SOIL MOISTURE CONSERVATION, CROPPING SYSTEMS AND SOIL FERTILITY EFFECTS ON SOIL AND MAIZE PERFORMANCE IN MACHAKOS COUNTY, KENYA

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MAY, 2019

DECLARATION

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

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I dedicate this Thesis to my loving husband Dr. Laban Mutwiri Muriithi (PhD) and dear son, Wise Munene Mutwiri for their prayers, moral support and encouragement. It’s a journey that we have walked together successfully.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASALs	Arid and Semi - Arid Lands
CAN	Calcium Ammonium Nitrate
DEAP	District Environmental Action plan
FAO	Food Agricultural Organization
FYM	Farm Yard Manure
GDP	Gross Domestic Product
GOK	Government of Kenya
GRIWAC	Gansu Research Institute for Water Conservancy
ICRAF	International Centre for Research on Agro-Forestry
KALRO	Kenya Agricultural and Livestock Research Organization
KNBS	Kenya National Bureau of Statistics
LGP	Length of Growing Period
LSD	Least Significant Difference
LR	Long Rains
RCBD	Randomized Complete Block Design
SR	Short Rains
SSA	Sub Saharan Africa
TSP	Triple superphosphate
UNCCD	United Nations Convention to Combat Desertification

ABSTRACT

The main causes of food insecurity in semi–arid parts of Kenya are low soil fertility, low and unreliable rainfall. These two causes are the main challenges facing small-scale farmers in food production especially in semi-arid areas of the country. To overcome these challenges, soil and water management technologies especially those in soil and water conservation need to be embraced. The aim of the study was to determine the effect of tied ridges, fertilizers and cropping systems on soil properties (moisture, pH and organic carbon), growth and yield parameters of maize; and to identify the most cost effective water and soil management technology. This study was carried out in four seasons at Katumani in Machakos County. The experiment was a 2 x 4 x 2 factorial, laid out in a randomized complete block design (RCBD). The treatments were: tied ridging, flat bed planting, farm yard manure 0 t/ha, farm yard manure 5 t/ha, nitrogen fertilizer 20 kg/ha, farm yard manure 5 t/ha + nitrogen fertilizer 20 kg/ha, maize mono crop and maize cowpea intercrop. Data collected included soil moisture content, soil pH, total organic carbon, growth parameters and maize yield. The results showed that, treatments with flat bed planting in maize mono crop significantly increased soil moisture content at 0–20cm depth as compared to tied ridging in maize cowpeas intercrop during short rains 2015. Application of farm yard manure at 5 t/ha increased soil moisture content at 2 and 4 weeks after planting. The soil moisture content ranged from 6.30% to 23.80%. During the short rains 2015, maize mono crop significantly increased vegetative growth in comparison to maize cowpeas intercrop. Treatment with flat bed and 20 kg N/ha in maize mono crop had the highest mean for vegetative growth. However, during the long rains 2016, treatment with tied ridging and 20 kg N/ha in maize mono crop registered the highest mean for vegetative growth. During the short rains 2015, treatments with maize mono crop significantly increased grain yield with a range of 1.35 t/ha 3.59 t/ha. Flat bed planting with farm yard manure 5 t/ha in maize cowpea intercrop significantly increased the grain yield by 165.93%. The harvest index during the short rains 2015 ranged between 0.35 and 0.48. Treatments with maize mono crop significantly increased gross benefit, net profit, gross margin and cost benefit ratio during short rains 2015 and long rains 2016. Application of farm yard manure 5 t/ha + 20 kg N/ha had the highest variable cost. The cost benefit ratio was positive during the short rains 2015 with a range of 1.47–2.98. The yield differences among the four seasons could have been as a result of variations/distribution in rainfall amount, soil moisture content and soil fertility as induced by the treatments. Flat bed planting increased the yields during the short rains 2015 when the amount of rainfall was high whereas tied ridging resulted in improved yields during short rains 2014, long rains 2015 and 2016 when rainfall amount was low. For the farmers to maximize yields and profits in the study area, adoption of flat bed planting with farm yard manure 5 t/ha and maize cowpeas intercrop during the seasons of high rainfall could be appropriate treatment combination according to the findings of this study. However, during seasons with low rainfall, tied ridging with 20 kg N/ha and maize mono crop could be recommended for adoption. Also, variations in seasonal rainfall should be considered when integrating different soil and water management practices because the effectiveness of different technologies vary with the seasons. Farmers in Machakos County may have to consider use of supplementary irrigation during the dry spells to increase soil moisture.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

In Sub - Saharan Africa (SSA), food insecurity is a threat and will persist to be so for a long time unless changes are effected to the present trends of food production (SDSN, 2013). About 95% of the world's population is found in the developing countries where the rural economy relies on rain-fed agriculture (Rockstrom *et al.,* 2003). In semi-arid and dry sub- humid Sub Saharan African countries, more than 95% of the agricultural farm land is rain-fed hence, and there is a likelihood that, farmers in these regions will continue to depend on rain-fed agriculture for future crop production (Classens *et al*., 2012).

The climatic zones in SSA normally have limited water availability with an annual average rainfall of between 300 to 900mm while the potential evapotranspiration is 1.5 to 4 times higher than precipitation. This makes the amount of water in the root zone usually rather limited. As a result, this reduces the variety and quantity of crops produced by the small-scale farmers. The low and unreliable rainfall together with low use of production inputs has led to low crop yields and food insecurity (Barron, 2005). The low crop yields are also linked to inadequate and extreme fluctuations in the availability of water required for plant growth. The impact of erratic rainfall on crop yield is important and therefore, efficient rain water management could be a major solution in the semi-arid areas (Haibu *et al.,* 2006).

Most regions of SSA have low crop production. This is mostly attributed to low nutrient availability as a result of continuous cropping and inadequate use of fertilizer rates (Breman *et al.,* 2001). In order to attain sustainable household and regional food security in these areas, it is important to increase crop production through application of external nutrient inputs. However, in most cases this is not within the reach of small scale farmers (Vanlauwe *et al.,* 2010). The small scale farmers apply inadequate inputs, which result to quick depletion of nutrients in the soil. In order to minimize the effect of these challenges, adoption of integrated soil fertility and water management (ISFWM) needs to be embraced by small scale farmers in arid and semi-arid lands.

Semi-arid areas are characterized by temporal and spatial variability of rainfall resulting to risk of serious drought (Demeke, 2003; Snyder and Tartwski, 2006). The annual total rainfall ranges between 200 and 600mm, with potential evapotranspiration of 5-8mm/day. The semi-arid environments are susceptible to hazards that affect agricultural production. In addition, the infiltration rates are low due to surface sealing and low organic matter content (Rockstrom *et al.*, 2003). This reduces the yields by up to 75% (Barron *et al.,* 2005). As a result, farmers in these regions have developed strategies to reduce risks and guard themselves against unfavorable weather conditions (Cooper *et al.*, 2008).

In most semi-arid areas, agricultural output and productivity is usually low due to unsustainable land use practices and low adoption of appropriate natural resource management technologies. Some of the land management practices which can improve agricultural production in semi-arid areas include: mulching, contours and tied ridges, cover cropping, application of organic and inorganic fertilizers. However, in Machakos County, the level of adoption of these land management practices is below the optimal levels (Manyatsi *et al.,* 2011). According to Mutuku (2017), only 21.4% of house hold heads in Machakos County have adopted land management practices. Kathuli *et al.,* (2014) also reported that, there is poor management of soils by small scale farmers in this region as a result of low adoption levels of natural resource management technologies. In order to improve crop production in Machakos County, interventions such as contour bunds, semi-circular bunds, water bunds, spreading basins and road run-off harvesting have been used (GoK, 2010).

Soils in semi–arid eastern Kenya are low in fertility (Macharia *et al.,* 2010). This has led to very low crop yields even when the rainfall is non–limiting. The decline in soil fertility has been attributed to continuous cultivation without adequate addition of nutrients in addition to nutrient loss through erosion and leaching (Gachimbi *et al.,* 2005). Therefore, there is need to come up with appropriate soil and water management practices to conserve the available soil moisture in these areas.

Tied ridging is one of the options proposed to increase surface water storage. Use of tied ridges has been reported in various studies in different regions. According to Heluf (2003) some of the studies reveal problems and failures, while others suggest great success. The success of tied ridges as a water conservation method is during low rainfall seasons. Studies done by Heluf (2003) in the semi-arid areas of Eastern Hararghe on the effects of moisture conservation on maize and sorghum crops revealed yield increase of up to 37% due to water conservation practices. Gicheru *et al.* (1998) as cited by Karuma *et al.,* 2014 reported that, tied ridges conserved the lowest amount of water in Laikipia District, Kenya and related this to the high evaporation losses as a result of exposed soil surface. Other studies indicating the failure of tied ridges were done by Asmare (2012) in Ethiopia who reported that, tied ridges and flat bed planting had no significant effect on the soil moisture content in all soil depths. Karuma *et al.* (2014) who worked in Machakos County observed that, tied ridges conserved the lowest amount of soil water during the long rains of 2013.

Farmers in Machakos County have experienced declining crop yields in recent decades. The average maize production is less than 0.5 t/ha which is only $^{1}/_{3}$ of the expected potential (NEMA, 2013). The population growth rate in Machakos County is high. The current population is estimated at about 1.1 million people from 264,500 households and with an annual population growth rate of 1.7% (KNBS, 2018). Consequently, there is increased demand for food consumption and increased chronic food insecurity is a common phenomenon (NEMA, 2013). The food security situation is worsened in this County by the continued poor crop performance due to inadequate rainfall. The County experiences erratic and unpredictable rains (less than 500mm annually) (NEMA, 2013).

1.2 Statement of the Problem

In Machakos County, the main factors limiting crop production include low soil moisture and inadequate nutrients in soils. The insufficient soil moisture is as a result of low and unreliable rainfall while the low soil fertility could be attributed to continuous cropping without soil fertility replenishment. In addition, most parts of the County have undulating topography with steep elevation which accelerates soil erosion and water loss through run off. Consequently, the little available water for crop use is lost from the crop land. This has led to low crop yields hence food insecurity for the ever growing human population. The poverty levels in this County are high (59.6%) against a national average of 47.2%. The County is ranked position 33 out of 47 Counties in reference to poverty. In order to address the low agricultural production, there is need to come up with interventions which can improve infiltration of water into the soil during the rainy season so as to make maximum use of the rain water.

Most of the past studies in Machakos County focused on a single water harvesting technology without integration with soil management practices. In addition, there is limited knowledge on the interaction of different soil and water management practices and their effects on crop production. A lot of efforts have been made in breeding improved crop varieties but this has not succeeded in achieving the expected potential in crop production.

As much as farmers have carried out soil fertility amendments through application of both organic and inorganic fertilizers, little attention has been paid on their effects on the soil properties. Also, information on economic performance of the various soil and water management practices is inadequate. This could make the farmers inconsistent in carrying out soil and water conservation practices in each season. The effectiveness of different soil and water management practices is affected by variations in seasonal rainfall creating a need to identify appropriate technologies. Due to variability of rainfall in arid and semi-arid areas, identification and recommendation of specific soil and water management practices remains a challenge, hence need to develop tailor made practices for Machakos County.

1.3 Research Objectives

The main objective of this study was to determine the effect of tied ridges, fertilizers and cropping systems on soil moisture content, organic carbon, pH and maize grain yields as well as to evaluate the profitability of different soil and water management practices in Machakos County.

The specific objectives of this research were to:

(i) Determine the effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on soil moisture content in different soil depths.

(ii) Evaluate the effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on growth parameters and yield of maize.

(iii) Determine the effect of farm yard manure, nitrogen fertilizer and cropping systems on soil pH, organic carbon and crop nitrogen content.

(iv) Evaluate the profit margin of different soil and water management practices in maize yields.

1.4 Research Hypotheses

The research hypotheses of this study were:

(i) $H_{0:}$ Tied ridges, farm yard manure, nitrogen fertilizer and cropping systems have no significant effect on soil moisture content in different depths.

(ii) $H_{0:}$ Tied ridges, farm yard manure, nitrogen fertilizer and cropping systems have no significant effect on growth parameters and yield of maize.

(iii) $H_{0:}$ Farm yard manure, nitrogen fertilizer and cropping systems have no significant effect on soil pH, soil organic carbon and crop nitrogen content.

(iv) $H_{0:}$ There are no significant economic implications of using different soil and water management practices in maize production.

1.5 Conceptual Frame work

The major problems in Machakos County are low maize production, food insecurity, water scarcity, poverty and soil fertility decline (Figure 1.1). This is due to unreliable rainfall and inappropriate farming practices. Climate variability affects rainfall intensity, frequency, spatial and temporal distribution. As a result, this in turn speeds up soil erosion and finally soil nutrient loss. High temperatures due to climate variability increases oxidation of organic matter affecting soil aggregate stability. The reduced soil aggregate stability makes soil highly vulnerable to erosion and finally leads to nutrient loss. These factors work together to lower agricultural productivity.

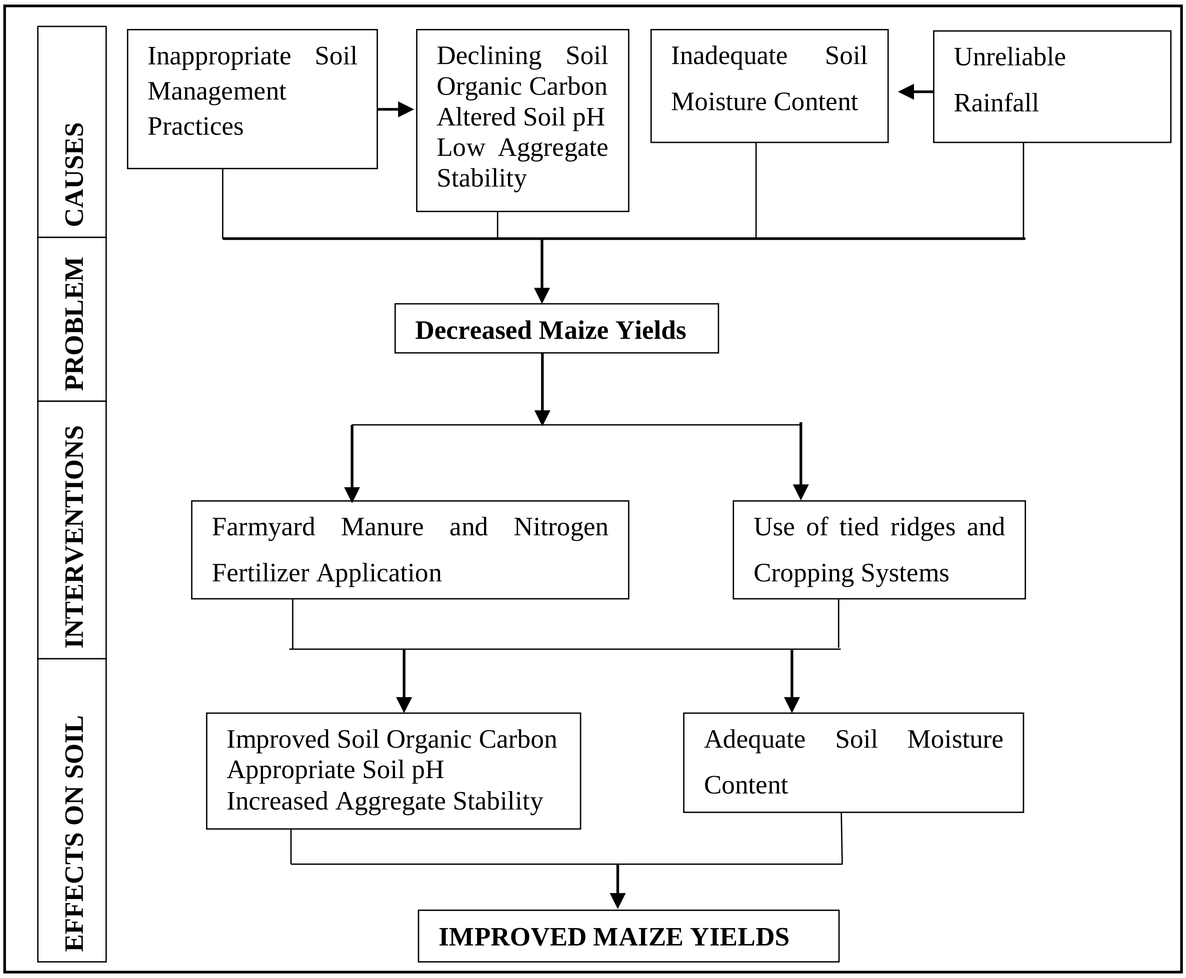

Figure 1.1 Conceptual framework showing the effects of soil and water

Inadequate soil moisture and low soil fertility in Machakos County are portrayed in low maize yields. By integrating various soil and water management practices it is expected that, soil moisture content and soil properties will be improved. This will lead to improved maize yields. In addition, determining the profitability of different soil and water management practices will help the farmers in choosing the best cost effective technology to adopt. To overcome these challenges, there is need for proper understanding of good soil and water management practices based on their interactions with rainfall. This may increase maize production and reduce poverty levels in Machakos County.

1.6 Significance of the Study

The results of this study will provide guidelines on integration of different soil and water management practices (tied ridges, farm yard manure, nitrogen micro-dosing and cropping systems). This will probably lead to increased yields and make the livelihoods of the small scale farmers better. In view of Kenya Vision 2030; regarding food production increase, this study may contribute to food security.

Information on the effects of various treatments on the soil properties will guide the farmers on use of most appropriate soil management practices which will maintain optimum soil properties. Economic analysis will assist the farmers in making sound production choices which will maximize the profits. The research is expected to contribute to suitable, sustainable and effective soil and water management practices aimed at increasing maize productivity in Machakos County. The findings will also contribute to scientific knowledge and give suggestion on viable coping mechanisms for future climate variability for farmers in the study area as well as contribute additional knowledge to research. The targeted beneficiaries will be farmers, policy makers, researchers in soil science and students/researchers.

1.7 Definition of Terms

Dry spell: A dry spell refers to two to four weeks long day without rainfall during the cropping period.

Cropping systems: Cropping systems refers to crops and crop sequences and the management technique employed in a particular field over a period of time.

Flat bed planting: Normal tillage without imposing water conservation structures

Tied ridging: Tied ridging is a water conservation practice that involves growing of crops on small ridges; established on the contour while blocking the furrows with cross –ties to retain rain water

Micro-dosing: Application of small quantity of mineral fertilizer together with seeds of the target crop in the planting hole at sowing or 2-4 weeks after sowing

Short rains: Short rains refer to cropping season which occurs between October and February in Machakos County

Long rains: Long rains refer to Cropping season which occurs between March and September in Machakos County

Growing period: Growing period is the duration of the year for annual crops when temperature, soil water supply and other factors permit crop growth and development.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Small scale farmers in semi-arid Sub-Saharan Africa (SSA) usually experience food shortages. This is due to declining crop yields, inadequate and extreme fluctuations in the availability of water for plant growth (Baron *et al.,* 2005). Water scarcity is more pronounced in semi-arid regions of SSA where agriculture is rain-fed and faces threat from frequent dry spells and drought (Rockstrom *et al.,* 2003).

Nyssen et al. (2009) stated that, nearly all tropical highlands face land degradation problems. In addition, inadequate plant nutrients due to land degradation are a major cause of low crop productivity and food insecurity (Samchez *et al.,* 2004). This is common where rain-fed agriculture is dominant. Failure by small scale farmers to intensify agricultural production in a manner that maintains soil productivity is the major cause of land degradation in Sub-Saharan Africa. Bossio *et al.* (2010) reported that, soil nutrient depletion and other forms of land degradation reduce water productivity, nutrient use efficiency and finally agricultural productivity.

Soil erosion is the major cause of nutrient loss especially where agronomic inputs are low and vegetation cover is scarce (Powlson *et al.*, 2011). Stolte *et al.*, (2009) reported that, soil erosion has a direct negative impact on the productivity of the land since soil, water and nutrients are lost. This means that, water conservation is an important aspect in crop production. Studies done by Baron (2005), Fofana *et al.*, (2003) and Snyman (2003) showed that, incorporation of soil fertility improvement measures make soil moisture conservation more profitable. Inadequate soil moisture content results to low crop yields (Stroosjder, 2009). Ineffective *in situ* soil and water conservation measures can lead to imbalanced soil hydrology (Araya, 2012). Proper soil and water conservation measures combined with appropriate soil fertility management practices can improve crop yields (Rockstrom *et al.*, 2010).

