Sharma and Abrol, 2008). Generally, tillage in agricultural systems influences crop production mainly through modification of soil structure, incorporation of fertilizer and other soil amendments like lime, weed control as well as alleviating both climatic and soil constraints (Carter, 2005). According to Lampurlanes and Cantero-Martinez (2006), tillage has been reported as effective in soil surface characteristics modification due to its influence on soil pore space, residue cover and surface roughness.

2.2.1 Conventional tillage

Conventional tillage has been practiced over a long time around the globe due to its numerous advantages which consist of loosening of the soil leading to increase in drainage, root development and acceleration of organic matter decomposition by soil micro-organisms and improvement of aeration (Okoth, Mungai, Ouma and Baijukya, 2014). Although soil management through conventional tillage has such merits as effective sowing, emergence and weed control, its negative effects as far as soil and water conservation is concerned, are more felt (Ngetich, Diels, Shisanya, Mugwe, Mucheru-Muna, and Mugendi, 2014). About 40% of the total world land occupied by agroecosystems is degraded due to mismanagement in the form of removal of crop residues and soil disturbance caused by tillage operations, thereby resulting in an array of negative effects on the productivity of crops (Kushwaha, Tripathi, and Singh, 2001).

In Sub-Saharan Africa, conventional tillage by ploughing and to an extent hand hoeing often results in crusting, compaction, and loss of structural stability in soils (Enfors, Barron, Makurira, Rockström and Tumbo, 2010). Due to excessive break down of aggregates, conventional tillage is associated with increased risk of runoff and soil erosion, affects the continuity of macropores, soil water availability as well as depth and distribution of roots (Martinez, Fuentes, Silva, Valle and Acevedo, 2008). Intensive tillage accelerates oxidation of organic matter by soil micro-organisms through changes in soil moisture and aeration, thus induces carbon loss, contributes to greenhouse gas emissions, and decreases production (Ben-hammouda, 2010).

In Eastern Africa there has been a notable decline in land productivity whereby, continuous cultivation without return of the plant nutrients and/or crop residue to the soil and the resultant loss of organic matter are major contributing factors (Gachene and Kimaru, 2003). In Kenya, farming systems include primarily animal drawn mouldboard ploughs, complemented by use of hand-hoes in certain locations (Rockstrom *et al.,* 2009). Disturbing the soil through conventional tillage, as commonly done in Kenya, has long-term negative effects on soil productivity (Miriti *et al.,* 2013). Compaction, impermeable hardpans, increased dissipation of organic matter, increased water erosion, as well as loss of soil water due to an increase of evaporative surfaces were observed by Miriti *et al.* (2013). These negative effects associated with conventional tillage have become the basis for advocating for minimum tillage by most researchers (Okoth *et al.,* 2014).

2.2.2 Minimum tillage

Minimum tillage is one of the cropping principles under conservation agriculture (CA), aimed at sustaining high crop yields with minimum negative consequences for the resource base –water , soil, and surrounding natural environment (Baudron, Tittonell, Corbeels, Letourmy, and Giller, 2012). Implementation of minimum tillage began in the early 1980s in different areas of Spain and other southern European countries with the aim of improving soil water retention and reducing erosion (Bescansa, Imaz, Virto, Enrique, and Hoogmoed, 2006; Ferna´ndez, Ferna´ndez, Gira´ldez Cervera and Perea Torres, 2007) Through the adoption of minimum tillage as a principal of conservation agriculture, the Great Plains region of the USA, once regarded as a dust bowl, has been turned into the granary of the world (Acharya, Hati, and Bandyopadhyay, 2005).

Although there has been limited adoption of conservation tillage in sub-Saharan Africa, efforts in applied research have been made particularly in Ghana, South Africa, Zambia, and Zimbabwe with a focus on minimum tillage-based systems (Rockstrom *et al.,* 2009). According to Ghuman and Sur (2001) minimum tillage is important in rain-fed agricultural production systems. It reduces soil loss due to better aggregate stability and the protective effect of crop residues left over the soil, increases soil water availability as well as the number of bio-pores that may facilitate root growth (Martinez *et al.,* 2008; Ngetich *et al.,* 2014). Proponents of minimum tillage practices as a component of conservation tillage attribute yield increase observed under this type of tillage to improved soil water retention and responsiveness to fertilizer (Grabowski, Haggblade, Kabwe, and Tembo, 2014)

Minimum tillage in Sub-Saharan Africa is considered as a means to increase food security and minimize environmental degradation, particularly in sub-humid and semi-arid areas that are characterized by frequent droughts and dry spells (Baudron *et al.*, 2012). Minimum tillage systems geared towards improved water management are considered to be better adapted for the resource limited smallholder farmers in rain fed, soil nutrient deficient and biomass poor agro-ecosystems (Rockstrom *et al.,* 2009). However, the effects of any selected tillage system vary with the site soil and climate characteristics of the site as well as crop species (Martinez *et al.,* 2008; Bescansa *et al.,* 2006). For some soils and climate conditions, increased compaction and bulk density, reduced soil temperature and infiltration, increased weed infestation and decreased oxygen diffusion are some of the negatives effects reported as arising from minimum tillage compared to conventional tillage (Pandey, Agrawal, and Singh, 2014). Kenyan soils are diverse and hence need to determine the appropriateness of different water conservation tillage systems (Miriti *et al.,* 2013).

2.2.3 Tillage effects on maize yields

The third most important cereal after wheat and rice is maize (*Zea mays L.*) (Ishaya, Tunku, and Kuchinda, 2008). Considering maize is the highest yielding cereal crop in the world, it is of great importance for many countries, especially where rapidly increasing population is already short of food supplies (Zamir, Javeed, Ahmed, Ahmed, Sarwar, Shehzad, Sarwar, and. Iqbal, 2013). Due to the rising populations, there are increasing demands that agricultural systems aims at producing greater yields through the more efficient use of natural resources (Halbrendt, Gray, Crow, Radovich, Kimurad, and Tamange, 2014). Improved household food security in the sub-Saharan Africa (SSA) region has been hindered by among other factors, poor fertility of the highly weathered soils and inappropriate soil management (Mupangwa *et al.*, 2012). Tillage as a soil management technique influences soil quality and plant growth by altering the physical, chemical and biological properties (Sharma and Abrol, 2008).

Ghuman and Sur (2001), in the subtropical climate of north-western Punjab on a sandy loam soil (Fluvisol), reported higher maize grain yields in minimum tillage with residue mulch (MTR) in comparison to conventional tillage. Martinez *et al.* (2008) reported no significant differences in wheat grain yield between the NT and CT, hence demonstrating that changes in soil moisture content due to no-tillage (NT) are not as great as to significantly influence crop production. Rockstrom *et al.* (2009) across a set of experiments in semi-arid and sub-humid locations in East and Southern Africa, demonstrated that minimum-tillage resulted to increased water productivity and crop yields, even with little or no crop residue mulch.

Moraru and Rusu (2013) in assessing the effects of different tillage methods (conventional tillage (CT), minimum tillage (MT) and no-tillage (NT)) on soil properties and production of wheat, maize and soybean concluded that water dynamics and soil temperature showed no differences that could affect crop yields. Thierfelder *et al.* (2013) in Zambia, observed an increase in maize yields under minimum tillage, in comparison to a conventionally tilled control on Lixisols, Acrisols and Allisols. Results from several experiments on tillage effects on crop yield are inconsistent especially with respect to locality and soil type (Ghuman and

Sur, 2001; Martinez *et al.,* 2008; Rockstrom *et al.,* 2009; Enfors *et al*., 2011; Moraru and Rusu, 2013)

2.2.4 Tillage effects on soil moisture

Soil moisture as an important factor effecting plant growth is influenced by different factors, such as, organic matter, polymer, mulch and different soil tillage application (Mujdeci, Kara, and Ali Lidar, 2010). Kosutic, Hunsjack, Flipovic, and Bogunovic, (2001) observed that, differences in the available soil water are significantly influenced by the applied soil tillage method and that the available soil water content differences between the no-till and conventional tillage systems at all observed layers(0-5,15-20 and 30-35 cm) were significant. Abu-Hamdeh (2004) observed that, in general, tillage significantly affects soil water content as well as water available to crops. According to Basset, Tishall, Hughes, and Thiband (2010), despite greater saturated water content and lower bulk density in soils under conventional tillage, water retained within the plant available range is lesser than in soils under no-till system.

Enfors *et al.* (2011) concluded that, at least in a shorter time perspective, combining ripping with mulch and manure application, a type of conservation tillage, seems to boost productivity during already good seasons, rather than stabilize harvests during poor rainfall seasons. Martinez *et al.* (2008) reported higher soil water content under no-till farming as opposed to conventional tillage. However, Rockstrom *et al.* (2009) across a set of experiments in semi-arid and sub-humid locations in East and Southern Africa, demonstrated that minimum-tillage resulted to increased water productivity, even with little or no crop residue mulch. Several experiments on tillage relations to soil moisture indicate significant differences among different tillage systems but the results vary with respect to locality and soil type (Ghuman and Sur, 2001; Rockstrom *et al.,* 2009; Martinez *et al.,* 2008;Enfors *et al*., 2011; Moraru and Rusu, 2013)

2.2.5 Tillage effects on soil organic carbon

Increased interest in the potential of soil as a carbon sink has been observed and is believed to have been prompted by the elevated levels of atmospheric carbon dioxide (Baker, Ochsner, Venterea, and Griffins 2006). There are rising concerns that the world's soils total organic carbon is decreasing and much of the blame has been laid on plow tillage practices resulting to bare soil conditions, and in turn, elevated soil organic carbon mineralization (Lal, Follett, Stewart,. and Kimble, 2007; La Scala, Lopes, Spokas, Bolonhezi, Archer and Reicosky, 2008). Though conventionally tilled soils have been considered by many as a depleted carbon reservoir, the general believe is that it can be recovered with appropriate soil and crop management (Lal, 2004). Conservation agriculture has been identified as one of the strategies for recovery of soil organic carbon (Paul, Vanlauwe, Ayuke, Gassner, Hoogmoed, Hurisso, Koala, Lelei, Ndabamenye, Six and Pulleman, 2013). According to the Conservation Technology Information Center in USA, conservation tillage could be defined as any tillage or planting system in which at least 30% of the soil surface is covered by plant residue after planting (Giller *et al.*, 2009).

The argument that widespread adoption of conservation tillage in the United States could sequester 24 to 40Tg of carbon per year formed the basis of global projections of 25Gt carbon sequestration in 50 years if all croplands are converted to conservation tillage (Lal, Follet, and Kimble, 2003). Conservation tillage especially no-till and mulching has been recommended globally as a strategy to stabilize atmospheric carbon dioxide concentrations by increasing carbon sequestration (Lal *et al.*, 2007). Kushwaha *et al.* (2001) in a tropical moist sub-humid climate observed that compared to reduced tillage alone, reduced tillage with residue retention led to a greater increase in the amount of carbon in both macro- and micro-soil aggregates. According to Al-Kaisi, Yin and Licht (2005), adopting perennial grass cropping systems along with reduced tillage in mid-west soils was an effective strategy to improve soil carbon sequestration.

In sub-humid subtropical climate, Ghuman and Sur (2001) observed improved soil quality due to increased organic carbon for a sandy loam soil (Fluvisol) under minimum tillage with mulch retention as opposed to conventional tillage. The general observation from previous studies is that, reduced tillage enhances the soil organic matter pool hence an important strategy of carbon sequestration (Ghuman and Sur, 2001; Bescansa *et al.,* 2006; Lal, *et al.,* 2007; Mulumba and Lal, 2008; Kahlon, Lal and Ann-Varughese, 2013). However, contrary reports associating conventional tillage with higher soil organic carbon (Mupangwa, Twomlow and Walker, 2013; Paul *et al.,* 2013), indicate that clear understanding of tillage effects on soil organic carbon is required especially for different soil types and climatic conditions (Singh and Malhi, 2006) given that rigorous empirical evidence of the benefits of no-tillage over conventional tillage in Sub-Saharan Africa is limited and inconsistent (Paul *et al.,* 2013).

2.3 Mulching

In many ancient civilizations, the practice of leaving crop residues as the surface stubble or flattened straw mulch has been widely used as a management tool for centuries (Acharya, Hati, and Bandyopadhyay, 2005). Applied as a soil-air interface, the effects of crop residue mulch have been reported as improvement of the physical conditions of the soil (Chakraborty, Nagarajan, Aggarwal, Gupta, Tomar, Garg, and Kalra, 2008). This is by enhancing soil aggregation; soil water conservation by checking evaporation, retarding runoff and increasing infiltration; favourable modification of soil temperature regime; improvement of soil chemical environment and biological activity; enhancement of carbon sequestration and ultimately improvement of crop productivity (Acharya *et al.,* 2005; Chakraborty *et al*., 2008; Mulumba and Lal, 2008).

To retain mulch, minimum tillage is necessary (Erenstein, 2003). Minimum tillage (MT) is known to be associated with high level of crop residue left at the soil surface and hence recognized as instrumental in conserving soil and water, saving energy, improving the environment, soil ecology, enhancing soil quality and crop yields (Mulumba and Lal, 2008). Kahlon *et al.* (2013) reported that long-term application of crop residue mulch under minimum tillage strongly impacted on the soil carbon concentration, physical and hydrological characteristics.

2.3.1 Effects of mulching on maize yields

Increasing food production in Sub-Saharan Africa has necessitated continued development of rain-fed agriculture achievable through improvement of water productivity and crop yields (Mupangwa, Twomlow, and Walker, 2007). There has been an arguement that the favourable effects of mulching on soil quality and resilience, soil temperature moderation and soil moisture, results to beneficial effects on crop growth and yields (Lal, 1998). Ghuman and Sur (2001) concluded that it is necessary to use residue mulch in order to improve crop production after observing higher maize yields under minimum tillage with mulching in comparison to minimum tillage without residue mulch. Enrichment of soil with plant nutrients by increasing fertilizer use efficiency and water availability through organic mulching application boosts crop production (Acharya *et al.*, 2005).

Shen, Zhao, Han, Zhou and Li,. (2012) after conducting an experiment in northern China, reported that under rain-fed conditions, straw mulching could increase not only the water use efficiency of maize but the yields as well. Doring, Brandt, Heb, Finckh and Saucke (2005) observed that light to moderate quantities of straw mulch did not affect crop yield in temperate climate on loamy silt soils, Danga and Wakindiki (2009) observed that straw mulching affected crop yield in a humid Kenyan highland. With reference to these findings, indication is that studies of mulching effects on crop yields for specific site, climate and soil type are necessary.

2.3.2 Effects of mulching on soil moisture

Among the main processes that influence soil water availability to crop in rain-fed agriculture are infiltration and soil evaporation (Mupangwa *et al.*, 2007). The rate of infiltration is determined by several factors including intensity and duration of the rainfall and nature of the soil surfaces. Hence, mulching being a beneficial soil surface management technique in the tropics (characterised by high rain-fall intensity), enhances infiltration while reducing runoff and soil loss (Adekalu, 2007). As such, one of the major advantages of mulch-based farming system is soil moisture conservation (Chakraborty *et al.,* 2008).

By reducing rain drop impact on the soil surface, mulching protects soil from water erosion, decreasing runoff velocity favours infiltration and the shielding of the soil surface from solar radiation by the mulch material reduces evaporation (Acharya *et al*., 2005). Mulumba and Lal (2008) reported that mulch application increased total porosity, available water capacity, soil aggregation and moisture content at field moisture capacity. Zhang (2005) observed that, mulching significantly reduced evaporation and improved the quantity and frequency of deep percolation, hence enhancing the groundwater recharge potential.

Mulching or covering the soil surface with a layer of plant residue is an effective method of reducing depletion of water within the root zone because it suppresses evaporation (Adekalu, 2007). Chakraborty *et al.* (2008) on comparing plant and soil water status in wheat under transparent and black polyethylene and rice husk mulch observed that all mulch treatments improved the soil moisture status. However, rice husk was found to be superior in maintaining optimum soil moisture condition for crop use. The advantages that go along with conserved soil moisture in the soil profile include moderated plant water status and soil temperature, resulting to better root growth and high grain yield (Kahlon *et al.*, 2013). Remarks by different researcher that the impact of mulching varies across locations and soils indicate the need for research on mulch-moisture relationships to be locality and crop specific (Erenstein, 2003; Giller *et al.*, 2009; Obalum *et al.*, 2012; Paul *et al*., 2013; Mupangwa *et al.*, 2013).

2.3.3 Effects of mulching on soil organic carbon

According to Lal *et al.* (2007) world’s soil carbon pool, being the third largest globally comprises of two distinct components (Soil Organic Carbon (SOC) and Soil Inorganic Carbon (SIC)) estimated at 1576 Gt and 938 Gt, respectively to a depth of 1m and approximately 50-75% of the original soil organic carbon pool has been lost. Land modifications associated with agriculture especially those resulting from conventional tillage, have contributed largely to loss of soil carbon due to erosion, mineralisation and leaching (La Scala et *al.*, 2008). On the other hand, crop residue retention, no till farming and incorporation of cover crops are among land use and soil management techniques that lead to carbon sequestration (Jacinthe, Lal and Kimble, 2002).

Acharya *et al*. (2005) observed that organic mulches add organic matter and plant nutrients to soil upon decomposition, thus they improve carbon sequestration. Crop residue is a major source of SOC, and as an indicator of soil quality, SOC influences all the indices of soil productivity including fertility (Obalum, Okpara, Obi and Wakatsuki, 2011). Therefore, this is a clear indication that information on the relationship that exists between crop residue mulch and SOC is vital as far as improving soil productivity is concerned. Furthermore, after observing a weak residue effect on aggregate stability and soil carbon due to insufficient residue retention rate associated with smallholder farms in sub-humid Western Kenya, Paul *et al.* (2013) recommended further research, for different climatic zones and soil types, to establish the relationship between mulching and soil organic carbon.

2.4 Summary and research gaps identified

The review of existing literature indicates that there is considerable interest in the effects of tillage and mulching on soil properties as well as on crop yields. The review identified that appropriate tillage and mulching for increased crop production is widely advocated for. However, the appropriateness of a particular tillage method and mulch application is site-specific. The effects of a particular tillage-mulch system will vary with the soil and crop species under the different agro-climatic conditions. Therefore, it is necessary to establish the suitability of a selected tillage method for a particular soil type and crop species. In the Central Kenya highlands region, there has been no clear evidence indicating the most suitable tillage-mulch system for this area. Thus, this research focused on addressing the gap by assessing the effects of tillage and mulching on maize yield, soil water content and organic carbon of Humic Nitisols in the central highlands of Kenya.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted in Kirege Primary School (S 00°20’07.0”; E 037°36’46.0”), Chuka division, in Tharaka-Nithi County, Kenya. The site lies at an altitude of 1526 m above the sea level on the Eastern slopes of Mt. Kenya (Figure 3.1).

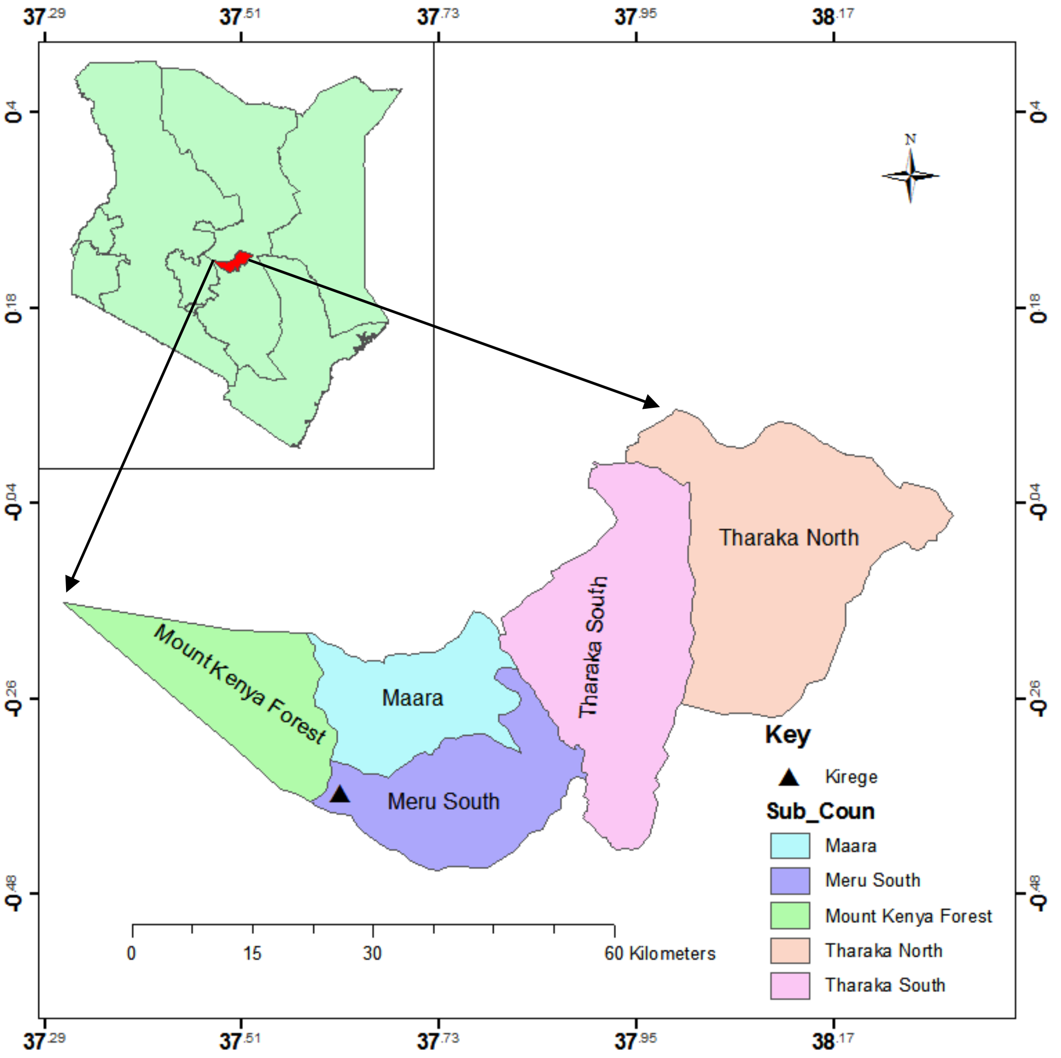

Figure 3. 1: Map of the study area

The study area is characterized by an annual mean temperature of 20°C and annual rainfall of between 900 mm to 1400 mm. The rainfall is bimodal with long rains (LR) from March to June and short rains (LR) from October to December (Jaetzold, Schmidt, Hornet and Shisanya, 2007). It is a predominantly maize growing area with an average farm size of 1 acre per household (Mugwe *et al.*, 2009). The predominant soil type in the region is Humic Nitisols which are very deep, well drained dark red to dark reddish brown soils with moderate to high inherent fertility (Jaetzold *et al.*, 2007). These Humic nitisols have an average of 0.15% of organic carbon, 0.02% of total nitrogen, and 0.01% of phosphorus (Jaetzold *et al.,* 2007). Soil pH is 4.75 and soil texture is majorly clay with the particle size distribution of clay being 72% and silt 20% (Ngetich *et al.*, 2014).

Agriculture in Chuka division is characterized by smallholder mixed farming activities. The cash crops include bananas (*Musa paradisiaca*) coffee (*Coffea arabica*,) and tea (*Camellia sinensis*) while food and horticultural crops are maize (*Z. mays*) beans (*P. vulgaris*), Irish potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*), cabbages (*Brassica oleracea*), kales (*Brassica. oleracea L.*), tomatoes (*Solanum lycopersicum*) and onions (*Allium cepa*). Nearly all farmers in the region practice dairy farming under zero and/or semi-zero grazing and the need for fodder is a main constraint (Mugwe *et al.*, 2009). The farmers primarily rely on small-scale rain-fed farming, which is mostly non-mechanized and involves minimal use of external inputs (Ngetich *et al.,* 2014).