In semi-arid areas, massive runoff and soil erosion is a common occurrence in small scale farms resulting to decline in crop production (ICRISAT and UNEP, 1986). As a result, farmers realized that, failure to adopt appropriate water conservation techniques for rain-fed agriculture led to loss of rain water and frequent crop failures. To overcome these soil erosion challenges, several cost effective, indigenous soil and water conservation techniques have been used in different areas (Wakindiki and Ben- Hur, 2002).

Soil impoverishment in Machakos County is as result of poor farming practices and high costs of inorganic fertilizers (Shisanya *et al.,* 2009). This has led to continued decline in soil fertility and land productivity. In addition, nutrient loss and water deficit especially at the plant root zone is an important factor that affects crop productivity (Bossio et al., 2010). Increased soil moisture storage at the root zone (*in situ* rain water conservation) technology reduces runoff and soil loss (Ngigi *et al.,* 2006).

2.2 Effect of Tied-Ridging on Soil Moisture Conservation

Soil moisture is one of the key factors that affect crop production because plants require adequate soil moisture. The quantity of water needed by crops may differ depending on the crop species and the stages of crop growth. Soils are able to store only limited quantity of water and only a small portion of this stored water is available for plant use (Goyal, 2007). Most arid and semi-arid regions encounter the problem of insufficient and unreliable soil moisture. In addition, there is high rate of evaporation during the growing period. Rain storms are usually experienced during the rainy season in semi-arid areas. Soils in these areas normally cannot absorb the quantity of water which falls in such a short time resulting to surface runoff (Justine *et al.,* 2003).

The prevailing climatic conditions in semi-arid regions require economic use of the limited quantity of rainfall as efficiently as possible. Water harvesting is one of the methods which can be used to make proper use of surface runoff. Another method is increasing infiltration and storage of rain water. When there is increased amount of water available for crops' use, this results to improved yields (Justine *et al.,* 2003). In arid and semi-arid regions, inadequate water is usually a serious limiting factor for vegetative growth.

In dry land areas, surface and ground water sources are usually too saline for irrigation. This leaves precipitation as the major source of water for plant growth (Xiao *et al.,* 2006). Establishment of vegetative growth is normally slow due to prevailing critical moisture stress conditions emanating from low and erratic rainfall. Some studies which were done in the dry sloping land of Sub-Saharan Africa indicated that, about 5-10% of the precipitation is lost as runoff while 45-50% is transpired by plants and 45-50% evaporates. In order to make maximum use of the available rainfall, there is need to adopt more efficient soil management practices which can retain surface runoff and reduce evaporation. Micro-catchment water harvesting and moisture conservation practices like mulching and tillage have been used to increase yields in crops like wheat, sorghum and trees (Zhang *et al.*, 2006).

Tied ridging is a water conservation method that entails growing of crops on small ridges established on the contour. The furrows are blocked with cross-ties in order to retain rain water (Twomlow and Bruneau, 2000). Tied ridges are physical soil and water conservation practice that when aligned parallel to the contour lines controls soil erosion and surface drainage (FAO, 2008). Imposing tied ridges enhances soil moisture conservation which improves crop production in arid and semi - arid regions (Jensen *et al.,* 2003, Motsi *et al.,* 2004, McHugh *et al.,* 2007, Araya and Stroosnijder, 2010).

In Eastern Africa, tied ridging has been a common practice for a long time (Baron *et al.,* 2005). In countries like Ethiopia, traditionally, tied ridging is usually done 4-6 weeks after planting maize in order to break the soil surface crusts and enhance infiltration (Biazin and Stroosnijder, 2012). Use of tied ridges has been practiced successfully in parts of Tanzania for a couple of years in marginal areas to conserve water (Dagg and Mac Carberry, 1986). In relation to soil and water conservation, tied ridges have the ability to substantially improve crop production. Maize yield with tied ridging in years with dry to near normal rainfall was improved by 42% even without addition of nutrient inputs (Jensen *et al.,* 2003).

Studies in the semi-arid Ethiopia have indicated that, tied ridges on slopes less than 3% reduced runoff by more than 75% compared with control practice. Tied ridges are more advantageous with less steep terrain and more permeable soils where they may increase capture and infiltration of water (Giller *et al.,* 2009). Biazin and Stroosnijder (2012) reported that, tied ridges enhanced rain water harvesting and improved maize production.

In areas where small scale farmers use hand implements or animal traction to grow low value subsistence crops, tied ridging has been reported to improve water infiltration and therefore it is considered as an effective soil and water conservation practice especially in arid and semi-arid regions (FAO, 2008). Tied ridges are more effective in terms of water infiltration in drier areas (< 1000mm rainfall per year) and on gentle slopes (< 7%) as compared to wet areas or humid areas (Araya and Stroosnijder, 2010). The effectiveness of tied ridging depends on soil type, slope, rainfall and design characteristics (Floor *et al.*, 2000). Njihia (1979) as cited by Karuma *et al.* (2014) who worked in Machakos County Kenya, reported that, use of tied ridges made it possible to produce maize in low rainfall years when flat planted crops gave no yields. In some parts of Botswana, use of tied ridges showed negative effects on productivity as a result of adverse weather conditions. According to DLFRS, (1984), the failures of the tied ridges may have been as a result of the higher soil temperatures created within the ridge. This may lead to negative impact on seed germination and shallow penetration of moisture into the soil as compared to that on flat soil when the rainfall is light.

2.3 Effect of Farm Yard Manure Application on Nutrient Availability and Soil Moisture Content

Farm yard manure constitutes litter (straw or other vegetable refuse), dung and urine from animals. The quality of farm yard manure varies depending on the composition of these components and the proportion in which they are present. The quantity of litter in the manure material determines the breakdown of the mixture and the final constituents of the farm yard manure produced (Chandy, 2010). When farm yard manure is applied to the soil, it leads to humus formation which enhances the formation of granular and crumby soil structure. The ability of farm yard manure to enhance formation of water stable aggregates has a major impact on soil structure and soil physical characteristics. Presence of increased percentage of water stable aggregates, increases infiltration, porosity and the ability of soil particles to hold water. In addition, it also minimizes compaction and soil erosion (Bloom *et al.*, 1999).

In sandy soils, the organic matter promotes the formation of soil granules which results to improved water and nutrient retaining capacity of the soils. Humus has the ability to impart black color to the soil making it to absorb increased amount of radiation. This helps to maintain suitable soil temperatures for microbial activities (Chandy, 2010). According to Bloom *et al.,* (1999), addition of farm yard manure to silt clay with high organic matter contents enhances macro-aggregation which inhibits structural degradation. Application of farm yard manure improves soil physical properties and reduces the energy required for tillage. It also promotes seedling emergence and crop root penetration. Reports by Nareeed *et al.* (2010) showed that, application of farm yard manure significantly reduced the soil bulk density and improved circulation of air in the soil, water holding capacity and porosity.

Shirani *et al.* (2002) reported that, total porosity of a soil increases with the incorporation of farm yard manure. Farm yard manure also facilitates water percolation and reduces soil crusting and compaction. In addition, it reduces surface run off during the initial stages of rainfall hence minimizing the rate of soil erosion (Biamah *et al.*, 2003). Application of farm yard manure leads to rapid increase in chemical activities of the soil. During the decomposition of farm yard, various organic acids are released and synthesized. The carbon oxide produced during the decomposition dissolves in water to form hydro carbonic acid. This makes the soil solution to become acidic for a short period (Chandy, 2010).

Abasi *et al.* (2007) as cited by Mubaraka *et al.* (2010) reported that, transformations of nitrogen in the soil are determined by the interaction of environmental, soil factors and the composition of the substrate. The C/N ratios play an important role in decomposition. Those plant and animal residues that have C.N ratios of 30:1 and above have little nitrogen to allow for rapid decomposition. This implies that, micro-organisms will take $NH4^{+}$ and $NO3^{-}$ out of the soil to facilitate decomposition; removing these elements from the soil. On the other hand, plant and animal residues with low C/N ratios (20:1 and less) have enough nitrogen for the micro-organisms to break down the residues without removing it from the soil (Goings, 1999).

Nahm (2004) observed that, decreasing the C/N ratio accelerates nitrogen mineralization rate. At C/N ratios below 15:1, he observed an increase in net mineralization and also discovered that organic materials with C/N ratio of 15:1 or more had a likelihood of causing net immobilization. Ghoshal (2002) reported that, application of farm yard manure improves the rate of supply as well as pool size of available nitrogen in the dry land. It also sustains the enhanced nitrogen pool throughout the annual cycle. Farm yard manure conserves nitrogen during the first phase of crop cycle. This decreases nitrogen loss and provides better synchronization of nitrogen availability and crop demand in the final stages of the growth cycle. According to Mohanty et al. (2010) nitrogen mineralization from crop residues is affected by the concentration of N, hemicelluloses, lignin and C/N ratio. They also observed that, the quality of farm yard manure depends on the type of crop residues used since their composition is different. Farm yard manure constitutes a complex of animal excreta and plant residues with different mineralization kinetics ranging from relatively resistant lignin to readily available NH_4^+ and volatile fatty acids.

The value of farm yard manure as a source of nutrient or soil amendment is known but the ability of farm yard manure to neutralize soil acidity is less understood (Chandy, 2010). Long term field and greenhouse studies have shown that, farm yard manure has a buffering effect on H^+ production and release from soil complex (Bloom et al., 1999). The organic matter produced by farm yard manure develops buffering capacity in the soil which in turn decreases the effect of pH on plant growth. Continuous application of farm yard manure for a number of years can play a key role in amending saline and alkaline soils (Chandy, 2010; Keshavarz *et al.*, 2012).

Use of farm yard manure can raise soil pH since it buffers H^+ ions, and releases nutrients like calcium and magnesium present in the manure. This means that, application of farm yard manure supplies nutrients needed for plant growth and also lowers soil acidity. This improves the availability of phosphorus and decreases Al toxicity (Bloom *et al.*, 1999). Ashiono *et al.* (2006) reported that, application of farm yard manure increased electrical conductivity of the soil, organic carbon and soil moisture content of cold tolerant sorghum in the dry highlands of Kenya.

About 88% of the resource poor subsistence farmers in semi-arid lands of eastern Kenya use farm yard manure as their main soil fertility input. According to Kihara *et al.* (2011) combining crop residues and farm yard manure in these regions led to increased maize yield. Studies done by Miriti *et al.* (2011) showed that, the highest yield was obtained with 80 kg N/ha when combined with farm yard manure. Farmers in Machakos County mostly use farm yard manure to supply nutrients to the soil. However, its major limitation is the low quantities applied as a result of increased labor required and the poor feeds given to livestock which reduce the quantities produced ((Classens *et al.*, 2012).

2.4 Effect of Nitrogen Fertilizer and Farm Yard Manure on Crop Yields

The main objective of integrated nutrient management is to maintain soil fertility and plant nutrient supply to an optimum level. This sustains crop productivity and minimizes nutrient loses to the environment. Usually this can be achieved through efficient management of all nutrient sources such as soil minerals, decomposing soil organic matter, mineral and synthetic fertilizers, animal manures and composts, by- products and wastes, plant residue and biological N-fixation (Sign *et al.,* 2002).

In order to maintain sustainable crop production, combined use of chemical and organic fertilizers has been found to be greatly beneficial. Various researchers in their studies have argued that, integrating chemical and organic fertilizers to overcome the deficiency of several micronutrients in crop fields is advantageous. Other studies have also pointed out that, combining organic and inorganic fertilizers led to increased yields in comparison to sole organic or inorganic fertilizers (Briggs *et al.,* 2002). In relation to grain yield, Vanlauwe *et al.* (2010), reported an increase of up to 400% over the control as a result of using both organic and inorganic fertilizers.

Inorganic fertilizers are usually used to supplement the natural soil nutrient supply to provide nutrients required by the crops. Nitrogen is one of the primary macro–nutrients which plays a key role in obtaining the maximum economic yields. However, it's normally one of the most limiting factors in soils for improved crop production. Plants absorb nitrogen in large amounts in comparison to other primary macro–elements (Kotschi, 2013). Nitrogen ought to be balanced with other nutrients. In most plants, nitrogen is taken up inform of nitrate ion (NO_3^-) and to a lesser extent in the ammonium ion form (NH_4^+). The growth of plants mostly improves when a combination of ammonium and nitrate nitrogen is used (Wopereis *et al.,* 2006).

Combining inorganic fertilizers together with farm yard manure has been reported to improve the soil structural index, infiltration rate and water retention characteristics (Chandy, 2010). Inorganic fertilizers increase the amount of readily available nutrients to plants. Integrating inorganic fertilizers with organic manures promotes soil health and improves soil fertility (Iqbal *et al.,* 2012). When organic wastes are combined with inorganic fertilizers they improve both soil fertility and plant quality. Composted organic wastes can be used to substitute 25% of inorganic nitrogen fertilizers (Mahound *et al.,* 2009).

Mohsin *et al.* (2010) reported that, integrating inorganic and organic materials led to sustainable crop production and concluded that, combining inorganic fertilizers and farm yard manure is essential in improving crop yields. Mwangi *et al.* (2010) observed an increase in maize yields as a result of combining farm yard manure and inorganic fertilizers. Studies done by Achieng *et al.* (2010) in Western Kenya showed that, farm yard manure had 108% grain yield increase as compared to sole inorganic fertilizer. They also observed that, farm yard manure had 4% grain yield advantage over inorganic fertilizer on Ultisols during the dry season and attributed this to its ability to improve the water holding capacity of the soil.

Tasneem *et al.* (2004) observed that, different levels of organic and inorganic fertilizers significantly influenced the number of grains per cob in a study conducted to determine the effectiveness of farm yard manure, poultry manure and nitrogen in relation to corn productivity. Tolessa and Friesen (2001) reported that, the growth and yields of maize increased significantly with the use of enriched farm yard manure by 40% as opposed to conventional farm yard manure. Wakene *et al.* (2001)

found out that, NP fertilizers and farm yard manure significantly increased grain yields.

Gikonyo and Smithson (2004) stated that, there was a significant increase in yields by 0.46 to 1.3 t/ha in their experiments in high and medium rainfall areas of Kenya. Studies done by Ouedrago and Mando (2010) revealed that, integrating organic materials and inorganic fertilizers increased yields. This is in comparison to when nitrogen fertilizer in form of urea was applied alone. Alemu and Bayo (2005) observed that, sorghum grain yield ranged from 0.54 t/ha in the control to a maximum of 3.77 t/ha with the application of 120 kg N/ha. This accounted for an increase of 3.23 t/ha yields in comparison to the control treatment.

Kogbe and Adediran (2003) observed that, maize grain yield increased with rise in nitrogen rates while the control recorded the least yields. Average corn yield in U.S A was predicted to decline by 41% without use of inorganic fertilizers (Stewart, 2003). Cakmak *et al.* (2010) and Solhi *et al.* (2012) found that, application of nitrogen was the most influential in relation to increasing crop production. They also reported that, nitrogen played a key role in plant nutrition.

2.4.1 Effect of organic fertilizers on crop production

Organic materials are important in soil fertility management (Ouattara *et al.*, 2007). This is because, being a source of nutrients, they affect nutrient availability and determine the release pattern of nutrients available for plant use (Islam *et al.*, 2011). When fallow vegetation or crop residues are incorporated into the soil, they enhance water infiltration and retention. The soil organic matter content also determines the cation exchange capacity of the soil (Kincaid, 2002). The benefits and limitations of specific organic inputs are influenced by the quality of the organic material, the soils' organic matter pool to which they contribute as well as on site features (Magid and Kjaer guard 2001; McNair Bostick *et al.,* 2007).

The effect of organic inputs on soil organic matter dynamics can be resilient, temporary or slightly long term. Organic materials of high stability with low carbon - nitrogen ratio are gotten as a result of composting (McDonagh *et al.,* 2001). The nature of the material used and the extent of decomposition determine the type of compost (Mishra *et al.,* 2001). Those composts whose origin is from cereal crop residue release nutrients slowly into the soil over longer period as compared to crop residues (Mando *et al.,* 2001); Sanchez *et al.,* (2004) and Ouedraogo, (2004).

Compost can also act as a soil ameliorant which is capable of changing the pH, moisture content, structure and nutrient contents of the soil (Semple *et al.,* 2001). Compost is a source of carbon hence; it helps to improve the cation exchange capacity, physical and biological characteristics of the soil. When compost is applied to the soil, it retards crust formation, reduces runoff and effectively combats degradation of the structure of those soils which are highly unstable (Albiach *et al.,* 2001; Bresson *et al.,* 2001). In addition, compost also increases soil microbial biomass and earthworm population (Carpente–Bogs *et al.,* 2000). Compost enhances bioremediation. This is because it can support diverse populations of micro-organisms (bacteria and fungi) with the potential to degrade a number of pollutants (Kapanen and Itavaara, 2001).

The impact of organic amendment on long term carbon storage could be minimal in tropical soils (Mandal *et al.,* 2007). Several studies have highlighted their beneficial effects on nutrient recycling (Ngo *et al.,* 2012; Kaur *et al.,* 2005). Ikerra *et al.* (2006) reported an increase in soil pH as a result of compost application. When organic manures are incorporated into the soil, they improve soil fertility, soil structure, water retention and biological activity. However, these sources are not adequate to sustain soil fertility. Therefore organic fertilizers ought to be used in combination with other sources of nutrients (Mahmound *et al.,* 2009).

2.4.2 Effect of inorganic fertilizers on crop production

Nutrient deficiency is one of the major limiting factors in the development of an economically profitable agriculture (Fageria and Baligar, 2005). It is estimated that, 30 to 50% of the increase in world food production since 1950's was due to use of inorganic fertilizers (Higgs *et al.,* 2002). However, majority of the farmers rarely use these type of fertilizers. This is because of the high costs, uncertainty about economic returns to fertilizing food crops and also lack of information on the types and rates of fertilizers to be applied (Hopkins *et al.,* 2008).

Amongst the three primary macro-nutrients (NPK), nitrogen is the most important plant nutrient. This is because it is the primary raw material required for plant growth. In addition, it has been found to be an essential constituent of metabolically active compounds like amino-acids, proteins, enzymes and co-enzymes to some non-proteinous compounds (Brandy and Weil, 2002). Nevertheless, it is the most frequently deficient compared to phosphorus and potassium (Hopkins *et al.,* 2008). Maximum nitrogen uptake by the maize plant takes place a month just before tasseling and silking (Hammons, 2009).

Reasonable amount of nitrogen is lost through denitrification, leaching, volatilization and removal by crops (Castellano *et al.,* 2014). When nitrogen is inadequate during silking, it leads to reduced grain yields. In order to realize the potential of modern hybrids, availability of nitrogen in the soil solution for plant uptake is important. Nitrogen stress results to poor kernel formation, increased abortion and low grain yield. Maize requires higher amounts of nitrogen fertilizer compared to other cereals (Dinnes *et al.,* 2002). However, high nitrogen applications increase the cost of production. It also results to serious problems of nitrate build up in surface and ground water. To ensure efficient use of nitrogen in cropping systems, it has to be applied as per the recommendations (Hopkins *et al.,* 2008).

2.4.3 Effect of fertilizer micro-dosing on crop yields

Micro-dosing refers to the application of small amounts of fertilizer next to the emerged plant starting from 3 to 6 weeks after the plant has emerged. This is usually done after weeding and when there is enough moisture in the soil. Fertilizer micro -dosing can also be defined as point application of relatively small amounts of fertilizer (2-6g/ hill) in cereal crop production (Ali and Raouf, 2012). The fertilizer may be applied together with the seed at planting time or as a top-dress 3 to 4 weeks after germination. Micro-dosing significantly reduces the recommended amount of fertilizer that small scale farmers ought to apply per hectare (ICRISAT, 2009).

When fertilizers are applied as micro-doses, it ensures more precise and better timed fertilizer placement. This in turn enhances proper utilization of the fertilizer (Sanginga and Woomer, 2009). The micro - dosing technology may also be integrated with other practices like water harvesting and Zai planting holes. It can also be combined with livestock manure or crop residue and compost made from kitchen and garden wastes. Several studies have revealed that, maize yields increase with fertilizer micro-dosing as compared with the control (Sanginga and Woomer, 2009; Okebalama *et al.,* 2014). Fertilizer micro-dosing has the ability to greatly increase yields across agro-ecological zones and rainfall conditions (Ali and Raouf, 2012). In addition, fertilizer micro- dosing can also improve the harvest index (Hayaishi *et al.,* 2008).

Plant height was significantly increased from 19 to 31% through fertilizer micro-dosing (Aune and Ousman, 2011). Crops under micro-dosing perform better under water stress conditions. This is because the crops larger root systems are more efficient at exploiting moisture at greater depths. This mostly happens later in the season when soil moisture at the surface of the soil is low (ICRISAT, 2009). Any small doses which are capable of correcting soil essential nutrients deficiencies can make the root systems to develop and capture more water increasing the yields. Micro - dosing enhances more rapid growth. As a result, this helps to avoid early season drought reducing the impact of end of season drought while increasing crop yields (Tarkalson *et al.,* 2009).

2.4.4 Effect of organic and inorganic fertilizer application on crop nutrient uptake

The ability of plants to take up nutrients and efficiently utilize them is genetically determined. However, this can be modified by plant interaction with the environmental factors (Baligar *et al.,* 2001). When nutrient inputs are balanced with crop removal, this minimizes the accumulation of nutrients and reduces the cost involved in soil fertility management. The nutrient uptake and removal is influenced by crop yield, variety and soil fertility. Climatic conditions also affect crop nutrient uptake. Low soil moisture, poor aeration, low soil temperature and nutrient imbalances limit plant nutrient uptake (CFI, 1998).

Maximum nutrient uptake varies from one crop to another and takes place before maximum growth rates occur. However, plants require a balanced supply of nutrients throughout their growing period (Jones *et al.,* 2011). Low nutrient uptake in the initial stages of plant development lowers nutrient amount for the seed. This affects both yield and quality. Therefore, the application of nutrients should be timed such that, they are available before the peak of crop nutrient requirement (Jones *et al.,* 2011).

Adequate supply of nutrients during the early stages of plant growth enhances maximum crop yields. Nutrient uptake is also determined by the ability of the roots to absorb nutrients and the concentration at the root's surface (Jones and Jacobsen, 2001). During the plant growth, roots spread out both laterally and vertically. This enables them to benefit from the areas within the soil that contain more water and nutrients. When the soils are dry, plants have problems in absorbing nutrients. This is because plants absorb nutrients in ionic forms whereas most nutrients are elemental. This implies that, during the dry spells, nutrient levels in plant tissues may be lower than normal (Sanchez *et al.,* 2004).

Tillage practices affect soil temperature, moisture and aeration. This in turn influences nutrient uptake (Jones *et al.,* 2011). Fertilizer placement method may increase or reduce nutrient uptake in relation to the prevailing conditions (Jones *et al.,* 2011). Phosphorus uptake increased with increasing rates of nitrogen and phosphorus application at different stages of maize growth (Mahmound *et al.,* 2009). When Phosphorus content was between 0.15% and 0.22% with nitrogen rates at 5 to 200 kg /ha, the nitrogen content of maize grain was between 1.36% and 1.75%. The amount of nitrogen content in maize grains also increased with increasing nitrogen application (Malathesh, 2005).

When farm yard manure was applied at a rate of 12 t/ha together with fertilizer levels of up to 60 kg N /ha, 30 kg P_2O_5 /ha and 30 kg K_2O /ha, it significantly improved the uptake of nitrogen by the maize crop. Nitrogen uptake by crops was consistent when compost was applied together with nitrogen fertilizer (Malathesh, 2005). The response of crops to phosphorus application was affected by the availability of phosphorus in the soil solution and the ability of the crop to absorb it (Mahmound *et al.*, 2009).

2.5 Effect of Soil Organic Carbon on Soil Fertility

Soil organic carbon determines soil quality since it affects soil structure. In turn, the soil structure influences soil stability and water holding capacity of the soil. One of the most important components of soil organic matter is carbon. When soil micro-organisms break down organic matter, nutrients are released. These nutrients are used up by the crops. The process of decomposition also gives humus, which increases the level of carbon in the soil (Fu *et al.*, 2004)).

A positive relationship between levels of soil carbon and microbial levels in the soil was reported by Fang *et al.* (2008). They attributed this to the fact that, humus is a product of soil microbial activity. Environmental factors such as topography, parent material, soil depth and land use affects soil organic carbon (Fu *et al.*, 2004). Soil carbon is also affected by precipitation and temperature that are influenced by topography (Tsui *et al.*, 2004). During the rainy season, the soil microbial biomass is usually higher in comparison to the dry season. According to Fang *et al.* (2008), soil organic carbon is affected by the clay content in the soil. In addition, the amount of soil organic carbon increases with increase in soil temperature.

Studies done by Sebetha (2015) showed that, cowpeas mono crops had high soil organic carbon. He attributed this to improved soil structure and fertility, which led to high carbon content. Intercropping legumes with cereal crops can increase soil nitrogen. This leads to improved soil fertility which in turn increases soil carbon (Conant *et al.,* 2001). Alvarez (2008) reported that, application of nitrogen fertilizer resulted to increased carbon sequestration to the system. However, Sebetha (2005) stated that, soil organic carbon was not affected by application of nitrogen fertilizer. Studies by Russel *et al.* (2009) revealed that, application of nitrogen fertilizer offset gains in carbon inputs to the soil in such a way that, soil carbon sequestration was zero even with 48 years of nitrogen application.

2.6 Effect of Cropping Systems on Crop Yields

Cropping system can be defined as crops and crop sequences and the management techniques employed in a particular field over a period of years (Ghanbari *et al.,* 2010). On the other hand, monocropping refers to the growing of only one crop on a piece of land in a cropping season. Repetition of this practice year after year becomes monoculture. The growing of two or more crop species simultaneously on the same field during a growing season is termed as intercropping (Dahlmann and Von Fragstein, 2006). In order to improve food security, the current major emphasis in the use of land resources is aimed at improving the productivity and sustainability of different cropping systems.

The commonly used cropping systems are crop rotation, intercropping or mixed cropping and strip cropping (Fosu and Tetteh, 2008). Maize and cowpea are important components of mixed cropping in many countries. However, most small scale farmers cultivate them either as a mono crop or in rotation. In most cases, monocropping is carried out in large scale commercial farms. Most of the small scale farmers practice intercropping since their farms are less than 2 ha (Ghanbari *et al.,* (2010).

Monocropping and crop rotation have been reported to give higher yields than mixed cropping by some researchers. However, crop rotation of maize and cowpea performed better than mixed cropping of maize and cowpea (Hardter *et al.,* 1991). When crops are grown in rotation, they improve soil fertility and increase yields as compared to those grown as mono crops. Therefore, in order to achieve long-term agricultural productivity and sustainability, it is advisable to combine crop rotation with other fertility management practices (Snyman, 2003).

Several studies have suggested that, reduced yields have occurred due to continuous monocropping of cereals. A significant yield decline in maize monocropping system over a period of several cropping seasons was reported by Zhang *et al.,* (2003). This was attributed to the allelopathic effects and the phytotoxic substances produced during decomposition of the maize plant residues in the soil which made the growth of the succeeding crop stunted reducing crop yields (Horst and Hardter, 1991).

The adverse effects of monocropping on yield could partly be addressed through nitrogen and phosphorus application (Hardter, 1991). Studies done by Twomlow et al. (2010) showed that, maize grain yield was increased in monocropping when 17 kg N /ha ammonium nitrate fertilizer was applied. Continuous cropping reduced soil fertility and resulted to lower exchangeable Ca, K, mg, organic carbon, total nitrogen contents, enzyme activities and effective cation capacity. Soil acidification with lower pH values and higher exchangeable Al and Mn were reported as a result of continuous maize mono cropping (McCown *et al.,* 2012).

Intercropping facilitates better efficient use of growth resources and ensures more sustainable yields. It also controls weeds, lowers nitrogen losses as well as reducing disease causing micro-organisms (Dahlmann and Von Fragstein, 2006). Competition for growth requirements may occur in intercropping systems. To overcome this challenge, it is important to select crops which are compatible (Zhang *et al.,* 2006; Seran and Brintha, (2009). Legume-cereal intercropping especially maize-bean intercropping is common throughout Eastern and Southern Africa (Giller, 2009). The small scale farmers in East Africa usually intercrop maize with grain-legume. Common beans are often replaced by cowpea or groundnut in drier areas (Mucheru – Muna *et al.,* 2010).

Most intercropping systems have been found to be better than mono crops in relation to yield increase (Zhang *et al.,* 2010). The main objective of intercropping is to maximize crop yields through efficient use of labor and land (Mucheru -Muna *et al.,* 2010). Incorporating legumes in a cereal cropping system is important. This is because they improve soil fertility and the productivity of the succeeding cereal crops (Ghosh *et al.,* 2007). Intercropping is a common practice in most rain-fed areas of the world and in the tropics (Tsubo *et al.,* 2005; Dhima *et al.,* 2007). The reason being that, intercropping helps in soil conservation, weed control, prevents lodging and increases the yield (Chen *et al.,* 2004; Poggio, 2005).

The canopy cover given by the legumes in the initial stages of growth reduces soil loss through erosion mostly on steep lands as well as controlling weeds. The quantity of mineral nutrients to be removed from the soil varies from one crop to another (Tulu, 2002). This means that, where intercropping is practiced, different amounts of nutrients are removed from the soil. This depends on the crops' requirement (Logah, 2009). In soils which are poor in nitrogen, intercropping maize and cowpea is recommended. This is because cowpeas get the majority of their nitrogen from the atmosphere and therefore do not compete with maize for soil nitrogen (Vesterager *et al.,* 2008).

In addition, cowpeas supply protein for human and livestock consumption and acts as an insurance cover against total crop failure. Maize cowpea intercrop also increases the amount of the primary macro-nutrients compared to maize mono crop (Dahmardeh *et al.*, 2010). Those legumes with effective biological fixation can be grown with less fertilizer application. The advantages of intercropping can be increased by applying the correct amount and type of fertilizer (Vanlauwe *et al.,* 2010).

Studies done in the semi-arid areas of Kenya by Karuma *et al.,* (2014) showed that, maize mono crop produced significantly higher weights (8.51 kg/ha) while the intercrop recorded 7.59 kg/ha. The intercropping also significantly reduced the mean yields by 11% (from 3.71 to 3.31 kg/ha) in maize grain. The biomass was also reduced by 7.3% (from 8.18 to 7.59 kg/ha). Intercropping has several environmental advantages like mitigation of runoff and erosion, improvement of soil properties, increase in bio-diversity and reduction of herbicide use (Celette *et al.,* 2010).

Intercropping ensures that, growth resources are efficiently utilized both in time and space (Rodrigo *et al.,* 2000). The above and below ground interaction between intercropped species leads to improved crop yields (Liu *et al.,* 2006). There is a close relationship between crop growth and final yield of an intercropping system. However, intercropping can result to competition for growth requirements like light, water and nutrients between crops reducing the crop yields. A major challenge faced by farmers in intercropping is selecting the most suitable crop species and the best planting densities (Gao *et al.*, 2010).

Other short comings related to intercropping include the extra labor required in sowing, weeding and harvesting the seed mixture (Lithourgidies *et al.,* 2011). It is also expensive especially when the two intercrops require different types of chemicals and fertilizers. There is also the extra work involved in separating the mixed grains, unreliable market for the mixed grains, lodging problems and losses of grain during harvesting (Carruthers *et al.*, 2000).

2.7 Effect of Soil Management Practices on Profitability in Crop Production

The integration of profit margin in soil and water management practices is a research area which has not been fully exploited (Basso *et al.*, 2011). The challenges of soil and water management practices are costs, adaptability and effectiveness. These in turn affects the level of adoption by farmers (Babalola *et al.,* 2007). The costs involved in various operations and the returns from the produce can be used to estimate the true value of relative benefits and cost of various agricultural land and water management options (Dresch *et a*l., 2004). In order to be able to suggest viable recommendations for improving soil fertility management practices to the small scale farmers, there is need to identify the available organic materials and nutrients within their reach (Dresch *et al.,* 2004).

Most of the previous studies relating to soil and water management practices have not addressed the economic aspect. This necessitates the need to carry out profit margin analysis on various soil and water management practices. This will help to establish the most cost effective practice to be recommended for adoption by farmers. Production of health and good quality crop will help the farmers to maximize profits (Barut *et al*., 2011). They also need to choose appropriate cropping systems since some are more economical than others. Dahmardeh *et al.,* (2010) reported that, intercropping was more profitable than mono cropping because of the yield advantage of the two crops.

2.8 Summary of the Literature Review and the Study Gaps Identified

The review of the existing literature shows that, studies done on the effect of tied ridges on soil moisture has conflicting results. Some of the researchers reported increased soil moisture due to tied ridges while in other studies, the tied ridges conserved less soil moisture as compared to the normal tillage practiced by the farmers. However, most of the studies have indicated success of tied ridges especially during the seasons when rainfall was low.

The studies which have reported failure of tied ridges to conserve soil moisture are mostly during the seasons when rainfall is high. Most of the past studies on the effectiveness of tied ridges were not season specific resulting to conflicting information regarding their efficiency. As a result, there is no clear documented literature regarding the effectiveness of tied ridging as a water conservation method in relation to seasonal variations in rainfall. Farmers in semi-arid areas are not consistent in adopting the use of tied ridges due to these conflicting findings. The integration of cropping systems, organic and inorganic fertilizers to soil and water management practices has not been exhaustively researched on.

The literature has also showed that, very few studies have addressed the profitability of various soil and water management practices which could affect the rate of adoption. Most of the work done in relation to integrating soil and water management practices in Machakos County is based on survey with limited field experiments. This means that, it is important to evaluate the effect of tied ridges, fertilizers and cropping systems on soil properties and maize yields as well as finding out the profitability of integrating different soil and water management practices.

The review has also pointed out that, integrating different soil and water management practices is widely advocated for. However, the suitability of a soil and water conservation method is site specific. This means that, the effects of an integrated soil and water conservation method will vary with the soil and crop species under different agro-climatic conditions. Although the integration of water harvesting and nutrient management is important in increasing and sustaining crop production, there is limited information on their interaction in the semi-arid areas of Machakos County. The data on fertilizer use in the County is also scanty reflecting low use of agricultural inputs. Therefore, there is need to address the interaction of tied ridges, fertilizers and cropping systems in relation to soil properties and maize yields in Machakos County.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Site Description

The experiment was carried out in Kenya Agricultural and Livestock Research Organization (KARLO) Katumani in Machakos County which is located in the Eastern part of Kenya. The County boarders Nairobi and Kiambu Counties to the West, Embu County to the North, Kitui County to the East and Makueni County to the South (Jaeztold et al., 2006) (Figure 3.1). The County covers a total area of 6,208 km$^{2;}$ with an estimated population of 1,098,584 people (GoK, 2011).

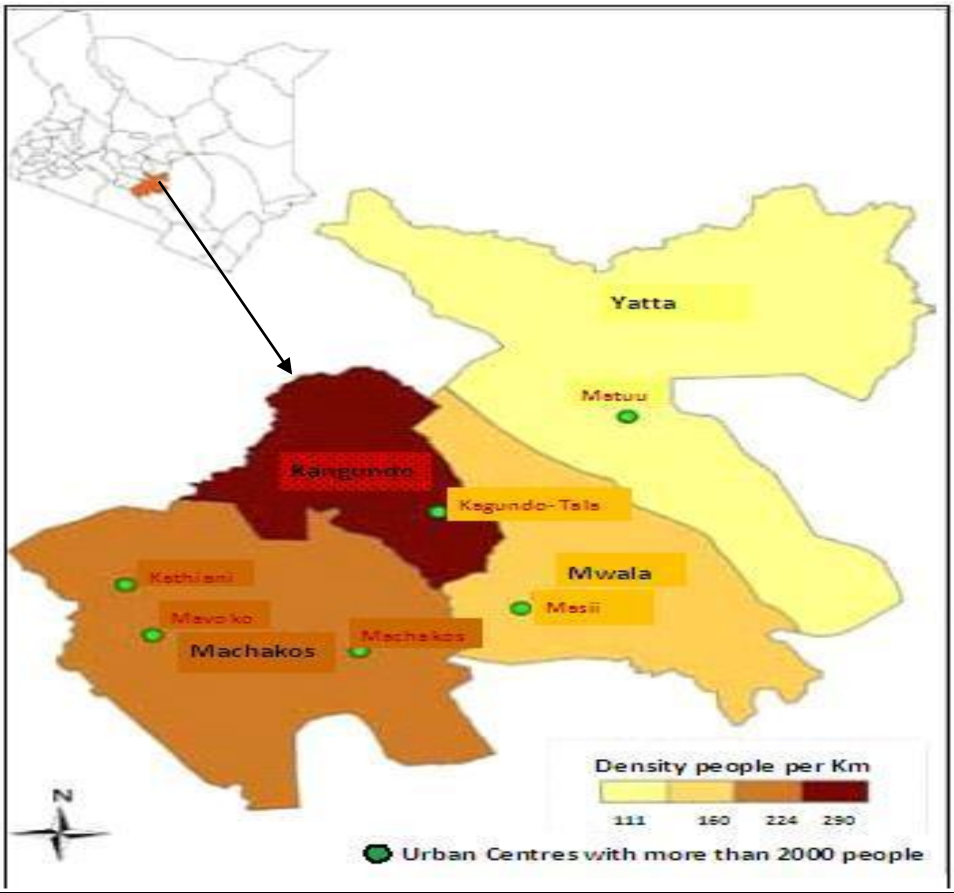

Figure 3.1: Map of Kenya showing the study area (NEMA, 2013)

Machakos County is located in the semi-arid areas of Eastern Kenya and is dominated by agro-climate zones IV and V (Jaetold et al., 2006; Karuma *et al.,* 2014). The elevation across this County ranges between 400 to 2100 meters above the sea level (Claessens *et al.,* 2012). The climate in Machakos County is characterized as semi-arid with bimodal rainfall pattern, giving two unique rainy and dry seasons. The mean annual rainfall in Machakos County ranges between 500-900 mm; with a high inter-seasonal rainfall variation and the co-efficient of variation is 28% ((Mora-Vallejo *et al.,* 2008). There are two rainy seasons: short rainy season from October / November up to January / February and the long rainy season from March to August / September (Mora-Vallejo *et al.,* 2008). About 80% of the mean annual rainfall falls in the two rainy seasons (Rao and Okwach, 2005).

Southward and Northward movements of inter tropical convergence zone results in two rainy seasons in a year (Anyah and Semazzi, 2007). The rainy seasons can be completely wet and mostly late or sudden resulting in floods and inundation. A general increase in the intensity of high rainfall events related in part with the increase in atmospheric water vapor is a common phenomenon in the semi-arid region of Eastern Kenya (Christensen *et al.,* 2007).

Although the short and long rainy seasons receive the same amount of rainfall, the short rainy seasons are more reliable because they are more evenly distributed; hence more important for crop production (Rao and Okwach, 2005). Droughts are common phenomena and they occur in cycles of 4 to 5 years. This has a negative impact on the growing seasons which in turn affects food security in the County (Mora-Vallejo *et al.,* 2008). The mean annual temperatures range from a mean minimum of 15^{o} C to a mean maximum of 25^{o} C. October and February are the hottest months while July is the coolest month (Muhammed *et al.,* 2010). According to the Central Bureau of Statistics, 60% of the population in Machakos County are below the poverty line with less than 1US$ per person in a day (CBS, 2003). The

County supports a variety of agricultural activities occupying almost half of the County's total surface area (Mora-Vallejo *et al.,* 2008).

The common land use systems are rain-fed and mixed crop-livestock farming systems which support mainly the small scale semi-subsistence sector (Muhammed *et al.,* 2010). The most key staple crop is maize (*Zea mays L.).* Other crops grown include: common beans *(Phaseolus vulgaris L.),* cowpea (*Vigna unguculata L.),* pigeon pea *(Cajanus cajan L.),* bulrush millet (*Pennisetum americanum L.)* and sorghum (*Sorghum biclor L.).* Some farmers also grow vegetables, fruit trees and tuber crops like cassava (*Manihot esculata L.).* Coffee (*Coffea arabica L.)* and cotton (*Gossypium spp L.)* are grown in the County as cash crops. However, the yields of these crops are generally low and crop failure is a common occurrence (Claessens *et al.,* 2012).

In Machakos County, majority of the soils reflect largely metamorphic parent rock and rainfall patterns which play a key role in their formation. The dominant soils are Alfisols, Ultisols, Oxisols and Lithic soils (FAO, 1970). These soils have low fertility and are highly susceptible to erosion. In addition, less than 20% of the soils are well drained. The most common vegetation in this County is dry bush with trees and in the higher areas, savannah with scattered trees. Katumani is located in agro-ecological zone IV and is dominated by chromic Luvisols (Siderious and Mucheru, 1977).

3.2 Experimental Treatments and Design

Field experiments were carried out in KALRO Katumani in Machakos County during SR 2014, LR 2015, SR 2015 and LR 2016. The experiment was factorial and laid out as a randomized complete block design (RCBD). The treatments were tied ridges, flat bed planting, farm yard manure 0 t/ha, farm yard manure 5 t/ha, 20 kg N/ha, farm yard manure 5 t/ha + 20 kg N/ha, maize mono crop and maize cowpeas intercrop. This gave a total of 16 treatment combinations. The treatments were replicated 4 times (Table 3.1).