3.2 Experimental design

The experimental design was a split plot arranged in randomized complete block design (RCBD). Two mulch levels, residue removal (W) and residue retention (R) were applied under two tillage methods conventional tillage (CT) and minimum tillage (MT). Tillage was treated as the main plot and mulching the sub-plot. A combination of the factors resulted in four treatments and a control which were replicated thrice (Table 3.1). The treatments were: Conventional Tillage with Residue application (CTR); Conventional Tillage Without residue application (CTW); Minimum Tillage with Residue application (MTR), Minimum Tillage without Residue application (MTW) and a Control (Cntrl).

Table 3. 1: Experimental treatments

Treatment	Abbreviation
Conventional Tillage without residue	CTW
Conventional Tillage with residue	CTR
Minimum Tillage without residue	MTW
Minimum Tillage with residue	MTR
Conventional Tillage without inputs	Cntrl

The plot size was 7 m by 7 m with a 1 m wide alley separating plots within a block and 2 m wide alley left between blocks. The test crop was maize, H516 variety. The experiment was conducted for two seasons, long rains 2014 (LR14) and short rains 2014 (SR14).

3.4 Management of the experiment

For the conventional tillage treatment plots, ploughing was done by hand hoeing to a depth of about 0.15 m at the beginning of the season, and weeding was done using hand hoe when required, to ensure clean fields as much as possible throughout the seasons. To minimize weed problems in the minimum tillage plots, weed control was carried out during off season periods using herbicide (Glyphosate) and manual uprooting of weeds was done in the course of the season to minimize soil disturbance. Three maize seeds per hill were planted, with a spacing of 0.75 m between rows and 0.25 m within rows, and were thinned out to two plants per hill two weeks after emergence to attain the recommended plant density of 53,333 plants ha^{-1} (Jaetzold *et al.*, 2007). For the residue retention treatments, maize stover from the previous cropping season was broadcasted at the rate of 3 Mg ha^{-1}, a week after emergence. Inorganic fertilizers (Urea and triple super phosphate, TSP) were spot applied during planting except under the control treatment. Triple Super Phosphate was applied to give a total of 90 kg P ha^{-1} while Urea was applied at a rate of 120 kg N ha^{-1}.

Pests were controlled when necessary following conventional best practices such as application of bull dock to control maize stalk borer. A Polyvinyl chloride (PVC) access tube for soil moisture determination was installed at the beginning of the experiment in the middle of each plot. To achieve this, access channels for soil moisture measurement were established manually by drilling through the soil with an auger and installing PVC tubes (130 cm long and 5.3 cm internal diameter) with a watertight lid at the bottom. Precautions to avoid air gaps in the space between the channels and the PVC tubes were taken by carefully re-filling the area with soil for tight contact. To prevent entry of surface run-off to the PVC tubes, 20 cm of the tubes was left protruding above the soil surface. The experimental site was surrounded by a number of maize border rows as a buffer-zone against damage by rodents or livestock.

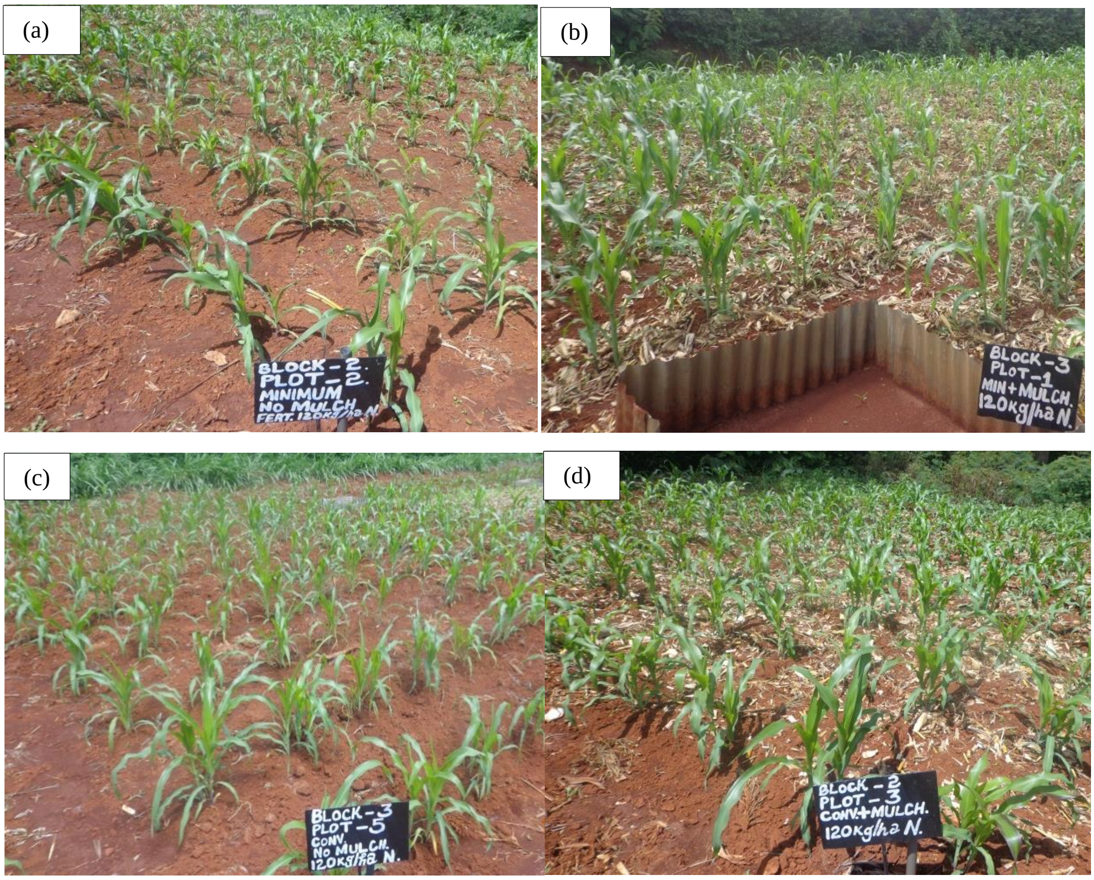

Plate 3. 1: Minimum and conventional tillage plots: (a) minimum without mulch, b) minimum with mulch (c) conventional without mulch, and d) conventional with mulch

3.5 Variables measured

The variables measured were: soil organic carbon content, soil moisture content, grain and stover yields and rainfall amount.

3.6 Data collection

Data was collected as described below.

3.6.1 Soil organic carbon sampling

Soil sampling to a depth of 20 cm before land preparation and residue application, for each plot (15 plots) was done. The initial sampling was done in March 2014 while the final sampling was done in March 2015 after harvesting the short rains 2014 maize crop. Soil organic carbon samples were taken using undisturbed soil auger of 5 cm diameter. The sampling holes were arranged in a zigzag manner, and in such a way that three sub-samples representing the whole plot were collected. The three sub-samples from the same plot were put into a basin, clods were broken up and soil mixed thoroughly (this was the composite sample). Using a small cup, a sample of about 1 kg was taken from the composite sample and packed in a plastic bag with a label indicating the plot and block numbers. This was repeated for each treatment plot hence 15 samples in total to a depth of 20 cm were collected. The 1 kg soil sample for each treatment plot, well packed and labelled was then stored in a safe place in plastic bags that were properly closed to avoid any contamination.

3.6.2 Soil moisture content measurement

Soil moisture content was determined weekly in each plot. The moisture determination was done none-destructively using diviner 2000 and access tubes (Polyvinyl chloride (PVC)) installed in the middle of each plot. The portable probe was inserted into a PVC access tube to measure soil moisture content at regular intervals of 10 cm down through the soil profile (since it takes the readings through the wall of a PVC access tube). Diviner 2000 recorded data from all levels in the soil profile to the depth of 100 cm after which the data was downloaded at the end of each season and processed in MS excel.

3.6.3 Grain and stover yields

At harvest grain and stover (above-ground biomass minus grain) yields were estimated from a net plot measuring 38.1 m^2 obtained by leaving out guard rows and the first and last maize plants in each row to minimize the edge effect. During harvest, maize ears from the net plot were manually separated from the stover, sun-dried, and packed in gunny bags before hand threshing. After threshing, moisture content of the grains was determined using a moisture meter. The following measurements were taken at harvest of the maize crop for each of the two cropping season: actual number of stands per net plot at harvest; number of ears harvested per net plot; fresh weight of all cobs with grains in (kg) from the net plot; dry weight of all the cobs with grains in (kg) from the net plot; dry weight of the grains in (kg) after threshing all the dry cobs from the net plot and fresh weight of all stover from the net plot in kg. The above information was used to calculate grain and stover yields per unit area. The grain and stover yield was then converted to a per hectare basis at 12.5% moisture content as final grain and stover yield.

3.6.4 Rainfall data

Daily rainfall was measured using an automatic rain gauge installed at the site (Plate 3.2) throughout the study period. The rain gauge was a tipping-bucket, data logging, Hobo, model; RG3-M (manufactured by Onset Computer Corporation Company) with a 0.2 mm resolution. The data logger was launched at the beginning of the season and read at the end of each season, although frequent checks were done to monitor its functionality. Besides the data logging rain gauge, a backup manual rain gauge was mounted nearby. Once read, the data was exported using HOBO ware Pro Version 3.2.2 and further processed in Ms Excel. Daily rainfall was calculated by multiplying the number of tips per day (09:00 h) by 0.2 mm tipping bucket resolution of the rain gauge.

Plate 3. 2: Automatic rain gauge installed at the site

3.7 Laboratory analysis

In the laboratory, each soil sample was given a laboratory number. They were then dried in an air-forced oven at 300C. When dry the soil samples were then cleaned off stones and plant residues. Samples were then ground in a stainless steel soil grinder and passed through a 0.5 mm sieve and analysed for organic carbon.

3.7.1 Determination of soil organic carbon

Soil organic carbon determination of was based on the modified Walkley-Black chromic acid wet oxidation method described by Ryan, George and Rashid (2001). The moisture content of air-dried soil samples which had been ground to pass through a 0.5 mm sieve was determined. Since presence Ferrous (Fe^{2+}) iron in soils, leads to high results for the dichromate-ferrous sulphate titration, the soil samples were air-dried to ensure that insignificant amounts of soluble iron compounds were present. One gram of the air-dried soil was accurately weighed into a dry tared 250 ml conical flask. Accurately, 10 ml 1 N $K_2Cr_2O_7$ was added and the flask swirled gently to disperse the soil in the solution. Then 20 ml concentrated H_2SO_4, was then added directing the stream into the suspension and the flask immediately swirled until the soil and the reagent were mixed.

A 200°C thermometer was inserted and while swirling the flask, the contents were heated for half a minute over a gas burner and gauze until the temperature reached 135°C. Heat was removed when the digesting solution reached 135°C because the dichromate thermally decomposes at 150°C causing significant errors. The contents were then set aside to cool slowly on an asbestos sheet in a fume cupboard. Two blanks (without soil) were run in the same way to standardise the $FeSO_4$ solution. Cooling was done for 30 minutes and the mixture was diluted to 200 ml with deionised water. $FeSO_4$ titration using the "ferroin" indicator was done and thereafter, calculation to determine the percentage carbon content was done using equation 1.

$$2Cr_2O7^{2-} + 3C + 16H+ \rightarrow 4Cr^{3+} + 8H_2O + 3CO2\uparrow \qquad \textit{Equation 1}$$

1 ml of 1 N Dichromate solution is equivalent to 3 mg of carbon. Where the quality and normality of the acid/dichromate mixture used were as stated in the method, the percentage carbon was determined from equation 2:

$$\text{Organic Carbon (\%)} = \frac{0.003\ \text{g} \times \text{N} \times 10\ \text{ml} \times \left(1 - \frac{\text{T}}{\text{S}}\right) \times 100}{\text{ODW}} \qquad \textit{Equation}\ 2$$

Where:

N = Normality of $K_2Cr_2O_7$ solution

T = Volume of $FeSO_4$ used in sample titration (ml)

S = Volume of $FeSO_4$ used in blank titration (ml)

ODW = Oven-dry sample weight (g)

3.8 Data Analyses

Data on soil organic carbon, soil moisture content and maize yield were subjected to analysis of variance (ANOVA) using SAS 9.2 (SAS Institute, 2004). To determine the change in the soil organic content, the soil organic carbon content data at the beginning and end of the experiment was subjected to pairwise comparisons using student t-test. Differences between treatments means was tested using least significant difference (LSD) at the 5% level of significance.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Rainfall distribution during the study

The two cropping seasons long rains 2014 (LR14) and short rains 2014 (SR14) were characterized by variation in rainfall patterns (Figure 4.1). The total rainfall received during the LR14 was 626.1 mm while in SR14, it was 815.4 mm. The rainfall event with the highest amounts had 58 mm in long rains 2014 while in the short rains 2014, it was 88 mm. In both seasons, rainfall events below 20 mm day^{-1} were frequent (Figure 4.1) but five events above 60 mm day^{-1} were recorded in the SR14 season which had higher rainfall.

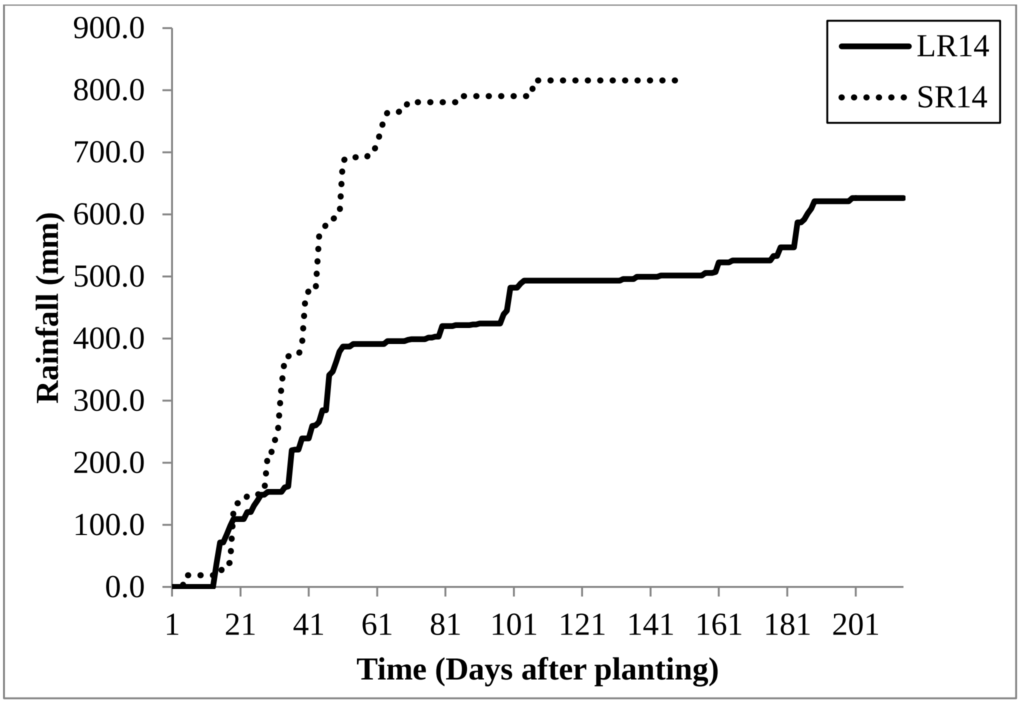

Figure 4. 1: Cumulative rainfall at Kirege as observed for 2 consecutive seasons (Long rains (LR) 2014 and Short rains (SR) 2014)

During the study, each season was characterised by a wet and dry period. In Sub-Saharan Africa, most commonly experienced are the effects of rainfall deficiency rather than excess, manifested inform of the crop failures due to deficit in soil moisture caused by dry spells (Alam *et al.*, 2011). This explains the kind of observation made during this study whereby, dry periods were common between the seasons. These occurred between 84 and 112 days after planting in the long rains 2014 and between 87 and 122 days after planting in the short rains 2014 season. The dry periods sometimes coincide with the flowering stage of the maize crop which according to Balarios and Edmaedes (1993) is the most critical stage in maize drought stress.

According to Alam *et al.* (2011), rainfall being one of the climatic variables is the most important because of its two extreme effects as a limiting resource, such as in the case of droughts and as an agent of catastrophe, such as in the case of floods. Sub-humid zone of Central Kenya experiences extreme climate events whereby even during wet seasons, consecutive rainfall events are intercepted by a prolonged dry period (Guto *et al.*, 2012; Ngetich, Mucheru-Muna, Mugwe, Shisanya, Diels and Mugendi, 2014) and such was the case during this study. Though characterized by different rainfall pattern, a dry period intercepted the rainfall events in both long rains and short rains 2014. An intra-seasonal dry spell of 28 days (between 84 days and 112 days after planting) was experienced during long rains 2014 whereas during short rains 2014 a meteorological drought period of 35 days (between day 87 and 122 after planting) was experienced towards the end of the season.

According to Araya and Stroosnijder (2010), meteorological droughts are important causes of low yield in many drought-prone environments and in this study the lowest yields were recorded during short rains 2014 season. Twomlow, Riches, O’Neill, Brookes, and Ellis-Jones, (1999) observed that, distribution and reliability of rainfall are often more important than total rainfall. The results of this study agree with this observation because despite having cumulatively less rainfall in long rains 2014, the harvest was better due to the good distribution of the rainfall in comparison to short rains 2014 season.

4.2 Effects of tillage and mulching on maize yields

As a result of the combined effect of tillage and mulching, maize grain and stover yields varied between 1.8 – 5.5 Mg ha^{-1} and 3.9 – 7.6 Mg ha^{-1}, respectively (Table 4.1). The highest grain yield (5.5 Mg ha^{-1}) and stover yield (7.6 Mg ha^{-1}) were recorded in the long rains 2014 season. Significant (p=0.0031) difference in stover yield was recorded only in long rains 2014 under conventional tillage with residue (CTR), minimum tillage with residue (MTR) and minimum tillage without residue (MTW). In comparison to the control, percentage increase in stover yield was 72%, 57% and 48% for conventional tillage with residue, minimum tillage without residue and minimum tillage with residue, respectively (Table 4.1).

Table 4. 1: Maize yield (Mg ha^{-1}) response to tillage and mulching, during long rains 2014 (LR14) and short rains 2014 (SR14) in Kirege

	LR14		**SR14**	
	Grain	Stover	Grain	Stover
Treatment		**(Mg ha^{-1})**		
CTR	4.7^{ab}	7.6^{a}	2.4^{abc}	3.9^{a}
CTW	4.5^{b}	6.2^{ab}	1.9^{bc}	6.2^{a}
Control	3.4^{c}	4.4^{b}	1.8^{c}	3.9^{a}
MTR	5.3^{ab}	6.5^{a}	2.6^{abc}	4.3^{a}
MTW	5.5^{a}	6.9^{a}	2.8^{a}	3.9^{a}
LSD	0.89	1.85	0.15	2.89
P	0.0029	0.0031	0.039	0.373

(CTR=Conventional tillage with residue; CTW=Conventional tillage without residue; MTR=Minimum tillage with residue; MTW= Minimum tillage without residue). Same superscript letters in the same column denote no significant difference between treatments.

In long rains 2014 season, there was significant (p=0.0029) difference in grain yields between, conventional tillage without residue (CTW), conventional tillage with residue (CTR), minimum tillage without residue (MTW) and minimum tillage with residue (MTR) treatments and the control (Table 4.1). Minimum tillage without residue (MTW) had a significant increase of 62% in grain yield, minimum tillage with residue (MTR) increased by 56%, conventional tillage with residue (CTR) increased by 38% and conventional tillage without residue (CTW) increased by 32%. The grain yield increase for minimum tillage treatments was higher (over 50%) than for conventional tillage treatments. Compared to the control, there was a significant (p=0.039) difference in grain yield only under minimum tillage without residue (MTW), with a 56% yield increase, in the short rains 2014 (Table 4.1).

Independent effect of tillage resulted to significant (p=0.01) difference in stover yields between minimum and conventional tillage during the long rains 2014 (Table 4.2).

Table 4. 2: Maize yield (Mg ha^{-1}) response to tillage, during long rains2014 (LR14) and short rains 2014 (SR14) in Kirege

	LR14		**SR14**	
	Grain	**Stover**	**Grain**	**Stover**
Treatment		**(Mg ha^{-1})**		
MT	4.0389^{a}	5.1983^{b}	1.8289^{b}	3.3692^{b}
CT	4.2924^{a}	5.9248^{a}	2.1607^{a}	4.5869^{a}
LSD	0.3710	0.5317	0.2872	1.2100
p value	0.1649	0.0110	0.0266	0.0488

(CT=Conventional tillage; MT=Minimum tillage) Same superscript letters in the same column denote no significant difference between treatments.

Conventional tillage had significantly (p=0.01) higher yields than minimum tillage by 0.73 Mg ha^{-1}. Grain yield was not significantly different between treatments during long rains 2014 season (Table 4.2). In the short rains season, there was significant difference in grain yield (p=0.03) and stover yield (p=0.05) between minimum and conventional tillage (Table 4.2). Conventional tillage had significantly higher grain (p=0.03) and stover (p=0.05) yield than minimum tillage. A significant ($p \leq 0.05$) yield difference of 0.33 Mg ha^{-1} for grain and 1.22 Mg ha^{-1} for stover was recorded between conventional and minimum tillage. Overall, conventional tillage significantly ($p \leq 0.05$) out-yielded minimum tillage, except for grain yield during long rains 2014 season when the difference between the two treatments was not significant (p=0.16) (Table 4.2).

Mulching alone significantly (p=0.02) increased stover yield during the long rains 2014 season by 0.63 Mg ha^{-1} (Table 4.3). The treatment without residue generally out-yielded the residue treatment except during the long rains 2014 season. There was no significant difference in grain yield (p=0.21) during the long rains 2014, as well as in grain (p=0.54) and stover (p=0.24) yield in the short rain 2014 season (Table 4.3).

Table 4. 3 Maize yield (Mg ha^{-1}) response to mulching, during long rains 2014 (LR14) and short rains 2014 (SR14) in Kirege

	LR14		**SR14**	
	Grain	**Stover**	**Grain**	**Stover**
Treatment	**(Mg ha^{-1})**			
Residue	4.0513^{a}	5.8785^{a}	1.9530^{a}	3.6336^{a}
Without residue	4.2800^{a}	5.2446^{b}	2.0367^{a}	4.3225^{a}
LSD	0.3710	0.5317	0.2872	1.2100
p value	0.2073	0.0228	0.5421	0.2424

Same superscript letters in the same column denote no significant difference between treatments

In both long rain and short rain seasons, the grain yield was less than 6 Mg ha^{-1} which is the potential yield in the area according to Rockstrom *et al.* (2009). This could be attributed to the drought that coincided with the crops' flowering, cobing and grain filling stage in both seasons, thus compromising the yielding capacity of the crop. These results agree with studies by Mucheru-Muna *et al.* (2014) and Mupangwa *et al*. (2007). According to Balarios and Edmaedes (1993), drought stress occurs with different intensity at any plant development stage from germination to physiological maturity and flowering is the most critical stage in maize drought stress. Araya and Stroosnijder (2010), observed that the impact of drought stress on crop productivity is particularly severe when the drought coincides with the moisture-sensitive stage of the crop. Though the drought period was experienced in both seasons, it occurred for a slightly longer period (35 days) in the short rains 2014 compared to long rains 2014 which had 28 days of dry spell. This explains the lower grain yields, ranging from 1.8 – 2.8 Mg ha^{-1} compared to the potential yield of 6 Mg ha^{-1}, observed in the short rain 2014 season.

The yield performance in the conventional tillage treatment was significantly (p=0.05) higher than in the minimum tillage, except for grain yield in long rains 2014. According to Ghuman and Sur (2001), a minimum lag period of two years in tropical climates is expected, before realizing yield improvement under minimum tillage. Thus, the low yields results following initial use of minimum tillage could be attributed to the lag period of improvement associated with it. Moreover, absence of tillage can result in higher run-off and lower infiltration leading to lower yields (Sime *et al.*, 2015). Rockstorom *et al.* (2009) made similar observation that minimal tillage may result to; higher surface runoff, low rainfall infiltration and subsequently lower yield levels. According to Brouder and Gomez (2014), minimum tillage generally resulted in lower yields compared to conventional tillage in the short-term, and occasionally these reductions could be linked to direct effects such as increased soil compaction. This notwithstanding, tillage whether conventional or minimum, significantly affected both grain ($p=0.0042$) and stover ($p=0.0003$) yield during the low but well distributed rainfall in the long rains 2014 rather than during the high rainfall in short rains 2014 season. This agrees with the observation by Twomlow *et al.* (1999) that distribution and reliability of rainfall are often more important than total rainfall.