Table 3.1 Experimental treatments

Main Treatments	Fertilizers	Cropping Systems
Tied ridges (W2)	Farm yard manure 0 t/ha (F1)	Maize mono crop (C1) Maize cow peas intercrop (C2)
	Farm yard manure 5 t/ha (F2)	Maize mono crop (C1)
		Maize cowpeas intercrop (C2)
	Nitrogen fertilizer 20 kg N/ha (F3)	Maize mono crop(C1) Maize cow peas intercrop (C2)
	Nitrogen fertilizer 20 kg N/ha + farm yard manure 5 t/ha (F4)	Maize mono crop (C1) Maize cow peas intercrop (C2)
Flat bed planting (W1)	Farm yard manure 0 t/ha (F1)	Maize mono crop (C1) Maize cow peas intercrop (C2)
	Farm yard manure 5 t/ha (F2)	Maize mono crop (C1) Maize cow peas intercrop (C2)
	Nitrogen fertilizer 20 kg N/ha (F3)	Maize mono crop (C1) Maize cow peas intercrop (C2)
	Nitrogen fertilizer 20 kg N/ha + farm yard manure 5 t/ha (F4)	Maize mono crop (C1) Maize cow peas intercrop (C2)

The spacing of the tied ridges was 90cm tied at 2.5 m interval. The ridges were 30 cm high and ties (cross ridges) 20 cm high. The size of each plot was 5.4 m x 3.6 m with a net plot of 3.4 m x 1.6 m. The plots were laid out in the field in 4 blocks with each block having 16 treatments randomized within the block; making a total of 64 plots (Appendix 1). The distance between the blocks was 2 m and between the plots 1 m.

3.3 Characterization of the Farm Yard Manure used in the Experiment

Before the start of the field experiment, the farm yard manure was analyzed for pH, total N, total organic carbon, available P and exchangeable cations (Ca, Mg, Mn, Fe and Zn) following the procedures outlined by Okalebo *et al.,* (2002). The results are presented in Table 3.2.

Table 3.2 Chemical composition of the farm yard manure used in the experiments

		%		Cmol/ kg				Ppm		
Seasons	**pH**	**N**	**OC**	**K**	**Ca**	**Mg**	**P**	**Mn**	**Fe**	**Zn**
Short rains 2015	8.96	1.26	7.40	13.50	18.5	8.5	785	258.3	160.84	30.25
Long rains 2016	7.94	1.00	6.35	14.58	15.4	6.9	730	245.2	164.48	41.15

The analysis revealed that, the pH for the farm yard manure applied during the SR 2015 had a higher pH value (8.96) compared to that used during the LR (7.94). However, in both seasons, the pH of the manure used was slightly alkaline (pH > 7.0). This indicated that, the concentration of the hydroxyl (OH-) ions was higher than the concentration of the hydrogen (H+) ions. The % nitrogen content in the farm yard manure was high during the SR (1.26%) in comparison to LR (1.00%) while the organic carbon was also higher during the SR (7.40%) compared to LR (6.35%) (Table 3.2).

3.4 Characterization of Soils in the Experimental Site

The characterization of soils in the experimental site was also done and the results shown in Table 3.3. The texture ranged from clayey loam to sandy clay at 0-15cm, 15-30cm, 30-60cm and 60-90cm depth. The analysis also revealed that, the soils had a clay texture throughout the profile but increased sand content in the surface layer. The soil test also showed that, the soil was moderately acidic with a pH range of 5.83 to 6.54.

The total soil nitrogen (N) was low since it ranged between 0.05 to 0.08%. The phosphorus (P) range was between 15-33% which is rated as medium (Brennan et al., 2013). The potassium (K) content was low with a range of 0.35 to 0.87. Similarly, calcium (Ca) and zinc (Zn) were in the low range (Table 3.3). The soil organic carbon content was also low since the range was between 0.37- 0.72% which was below the recommended amount of 1% (Brennan *et al.*, 2013).

Table 3.3 Textural and chemical properties of soils in the study site

Soil depth (cm)	**0 - 15cm**	**15 - 30cm**	**30 - 60cm**	**60 - 90cm**
Sand (%)	68	69	62.5	50.5
Clay (%)	25.3	23.5	31.5	40
Silt (%)	6.7	7.5	6	9.5
Textural class	SCL	SCL	SCL	SC
Soil PH	6.62	6.54	6.1	5.83
Organic carbon (C) (%)	0.72	0.67	0.55	0.37
Total nitrogen (N) (%)	0.08	0.07	0.06	0.05
Phosphorus (P) (ppm)	33.75	31.25	20	15
Potassium (K) (me %)	0.87	0.81	0.65	0.35
Calcium (Ca) (me %)	1.82	1.73	1.9	1.1
Zinc (Zn) (ppm)	2.36	1.63	1.18	1.04

SCL:** *Sand, clay, loam,* ***SC: *Sand clay*

3.5 Seedbed Preparation and Planting of Maize

Seedbed preparation was done by slashing the vegetation manually using slashers and later dug using forked jembes. The soil clods were broken in order to obtain a medium tilth. This was followed by the field being lined and pegs put to demarcate the blocks and plots. Tied ridges were imposed during seed bed preparation. The first planting was on 4th October 2014, the second on 25th March 2015, the third on 6th November 2015 and the fourth on 14th April 2016 at the onset of the rains. The test crop was maize var. KDV1 (a short duration seed recommended for dry areas) which was planted at a spacing of 90cm between the rows and 30cm within each row. The cowpea variety planted was K80. Two seeds were sown per hill at a spacing of 30 cm in between the maize rows in the plots.

At planting, phosphorus was applied as Triple super phosphate (TSP, 20.75% phosphorus) at a rate of 15 kg /ha. Farm yard manure was applied at a rate of 5 t/ha three weeks before planting in the plots where manure was a treatment. The basis for these quantities was on the recommended rate for the study area (Mora-Vallejo *et al.*, 2008). Four weeks after planting, top dressing was done using Calcium ammonium nitrate (C.A.N) at a rate of 20 kg N/ha in the plots where nitrogen fertilizer was a treatment. The fertilizer was applied as a micro-dose. This was done when there was enough moisture in the soil. Weed control was manually done using a garden hoe. Weeding was done twice during the growing period to ensure a weed free field.

Pest and disease incidences were minimal during the growing period of the crop. However, routine spraying was done using Duduthrin (active ingredient: Lambdacyhalothrin 17.5g /L) to manage leaf eating insects. Thunder (active ingredient: Imidacloprid 100g /L + Beta - cyfluthrin 45g /L) and Marshal (active ingredient: 35% Carbosulfan) was used to control aphids. The pesticides were sprayed four times during the growing period at an interval of 14 days.

3.6 Data Collection

3.6.1 Rainfall data

The rainfall data was recorded on daily basis using a rain gauge installed at Katumani Research Station meteorological department. The monthly averages were then computed. The total amount of rainfall received for each season was also calculated.

3.6.2 Determination of soil moisture content

The soil moisture content was determined at planting and thereafter at an interval of two weeks up to the 8th week of the experiment. The soil moisture content was taken non-destructively using a calibrated portable neutron probe (the neutron probe was calibrated using field measurements in the calibration models with 2-inch access tubes) was inserted into a PVC access tube. This was used to measure soil moisture content at regular intervals of 20 cm down through the soil profile since the neutron probe takes readings through the wall of a PVC access tube. The soil moisture content was calculated on volumetric basis. The data from all the soil profile levels up to a depth of 60 cm was collected. The data was then downloaded at the end of each season and processed in MS excel and then subjected to statistical analysis.

3.6.3 Maize growth measurements

Data for the maize growth parameters was obtained by measuring the plant height, number of leaves per plant, leaf length, leaf width and leaf area. The growth data was collected at 40, 60 and 80 days after planting in all the cropping seasons and the averages computed. When collecting data on the number of leaves per plant, ten maize plants were randomly selected and tagged from the middle row in each plot leaving out the boarder plants. The total numbers of leaves per plant were then counted and their averages calculated. For the maize plant height, ten plants were randomly selected and tagged from the middle row leaving out the boarder plants in each plot. The height was then measured using a meter ruler starting from the soil surface to the tip of the plant in meters. The averages were then calculated for all seasons.

For the maize leaf length and width, ten plants from the middle row were randomly selected and the third leaf from each plant was tagged for length and width measurements. The length was taken using a meter rule from the base to the tip while the same leaf was measured at the middle part for the width. The measurements were recorded in meters. To get the plant leaf area index, the collected data on the maize leaf length and width from the ten randomly selected plant leaves were used. The plant leaf area was calculated in m^2 using the formula (Equation 1):

Leaf area (m^2) = leaf length (m) x leaf width (m) x maize crop factor ……… Eq. 1.

*Where the crop factor for maize = 0.85

To determine the yield and yield components of maize, the following data were collected at maturity stage during harvesting: cobs weight, number of ears per plant, stover yield, dry biomass yield, grain yield and harvest index. The grain and straw harvesting was done at the end of each cropping season. From a net plot of 3.4 x 1.6 m, the whole plants were harvested (apart from the border rows) by cutting at the ground level using a panga. The plants were then weighed as total biomass using an electronic weighing balance and the weight recorded.

The sub samples were then separated into ears (cob and grains) and stover (stem, leaves and husks). The plant parts (ears and stovers) were weighed using an electronic balance and recorded as fresh weight. This was followed by drying the samples, shelling and threshing after which the ears were further separated into cobs and grains. The dry weight was taken using an electronic weighing balance. All the weights were converted and calculated on a dry basis. The total yield from each plot was converted into tones/ha (Equation 2).

Total crop yield (ton/ha) = grain yields (ton/ha) + dry matter yields (ton/ha).....Eq. 2

Harvest index can be defined as the ratio of the economic yield (grain yield) to the total crop yield at harvest (grain and biomass yields). Harvest Index of the maize crop was calculated by the method described by Bange *et al.* (1998) (Equation 3).

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Total crop yield}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eq. 3}$$

Where: Economic yield = grain yield

3.6.4 Soil sampling and analysis of the soils in the experimental site

Soil sampling was done prior to the experiment in order to characterize the soils in the study site. At the end of the cropping season, soil sampling and analysis was also done. The textural and chemical properties of the soil were determined. This was done by taking soil samples at 0-15 cm depth, 15-30 cm depth, 30-60 cm depth and 60-90 cm depth. The soil samples were taken using a soil auger diagonally. The collected soil sub-samples were then put into a container. The soil clods were broken down and the soil sub-samples thoroughly mixed to get a composite soil sample. The soil samples were then taken for laboratory analysis at KALRO headquarters in Nairobi. In the laboratory, part of the soil samples was air-dried, crushed using a wooden mortar and pestle; then sieved through a 2 mm mesh. Physical and chemical properties of the soil were determined using standard procedures outlined by Rowell (1993).

At the end of the cropping season, soil sampling and analysis was also done. Soil samples were taken diagonally using a soil auger from the bases of ten plants selected randomly from each plot. In plots with maize cowpea inter crop, the soil samples were taken between the maize and cowpea rows. The samples from each plot were thoroughly mixed to get a composite sample which was packed and taken for laboratory analysis. In the laboratory, pH and organic carbon were determined from the soil samples.

3.6.5 Determination of soil pH

The soil pH_{water} was measured in a 1:2.5 soil water ratio using a glass electrode pH meter using the procedures as outlined by Okalebo *et al.,* (2002). Approximately 25 g of soil was weighed into a 100 ml polythene beaker and 50 ml of distilled water was added to the soil. This was followed by stirring the soil-water solution thoroughly after which, the solution was allowed to stand for 30 minutes. The pH meter was then calibrated with buffers of pH 4.01 and 7.00, then the pH was read by immersing the electrode into the upper part of the soil solution; the pH values were then read and recorded.

3.6.6 Determination of total nitrogen, organic carbon, available phosphorus, calcium and potassium in the soil

Total N was determined by modified micro-Kjeldahl method (Bremner, 1996) (Appendix 3) and organic carbon by using modified Walkley and Black wet oxidation procedure described by Ryan *et al.*, (2001) (Appendix 4). Phosphorous was extracted by Mehlich-1 method (Sonon, 2008; Savoy, 2009) (Appendix 5). Calcium and potassium in the soil was determined by using, Mehlichl double acid extraction method (Kissel and Sonon, 2008; Savoy, 2009) (Appendix 6).

3.6.7 Determination of profit margin

The data which was used for calculating the profit margin was collected at specific time for each activity. The collected data put into account all the activities which were done from land preparation stage up to harvesting time in each experimental treatment. The variables which were used to determine the profit margin included: cost of labor for land preparation (where the extra cost of imposing the tied-ridges was put into consideration), cost of labor for planting, weeding, spraying and harvesting. The extra costs incurred in planting, weeding, spraying and harvesting in plots with maize cowpea intercrop was considered.

The other costs which were put into account included the cost of pesticides used, cost of maize and cowpea seeds, cost of the fertilizers applied and the cost of farm yard manure used. The cost of calcium ammonium nitrate and farm yard manure was only considered in plots where they were used as treatments. The cost of triple super phosphate was considered for all the experimental plots. The labor rates used were based on the prevailing local rates in the study area while the prices of the various inputs were mainly from the local farmers and agro-input retailers. The profit margin analysis was done using farm gate prices of the various inputs (CIMMYT, 1998). The prices of various inputs are recorded in Table 3.4.

Table 3.4 Prices used to calculate profit margin for various soil and water management practices

Prices	Market rates (Ksh)
Cost of TSP	100 / kg
Cost of CAN	75 / kg
Cost of maize seeds	200 / 2 kg packet
Cost of cowpea seeds	80 / 2 kg packet
Cost of marshall (chemical)	1600 /litre
Cost of bulldock (chemical)	300 / litre
Cost of FYM	40 / 35 kg
Cost of labor	200 / day
Price of maize grains	2700 /90 kg bag
Price of stovers	500 / 40 kg
Price of cowpea	50 /kg

The net profit was calculated using Equation 4

$$\text{Net profit (Ksh/ha)} = \text{Gross benefits (Ksh/ha)} - \text{Total costs (Ksh/ha)} \quad \text{(Eq. 4)}$$

Gross margin (%) (GM) was calculated using Eq. 5

$$GM = \frac{\text{Gross benefits (Ksh/ha)} - \text{Variable costs (Ksh/ha)} \times 100}{\text{Gross benefit (Ksh/ha)}} \quad \text{(Eq. 5)}$$

Return to labor (RTL) (Ksh/ha) was calculated as shown in Eq. 9

$$\text{RTL} = \frac{\text{Gross benefits (Ksh/ha)-Cost of inputs (Ksh/ha)}}{\text{Cost of labor (Ksh/ha)}} \qquad \text{(Eq. 6)}$$

$$\text{Cost benefit ratio} = \frac{\text{Total gross benefits}}{\text{Total variable costs}} \qquad \text{(Eq. 7)}$$

For the farm yard manure, labor for collection, transport and application was put into consideration (Table 3.4). Maize stover was used as cattle feed in the area; hence a source of income. In order to determine the total income, maize stover yield and grain yield from each plot was used. The market price for each one of them at the harvesting time was used to calculate the total income from the sale of the stovers and grains. The collected data was then subjected to statistical analysis.

3.7 Statistical Data Analysis

All the collected data was subjected to analysis of variance (ANOVA) using Genstat 15th Edition software. In order to test if the collected data was normal, the normality test was done by drawing the probability distribution plot before analyzing the data. Where the graphical analysis showed that the residues were within the limit of the confidence level, this was an indication that the residuals were following the Gaussian normal distribution. The residual plots were also used to check the normality and equal variance assumption of the ANOVA. Where the graph formed a straight line through the origin (0, 0), the residuals were considered to be perfectly normally distributed. The s-bend at the extremes of the graph indicated that, the residuals were somewhat bunched at the tails.

The collected data was analyzed using Randomized Complete Block Design (RCBD) for factorial treatment structure. The ANOVA output was used to determine whether there were significant differences between the treatment means. Where the means were significantly different, Fisher's protected Least Significance Difference (LSD) was used to determine which treatment means were significantly different from each other at $P < 0.05$.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Rainfall Distribution during the Experimental Period

The rainfall amounts varied among the four seasons under study. The short rains 2014 and long rains 2015 seasons had poorly distributed rainfall because the dry days were almost three times the number of wet days. In both seasons, the most critical months for rapid crop growth had very little rainfall (December and January). In addition, at the beginning of the season, the amount of rainfall received was low (26.0mm). During the short rains 2014, almost half of the rainy days were concentrated in one month (November) with 117 dry days and only 34 rainy days. Also, during the long rains 2015, the dry days were 123 with only 30 rainy days (Table 4.1).

Table 4.1 Rainfall Pattern at Katumani Research Station during Short Rains 2014 and Long Rains 2015

Short Rains 2014				**Long Rains 2015**			
Month	**Rainfall (mm)**	**Rainy days**	**Dry days**	**Month**	**Rainfall (mm)**	**Rainy days**	**Dry days**
Oct-2014	26.4	5	26	March-2015	76.3	5	26
Nov-2014	81.2	15	15	April-2015	44	8	22
Dec-2014	41.6	9	22	May-2015	14.8	7	24
Jan-2014	1.5	2	29	June-2015	9.7	6	24
Feb-2014	70.9	3	25	July -2015	1.3	4	27
Total	**221.6**	**34**	117	**Total**	**146.1**	**30**	**123**

During the short rains 2015, most of the season's rainfall was received the first two months (November and December) after planting which gave the crop a good start. Thereafter, little showers continued throughout the growing period showing fairly even rainfall distribution. The rainy days were 65 which was almost equal to the number of dry days (87 days) and therefore, even distribution of rainfall. However, during the long rains 2016, the rainfall distribution was poor with 70% of the total rainfall received falling in one month and in only 9 days (May). In addition, the dry days were 125 which was almost 5 times the number of wet days (20 days) indicating poor rainfall distribution with a prolonged dry spell during the growing period (Table 4.2).

Table 4.2 Rainfall Pattern at Katumani Research Station during Short Rains 2015 and Long Rains 2016

Short Rains 2015				**Long Rains 2016**			
Month	**Rainfall (mm)**	**Rainy days**	**Dry days**	**Month**	**Rainfall (mm)**	**Rainy days**	**Dry days**
Nov- 2015	266.9	24	6	Apr-2016	24.6	7	15
Dec-2015	222.4	13	18	May-2016	67.1	9	22
Jan-2016	30.6	10	21	June- 2016	4.1	3	27
Feb-2016	25.4	12	17	July- 2016	0	0	31
Mar-2016	29.5	6	25	Aug-2016	0.2	1	30
Total	**574.8**	**65**	**87**	**Total**	**96**	**20**	**125**

The amount of rainfall received during the short rains 2015 was high (574.8 mm) compared to short rains 2014 (221.6 mm), long rains 2015 (146.1 mm) and long rains 2016 (125.0 mm). Also, the rainfall distribution during the short rains 2015 was fairly evenly distributed throughout the growing period compared to the other three seasons (short rains 2014, long rains 2015 and long rains 2016) (Fig. 4.1).