Mulching was found to be a suitable agronomic practice for enhancing the soil moisture and consequently crop yield (Acharya *et al*., 2005; Chakraborty *et al.*, 2008; Mulumba and Lal, 2008). However, the current study concurs with the findings of Mupangwa *et al.* (2012), which recorded higher stover yields in comparison to grain yield, indicating that the soil moisture conserved was just enough to positively impact on stover production but was inadequate for conversion of accumulated biomass into grain. Although the grain yield was below the potential yield of 6 Mg ha^{-1} in the area, a higher percentage increase (over 50%) in yield under minimum tillage treatments compared to the conventional tillage treatments is an indication of positive response to minimum tillage. Better yields recorded under conventional tillage with residue compared to conventional tillage without residue, is an indication of positive response to mulching. A higher percentage increase in grain and stover yields under minimum tillage without residue compared to minimum tillage with residue could be due to yield depression resulting from nitrogen immobilization associated with residue retention under minimum tillage with residue (Thierfelder *et al.*, 2013).

Generally, there is an indication towards yields improvement through minimum tillage and mulching. These treatments yielded better than conventional ones despite the drought stress experienced at flowering and grain development stage of the maize. This observation agrees with Mpangwa *et al.* (2012) that maize yield improved under a mulching treatment despite low rainfall in one of the seasons. Bescansa *et al.* (2006) explained that higher yield results under minimum tillage and mulching could also be due to better soil water retention resulting from changes in the pore-size caused by minimum tillage and mulching. Results of this study show that there is substantial difference between minimum tillage and mulching and the conventional practices, with minimum tillage and mulching yielding higher results. In agreement with this are the findings of Ghuman and Sur (2001), who reported that minimum tillage in conjunction with mulching improved soil quality and crop yields due to increased infiltration of rainfall water into the soil profile and reduced soil erosion. Similarly, Thierfelder *et al.* (2013) observed consistently higher yields in minimum tillage and mulching compared to conventional control.

4.3 Effects of tillage and mulching on soil moisture

Figure 4.2 a, b, c and 4.3 a, b c shows the combined effect of tillage and mulching on soil moisture trends. Average soil moisture content varied under different treatments at 0 – 0.30 m depths (Figure 4.2 a, b and c). In the long rains 2014, cumulatively about 221.4 mm of rain fell in the first 37 days after planting (Figure 4.2d) and soil moisture content increased simultaneously in all treatments, within the three depths. (Fig. 4. 2 a, b and c). From 38 days after planting, soil water content declined for all the treatments (Fig. 4. 2 a, b and c).

Thereafter, the general trend at the three depths was such that, soil moisture content fluctuated as influenced by rainfall until at 84 days after planting. There was a tendency towards a tillage-mulch effect on moisture content (p=0.21) under minimum tillage without residue within the top 0.10 m. During the entire wet period minimum and conventional tillage without residue had consistently higher moisture content within the top 0.10 m depth. At 0.20 m and 0.30 m depths soil moisture content was highest under minimum tillage without residue and conventional tillage without residue respectively (Fig. 4.2 a, b and c).

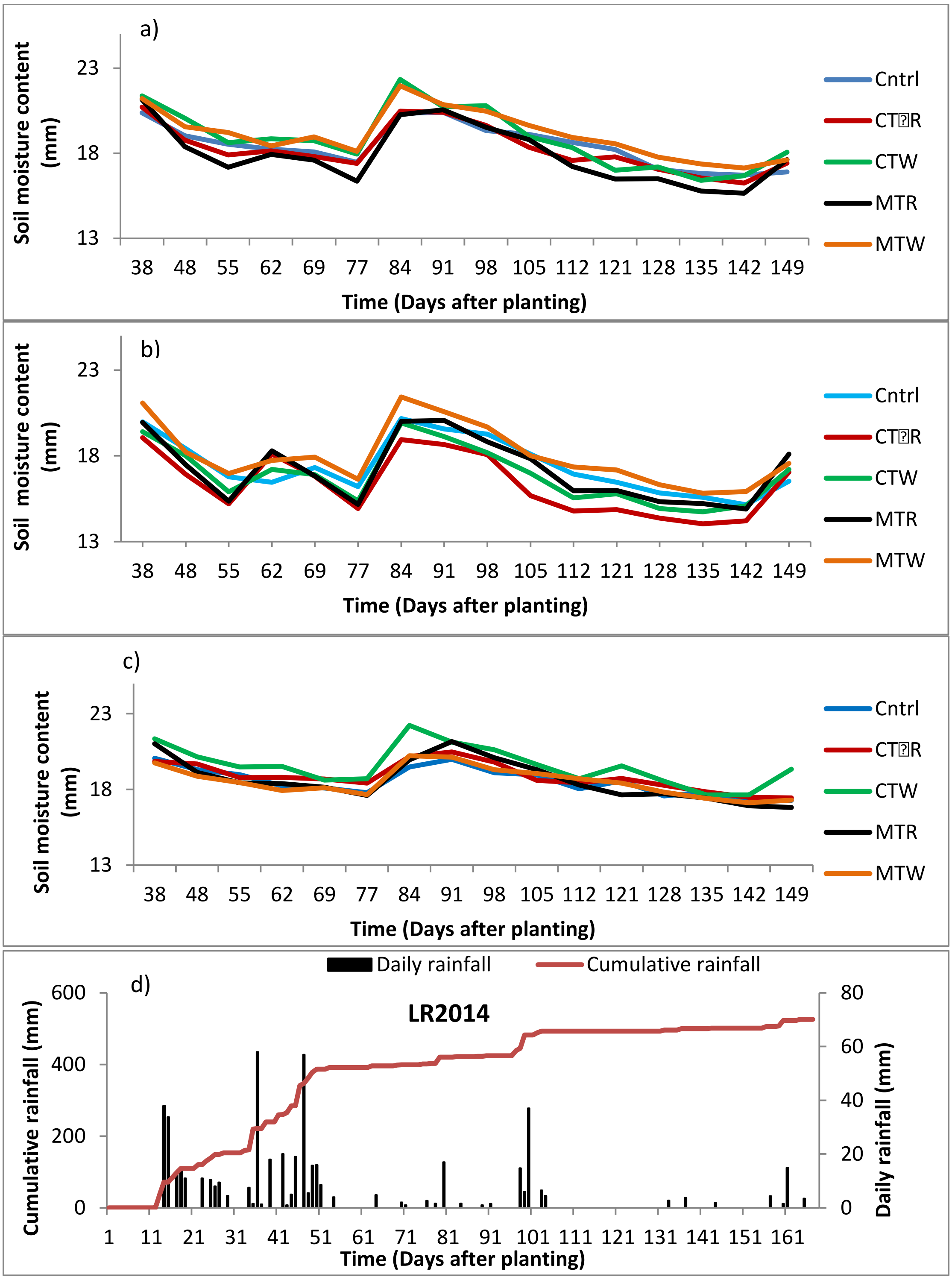

Figure 4. 2: Soil moisture changes under different treatments in 0–30 cm soil profile, a) 10 cm depth, b) 20 cm depth, c) 30 cm depth and d) Daily rainfall distribution and cumulative rainfall, during long rains 2014 season in Kirege

During the short rains 2014, higher rainfall amount was experienced (Figure 4.3d) and the magnitude of soil moisture build up increased but the trends were similar to those observed in long rains 2014. Soil moisture fluctuated concurrently in all treatments reaching the highest peak at 46 days after planting following trends similar to those in long rains 2014 (Figure 4.3 a, b and c). There was more moisture in the soil profile under minimum tillage treatments than under conventional tillage treatments within the top 0.10 m depth. At 0.20 m depth, both minimum and conventional tillage without residue had higher, though not significant (P=0.21) soil moisture content while at 0.30 m depth, more moisture content was recorded under conventional tillage with residue.

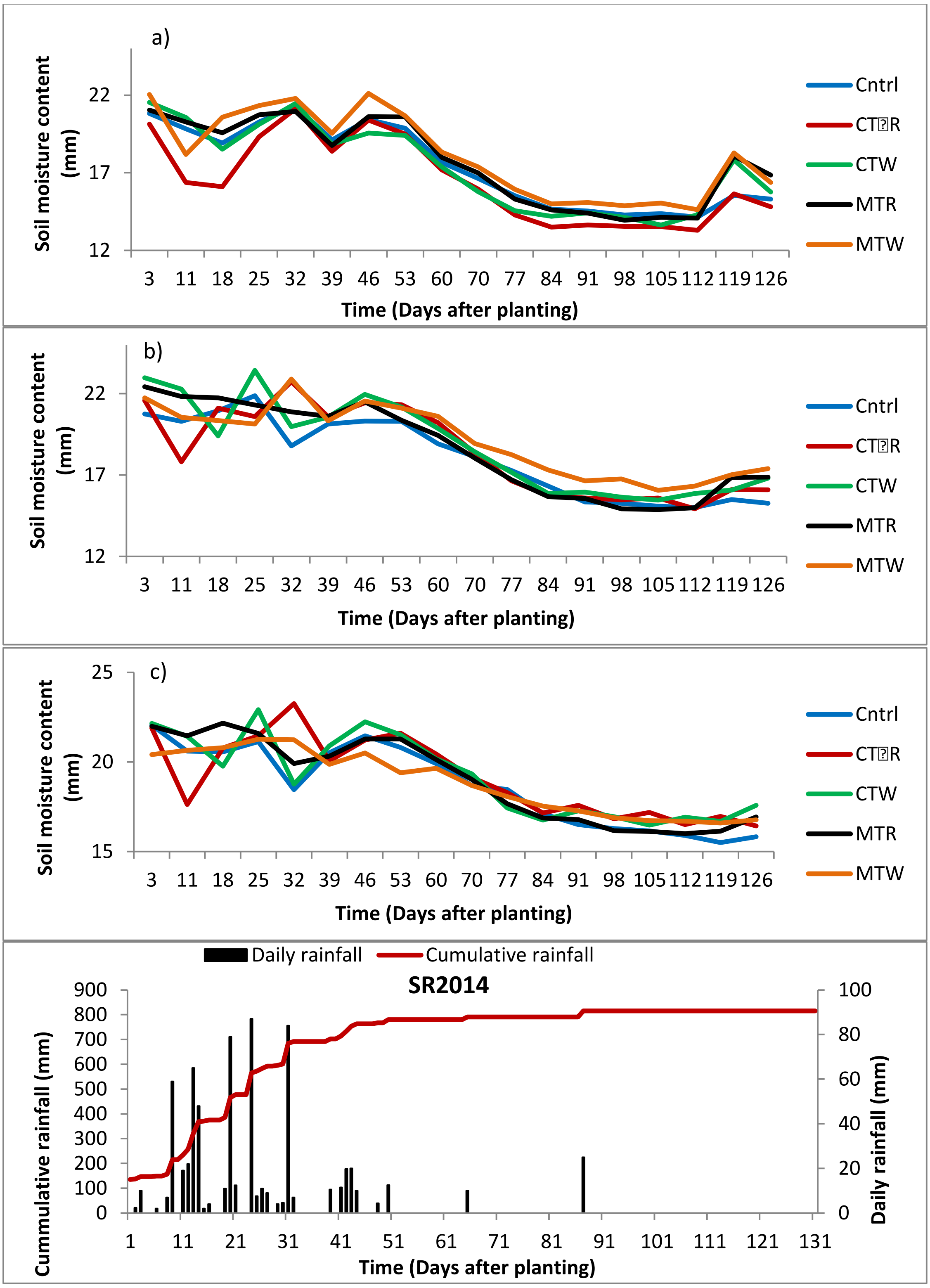

Figure 4. 3: Soil moisture changes under different treatments in 0–30 cm soil profile, a) 10 cm depth, b) 20 cm depth, c) 30 cm depth and d) Daily rainfall distribution and cumulative rainfall during the short rains 2014 season in Kirege

There was a distinct dry period within each season whereby, in the long rains 2014 season this commenced 85 days after planting (Figure 4.2d). Soil moisture in the profile reduced simultaneously in all treatments although the reduction occurred earlier and at a faster rate in the case of conventional and minimum tillage without residue compared to those that had residue (Figure 4.2a, b and c). In the short rains 2014, the dry period started 47 days after planting and soil moisture reduction in the soil profile was faster under conventional tillage treatments (Figure 4.3a, b and c). Within the top 0.10 m depth, soil moisture under minimum tillage treatments was consistently higher compared to the conventional tillage treatments. Significant (p=0.05) treatment effect was observed within the top 0.10 m depth at 119 days after planting.