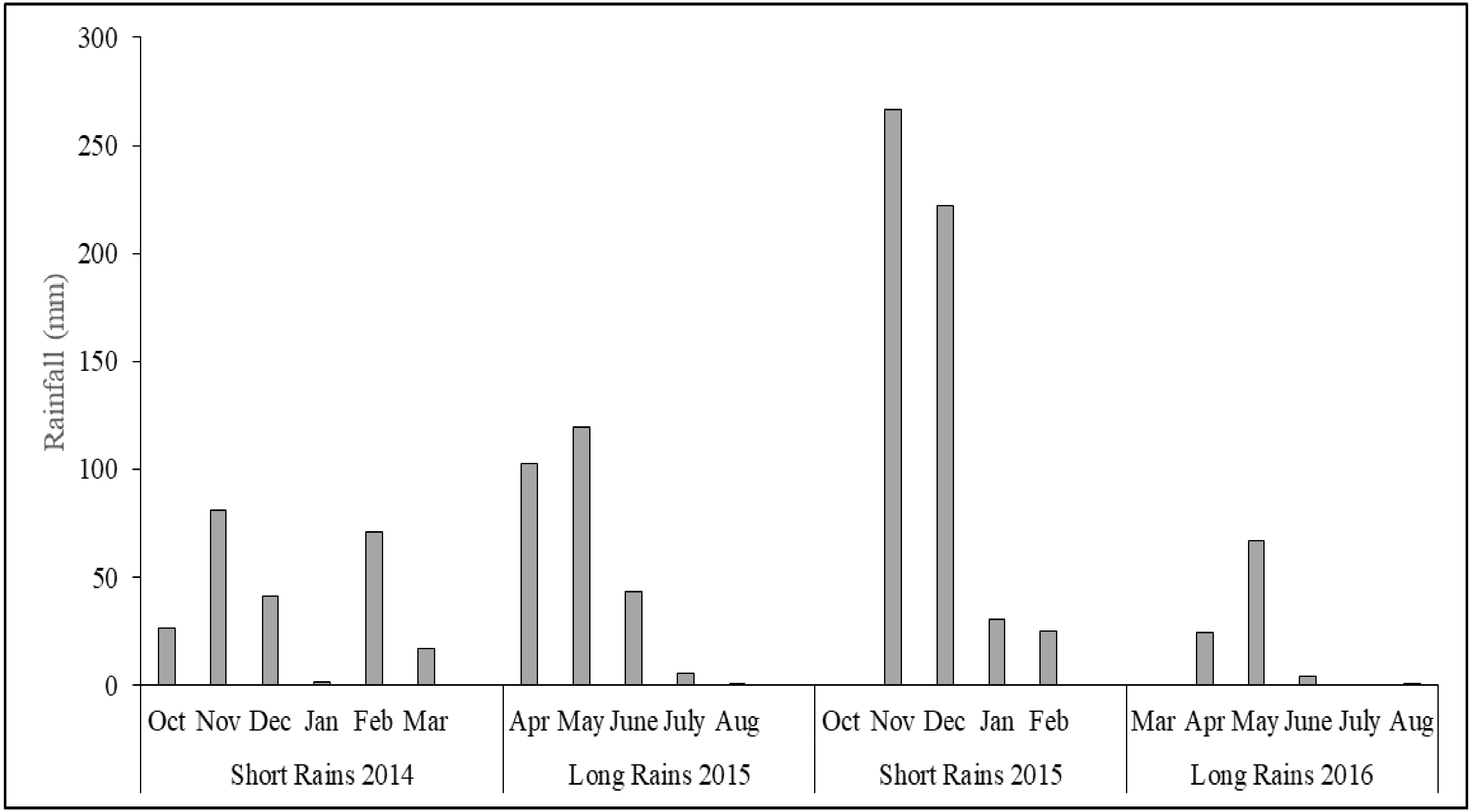

Figure 4.1 Monthly Rainfall Distribution Short Rains 2014, Long Rains 2015, Short Rains 2015 and Long Rains 2016

4.2 Effect of Tied Ridges, Farm Yard Manure, Nitrogen Fertilizer and Cropping Systems on Soil Moisture Content

The interaction between tied ridges, farm yard manure, nitrogen fertilizer, and cropping systems had significant effect ($P < 0.05$) on the soil moisture content at 0-20 cm soil depth during all the sampling periods. The soil moisture content significantly increased at 6 weeks after planting (WAP) compared to the other weeks. The moisture content also varied with weeks after planting and the soil depth. However, there were no significant treatment effects on soil moisture in depths 20-40 cm and 40-60 cm during all the sampling periods (Table 4.3).

Generally, during all sampling periods, treatment combinations with flat bed planting had more soil moisture than those on tied ridging at 0-20 cm depth. The soil moisture content ranged from 6.30% to 23.80% across the 8WAP. The soil moisture content in all the treatments significantly ($P < 0.05$) increased at 6WAP and 8WAP as compared to 2WAP and 4WAP. Treatment combinations with flat bed in maize mono crop gave significantly ($P < 0.05$) higher means for soil moisture content compared to those with tied ridging in maize cowpeas intercrop (Table 4.3).

The initial soil moisture content was higher than that observed at 2WAP and 4WAP. The highest value for soil moisture content was observed from treatment W1xF3xC1 (23.80%) at 6WAP. This was a percentage increase of 1.59% above W1xF1xC1 (22.21%) which was the control. This was followed by treatment W1xF2xC1 (23.78%); a percentage increase of 1.57% more than the control. The lowest value for the soil moisture content was given by treatment W2xF2xC2 (6.30%); a decrease of 3.68% below the control (Table 4.3).

Table 4.3 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on soil moisture content during short rains 2015 at different depths

	0-20 cm Depth					20-40 cm Depth					40-60 cm Depth				
Treatments	**Initial MC**	**2 WAP MC**	**4WAP MC**	**6WAP MC**	**8 WAP MC**	**Initial MC**	**2WAP MC**	**4WAP MC**	**6WAP MC**	**8WAP MC**	**Initial MC**	**2WAP MC**	**4WAP MC**	**6WAP MC**	**8WAP MC**
W1xF4xC1	21.31ab	13.53a	11.14a	23.56a	20.56a	23.94	17.99	16.37	21.22	18.22	22.89	18.59	16.55	17.16	16.90
W1xF2xC1	22.04a	13.95a	11.60a	23.78a	20.78a	23.88	18.31	16.72	23.20	20.20	22.84	19.83	17.55	19.31	19.04
W1xF3xC2	21.14ab	13.53a	11.49a	23.31ab	20.31ab	22.99	16.72	15.65	22.19	19.19	22.63	18.94	16.96	17.62	17.36
W1xF1xC1	20.18abc	13.55a	9.98abcde	22.21abcd	19.21abcd	23.08	17.70	14.88	19.60	16.60	22.39	18.71	15.37	16.00	15.74
W1xF3xC1	19.70abcd	12.44abc	10.45abc	23.80a	20.80a	22.99	16.72	15.65	22.19	19.19	22.45	18.49	17.16	17.72	17.46
W1xF4xC2	19.64abcd	12.37abc	10.14abcd	22.97abc	19.97abc	23.94	17.99	16.37	21.22	18.22	22.63	18.33	16.43	17.39	17.13
W1xF2xC2	19.38abcd	12.51abc	10.76ab	22.02abc	20.02abc	22.83	16.90	15.42	20.92	17.92	22.68	18.15	17.26	16.65	16.38
W2xF2xC1	19.13abcd	11.04bcd	8.01cdef	21.89abcde	18.89abcde	23.88	18.31	16.72	23.20	20.20	22.89	18.45	15.35	19.49	19.23
W2xF4xC1	18.43abcde	10.22cd	7.100f	20.66de	17.66de	23.66	18.56	14.56	21.75	18.75	24.48	19.00	16.63	17.05	16.79
W2xF3xC1	18.33bcde	10.43cd	6.71f	21.28cde	18.28cde	23.90	17.81	15.58	23.12	20.12	22.61	18.52	16.23	18.50	18.24
W2xF4xC2	17.78bcde	10.39cd	8.16bcdef	21.15cde	18.15cde	23.85	18.07	15.91	24.02	21.02	23.82	18.73	16.81	18.09	17.83
W2xF1xC2	17.31bcde	9.89d	7.51def	21.32abc	18.16cde	22.95	12.84	15.95	22.86	19.86	22.26	17.56	17.26	17.79	17.53
W2xF1xC1	17.16bcde	9.70d	7.42def	21.29bcde	18.29bcde	23.02	16.80	15.28	23.39	20.39	21.63	18.70	16.64	18.67	18.41
W2xF3xC2	16.58cde	9.75d	7.43ef	19.96e	16.96e	22.18	15.58	13.98	20.98	17.95	22.38	17.03	15.24	14.32	14.06
W2xF2xC2	15.55de	9.06d	6.30f	20.41de	17.41de	21.32	15.16	13.52	20.97	17.97	22.34	17.26	15.58	17.23	16.99
W1xF1xC2	13.61e	13.19ab	10.67abc	22.32abcd	19.32abcd	23.16	16.70	14.32	19.07	16.07	22.58	18.29	16.96	15.74	15.48
P value	0.01	< 0.001	< 0.001	< 0.001	< 0.001	0.18	0.21	0.40	0.11	0.11	0.96	0.87	0.65	0.40	0.42
s.e.d	1.48	0.85	0.94	0.71	1.04	1.53	1.22	0.82	1.16	1.70	0.95	0.91	0.84	1.30	2.02

*Means with the same letter in each column are not significantly different at P < 0.05.

***WAP:** Weeks after planting, **MC:** Moisture Content, **W1:** Flat bed planting, **W2:** Tied ridges, **F1:** Farm yard manure **0t /ha, F2:** Farm yard manure 5 t/ha, **F3:** 20 kg nitrogen fertilizer /ha, **F4:** Farm yard manure + 20 kg nitrogen fertilizer /ha, **C1:** Maize mono crop, **C2:** Maize – cowpea intercrop.*

At 0-20 cm depth, across the 8WAP, treatment W1xF2xC1 registered significantly higher soil moisture content than treatment W2xF1xC2. This means that, maize mono crop with FYM 5 t/ha under flat bed increased soil moisture content more than maize-cowpeas intercrop without fertilizer under tied ridging. In addition, treatment W1xF3xC2 had significantly higher soil moisture content than treatment W2xF3xC2. This implies that, maize cowpeas intercrop with 20 kg N/ha under flat bed retained more water than maize cowpeas intercrop with 20 kg N/ha under tied ridging. Also, treatment combination with W1xF4xC1 registered significantly higher soil moisture content in comparison to treatment W2xF2xC2. This showed that, maize mono crop with an addition of 20 kg N/ha + FYM 5 t/ha under flat bed planting resulted to more increased soil moisture content compared to maize cowpeas intercrop with an addition of FYM 5 t/ha under tied ridging (Table 4.3).

In addition, treatment W1xF2xC1 registered higher soil moisture content in comparison to treatment W1xF1xC2. This indicates that, maize mono crop with an addition of FYM 5 t/ha under flat bed increased soil moisture content than maize cowpeas intercrop without farm yard manure under flat bed. These results generally show more moisture content in treatments under flat bed than under tied ridging (Table 4.3).

The significantly ($P < 0.05$) higher soil moisture content observed in treatments where farm yard manure was applied compared to those without could be due to farm yard manure improving water holding capacity and porosity of the soil. This is consistent with results reported by Nareed *et al.* (2010) that, application of farm yard manure increased soil moisture content. This is because farm yard manure increases water percolation, reduces soil crusting and compaction (Shiran *et al.*, 2002). The farm yard manure also reduces surface run-off during the initial stages of rainfall minimizing soil erosion (Biamah *et al.*, 2003). The humus content formed from the manure could have helped in maintaining the soil physical structure enhancing better soil moisture retention. When organic inputs are incorporated into the soil, they increase water absorption, reduce run-off as well as improving soil moisture content (Dejene and Lemlem, 2012).

Application of farm yard manure increases the percentage of stable aggregates due to humus formed which, in turn leads to increased infiltration, porosity and the water holding capacity of the soil. This contributed to the increased soil moisture in treatments where farm yard manure was applied. When farm yard manure is applied in sandy soils, it releases organic matter, which cements the soil particles together improving water retaining capacity of the soil. In addition, application of farm yard manure to silt clay with high organic matter content enhances macro-aggregation preventing structural degradation (Chandy, 2010). Therefore, this explains why the addition of farm yard manure led to increased soil moisture. These findings agree with the work done by Boateng *et al.* (2006) and Adelege *et al.* (2012) who reported that, use of farm yard manure improved soil moisture content. In addition, Hulihalli and Patil (2009) also reported increased soil moisture content as a result of farm yard manure application as compared to those treatments which had no farm yard manure. Similar results were also observed by Dejene and Lem lem, (2012) who reported that, application of farm yard manure significantly ($P < 0.05$) increased the soil moisture content as compared to those treatments without farm yard manure.

Treatments without farm yard manure recorded the lowest values for soil moisture content. This could be due to the soils in the experimental site being naturally low in organic matter. The low organic matter in these soils makes them prone to water erosion hence the reduced soil moisture content (Cornelis *et al.,* 2006). The soils also have low residue returns and high temperatures leading to faster decomposition. This coupled with low amount of rainfall results to low water holding capacity.

Generally, treatments with maize mono crops had significantly ($P < 0.05$) higher soil moisture content compared to those with maize cowpeas intercrops (Table 4.3). The increased soil moisture content could have been as a result of increased plant density in treatments with maize cowpeas intercrop. The high plant population led to higher water extraction from the soil leaving less water in the soil compared to those treatments with maize mono crop only (Karuma *et al.*, 2014). Steiner (2002) reported that, cropping system that offer quick surface cover promotes soil water content by reducing evaporation and increasing infiltration.

Canopy cover of dense cowpea cultivar normally plays a significant role in soil moisture retention due to decreased evaporation rate from the soil surface. The expectation was that, intercropping would conserve more soil moisture as reported in some of the previous studies but this did not happen. Explanation for the different observation could be due to the type of the cowpea cultivar used in this study. The cowpeas cultivar used (K80) was less dense and therefore may have not offered sufficient canopy cover to reduce water evaporation. Also intercropping increases moisture competition especially where there is low humidity like in Machakos County. High relative humidity favors low evaporation.

The work by Lithourgidies *et al.* (2011) showed that, intercropping has the benefits to use water from different soil layers by the companion crops and it facilitates overall water use efficiency. However, in this study, intercropping played no significant role on soil moisture conservation. These findings agree with the work done by Sebetha *et al.* (2015) who reported that, treatments with maize mono crop conserved more soil moisture as compared to those with maize intercropping. These authors also suggested that, the type of cowpea cultivar used affects the amount of moisture conserved in the soil. Karuma *et al.* (2014) reported that, plots with maize mono crop had higher soil moisture compared to those with maize bean intercrop. Increased plant density per plot could have resulted in higher moisture extraction from the soil therefore lowering the amount of available soil moisture (Passioura and Angus, 2010).

The differences observed in soil moisture content in different weeks and depths could be related to the amount of rainfall received, soil evaporation, transpiration and water crop uptake (Mujdeci *et al.,* 2010). Treatments under flat bed planting had higher soil moisture content compared to those under tied ridges during the short rains 2015. This could be attributed to higher evaporation losses in plots under tied ridges than flat bed plots due to increased soil surface area (Karuma *et al.,* 2014). The low soil moisture content in treatments with tied ridging could also be related to the fact that, the rainfall amount was high (574.8mm) (Table 2). This could have led to ponding in tied ridges reducing water infiltration hence low soil moisture. In addition, tied ridging is normally used as a prevention measure against runoff (Asamare, 2012).These findings agree with those of Asamare (2012) who found less soil moisture content in tied ridges in sorghum production in Ethiopia.

The higher initial soil moisture content compared to that at 2WAP and 4WAP content in all the treatments could be explained by the fact that, this was at the beginning of the rain season and therefore, the moisture increased as a result of rainfall received (Figure 4.1). In addition, at this early stage of growth, the crops required less amount of water for their growth since the rate of growth was minimal and the roots had not developed completely. The decline in soil moisture content at 4 WAP could be related to the fact that, the rainfall had decreased and also the crop vegetative growth at this time was quite vigorous. This resulted in increased water uptake by the crop thus lowering water in the soil. Soil moisture was minimal during the reproductive stage (4WAP) due to high uptake of soil water by plants at this stage. It may be assumed that, critical moisture requirements and high water uptake by plants was during the 4^{th} week stage of growth since the soil moisture content was lower.

The increased soil moisture content at 6 weeks after planting could be explained by the fact that, at this stage of plant growth, the rate of vegetative growth had reduced. This is because the crop was approaching maturity. Therefore, there was reduced water uptake by the crop from the soil leaving much of the water in the soil. In addition, there was high canopy cover during this stage. This meant that, evaporation from the soil surface was reduced which resulted to high availability of soil at the root zone. Ghanbari *et al.* (2010) reported that, water uptake from soil layers increased due to increased root density in the upper layers hence decreasing water dissipated by evaporation. This explains the reason why at 6 WAP, the soil moisture was high. The findings from this study agree with the work done by Karuma et al. (2014) who reported that, flat bed planting retained more soil moisture compared to tied ridging in Mwala district. The same study also showed that, > 80% of the gained rain water due to tied ridges was lost as drainage out of the root zone. Gicheru et al. (1998) as cited by Karuma *et al.* (2014) who worked in the marginal areas of Laikipia district also observed that, tied ridges conserved the lowest amount of water and attributed this to high evaporation losses due to increased soil surface area.

4.2.1 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on soil moisture content at 0-60 cm depth during short rains 2015

During the short rains of 2015 at 0-60 cm soil depth, the interaction between tied ridges, fertilizers and cropping systems was significant on soil moisture content ($P = 0.011$) (Table 4.4). Generally, treatments under flat bed recorded higher soil moisture content in comparison to those under tied ridging. In addition, treatments with maize cowpeas intercrop under tied ridging had low soil moisture content compared to those with maize mono crop under flat bed.

The highest value was observed in the treatment W1xF2xC1 (229.9%). This was a percentage increase of 15.8% over the control (W1xF1xC1) (214.1%). This was followed by treatment W1xF4xC1 (228.3%), a percentage increase of 14.2% above the control. The lowest value for soil moisture content was given by treatment with flat bed without fertilizer in maize cowpeas intercrop (W1xF1xC2) (199.7%) which was a decline of 28.6% below the control (Table 4.4).

Treatment with W1xF2xC1 (229.9%) had significantly ($P < 0.05$) higher soil moisture content than treatment W1xF1xC2 (199.7mm). This means that, maize mono crop with an addition of FYM 5 t/ha under flat bed increased soil moisture content more than maize cowpeas intercrop without FYM under the flat bed treatment. Also treatment W1xF4xC1 (228.3%) registered significantly higher soil moisture content than W2xF4xC1 (204.1%). This shows that, maize mono crop with an addition of FYM 5 t/ha + 20 kg N/ha under flat bed led to more soil moisture content than maize mono crop with an addition of FYM 5 t/ha + 20 kg N/ha under tied ridging (Table 4.4).

Table 4.4 Interaction effects of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on soil moisture content at 0-60 cm depth during short rains 2015

Treatments	Moisture content (%) at 0-60 cm soil depth
W1xF2xC1	229.9a
W1xF4xC1	228.3a
W1xF3xC2	223.8ab
W1xF3xC1	222.5abc
W2xF4xC2	216.5abcd
W2xF2xC1	215.8abcd
W1xF1xC1	214.1abcd
W1xF4xC2	214.1abcd
W1xF2xC2	213.9abcd
W2xF1xC1	207.6bcd
W2xF3xC1	205.9bcd
W2xF4xC1	204.1cd
W2xF1xC2	203.1cd
W2xF3xC2	202.2d
W2xF2xC2	200.2d
W1xF1xC2	199.7d
P value	0.011
s.e.d	9.66

*Means with the same letter in each column are not significantly different at P < 0.05

***WAP:** *Weeks after planting*, **MC:** *Moisture Content*, **W1:** *Flat bed planting*, **W2:** *Tied ridges*, **F1:** *Farm yard manure 0t /ha*, **F2:** *Farm yard manure 5 t/ha*, **F3:** *20 kg nitrogen fertilizer /ha*, **F4:** *Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha*, **C1:** *Maize mono crop*, **C2:** *Maize-cowpea intercrop.*

Similarly, treatment W1xF2xC1 (229.9%) had significantly (P < 0.05) higher soil moisture content than treatment W2xF1xC2 (203.1%). This indicates that, maize mono crop with an addition of FYM 5 t/ha under flat bed resulted in more increased soil moisture content than in maize cowpeas intercrop without FYM under tied ridging treatment. In addition, treatment W1xF3xC2 (223.8%) significantly increased soil moisture content more than treatment W2xF3xC2 (202.2%). This shows that, treatment of maize cowpeas intercrop with 20 kg N/ha under flat bed had more soil moisture content than maize cowpeas intercrop with 20 kg N/ha under tied ridging. (Table 4.4). The low soil moisture content in treatments without farm yard manure could be explained by the fact that, soils in the study area are naturally low in organic matter. This is because of the low residue returns and high temperature leading to fast decomposition coupled with low rainfall. As a result, these soils have low water holding capacity (Cornelis, 2006 as cited by Chepkemoi, 2012).

4.3 Effect of Tied Ridges, Farm Yard Manure, Nitrogen Fertilizer and Cropping Systems on Maize Growth Parameters

In both SR 2015 and LR 2016 (40 days after planting), the interaction between tied ridges, fertilizers and cropping systems had significant effect ($P < 0.05$) on plant height, number of leaves/plant, leaf width and leaf area. Generally 40 DAP during the SR 2015, treatments with maize mono crops recorded significantly higher means for all the growth parameters measured than treatments with maize cowpeas intercrop (Tables 4.5 and 4.6).