At the end of the long rains 2014 season and relative to the control, the soil water content was greater by 9% under minimum tillage with residue, 6% under minimum tillage without residue, 4% under conventional tillage with residue and 3% under conventional tillage without residue (Figure 4.2). At the end of the SR14 season and in comparison to the control, soil moisture was more by 10% under minimum tillage with residue, 7% under minimum tillage without residue, 3% under conventional tillage without residue and less by 3% under conventional tillage with residue (Figure 4.3).

The singular effect of tillage (figure 4.4 and 4.5) and mulching (figure 4.6 and 4.7) on soil moisture resulted to similar trend as their combined effect (figure 4.2 and 4.3). During long rains 2014, both minimum tillage and conventional tillage started with an increase in soil water content in the top 0-0.30 m soil depth after the onset of the rains, suggesting some initial water harvesting (Figure 4.4 a, b, c).

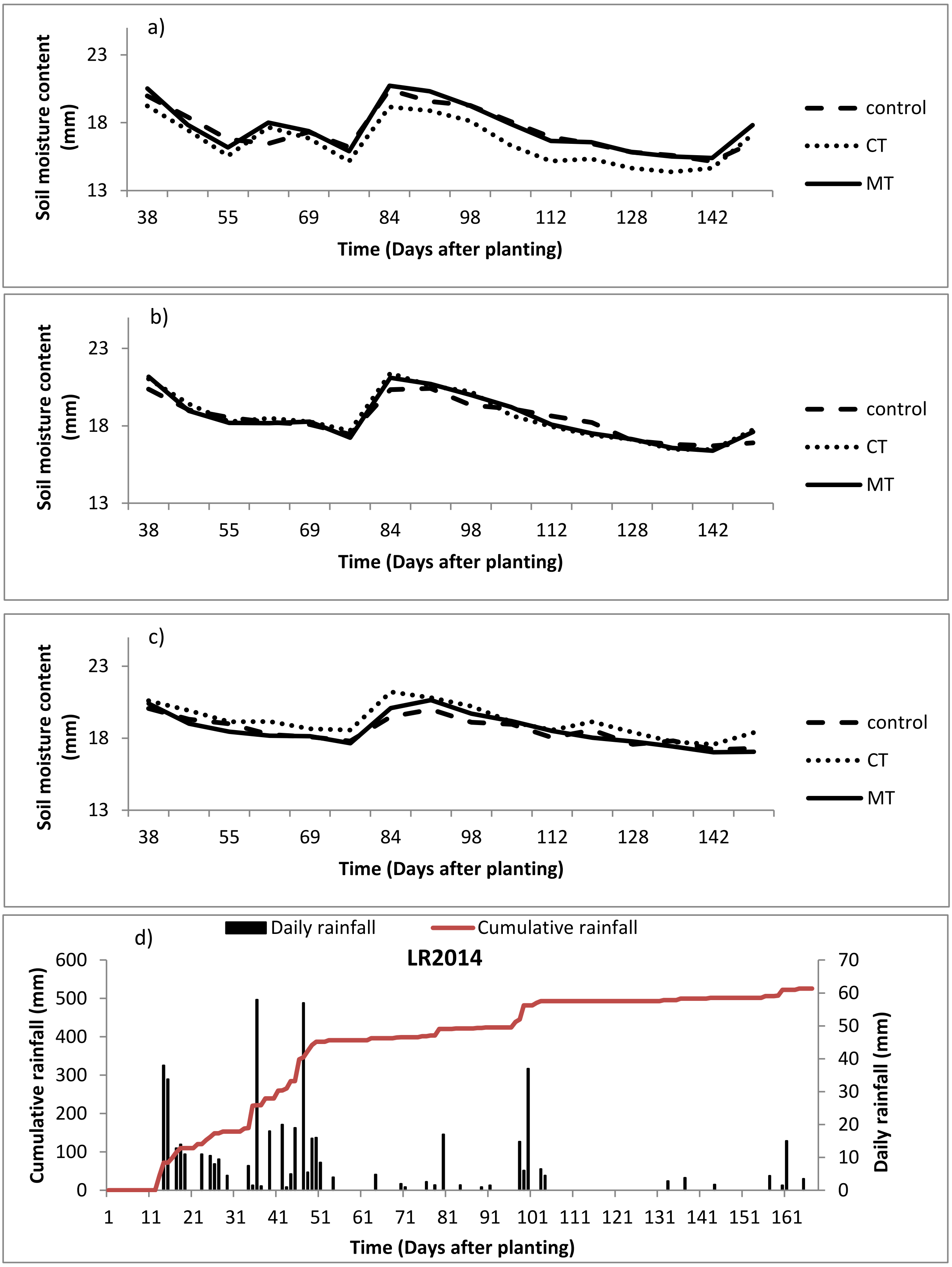

Figure 4. 4: Soil moisture changes under conventional (CT), minimum (MT) tillage and control in 0-30 cm soil profile, a) 10 cm depth, b) 20 cm depth, c) 30 cm depth, d)Daily and cumulative rainfall during the long rains 2014 season in Kirege

Soil water content in the profile increased until 38 days after planting when it started declining in the three treatments at the three depths (Figure 4.4a, b and c). However, the decline was faster and greater under conventional tillage than minimum tillage. From 55 days after planting, soil moisture in the profile fluctuated in all the treatments at the three depths (0.10 m, 0.20 m and 0.30 m) as influenced by the rainfall until 84 days after planting. Soil water content varied between the two tillage methods. (Figure 4.4 a, b, c) though the difference was not significant ($p \geq 0.10$). Within the top 0.10 m depth, soil water content was higher under minimum tillage, within 0.20 m similar trend was observed under both minimum and conventional tillage and within 0.30 m depths conventional tillage had higher soil water content.

During short rains 2014, after the onset of rain, both minimum and conventional tillage recorded an increase in soil water content in the top 0-0.30 m soil depth, suggesting some initial water harvesting (Figure 4.5 a, b, c). Soil water content in the profile increased until the third day after planting (Figure 4.5a, b and c). Thereafter, soil moisture fluctuated in minimum tillage, conventional tillage and control as influenced by the rainfall in a uniform trend at the three depths (0.10 m, 0.20 m and 0.30 m) until 46 days after planting. Soil moisture content varied between the minimum and conventional tillage in comparison to the control (Figure 4.5 a, b, c). Soil moisture was consistently higher under minimum tillage and lower under conventional tillage compared to the control within the top 0.10 m depth.

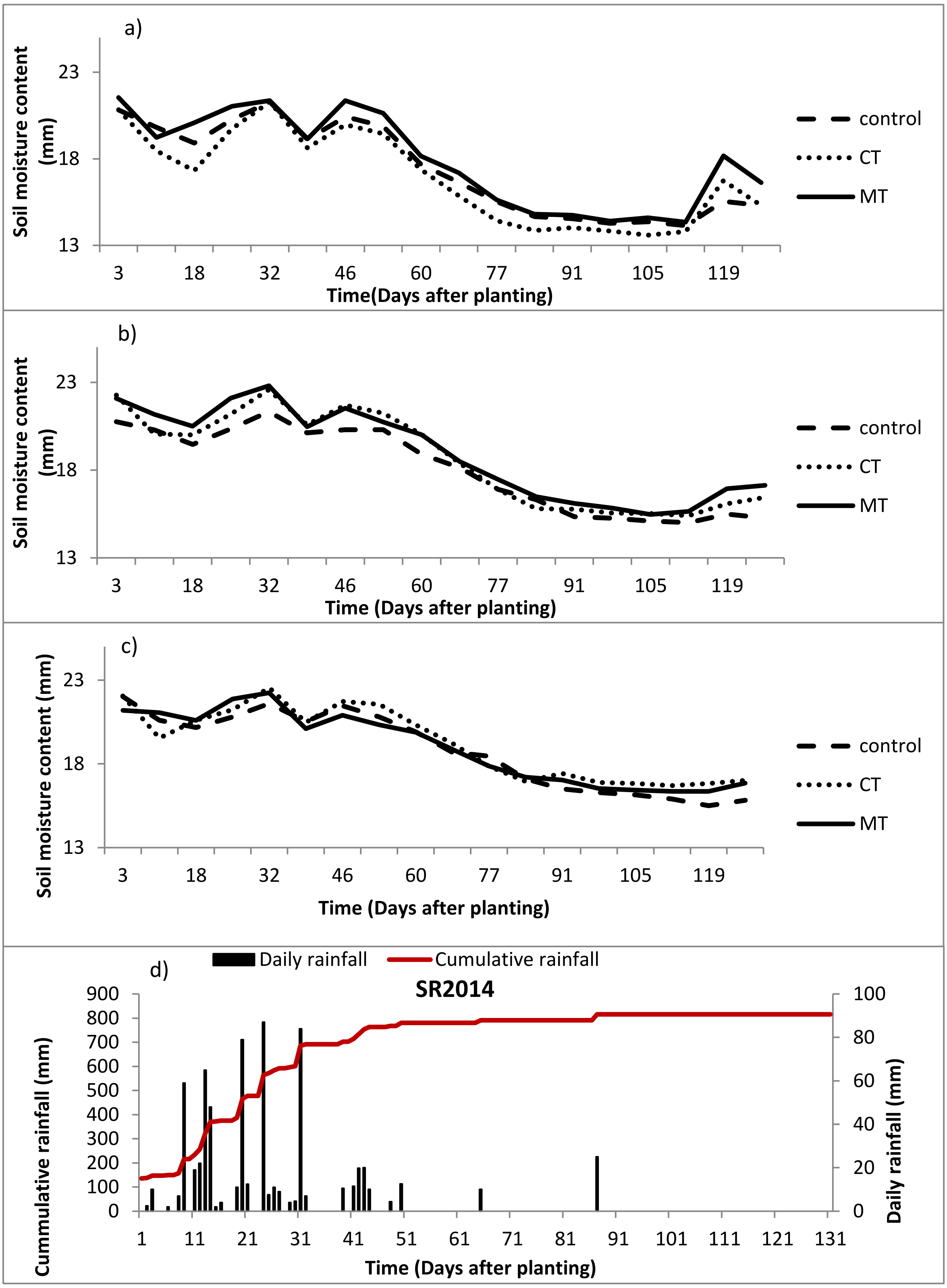

Figure 4. 5: Soil moisture changes under conventional (CT), minimum (MT) tillage and control in 0-30 cm soil profile, a) 10 cm depth, b) 20 cm depth, c) 30 cm depth and d) Daily and cumulative rainfall during short rains 2014 season in Kirege.

Within 0.20 m where the two tillage methods, minimum and conventional, recorded a higher soil moisture content than the control and 0.30m depths where they barely differed with the control. During the dry period, water content in the soil profile decreased over time under all the treatments. Within the top 0.10 m depth of the soil profile, conventional tillage followed closely by control experienced faster decline in soil moisture than minimum tillage. However, soil profile under both minimum and conventional showed similar trends in moisture decline as the control within 0.20 m and 0.30 m depths. In all the three depths there was no significant ($p \geq 0.10$) difference among treatments.

Results of singular effect of mulching during the long rains 2014, showed that soil water content remained higher, ($p=0.1052$), in the treatment without residue than the residue treatment within the 0.20 m depth as opposed to within 0.10 and 0.30 m depths where the two treatments showed similar trend (Figure 4.6 a, b, c).

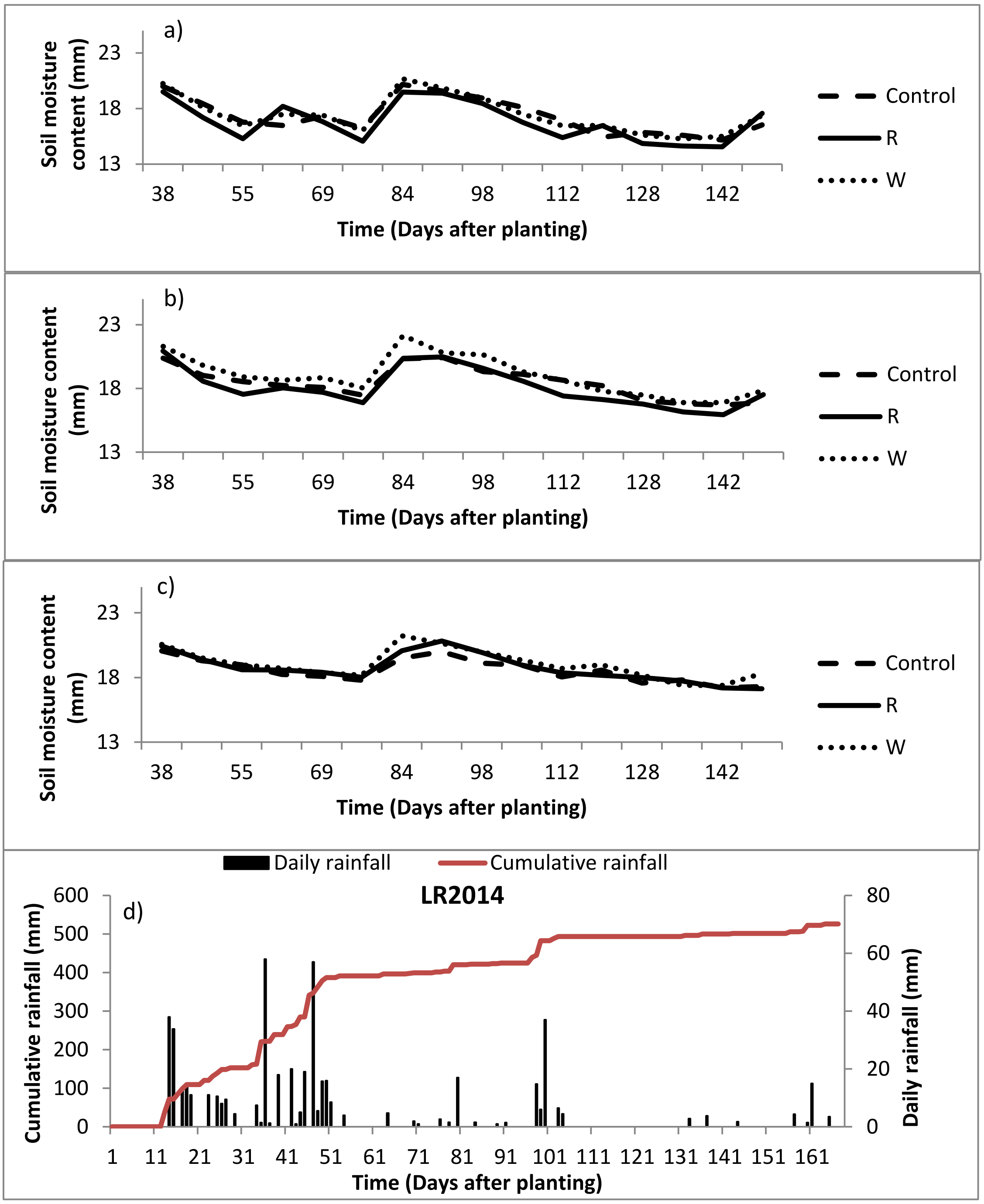

Figure 4. 6: Soil moisture changes under residue (R), without residue (W) and a control in 0-30 cm soil profile, a) 10 cm depth, b) 20 cm depth, c) 30 cm depth and d) Daily and cumulative rainfall during the long rains 2014 season in Kirege

In short rains 2014, moisture content of the soil profile (Figure. 4.7 a, b, c) closely followed the seasonal rainfall pattern (Figure 4.7d).

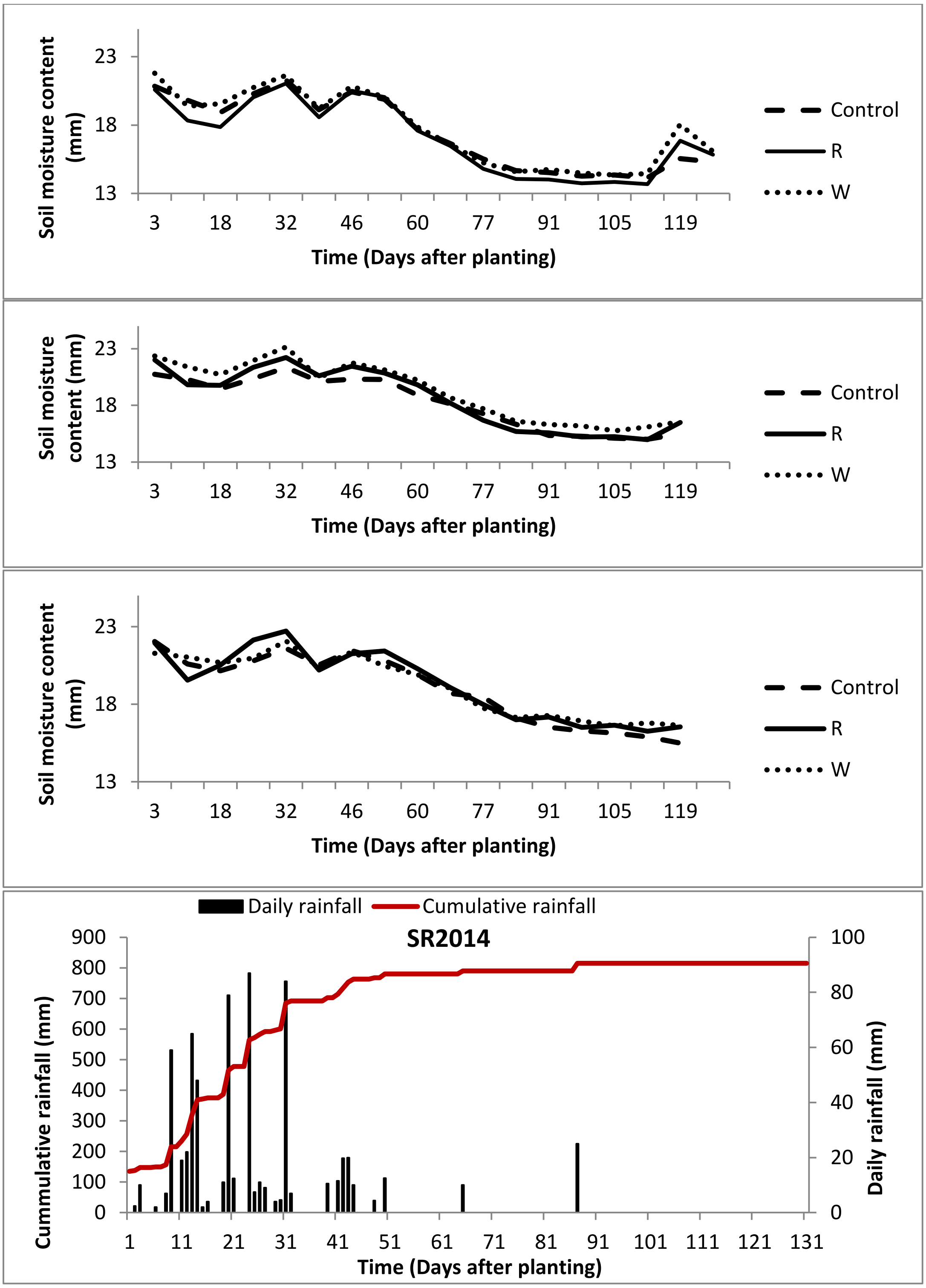

Figure 4. 7: Soil moisture changes under residue (R), without residue (W) and a control in 0-30 cm soil profile, a) 10 cm depth, b) 20 cm depth, c) 30 cm depth and d) Daily and cumulative rainfall during the short rains 2014 season in Kirege

Though not significant (p=0.1052), soil water content differed between treatment with residue mulch, those without residue and the control (Figure 4.7a, b, c). Both residue and without residue treatments started with an increase in soil water content in the top 0-0.30 m soil depth (Figure 4.7a, b, c), suggesting some initial water harvesting until the third day after planting. Thereafter, soil moisture fluctuated in all treatments from the fourth day after planting as influenced by the rainfall events. During dry period of each season which started at 46 days after planting, there was faster decline in soil moisture under without residue treatment than under the residue treatment, within the 0.30m depth. However, soil profile with or without residue, showed similar trends in moisture decline as the control within 0.10 and 0.20 m depths. At the end of the season there was less moisture under residue than under without residue treatment at all depths.

Each season was characterized by a period of water accumulation (wet period) and a period of water depletion (dry period) in the soil profile. With reference to rainfall pattern during the two experimental seasons (Figure 4.1), much of the rains were received in the first half of the season while for the rest of the season, dry periods dominated. During water accumulation period early in the seasons, soil water content increased due to the influence of rainfall and larger values of soil moisture content were recorded in minimum and conventional tillage without residue following rainfall events within the top 0.20 m depth (Figure. 4.2a, b, c and 4.3a, b, c). There was better rainfall capture without than with mulching following rainfall events.

These results could be explained by the observation made by Bescansa *et al.* (2006) that higher soil moisture content cannot solely be associated with mulching. Moraru and Rusu (2013) observed that penetration of the rainwater and consequent increase of the water storage in the soil profile is influenced by several factors like amount and intensity of rainfall in addition to the soil qualities that are closely interdependent and influenced by tillage system, soil texture and compaction. Mulching with organic materials serves as a barrier to runoff. Nonetheless, for some soils mulch does not substantially decrease runoff but drastically reduces soil erosion since runoff water is filtered through the mulch and is often clear with little sediment (Acharya *et al.*, 2005). This filtered sediment could result to pore-sealing in mulched treatments and hence low infiltration. Ogban *et al.* (2008) on observing low infiltration rate in the mulch incorporated plots attributed the results to pore sealing and surface crusting. Thus, low soil moisture observed under residue treatment compared to the one without residue after rainfall events, could be linked low infiltration rate resulting from pore-sealing in residue treatment.

However, as the season progressed and especially after the wet period, total soil moisture changes were characterized by gradual decline in all the treatments but the decline was faster in treatment without residue than the one with residue (mulched) and in conventional tillage than in minimum tillage. According to Acharya *et al.* (2005), mulching reduces evaporation from the soil surface by retarding the intensity of the radiation and wind velocity on the mulched surface. This explains why soil moisture decline was faster in treatment without residue than the one with residue. Because of the improved aggregate stability and improved soil structure associated with minimum tillage, a higher proportion of mesopores is achieved. Bassett *et al.* (2010) observed that, minimum tillage results to greater plant available water of the soil as opposed to conventional tillage where the mechanical inversion of the soil during tillage creates macropores and increases soil porosity. As such, conventional tillage in this study enhanced faster decline of soil moisture in the top soil during the dry period.

The faster decline in soil moisture under minimum tillage without residue in comparison to minimum tillage with residue, could also be due was continuous withdrawal of water by the developing crop and by the end of the growth period, the soil had been dried at least affecting the top 15 cm profile (Bescansa *et al,* 2006). Furthermore, maize yields were highest under the same minimum tillage without residue treatment indicating that the soil moisture conserved was available to the crop for accumulation of biomass that was later converted into grain. The soil moisture content, within the top 0.10 m depth of the soil profile, was highest for minimum tillage with residue and minimum tillage without residue treatments by the end of the experiment. Since there was no significant difference (P=0.1003) in terms of soil water content at the end of the experiment between minimum tillage with residue and minimum tillage without residue, it is an indication of a greater tillage effect than mulching effect on soil water content in the short-term.

Considering the singular effect of tillage (figure 4.4 and 4.5), both minimum and conventional tillage did not show significant ($p \geq 0.10$) influence on soil water content observed in the top 0-0.30 m of the soil profil. However, minimum tillage treatment had the highest soil water content during the period of soil moisture decline in both seasons, when the crop was at a moisture sensitive stage (flowering). Regardless of the sporadic periods of soil profile refilling in response to rainfall received during dry period, there was a decline in soil water content between 84 and 100 days after planting in both seasons. This decline in soil water in the top 0-0.30 m could have been a result of water extraction by the maize crop. This period coincided with grain development stage of the maize crop when the demand for water by the crop could be substantial leading to increased water extraction from the soil. Thierfelder and Wall (2009) highlighted that, most of the plant roots are usually in the surface horizons and for the maize crop despite the roots having been observed to penetrate to about 750 mm, much of the water used by the plants was accessed within 0-0.30m of soil depth.