4.3.1 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters 40 days after planting (Short rains 2015)

For all the growth parameters measured during SR of 2015, treatment with flat bed plus 20 kg N/ha in maize mono crop (W1xF3xC1) recorded the highest values. The lowest values were observed from treatments in tied ridging without fertilizer input and maize-cow pea intercrop (W2xF1xC2). The highest value for plant height was recorded in treatment combination of flat bed, 20 kg N/ha and maize mono crop (W1xF3xC1) (0.50 m). This was an increase of 56.25% above the control (W1xF1xC1) (0.32 m). Treatment W2xF1xC2 (0.28 m) significantly ($P < 0.05$) decreased the plant height by 12.5% below the control. In addition, treatment W1xF3xC1 (0.50 m) registered significantly higher values for plant height than treatment W2xF1xC1 (0.31 m). This means that, maize mono crop with an addition of 20 kg N/ha under flat bed increased plant height more than maize mono crop without fertilizer input under tied ridging. Also treatment W1xF2xC1 (0.41 m) recorded significantly higher plant height than treatment W2xF1xC2 (0.28 m). This implies that, maize mono crop with an addition of FYM 5 t/ha under flat bed increased plant height more than maize cowpeas intercrop without fertilizer input under tied ridging (Table 4.5).

For the number of leaves/plant, treatment W1xF3xC1 (7.08) recorded the highest value which was an increase of 18% over the control (W1xF1xC1) (6.0). Treatment W1xF3xC1 significantly ($P < 0.05$) increased the number of leaves/plant by 18% over the control (W1xF1xC1) while treatment W2xF1xC2 (5.57) reduced the number of leaves per plant by 7.33% lower than the control. Also, treatment W1xF3xC1 recorded significantly higher means for number of leaves per plant compared to W1xF3xC2 (5.56). This implies that, maize mono crop with 20 kg N/ha under flat bed resulted in more number of leaves per plant than maize cowpeas intercrop with 20 kg N/ha under flat bed (Table 4.5).

Table 4.5 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 40 days after planting (Short Rains 2015)

Treatments	Plant height (m)	Number of leaves/ plant	Leaf length (m)	Leaf width (m)	Leaf area (m^2)
W1xF2xC1	0.41abc	7.08a	0.50abc	0.079abcd	0.034abcd
W1xF3xC1	0.50a	7.08a	0.55a	0.086a	0.04a
W1xF4xC1	0.45ab	7.02ab	0.53ab	0.084ab	0.038ab
W2xF4xC1	0.37bcde	6.90ab	0.49abcd	0.082abc	0.034abcd
W2xF2xC1	0.36bcde	6.66abc	0.47bcd	0.077bcde	0.03bcde
W1xF4xC2	0.39abcd	6.61abcd	0.51abc	0.079abcd	0.034abcd
W2xF3xC1	0.35bcde	6.48abcd	0.46bcd	0.075cde	0.030bcde
W1xF2xC2	0.35bcde	6.32abcde	0.43cd	0.075cde	0.029cde
W2xF4xC2	0.32cde	6.30abcde	0.44cd	0.074cde	0.028cde
W2xF2xC2	0.37bcde	6.29bcde	0.46bcd	0.077abcde	0.03bcde
W2xF1xC1	0.31cde	6.04cde	0.43cd	0.073de	0.027cde
W1xF1xC1	0.32cde	6.00cde	0.45cd	0.072de	0.028cde
W2xF3xC2	0.29de	5.93cde	0.43cd	0.069e	0.026de
W1xF1xC2	0.29de	5.83de	0.43cd	0.07e	0.026de
W2xF1xC2	0.28e	5.57e	0.41d	0.069e	0.025e
W1xF3xC2	0.32cde	5.56e	0.43cd	0.072de	0.027cde
P value	0.012	< 0.001	0.033	0.002	0.007
S.e.d	0.06	0.4	0.04	0.0044	0.004

*Means with the same letter in each column are not significantly different at P < 0.05.

***W1:** *Flat bed planting*, **W2:** *Tied ridges*, **F1:** *Farm yard manure 0t /ha*, **F2:** *Farm yard manure 5t/ha*, **F3:** *20kg nitrogen fertilizer /ha*, **F4:** *Farm yard manure 5t/ha + 20kg nitrogen fertilizer / ha*, **C1:** *Maize mono crop*, **C2:** *Maize – cowpea intercrop.*

Treatment with flat bed and 20 kg N/ha in maize mono crop (W1xF3xC1) had the highest value for the leaf length (0.55 m), an increase of 22.22% above flat bed without fertilizer in maize mono crop (W1xF1xC1) (control). The lowest numerical mean for the leaf length was observed from treatment with tied ridging, without fertilizer in maize cowpeas intercrop (W2xF1xC2) (0.41 m), a decrease of 8.89% below the control. Treatment W1xF4xC1 (0.53 m) significantly (P < 0.05) increased leaf length more than W1xF3xC2 (0.43 m). Also treatment W1xF2xC1 (0.5 m) significantly resulted in higher leaf length than W2xF1xC2 (0.43) (Table 4.5)

The highest value for leaf width was in treatment with flat bed, 20 kg N/ha in maize mono crop (W1xF3xC1) (0.086 m), an increase of 19.44% over the control (W1xF1xC1) (0.072 m). The lowest value for leaf width was recorded in treatment with tied ridging without fertilizer in maize cowpeas intercrop (W2xF1xC2) (0.069 m), a decline of 4.17% below the control. Treatment W1xF2xC1 (0.079 m) registered significantly ($P < 0.05$) higher leaf width than treatment W2xF1xC2 (0.069 m). Also treatment W1xF4xC1 (0.084) significantly increased leaf width more than W2xFx1C1 (0.073 m) (Table 4.5)

The highest value for leaf area was observed from flat bed with 20 kg N/ha in maize mono crop (W1xF3xC1) (0.04 m^2), 100% increase above the control (W1xF1xC1) (0.028 m^2). The lowest mean was given by treatment with tied ridging without fertilizer in maize cowpeas intercrop (W2xF1xC2) (0.025), a decline of 25% below the control. Treatment W1xF2xC1 (0.034 m^2) significantly ($P < 0.05$) increased leaf area more than treatment W2xF1xC2 (0.025 m^2) (Table 4.5)

4.3.2 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters 40 days after planting (Long rains 2016)

During the LR of 2016, generally treatments under tied ridges had higher vegetative growth than those under flat bed after 40 days of planting. In addition, treatments with maize mono crop registered higher vegetative growth than treatments with maize-cowpeas intercrops. Treatment of tied ridging, 20 kg N/ha in maize mono crop (W2xF3xC1) registered the highest values for all the growth parameters measured while the lowest values were recorded by flat bed without farm yard manure in maize cowpeas intercrop (W1xF1xC2) (Table 4.6).

The highest value for plant height was recorded by treatment W2xF3xC1 (0.47 m), an increase of 46.88% above the control (W1xF1xC1) (0.32 m). The lowest value for plant height was from treatment W2xF1xC2 (0.3 m). Treatment W1xF4xC1 (0.37 m) significantly ($P < 0.05$) increased plant height more than W1xF1xC2 (0.33 m) Also treatment W1xF4xC2 (0.34 m) significantly had higher plant height than W1xF3xC2 (0.32) (Table 4.6).

Table 4.6 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 40 days after planting (Long rains 2016)

Treatments	Plant height (m)	Number of leaves/ plant	Leaf length (m)	Leaf width (m)	Leaf area (m^2)
W1xF2xC1	0.30c	5.70bcdef	0.46	0.079d	0.032c
W1xF3xC1	0.38abc	6.27abc	0.51	0.086abcd	0.037abc
W1xF4xC1	0.37abc	6.12abcde	0.49	0.083bcd	0.035bc
W2xF4xC1	0.36bc	6.21abcd	0.5	0.085abcd	0.036abc
W2xF2xC1	0.37bc	6.10abcde	0.5	0.08abcd	0.036abc
W1xF4xC2	0.34c	5.34ef	0.47	0.08bcd	0.032c
W2xF3xC1	0.47a	6.73a	0.56	0.092a	0.044a
W1xF2xC2	0.36abc	5.67bcdef	0.47	0.080d	0.030c
W2xF4xC2	0.36bc	5.43def	0.49	0.080d	0.034bc
W2xF2xC2	0.45ab	6.40ab	0.54	0.09ab	0.042ab
W2xF1xC1	0.31c	5.59bcdef	0.47	0.082cd	0.033c
W1xF1xC1	0.32c	5.53cdef	0.47	0.079d	0.030c
W2xF3xC2	0.45ab	6.04abcde	0.54	0.09ab	0.042ab
W1xF1xC2	0.33c	5.46cdef	0.46	0.080d	0.032c
W2xF1xC2	0.30c	5.70bcdef	0.46	0.080d	0.032c
W1xF3xC2	0.32c	5.60bcdef	0.46	0.077d	0.030c
P value	0.033	0.01	0.104	0.013	0.032
S.e.d	0.05	0.42	0.03	0.005	0.004

*Means with the same letter in each column are not significantly different at $P < 0.05$.

W1:** Flat bed planting**, W2:** Tied ridges**, F1:** Farm yard manure 0t /ha**, F2:** Farm yard manure 5 t/ha**, F3:** 20 kg nitrogen fertilizer /ha**, F4:** Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer / ha, **C1:** Maize mono crop**, C2:** Maize – cowpea intercrop**.

Treatment W2xF3xC1 (6.73) registered the highest number of leaves/plant representing 21.70% increase over the control (W1xF1xC1) (5.53). The lowest value was recorded by treatment W1xF4xC2 (5.34); a decrease of 3.44% below the control. Treatment W2xF2xC2 (6.40) significantly ($P < 0.05$) increased the number of leaves/plant more than treatment W1xF4xC2 (5.34). In addition, treatment W1xF3xC1 (6.27) significantly increased the number of leaves/plant more than treatment W1xF4xC2 (5.34) (Table 4.6).

For the leaf width, the highest value was recorded by treatment W2xF3xC1 (0.092 m); indicating an increase of 16.4% increase above the control (W1xF1xC1) (0.079 m). The lowest value was recorded by treatment W1xF3xC2 (0.077 m); a decrease of 2.53% below the control. Treatment W2xF2xC2 (0.09 m) significantly ($P < 0.05$) increased leaf width more than treatment W2xF1xC1 (0.082 m) (Table 4.6).

The highest value for the leaf area was recorded by treatment W2xF3xC1 (0.044 m^2) which was an increase of 46.67% above the control (W1xF1xC1) (0.03 m^2). The lowest value was registered by both treatments W1xF3xC2 and W1xF1xC1 (0.03 m^2). Treatment W2xF2xC2 (0.042 m^2) significantly ($P < 0.05$) increased leaf area more than W2xF1xC2 (0.032 m^2). Similarly, treatment W2xF3xC2 (0.042 m^2) had higher leaf area than treatment W2xF1xC1 (0.033 m^2) (Table 4.6).

4.3.3 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 60 days after planting

At 60 days after planting during short rains of 2015 and long rains 2016, the interaction between tied ridges, fertilizers and cropping systems had significant effect ($P < 0.05$) on plant height, number of leaves/plant, leaf length, leaf width and leaf area. During the short rains 2015, generally, treatments under flat bed planting had significantly higher vegetative growth than those under tied ridging. In addition, treatments with maize mono crop increased vegetative growth more than those under maize-cowpeas intercrop. Treatment with flat bed, 20 kg N/ha in maize mono crop (W1xF3xC1) recorded the highest values for all the growth parameters while the lowest values were registered by tied ridging without farm yard manure under maize cowpeas intercrop (W2xF1xC2) (Tables 4.7 and 4.8).

However, during the long rains 2016 generally, treatments with tied ridging had higher vegetative growth compared to treatments in flat bed during. Also, treatments with maize mono crop registered higher values for growth parameters as compared to those with maize-cowpea intercrop. Treatment combination of tied ridging plus 20 kg N/ha in maize mono crop (W2xF3xC1) recorded the highest values for all growth parameters, while the lowest values were recorded in tied ridging without farm yard manure in maize cowpeas intercrop (W2xF1xC2) treatment (Table 4.7 and 4.8).

4.3.4. Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 60 Days after Planting (Short rains 2015)

During the short rains 2015, treatment of W1xF3xC1 recorded the highest value for plant height (0.70 m), an increase of 34.62% over the control (W1xF1xC1) (0.52 m) while the lowest value was registered by treatment W2xF1xC2 (0.48 m). This was a decrease of 26.15% below the control. Treatment W1xF4xC1 (0.65 m) significantly ($P < 0.05$) increased plant height more than treatment W2xF3xC2 (0.49 m). Also treatment W1xFx2C1 (0.61 m) resulted in higher plant height than treatment W2xF1xC2 (0.48 m) (Table 4.7).

Regarding the number of leaves/plant, the highest value was registered by treatment W1xF3xC1 (10.78), an increase of 11.02% above the control (W1xF1xC1) (9.71). Treatment W1xF3xC2 (9.26) decreased the number of leaves per plant by 4.63% below the control while treatment W2xF2xC1 (10.36) significantly (P < 0.05) resulted in higher number of leaves/plant than treatment W2xF1xC1 (9.53). In addition, treatment W1xF3xC1 (10.78) significantly increased the number of leaves/plant more than treatment W2xF2xC2 (9.99) (Table 4.7).

Table 4.7 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 60 days after planting (Short Rains 2015)

Treatments	Plant height (m)	Number of leaves/plant	Leaf length (m)	Leaf width (m)	Leaf area (m^2)
W1xF3xC1	0.70a	10.78a	0.55a	0.079a	3.78a
W1xF4xC1	0.65ab	10.72ab	0.53ab	0.077ab	3.57ab
W1xF2xC1	0.61abc	10.78a	0.49abc	0.072abcd	3.16abcd
W1xF4xC2	0.59abcd	10.31abcd	0.50abc	0.072abcd	3.23abc
W2xF2xC2	0.57bcde	9.99bcde	0.45bcd	0.070abcde	2.89bcde
W2xF4xC1	0.57bcde	10.6ab	0.49abcd	0.075abc	3.18abcd
W2xF2xC1	0.56bcde	10.36abc	0.46bcd	0.069bcde	2.83bcde
W2xF3xC1	0.55bcde	10.18abcd	0.46bcd	0.068cde	2.73cde
W1xF2xC2	0.55bcde	10.02abcde	0.46bcd	0.067cde	2.64cde
W2xF4xC2	0.52cde	10.00abcde	0.44cd	0.066cde	2.59cde
W1xF3xC2	0.52cde	9.26e	0.43cd	0.065de	2.47cde
W1xF1xC1	0.52cde	9.71cde	0.44cd	0.065de	2.61cde
W2xF1xC1	0.51cde	9.53de	0.43cd	0.066de	2.50cde
W1xF1xC2	0.50de	9.53de	0.43cd	0.063e	2.43cde
W2xF3xC2	0.49de	9.63cde	0.43cd	0.063e	22.37de
W2xF1xC2	0.48e	9.28e	0.41d	0.062de	2.23e
P value	0.012	< 0.001	0.033	0.002	0.006
s.e.d	0.057	0.401	0.041	0.0045	0.4102

*Means with the same letter in each column are not significantly different at P < 0.05

**** W1:** Flat bed planting**, W2:** Tied ridges**, F1:** Farm yard manure 0 t /ha, **F2:** Farm yard manure 5t/ha, F3: 20 kg nitrogen fertilizer /ha**, F4:** Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha**, C1:** Maize mono crop**, C2: Maize:** Cowpea intercrop.*

The highest value for leaf length was recorded by treatment W1xF3xC1 (0.55 m) which was an increase of 25% above the control (W1xF1xC1) (0.44 m).

Treatment W2xF1xC2 (0.41 m) recorded the lowest value, a decrease of 6.82% below the control. The leaf length was significantly ($P < 0.05$) increased by treatment W1xF4xC1 (0.53 m) more than treatment W1xF3xC2 (0.43 m). Also treatment W1xF2xC1 (0.49 m) significantly ($P < 0.05$) increased leaf length more than treatment W2xF1xC2 (0.41 m) (Table 4.7).

In relation to leaf width, the highest value was recorded by treatment W1xF3xC1 (0.079 m) which was 21.54% increase over the control (W1xF1xC1) (0.065 m) and the lowest value was registered by treatment W2xF1xC2 (0.062 m). This was a decrease of 4.62% below the control. Treatment combination of W2xF4xC1 (0.075 m) significantly ($P < 0.05$) increased leaf width more than treatment W1xF3xC2 (0.065 m). Also, treatment W1xF4xC1 (0.077) significantly recorded higher leaf width than treatment W1xF2xC2 (0.067 m) (Table 4.7).

The highest value for the leaf area was recorded by treatment W1xF3xC1 (3.78 m^2), an increase of 44.83% above the control (W1xF1xC1) (2.61 m^2). The lowest value was observed from treatment W2xF1xC2 (2.23 m^2), a reduction of 14.46%. Significantly ($P < 0.05$) higher leaf area was recorded by treatment W1xF4xC1 (3.57 m^2) compared to treatment W2xF4xC2 (2.59 m^2). In addition, treatment W1xF4xC2 (3.23 m^2) significantly increased leaf area more than treatment W1xF3xC2 (2.47%) (Table 4.7).

4.3.5 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 60 days after planting (Long rains 2016)

At 60 days after planting (LR 2016), the highest value for plant height was recorded by treatment W2xF3xC1 (0.67 m), an increase of 31.37% above the control

(W1xF1xC1) (0.51 m) while treatments W2xF1xC1, W1xF1xC1 and W1xF2xC1 (0.51 m) had the lowest value. Treatment W2xF2xC2 (0.65 m) significantly (P < 0.05) had higher plant height than treatment W1xF4xC2 (0.54 m) similarly, treatment combination of W2xF3xC2 (0.65 m) significantly increased plant height more than treatment W2xF4xC2 (0.55 m) (Table 4.8).

Table 4.8 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 60 days after planting (Long Rains 2016)

Treatments	Plant height (m)	Number of leaves /plant	Leaf length (m)	Leaf width (m)	Leaf area (m^2)
W1xF3xC1	0.59abc	10.00abc	0.5	0.08abc	3.50abcd
W1xF4xC1	0.57abc	9.82abcde	0.49	0.07bcd	3.28bcd
W1xF2xC1	0.51c	9.30bcdef	0.47	0.07d	3.07d
W1xF4xC2	0.54c	9.04ef	0.47	0.07d	3.04d
W2xF2xC2	0.65ab	10.10ab	0.54	0.08abc	3.99ab
W2xF4xC1	0.56bc	9.91abcd	0.49	0.08abc	3.40abcd
W2xF2xC1	0.56bc	9.80abcde	0.49	0.08abc	3.40abcd
W2xF3xC1	0.67a	10.43a	0.55	0.085a	4.15a
W1xF2xC2	0.57abc	9.37bcdef	0.47	0.07bcd	3.10cd
W2xF4xC2	0.55bc	9.13def	0.49	0.07d	3.23bcd
W1xF3xC2	0.52c	9.30bcdef	0.46	0.07d	2.83d
W1xF1xC1	0.51c	9.23cdef	0.46	0.07d	2.88d
W2xF1xC1	0.51c	9.30bcdef	0.47	0.07d	3.07d
W1xF1xC2	0.53c	9.16cdef	0.46	0.07d	3.98ab
W2xF3xC2	0.65ab	9.74abcde	0.54	0.08abc	3.89abc
W2xF1xC2	0.53c	8.91f	0.49	0.07d	3.06d
P value	0.033	0.01	0.104	0.013	0.018
s.e.d	0.056	0.417	0.034	0.005	0.402

*Means with the same letter in each column are not significantly different at P < 0.05
**** W1:*** *Flat bed planting****, W2:*** *Tied ridges****, F1:*** *Farm yard manure 0t /ha,* ***F2:*** *Farm yard manure 5 t/ha, F3: 20 kg nitrogen fertilizer /ha****, F4:*** *Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha****, C1:*** *Maize mono crop****, C2: Maize:*** *Cowpea intercrop'*

Treatment W2xF3xC1 (10.43) had the highest value for the number of leaves/plant, an increase of 12.15% over the control (W1xF1xC1) (9.23) while the lowest value was observed from treatment W2xF1xC2 (8.91). This was a decrease of 4.19% below the control. The number of leaves /plant was significantly ($P < 0.05$) increased by treatment W2xF4xC2 (9.13) more than treatment W1xF4xC2 (9.04). The highest value for leaf width was registered by treatment W2xF3xC1 (0.085 m), an increase of 21.43% over the control (W1xF1xC1) (0.07m). Treatment W2xF3xC2 (0.08 m) significantly ($P < 0.05$) increased leaf width more than treatment W2xF1xC1 (0.07 m). Also treatment W2xF2xC1 (0.08 m) had higher leaf width than W1xF3xC2 (0.07 m). Treatment combination of W2xF3xC1 (4.15 m^2) had the highest value for the leaf area which was an increase of 30.60% above the control (W1xF1xC1) (2.88 m^2). The lowest value was registered by the control. Treatment W2xF2xC2 (3.99 m^2) significantly ($P < 0.05$) increased the leaf area more than treatment W1xF3xC2 (2.83 m^2) (Table 4.8).

4.3.6 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 80 days after planting (Short rains 2015)

During the SR 2015 (80 days after planting), the interaction between tied ridges, fertilizers, and cropping systems had significant effect ($P < 0.05$) on plant height, number of leaves/plant, leaf width, and leaf area (Table 4.9). Generally, treatments with maize mono crops had higher vegetative growth compared to those with maize-cowpeas intercrop. The highest value for plant height was recorded by treatment W1xF4xC1 (1.72 m), an increase of 16.22% above the control (W1xF1xC1) (1.48 m). The lowest value for plant height was recorded by treatment W2xF1xC2 (1.33 m), a decrease of 10.12% below the control. The plant height was significantly ($P < 0.05$) increased by treatment W1xF3xC1 (1.67 m) more than treatment W2xF1xC1 (1.49 m). Similarly, treatment W1xF2xC2 (1.65 m) significantly increased plant height more than treatment W2xF3xC2 (1.44 m) (Table 4.9).

Table 4.9 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 80 days after planting (Short Rains 2015)

Treatments	Plant height (m)	No. of leaves/ plant	Leaf length (m)	Leaf width (m)	Leaf area (m^2)
W1xF4xC1	1.72a	12.76a	0.67a	0.080ab	4.66a
W2xF4xC1	1.67ab	12.55abc	0.65abc	0.078abc	4.34abc
W1xF3xC1	1.67ab	12.54abc	0.66ab	0.082a	4.71a
W1xF2xC1	1.65abc	12.79a	0.64abc	0.077abcd	4.27abc
W2xF2xC1	1.62abcd	12.64abc	0.62abcd	0.074bcde	4.00abcde
W2xF2xC2	1.58abcde	12.50abcd	0.61bcde	0.074bcde	3.95bcdef
W2xF4xC2	1.52bcdef	12.31abcde	0.60cde	0.069defg	3.63cdefg
W1xF4xC2	1.51bcdef	12.67ab	0.64abc	0.074bcde	4.11abcd
W2xF3xC1	1.51bcdef	12.13abcde	0.58def	0.072cdef	3.63cdefg
W2xF1xC1	1.49cdefg	12.19abcde	0.56ef	0.069defg	3.39defg
W1xF1xC1	1.48defg	11.98cde	0.57def	0.068efg	3.42defg
W2xF3xC2	1.44efg	12.02bcde	0.57def	0.065fg	3.23fg
W1xF2xC2	1.39fg	12.34abcde	0.59cdef	0.069defg	3.52defg
W1xF1xC2	1.38fg	11.79e	0.58def	0.065fg	3.30efg
W1xF3xC2	1.37fg	12.05bcde	0.59cdef	0.068efg	3.51defg
W2xF1xC2	1.33g	11.83de	0.54f	0.064g	3.00g
P value	< 0.001	0.035	< 0.001	< 0.001	< 0.001
s.e.d	0.085	0.341	0.03	0.004	0.365

*Means with the same letter in each column are not significantly different at P < 0.05

**** W1:** Flat bed planting, **W2:** Tied ridges, **F1:** Farm yard manure 0t /ha, **F2:** Farm yard manure 5 t/ha, **F3:** 20 kg nitrogen fertilizer /ha, **F4:** Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha, **C1:** Maize mono crop, **C2:** Maize-cowpea intercrop*

Treatment W1xF2xC2 (12.79) recorded the highest value for the number of leaves /plant which was an increase of 6.76% above the control (W1xF1xC1) (11.98). The lowest value was observed from treatment W1xF1xC2 (11.79), a decrease of 1.59% below the control. The number of leaves/plant was significantly

(P < 0.05) increased by treatment W1xF4xC2 (12.67) compared to treatment W2xF1xC2 (11.83). In addition, treatment W1xF4xC1 (12.76) significantly increased the number of leaves/plant more than treatment W2xF3xC2 (12.02) (Table 4.9)

The highest value for plant leaf length was observed from treatment W1xF4xC1 (0.67 m), an increase of 17.54% over the control (W1xF1xC1) (0.57m). Treatment W2xF1xC2 (0.54 m) recorded the lowest value for leaf length which was a decrease of 5.26% below the control. Treatment W1xF3xC1 (0.66 m) significantly (P < 0.05) increased the leaf length more than treatment W2xF3xC1 (0.58 m). Also treatment W1xF2xC1 (0.64 m) registered significantly higher leaf length than W2xF3xC2 (0.57 m) (Table 4.9).

The highest value for leaf width was recorded from treatment W1xF3xC1 (0.082 m), an increase of 17.07% above the control (W1xF1xC1) (0.068 m). Treatment W2xF1xC2 (0.064 m) recorded the lowest values for leaf width which was a decrease of 5.88% below the control. Treatment W1xF4xC1 (0.08 m) recorded significantly (P < 0.05) increased leaf width compared to treatment W2xF3xC1 (0.072 m). In addition, treatment W2xF2xC1 (0.074 m) significantly increased leaf width more than treatment W2xF3xC2 (0.065 m) (Table 4.9).

Treatment combination of W1xF3xC1 (4.71 m^2) recorded the highest value for leaf area which was an increase of 37.72% above the control (W1xF1xC1) (3.42 m^2). The lowest value was registered by treatment W2xF1xC2 (3.0 m^2), a decrease of 12.28% below the control. Treatment W1xF2xC1 (4.27 m^2) significantly (P < 0.05) increased the leaf area more than treatment W2xF1xC1 (3.39 m^2). Similarly, treatment W1xF4xC2 (4.11 m^2) significantly increased leaf area compared to treatment W1xF1xC2 (3.30 m^2) (Table 4.9).

4.3.7 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 80 days after planting (Long rains 2016)

At 80 days after planting during the LR 2016, treatments with tied ridges had generally higher vegetative growth than those under flat bed. Also treatments with maize mono had more increased vegetative growth compared to those with maize cowpeas intercrop (Table 4.10).

Table 4.10 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize growth parameters at 80 days after planting (Long Rains 2016)

Treatments	Plant height (m)	No. of leaves/ plant	Leaf length (m)	Leaf width (m)	Leaf area (m^2)
W1xF4xC1	1.27bcd	11.60ab	0.7	0.07bcd	4.36bcd
W2xF4xC1	1.37abc	11.61ab	0.72	0.08ab	4.77ab
W1xF3xC1	1.24bcd	10.88bcdef	0.71	0.07bcd	4.34bcd
W1xF2xC1	1.31abc	11.22abc	0.65	0.07bcd	4.10bcde
W2xF2xC1	1.42ab	11.65a	0.66	0.08ab	4.48abc
W2xF2xC2	1.17cde	10.34ef	0.7	0.07bcd	4.33bcd
W2xF4xC2	1.08def	10.29f	0.66	0.06cde	3.80cde
W1xF4xC2	1.04ef	10.29f	0.66	0.07bcd	3.60de
W2xF3xC1	1.49a	11.77a	0.71	0.09a	5.27a
W2xF1xC1	1.31abc	11.44ab	0.65	0.07bcd	4.28bcd
W1xF1xC1	1.19cde	11.12abcd	0.63	0.07bcd	3.73cde
W2xF3xC2	1.18cde	11.18abc	0.7	0.07bcd	4.35bcd
W1xF2xC2	1.03ef	10.42def	0.65	0.06de	3.63cde
W1xF1xC2	1.03ef	10.40def	0.65	0.06de	3.61de
W1xF3xC2	0.94f	10.57cdef	0.65	0.05e	3.39e
W2xF1xC2	1.05ef	11.07abcde	0.66	0.07bcd	3.99bcde
P value	< 0.001	< 0.001	0.39	< 0.001	0.002
s.e.d	0.085	0.3742	0.039	0.0053	0.4355

*Means with the same letter in each column are not significantly different at $P < 0.05$

**** W1:** Flat bed planting, **W2:** Tied ridges, **F1:** Farm yard manure 0t /ha, **F2:** Farm yard manure 5t/ha, **F3:** 20 kg nitrogen fertilizer /ha, **F4:** Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha, **C1:** Maize mono crop, **C2:** Maize -cowpea intercrop*

The highest value for plant height was recorded by treatment W2xF3xC1 (1.49 m), an increase of 25.21% above the control (W1xF1xC1) (1.19 m). The lowest value was registered by treatment W1xF3xC2 (0.94 m), a decrease of 21.0% below the control. Treatment W2xF2xC1 (1.42 m) significantly ($P < 0.05$) increased plant height more than treatment W2xF3xC2 (1.18 m). In addition, treatment W1xF2xC2 (1.31 m) significantly had higher plant height compared to W1xF3xC3 (0.94 m) (Table 4.10).

The highest value for the number of leaves/plant was recorded by treatment W2xF3xC1 (11.77), accounting for 5.84% increase above the control (W1xF1xC1) (11.12). The lowest value for number of leaves/plant was observed from treatments W2xF4xC2 and W1xF4xC2 (10.29), a decrease of 7.46% below the control. Treatment W2xF4xC1 (11.61) significantly ($P < 0.05$) increased the number of leaves /plant compared to treatment W1xF2xC2 (10.42). Also treatment W2xF3xC2 (11.18) significantly had higher number of leaves/plant compared to treatment W1xF1xC2 (10.40) (Table 4.10).

Treatment combination of W2xF3xC1 (0.09 m) recorded the highest value for leaf width, representing an increase of 28.57% over the control (W1xF1xC1) (0.07 m). The lowest value was registered by treatment W1xF3xC2 (0.05 m), a decrease of 28.57% below the control. Treatment W2xF4xC1 (0.08 m) significantly ($P < 0.05$) increased the leaf width more than treatment W1xF2xC2 (0.06 m). Similarly, treatment W2xF2xC1 (0.08 m) significantly had higher leaf width than treatment W1xF1xC2 (0.06 m) (Table 4.10).

The highest value for leaf area was observed in treatment W2xF3xC1 (5.27 m^2), an increase of 41.29% above the control (W1xF1xC1) (3.73). The lowest value was recorded by treatment W1xF3xC2 (3.39m^2), a decrease of 9.12%. Treatment

W2xF4xC1 (4.77 m^2) significantly ($P < 0.05$) increased the leaf area compared to treatment W1xF4xC2 (3.80m^2) (Table 4.10).

Generally, vegetative growth during the SR 2015 was higher as compared to LR 2016. This could be attributed to the high amount of rainfall received in SR 2015 compared to LR 2016. During the SR 2015, treatments with flat bed planting in maize mono crop recorded increased means as compared to treatments with tied ridging in maize mono crop. However, during the LR 2016, treatments with tied ridging in maize mono crop resulted to increase in vegetative growth as opposed to flat bed with maize mono crop. The differences observed in both SR 2015 and LR 2016 between treatments with tied ridges and those with flat bed planting could be related to the differences in soil moisture (Khurshid *et al.*, 2006).

Application of farm yard manure 5 t/ha and nitrogen fertilizer 20 kg N/ha enhanced vegetative growth. This resulted in differences between treatments with fertilizer application compared to treatments where fertilizers were not applied. The increased plant density in maize cowpeas intercrop might have led to competition for growth resources in comparison to treatments with maize mono crop, hence resulting to differences between treatments with maize mono crop and those with maize cowpeas intercrop (Karuma *et al.*, 2014).

During the short rains 2015 at 40 and 60 days after planting, treatment with flat bed planting, 20 kg N/ha in maize mono crop (W1xF3xC1) recorded the highest value for all the growth parameters. This could be due to the readily available nutrients in nitrogen fertilizer upon its application. Therefore, the plants were able to take up the nitrogen which enhanced the vegetative growth. However, at 80 days after planting, the highest values were observed from treatment with flat bed, FYM

5 t/ha + 20 kg N/ha in maize mono crop (W1xF4xC1). This is because at this time, the farm yard manure had fully decomposed and released nutrients for plant use.

The application of farm yard manure and nitrogen fertilizer improved the nutrient levels as well as water storage in the soil. Nitrogen fertilizer plays an important role in vegetative growth because it is involved in protein synthesis, which promotes plant growth (Haris *et al.*, 1997 as cited by Hassan *et al.*, 2010). The improved soil moisture observed in flat bed planting led to increased vegetative growth during the short rains 2015. The maize mono crop had less plant density which minimized competition for growth resources hence better vegetative growth (Karuma *et al.*, 2014).

However, at 40, 60 and 80days after planting (SR 2015), treatment with tied ridging and FYM 0 t/ha in maize cowpeas intercrop (W2xF1xC2) gave the lowest values because the amount of soil moisture in treatments with tied ridges was low. In addition, there was no application of farm yard manure or nitrogen fertilizer resulting to low nutrient supply limiting vegetative growth. Also the maize cowpeas intercrop resulted to increased plant density. This might have increased competition for growth resources lowering the vegetative growth (Karuma *et al.*, 2014).

During the long rains 2016 when the rainfall amount was low, treatment combination of tied ridging, 20 kg N/ha in maize mono crop (W2xF3xC1) had the highest values for vegetative growth at 40, 60 and 80 days. This is probably because tied ridges were able to effectively conserve the little rain water which was available. Also application of 20 kg N/ha resulted to increased vegetative growth; since nitrogen was made readily available in soil solution for plant uptake. However, treatments with addition of farm yard manure 5 t/ha, whether under tied ridges or flat bed planting, reduced vegetative growth during LR 2016. This is probably because there was no enough moisture in the soil to enable mineralization of the farm yard manure to take place in order to release nutrients to the soil.

In addition, plants only take up nutrients in ionic form hence the low soil moisture was not sufficient to dissolve the nutrients. Limited nutrient up take contributed to reduced vegetative growth in treatments with farm yard manure (Zang *et al.,* 2010). The low values for vegetative growth observed from treatment with tied ridging without FYM in maize cowpeas intercrop (W2xF1xC2) at 40 and 60 days after planting during the LR 2016. This was as a result of low amount of nutrients which affected vegetative growth. The increased plant density in maize cowpeas intercrops could have also led to competition for growth resources limiting vegetative growth.

However, at 80 days after planting during the LR 2016, the lowest values for vegetative growth were recorded by flat bed planting with 20 kg N/ha in maize cowpeas intercrop (W1xF3xC2) treatment. The reason could be that at this stage of plant growth, the soils were too dry even for nitrogen fertilizer to be dissolved and absorbed in the soil which could have limited its uptake by the plant. The amount of rainfall received was very low (96.0mm) (Table 4.2) and poorly distributed (Fig. 4.1). This made treatments with flat bed planting to have reduced vegetative growth due to low soil moisture (Karuma *et al.,* 2014).

In both SR 2015 and LR 2016 seasons, treatments with 20 kg N/ha registered increased vegetative growth because application of nitrogen fertilizer to crops facilitates development of leaf area and lateral stem due to increase in the physiological indices. Nitrogen application also improves plant growth by increasing plant height and stem diameter during the end of the vegetative growth. In addition, nitrogen promotes plant growth, enhances leaf expansion and development (Okpara, 2000).

The increased leaf area in treatments with addition of nitrogen fertilizer agree with the findings of Adeleke and Haruna (2012) who reported significant response of maize leaf as a result of nitrogen application. The increased leaf area shows the important role played by nitrogen in promoting vegetative growth because nitrogen enhances cell division and is required in protein synthesis. The rate of growth and development processes are affected by high temperatures as well as inadequate rainfall (Birch *et al.,* 2003) hence, the differences in leaf area during SR 2015 and LR 2016. In addition, Asim *et al.* (2012) observed differences due to season, plant population and N fertilizer application on leaf area.

The findings from this study confirmed that, nitrogen is one of the most essential elements required for plant growth and development. Leaf area is determined by plant population and soil fertility (Okpara, 2000). This could be the reason why treatments with maize mono crop, FYM 5 t/ha, and 20 kg N/ha had significantly higher values for the growth parameters compared to treatments without farm yard manure only in maize cowpeas intercrop. The increased vegetative growth during the SR 2015 could be due to the high amount of rainfall received (574.8mm) (Table 4.2) which was evenly distributed (Fig. 4.1). Adequate availability of water to plants results in cell turgidity and finally higher meristematic activity of maize leading to more foliage development, higher photosynthetic rate and finally improved plant growth (Arnon, 1975 as cited by Hassan *et al.,* 2012).

The possible cause of reduced vegetative growth in treatments with tied ridging during the SR 2015 could be due to reduced soil moisture in these treatments. This may have been as a result of inversion and mixing of the top soil as the tied ridges were being constructed which may have reduced the fertility of the top soil. Also, due to the high amount of rainfall received (574.8mm), some water may have ponded in the plots with tied ridges at the beginning of the rain season which could have affected the germination as well as the growth of the crops. These findings are in line with the studies carried out by Khurshid *et al.* (2006) who reported that, taller plants were found in plots with flat bed planting as compared to those planted in tied – ridges during seasons of high rainfall.

An important finding in this study was that, there was increased plant height during SR 2015 compared to LR 2016. These differences may be attributed to differences in the amount of rainfall received and rainfall distribution during the growth period (Table 4.2 and Fig. 4.1). Increased plant height is important in that, height is related to the final grain yield as the stem of maize can conserve as a reservoir of labile non- structural carbohydrates which are mobilized as sugars and in turn translocated to the filling grains during the post flowering period (Karuma et al., 2014). The stems also play an important role in maintaining the rate of grain filling against longer term effects of persistent post flowering stress like drought (Edmeades and Lafitte, 1993, as cited by Karuma *et al.*, 2014). The current findings agree with the work done by Sebetha *et al.* (2015).

4.4 Effect of Farm Yard Manure, Nitrogen Fertilizer and Cropping Systems on Soil pH and Organic Carbon

The interaction between fertilizers and cropping systems had significant effect ($P < 0.05$) on the final soil pH. However, the interaction was not significant ($P = 0.092$) on soil organic carbon (Table 4.11).

4.4.1 Effect of farm yard manure, nitrogen fertilizer and cropping systems on soil pH

Treatments with addition of FYM 5 t/ha had higher soil pH values compared to those without fertilizer input. The highest value for the final soil pH was observed in treatment with FYM 5 t/ha in maize cowpeas intercrop (F2xC2) (6.32) with an increase of 6.04% above FYM 0t/ha in maize mono crop (F1xC1) (5.96) which was the control. This was followed by treatment FYM 5 t/ha in maize mono crop (F2xC1) which recorded a mean of 6.31, translating to 5.87% higher than FYM 0 t/ha with maize mono crop (F1xC1) (5.96) (Table 4.11).

Table 4.11 Interaction effect of farm yard manure, nitrogen fertilizer and cropping systems on soil organic carbon and pH

Treatments	Initial organic carbon (%)	Final organic carbon (%)	Change in organic carbon (%)	Initial soil pH	Final soil pH	Change in soil pH
F1xC1	0.67	1.03	0.36	6.54	5.96cd	-0.58cd
F1xC2	0.67	1.01	0.35	6.54	6.06c	-0.48bc
F2xC1	0.67	1.11	0.45	6.54	6.31a	-0.23a
F2xC2	0.67	1.13	0.47	6.54	6.32a	-0.22a
F3xC1	0.67	0.87	0.21	6.54	5.78e	-0.76e
F3xC2	0.67	0.92	0.26	6.54	5.84de	-0.70de
F4xC1	0.67	1.04	0.37	6.54	6.10bc	-0.44bc
F4xC2	0.67	0.99	0.32	6.54	6.12a	-0.42b
P value		0.092	0.092		< 0.001	< 0.001
s.e.d		0.0906	0.0906		0.0712	0.0712

*Means with the same letter in each column are not significantly different at P < 0.05.

***F1:** *Farm yard manure 0t /ha*, **F2: Farm yard** *manure 5t/ha,* **F3:** *20 kg nitrogen fertilizer /ha,* **F4:** *Farm yard manure 5 t/ha+ 20 kg nitrogen fertilizer /ha,* **C1:** *Maize mono crop,* **C2:** *Maize -cowpea intercrop*

The lowest value of final pH was given by treatment 20 kg N/ha combined with maize mono crop (F3xC1) with a mean of 5.78, representing a decline of 3.02% below FYM 0 t/ha in maize mono crop (F1xC1) (5.96). The highest change value for the soil pH was recorded in treatment FYM 5 t/ha in maize cowpeas intercrop (F2xC2) (-0.22) while the lowest was from 20 kg N/ha combined with maize mono crop (F3xC1) (-0.76) (Table 4.11).