Result for independent effect of mulching (Figure 4.6 and 4.7) showed that, neither residue retention nor the Without residue treatment had significant ($p=0.1052$) influence on soil water content in the top 0-0.30 m soil profile in both long and short rains 2014. In both seasons, the rate of drying of the soil was slow under residue retention at 0.30 m, resulting to water availability for relatively longer period during crop growth and development. Soil moisture conservation at lower depth might have been useful to maize crops during grain filling, even though rainwater was not available to the crop. This might have had positive effect on maize yield, which agrees with the findings of Charkraborty *et al.* (2008). Less soil moisture content under mulching indicated extraction of water to the maximum possible extent by the maize roots, demonstrating that crop residue conserved the soil moisture for the best use by the crop. Depletion of moisture from deeper layers was more and faster under without residue treatment probably due to upward flux of water to the drier layer above due to evaporation pull

Overall, the effect of tillage and mulching on soil moisture content may not be clear in the short-term, but there was an indication of a positive response to minimum tillage with or without mulching over time as also concluded by Enfors *et al.* (2011).

Similarly, Rockstrom *et al.* (2009) after a study in semi-arid and sub-humid locations in East and Southern Africa, concluded that minimum tillage resulted to increased water productivity, even with little or no crop residue mulch. Furthermore, according to Giller *et al.* (2009), the beneficial effects of mulching may not sufficiently offset the negative effects of minimum tillage especially during the initial years (<10) of minimum tillage. This observation by Giller et al. (2009) was for the characteristic soils widespread throughout sub-Saharan Africa. Thus, in the short-term tillage had greater influence on soil water conditions than crop residue which agrees with Bescansa *et al.* (2006).

4.4. Effects of tillage and mulching on soil organic carbon

Table 4.4 shows the combined effects of tillage and mulching on soil organic carbon content of the topsoil (0 - 0.20 m). There were no significant differences in soil organic carbon content between the treatments, at the beginning of the experiment. However, soil organic carbon content increased in all treatments tested by the end of the experiment.

Table 4. 4: Soil organic oarbon (%) as affected by tillage and mulching interaction at the beginning and end of the experiment, during long rains 2014(LR14) and short rains 2014 (SR14) in Kirege

	Soil Organic Carbon (%)			
Treatment	**Begn of exp**	**End of exp**	**Change**	***t* value**
CTR	1.65^{a}	1.84^{ab}	0.19	0.17
CTW	1.56^{a}	1.75^{ab}	0.19	0.37
Cntl	1.60^{a}	1.60^{bc}	0.00	0.99
MTR	1.84^{a}	2.25^{a}	0.41	0.15
MTW	1.82^{a}	1.89^{ab}	0.06	0.70
LSD	0.51	0.42		
P	0.65	0.03		

(Begn of exp=Beginning of experiment, End of exp=End of experiment, CTR=Conventional tillage with residue; CTW=Conventional tillage without residue; MTR= Minimum tillage with residue; MTW= Minimum tillage without residue; Cntl=Control). Same superscript letters in same column denote no significant difference between treatments.

The increase in soil organic carbon was highest in minimum tillage with residue followed by conventional tillage with residue, conventional tillage without residue and minimum tillage without tillage (Table 4.4). Significantly higher (p=0.0336) soil organic carbon was recorded at the end of the experiment, under minimum tillage with residue treatment in comparison to the control (Table 4.4). However, soil organic carbon measured in the 0 – 0.20 m layer of the Humic nitisol in Kirege, did not reveal any significant (p>0.1) treatment-induced change at the end of the experiment (Table 4.4).

Results for the singular effect of tillage showed that, at the beginning of the experiment there was no significant (p=0.4489) difference in percentage soil organic carbon between conventional tillage and minimum tillage in the 0.20 m layer of the soil (Table 4.5). However, at the end of the experiment, soil organic carbon was significantly (p=0.0172) different between conventional tillage and minimum tillage whereby a significant (p=0.01) increase in soil organic carbon was observed under minimum tillage. Soil organic carbon decreased by 0.04% under conventional tillage by the end of the experiment.

Table 4. 5: Soil organic carbon (%) as affected by tillage at the beginning and end of the experiment, during long rains 2014 (LR14) and short rains 2014 (SR14) in Kirege

Treatment	**Begn of exp**	**End of exp**	**Change**	***t* value**
CT	1.64^a	1.60^b	-0.04	0.67
MT	1.70^a	1.92^a	0.22	0.01
LSD	0.16	0.26		
p value	0.45	0.02		

(CT=Conventional tillage; MT=Minimum tillage) Same superscript letters in the same column denote no significant difference between treatments.

Table 4.6 shows the singular effects of mulching on soil organic carbon content of the top 0.20 m layer of the soil. Soil organic carbon measured at the beginning and end of the experiment did not reveal any significant ($p>0.1$) differences between residue and without residue treatments in the top 0.20 m of the soil. However, an increase in soil organic carbon was observed under residue and without residue treatment at the end of the experiment. Despite soil organic carbon content (actual) being greater in residue treatment at the beginning and end of the experiment, the increase (change) observed in without residue treatment was higher (Table 4.6).

Table 4. 6: Soil Organic Carbon (%) as affected by mulching at the beginning and end of the experiment, during long rains 2014(LR14) and short rains 2014 (SR14) in Kirege

Treatment	**Begn of exp**	**End of exp**	**Change**	***t* value**
R	1.70^a	1.76^a	0.05	0.67
W	1.63^a	1.75^a	0.13	0.06
LSD	0.16	0.26		
p value	0.18	0.96		

(R= Residue; W= without residue) Same superscript letters in the same column denote no significant difference between treatments.

Considering the low pH (4.75) of the soils in the study site, the general increase in soil organic carbon values at the end of the experiment suggests that the prevailing soil reaction was not favourable for accelerated microbial decomposition of organic matter in the soil. Such a condition allowed appreciable treatment-induced differences in soil organic carbon in the short-term. Generally, conventional tillage is associated with a decline in soil organic carbon (La Scala *et al.*, 2008; Lal *et al.*, 2007; Eynard *et al.*, 2005). Nonetheless, in some climates it can place crop residues at a depth in the soil where decomposition proceeds at a slower rate than that observed for surface soils or may also enhance organic matter association with soil clay and silt particles and thus encourage aggregation and consequently organic carbon storage (Thierfelder *et al.*, 2013). This explains the comparable soil organic carbon content between conventional tillage with residue, minimum tillage without residue and minimum tillage with residue treatments, which is consistent with Mupangwa *et al.* (2013) and Paul *et al.* (2013) findings.

In comparison to the control, significantly (p=0.0336) higher soil organic carbon content was recorded under minimum tillage with residue at the end of the experiment. This could be attributed to the decomposing maize residues which were applied every growing season as mulch after planting. This agrees with Obalum *et al.*, (2011), who concluded that crop residue is a major source of soil organic carbon which in turn is an important indicator of soil quality because it influences all the indices of soil productivity including fertility. Mostly, carbon accumulates in the first horizons on the conservation agriculture treatments, as highlighted by Giller *et al.* (2009). In this study, there was relatively more soil organic carbon in minimum tillage with residue, suggesting that organic matter originating from surface crop residue was slowly being incorporated into the soil by biological processes such as microbes, earthworms and termites (Baker *et al.*, 2007). The metabolic activities of the organisms in the soil under minimum-tillage leads to stabilized soil organic carbon resulting from increased fungal-mediated improvement in soil structure and the deposition of fungal-derived carbon macro-aggregates (Thierfelder *et al.*, 2013).

Soil organic carbon enhancement under minimum tillage with residue, may also be attributed to an increase in labile carbon pools resulting from less soil disturbance and residue retention, which is in line with Kahlon *et al.*, (2013) observation.

Although it is generally recognized that minimum tillage and mulching conserves soil and water, saves energy, improves the environment and enhances soil quality (Acharya *et al.,* 2005; Chakraborty *et al.,* 2008; Mrabet *et al.,* 2012; Johansen *et al.,* 2012; Dube *et al*., 2012; Palm *et al.,* 2014; Vanlauwe *et al.,* 2014), the direction and magnitude of mulch and tillage-induced changes vary with soil type, location and climate (Singh Kahlon *et al.,* 2013).

The statistically insignificant ($p>0.1$) change in soil organic carbon, in response to the combined effect of tillage and mulching at the 0–0.2 m soil depth was most likely due to the short-term implementation. Although there was an increase in soil organic carbon content in all the treatments by the end of the experiment, the quantity of soil organic carbon impacted by the various treatments (change) was small relative to the pool of soil organic carbon already present in the soil (at the beginning of experiment), which agrees with the results of Al-Kaisi *et al*. (2005).

The increase in soil organic carbon in the minimum tillage treatment is attributable to less oxidation of in-situ organic matter due to the absence of tillage. Ghuma and Sur (2001) on observing similar results highlighted that organic carbon content in soils that are managed with minimum rather than conventional tillage is usually higher. On the other hand, a decrease in soil organic carbon under conventionally tilled soils in this study agrees with the observation that soil cultivation generally results in a decline in soil organic carbon, by Obalum *et al*. (2011). La Scala *et al*. (2008) highlighted that tillage stimulates soil carbon losses by increasing aeration, changing temperature and moisture conditions, and thus favouring microbial decomposition. The weak residue effect on soil organic carbon may be attributed to the short-term implementation of mulching hence the soil organic carbon content impacted by this treatment is small relative to the initial soil organic carbon already present in the soil.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of findings

The findings of this study showed that tillage and mulching can have an effect on maize yield over time. The combined effect of tillage and mulching led to an increase in both stover and grain yields. Conventional tillage combined with mulch treatment gave the highest increase in stover yield compared to both conventional and minimum tillage without mulch. Thus mulching had a greater impact on stover yields than tillage. Minimum tillage with and without mulching increased grain yield compared to control. Thus minimum tillage with and without mulching is the best approach for increased maize grain production especially in the event of low but well distributed rainfall as opposed to erratic rainfall.

The study showed that in the short term, tillage and mulching do not affect soil water. Soil water content was positively influenced by tillage in combination with mulching. On average, minimum tillage with and without mulching recorded higher increase in soil moisture content compared to control, than both conventional tillage with and without mulching. Since minimum tillage in combination with mulching recorded the highest soil moisture content, it is best-fit for improved moisture content of the Humic nitisols compared to conventional tillage practices irrespective of the rainfall received.

Mulching alone did not affect soil carbon contents, while tillage did. Minimum tillage increased soil organic carbon contents while conventional tillage led to the reduction, at 0-0.20 m soil depth. This suggests that, switching from conventional tillage to minimum tillage improves soil organic carbon content.

5.2 Conclusion

The results of the two seasons experiment show significant impacts of minimum tillage and mulching on maize yields while indicating positive influence on soil moisture and improved soil organic carbon content of the Humic Nitisol in Tharaka-Nithi County. Therefore, in conclusion, short-term implementation of minimum tillage and mulching under the soil and climate conditions prevailing in Kirege

Tharaka-Nithi County enhances production, soil moisture content and improves soil conditions through carbon sequestration.

5.3 Recommendations

From the findings of this study, the following are recommended;

- Minimum tillage can be promoted for adoption by farmers in Kirege Tharaka-Nithi County for increased maize production.
- It is possible to improve soil moisture content through minimum tillage and mulching as surface management practices under the soil and climate conditions prevailing in Kirege Tharaka-Nithi County.
- Minimum tillage and mulching can lead to increased carbon sequestration under the soil and climate conditions prevailing in Kirege Tharaka-Nithi County.

5.4 Areas of further research

Further research is recommended on: long-term studies on the effects of mulching and tillage on maize yields, soil organic carbon and soil moisture content, under the soil and climate conditions prevailing in Tharaka-Nithi County; assessing the potential of minimum tillage and mulching to not only increase but also stabilize maize yields in Tharaka-Nithi County and evaluating the effects of mulching on water use efficiency of maize in Tharaka-Nithi County.

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