Treatment combination with FYM 5t/ha with maize mono crop (F2xC1) resulted to significantly ($P < 0.05$) higher final soil pH than 20 kg N/ha with maize mono crop (F3xC1). This means that, maize mono crop combined with FYM 5 t/ha increased the soil pH more than maize mono crop with 20 kg N/ha. Also, FYM 5 t/ha in maize cowpeas inter crop (F2xC2) registered significantly higher values for the final soil pH compared to maize cowpeas combined with 20 kg N/ha + FYM 5 t/ha (F4xC2). This means that, maize cowpeas intercrop with FYM 5t/ha increased soil pH more than maize mono crop with 20kgN/ha +FYM 5t/ha. Similarly, treatment with FYM 5t/ha in maize mono crop (F2xC1) had significantly higher values for soil pH than maize cowpeas intercrop with FYM 0 t/ha (F1xC2). This indicates that, maize mono crop with FYM 5 t/ha led to more increased soil pH than maize cowpeas crop with FYM 0 t/ha (Table 4.11).

The increased significant differences in pH observed in treatments where farm yard manure and nitrogen fertilizer were applied and those without fertilizer could be due to application of farm yard manure which could have increased the level of acidity in the soil. When farm yard manure is applied to the soil, it absorbs or binds hydrogen ions in the humic forms increasing the acidity in the soil (Ashiono et al., 2006). The farm yard manure which was applied was slightly alkaline with a pH value of 7.94-8.96 (Table 3.3) but did not neutralize the acidity in the soil.

The increased soil pH when FYM 5 t/ha was applied alone and when combined with 20 kg N/ha nitrogen could be due to the H^+ ions which were absorbed from the soil solution by humic substances (Tisade *et al.,* 1993 as cited by Innocent, 2014). Application of farm yard manure in the soil increases chemical activities in the soil which in turn increases soil acidity. During decomposition of the farm yard manure, several organic acids are released and synthesized. The carbon dioxide produced during decomposition dissolves in water to form hydro carbonic acid. This makes the soil solution to become more acidic (Chandy, 2010). This could be the reason why treatments with addition of farm yard manure had increased acidity. Therefore, if farm yard manure is applied continuously for a number of years, it can amend saline and alkaline soils (Chandy, 2010; Keshavarz *et al.,* 2012).

The optimum pH value for maize production ranges from 6.0-7.2. When the soil pH is less than 5.0, it leads to Al toxicity, reduces root development and increases manganese toxicity; reducing plant development. Maize does not tolerate pH conditions of less than 5.5 because in acidic soils, the roots of maize crop suffer impairment from Al toxicity. This in turn inhibits nutrient uptake resulting to root damage. Acidic soils also negatively affect availability of nutrients. Therefore, treatment combination of maize cowpeas intercrop and FYM 5 t/ha (F2xC2) led to the most ideal pH value (6.32) for maize growth. The findings from this study agree with the work done by Innocent (2014) who reported that, application of nitrogen fertilizers and farm yard manure raised the acidity of the soils in Rwanda.

4.4.2 Correlation and regression analysis of soil organic carbon and pH

The correlation and regression analyses showed that, there was a highly significant ($P < 0.001$) positive relationship between soil organic matter and soil pH

(Figure 4.11). The amount of soil organic carbon increased with an increase in soil pH. This could be related to the fact that, the humic acid produced during decomposition of organic matter has effect on H^+ ions absorption (Sebetha, 2015).

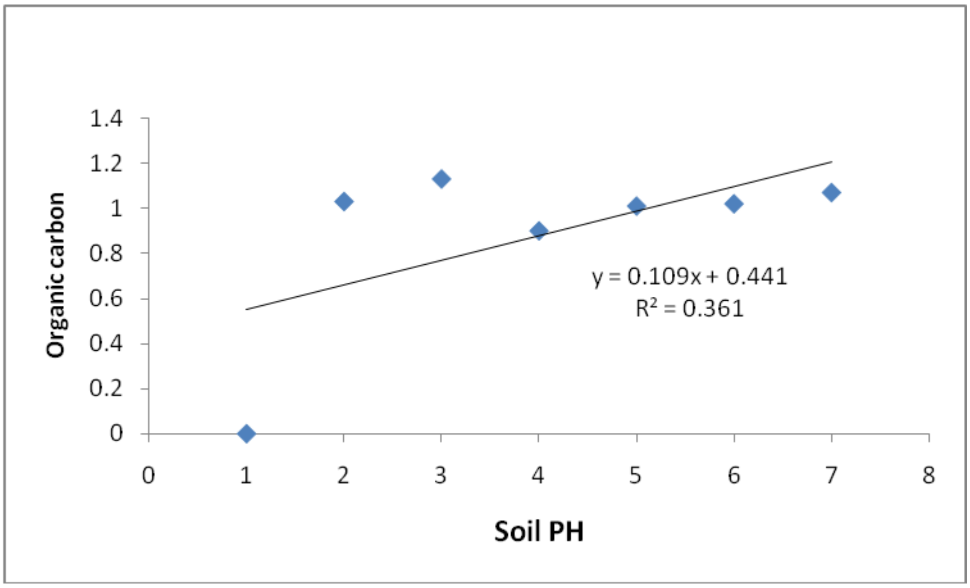

Figure 4.2: Relationship between soil organic carbon and soil pH

4.5 Effect of Farm Yard Manure, Nitrogen Fertilizers and Cropping Systems on Maize Crop Nitrogen Content

During the LR 2016, the interaction between fertilizers and cropping systems had highly significant effect ($P < 0.001$) on the %N content in both maize grains and stovers. However, during the SR 2015, the interaction effect was not significant (Table 4.12). During the LR 2016, generally, treatments with maize mono crop exhibited higher N content in both grains and stovers compared to those having maize cowpeas intercrop (Table 4.12). The treatments increased N content in maize stovers with 1.32% more than grains. This could probably be due to the low amount of rainfall received in the season (Table 4.1) which led to low soil moisture storage which affected vegetative growth more than grain filling.

Table 4.12 Interaction effect of farm yard, nitrogen fertilizer and cropping systems on maize grains and stovers nitrogen content

	SR 2015		LR 2016	
Treatments	**% N grains**	**% N stovers**	**% N grains**	**%N stovers**
F1xC1	1.56	0.85	0.26ab	1.43ab
F1xC2	1.59	0.67	0.03c	1.13bc
F2xC1	1.49	0.63	0.38a	1.68a
F2xC2	1.58	0.77	0.06bc	1.10bc
F3xC1	1.57	0.83	0.41a	1.73a
F3xC2	1.64	0.73	0.06bc	1.35bc
F4xC1	1.41	0.78	0.38a	1.41ab
F4xC2	1.47	0.78	0.08bc	1.09bc
P value	0.813	0.258	< 0.001	< 0.001
s.e.d	0.1474	0.0941	0.1165	0.1664

*Means with the same letter in each column are not significantly different at P < 0.05
***F1:** Farm yard manure 0t /ha, **F2:** Farm yard manure 5t/ha, **F3:** 20 kg nitrogen fertilizer /ha, **F4:** Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha, **C1:** Maize mono crop, **C2:** Maize – cowpea intercrop*

Maize mono crop combined with 20 kg N/ha (F3xC1) recorded the highest values of N content in both grains and stovers (grains: 0.41% and stovers 1.73% respectively). The percentage N content increase in grains, was increased by 57.69% above maize mono crop with FYM 0t/ha (F1xC1) (0.26%) which was the control. The lowest values of N content in grains was recorded in treatment maize cowpeas intercrop combined with FYM 0 t/ha (F1xC2) (0.03%), a decrease of 88.46% below the control (Table 4.12).

In both the maize grains and stovers of LR 2016, maize mono crop with 20 kg N/ha (F3xC1) registered significantly higher N content than maize cowpeas intercrop combined with FYM 5 t/ha (F2xC2). This means that, maize mono crop with 20kgN/ha increased the percentage N content in grains and stovers more than maize cowpeas intercrop under FYM 5t/ha (Table 4.12). Similarly, maize mono crop combined with FYM 5 t/ha (F2xC1) had significantly higher N content in both grains and stovers more than maize mono crop combined with FYM 0 t/ha (F1xC1); indicating that, maize mono crop under 20 kg N/ha resulted to increased N content in both grains and stovers compared to maize mono crop under FYM 0 t/ha (Sanchez, *et al.*, 2004) (Table 4.12).

However, during the SR 2015, the interaction effect between fertilizers and cropping systems was not significant on nitrogen content in stovers and grains. This could probably be due to the well distributed and high rainfall which ensured uniform uptake of N from the soil by the plants. Several researchers have reported that, plants have difficulty in absorbing nutrients in dry soils because most nutrients are elemental and not in ionic forms; hence, during the dry seasons, nutrient levels in plant tissues may be lower than normal (Sanchez and Dorge, 1999 as cited by Innocent, 2014). Nutrient uptake varies with stage of plant growth (Jones and Jacobsen, 2001). The lack of significant effect on N content agrees with the work done by Innocent (2014) in Rwanda who also observed no significance difference with the Interactions on % N in grains and stovers in maize.

4.6 Effect of Tied Ridges, Farm Yard Manure, Nitrogen Fertilizers and Cropping Systems on Yield and Yield Components of Maize

During SR 2014, LR 2015, SR 2015 and LR 2016, the interaction effect between tied ridges, fertilizers and cropping systems was significant ($P < 0.05$) on ears weight, grain yield and biomass yield (Table 4.13, 4.14, 4.15 and Table 4.16).

4.6.1 Effect of tied ridges, farm yard manure, nitrogen fertilizers and cropping systems on yield and yield components of maize (Short rains 2014)

During SR 2014, generally, the treatment combinations with maize mono crop under tied ridges had significantly higher values for all the yield and yield components compared to those with maize cowpeas intercrop under flatbed (Table 4.13).

Table 4.13 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on yield and yield components of maize (Short rains 2014)

Treatments	Cobs weight (t/ha)	Ears weight (t /ha)	No. of ears/ ha	Stover yield (t/ha)	Grain yield (t/ha)	Biomass yield (t/ha)	Harvest index
W2xF4xC1	0.23	1.53ab	1.84	1.11ab	1.23ab	3.73a	0.09
W2xF2xC1	0.29	1.59a	1.79	1.20a	1.30a	3.45ab	0.09
W2xF3xC1	0.26	1.26bcd	1.72	0.78efg	1.00bcd	3.41ab	0.08
W1xF4xC1	0.26	1.36abc	1.84	0.10abcde	1.10abc	2.63bc	0.08
W1xF2xC1	0.27	1.46abc	1.82	1.17a	1.15abc	2.52c	0.07
W2xF3xC2	0.18	0.87fgh	1.61	1.09abc	0.68fg	2.28cd	0.08
W1xF3xC1	0.23	1.16cdef	1.62	0.85defg	0.93cde	2.02cde	0.09
W2xF2xC2	0.21	1.01defg	1.59	1.05abcd	0.81def	1.89cdef	0.09
W2xF4xC2	0.19	0.92efgh	1.49	0.87defg	0.76def	1.84cdef	0.12
W2xF1xC1	0.21	1.17cde	1.75	0.71fg	0.96cde	1.82cdef	0.08
W1xF2xC2	0.21	0.10defg	1.65	0.92bcdef	0.79def	1.62def	0.08
W2xF1xC2	0.16	0.72gh	1.61	0.71fg	0.56fg	1.39ef	0.08
W1xF1xC1	0.45	0.90efgh	1.75	0.88cdefg	0.72efg	1.38ef	0.08
W1xF1xC2	0.13	0.65h	1.68	0.69g	0.52g	1.22ef	0.08
W1xF3xC2	0.13	0.62h	1.7	0.79efg	0.49g	1.14f	0.08
W1xF4xC2	0.16	0.78h	1.42	0.74fg	0.62fg	1.09f	0.08
P value	0.982	< 0.001	0.13	< 0.001	< 0.001	< 0.001	0.266
s.e.d	0.201	0.152	1.409	0.111	0.123	0.444	0.010

*Means with the same letter in each column are not significantly different at $P < 0.05$

***W1:** Flat bed planting, **W2:** Tied ridges, **F1:** Farm yard manure 0t /ha, **F2:** Farm yard manure 5t/ha, **F3:** 20kg nitrogen fertilizer /ha, **F4:** Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha, **C1:** Maize mono crop, **C2:** Maize – cowpea intercrop*

Treatments with tied ridging, farm yard manure 5 t/ha under maize mono crop (W2xF2xC1) recorded the highest value for grain yield (1.3 t/ha). This was an increase of 80.56% above the control (W1xF1xC1) (0.72 t/ha) (Table 4.13). The lowest value for grain yield was recorded by treatment with flat bed, 20 kg N/ha under maize cowpeas intercrop (W1xF3xC2) (0.49 t/ha), a decrease of 31.94% below the control. Treatment W2xF4xC1 (1.23 t/ha) significantly ($P < 0.05$) increased the grain yield more than the treatment with W1xF3xC1 (0.93 t/ha). Also, treatment W1xF2xC1 (1.15 t/ha) significantly increased the grain yield more than treatment W1xF2xC2 (0.79 t/ha) (Table 4.13).

The highest value for the stover yield was recorded by treatment W2xF2xC1 (1.20 t/ha), an increase of 36.36% over the control (W1xF1xC1) (0.88 t/ha). Treatment W1xF1xC2 (0.69 t/ha) had the lowest value for stover yield which was a decrease of 27.54% below the control. Treatment combination of W1xF2xC1 (1.17 t/ha) significantly ($P < 0.05$) had higher values for stover yield than treatment W2xF1xC1 (0.71 t/ha). In addition, treatment W2xF3xC3 (1.09 t/ha) significantly increased the stover yield compared to treatment W1xF4xC2 (0.74 t/ha) (Table 4.13).

Treatment combination of W2xF4xC1 (3.73 t/ha) had the highest value for biomass yield, an increase of 170.29% above the control (W1xF1xC1) (1.38 t/ha). The lowest value for biomass yield was recorded by treatment W1xF4xC2 (1.09 t/ha), a decrease of 21.01% below the control. Treatment W2xF3xC1 (3.41 t/ha) significantly ($P < 0.05$) increased biomass yield more than treatment W1xF1xC2 (1.22 t/ha). Similarly, treatment W1xF2xC1 (2.5 t/ha) significantly had higher biomass yield than treatment W1xF3xC2 (1.14 t/ha) (Table 4.13).

The treatment combination of W2xF2xC1 recorded significantly ($P < 0.05$) higher values for all the yield and yield components during the SR 2014 compared to W2xF1xC2. This means that, maize mono crop with an addition of FYM 5 t/ha under tied ridging increased the grain and stover yields more than maize cowpeas intercrop without fertilizer input under tied ridging (Table 4.13). The significant increase in grain and stover yields could be probably due to the low plant density in maize mono crop compared to that in maize cowpeas intercrop (Karuma *et al.,* 2014).

The increased plant density in the maize cowpeas intercrop could have led to competition for growth resources such as water which was not sufficient hence the reduced yields. Similar observations were made by Kurasu *et al.* (2015) who also reported reduced yields as a result of increased plant density. In addition, treatment W2xF3xC1 had significantly higher values for stover, grain and biomass yields compared to treatment W1xF3xC2. This shows that, maize mono crop with 20 kg N/ha under tied ridging led to more increased yields for stover, grains and biomass than maize cowpeas intercrop with 20 kg N/ha under flat bed (Table 4.13). These differences could be related to increased soil moisture content in the tied ridges compared to flat bed.

Similarly, treatment W2xF4xC1 had significantly ($P < 0.05$) higher values for stover, grain and biomass yields than treatment W1xF4xC2. This implies that, maize mono crop with FYM 5 t/ha + 20 kg t/ha under tied ridging resulted to more increased stover, grain and biomass yields compared to maize cowpeas intercrop with FYM 5 t/ha + 20 kg N/ha under flat bed. In addition, treatment W2xF2xC1 registered significantly higher values for stover, grain and biomass yields than treatment W1xF1xC1. This indicates that, maize mono crop with FYM 5 t/ha under tied ridging led to higher stover, grain and biomass yields compared to maize mono crop without farm yard manure under flat bed SR 2014 (Table 4.13). The application of FYM 5 t/ha increased the yield compared to treatment without fertilizer input. This point out the important role that is played by FYM in improving crop yields because of soil moisture increase effect and to some extent nutrients in the soil for plant use. These findings agree with the work done by Marschner *et al.* (2011) who reported increased crop yields due to application of farm yard manure.

4.6.2 Effect of tied ridges, farm yard manure, nitrogen fertilizers and cropping systems on yields and yield components of maize (Long rains 2015)

During LR 2015, generally treatments with maize mono crop under tied ridging had significantly ($P < 0.05$) higher values for stover, grain, biomass yields and yield components compared to those with maize cowpeas intercrop under flat bed (Table 4.14). The highest yield value for grain was observed from treatment with tied ridging, farm yard manure 5t/ha in maize mono crop (W2xF2xC1) (0.15 t/ha). This was an increase of 650% above the control (W1xF1xC1) (0.02 t/ha). The lowest grain yield was obtained in treatment W2xF1xC2 which had no grains (Table 4.14).

Table 4.14 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on yield and yield components of maize (Long rains 2015)

Treatments	Cobs weight (t/ha)	Ears weight (t /ha)	No. of ears/ha	Stover yield (t/ha)	Grain yield (t/ha)	Biomass yield (t/ha)	Harves t index
W2xF4xC1	0.046ab	0.19a	7.81a	0.95ab	0.14ab	1.50a	0.04ab
W2xF2xC1	0.041abc	0.19a	7.58a	0.76bcde	0.15a	1.44a	0.04ab
W2xF3xC1	0.52a	0.21a	7.35a	1.07a	0.15a	1.23ab	0.05a
W1xF4xC1	0.029bcd	0.14ab	6.20ab	0.89abc	0.11abc	1.31ab	0.04ab
W1xF2xC1	0.014de	0.07bcd	4.57abc	0.74bcdef	0.06cde	1.46a	0.02bcd
W2xF3xC2	0.028bcd	0.016d	7.35a	0.78bcd	0.09abcd	0.80d	0.04ab
W1xF3xC1	0.012de	0.061bcd	3.44bcd	0.75bcde	0.05cde	1.09bc	0.02bcd
W2xF2xC2	0.011de	0.050bcd	2.75bcd	0.71cdefgh	0.04de	0.91cd	0.02bcd
W2xF4xC2	0.011de	0.047cd	2.29cd	0.64defgh	0.04de	0.79d	0.01cd
W2xF1xC1	0.021cde	0.092bcd	4.13abcd	0.65defgh	0.07bcde	1.14bc	0.03abc
W1xF2xC2	0.004e	0.019d	1.14cd	0.59defgh	0.01e	0.92cd	0.00cd
W2xF1xC2	0.002e	0.010d	1.83cd	0.54fgh	0.00e	0.69d	0.00cd
W1xF1xC1	0.005e	0.026d	1.37cd	0.59defgh	0.02e	0.90efgh	0.01cd
W1xF1xC2	0.004e	0.020d	1.83cd	0.57efgh	0.02e	0.65h	0.01cd
W1xF3xC2	0.003e	0.015d	0.91cd	0.51gh	0.01e	0.62h	0.01cd
W1xF4xC2	0.00e	0.002d	0.45d	0.46h	0.00e	0.70d	0.00d
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
s.e.d	0.011	0.049	1.858	0.102	0.0369	0.152	0.011

*Means with the same letter in each column are not significantly different at P < 0.05

W1:** *Flat bed planting,* ***W2: *Tied ridges,* ***F1:*** *Farm yard manure 0 t /ha,* ***F2:*** *Farm yard manure 5 t/ha,* ***F3:*** *20 kg nitrogen fertilizer /ha,* ***F4:*** *Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha,* ***C1:*** *Maize mono crop,* ***C2:*** *Maize-cowpea intercrop*

The highest value for stover was recorded by treatment W2xFx3C1 (1.07 t/ha) while the lowest value was registered by treatment W1xF4xC2 (0.46 t/ha). Treatment W2xF2xC1 registered significantly higher yields compared to treatment W1xF2xC2). This means that, maize mono crop with FYM 5 t/ha under tied ridging resulted to more increased yields than maize cowpeas inter crop with FYM 5 t/ha under flat bed. The increased water trapped in the tied ridges together with reduced plant density in maize mono crops mighty have led to the increased yields. These findings are in line with the findings by Uwizzeyimana *et al.* (2018) who reported significant increase of yields due to increased soil moisture.

In addition, treatment W2xF4xC1 had significantly ($P < 0.05$) higher values for stover, grains and biomass yields than treatment W1xF4xC2. This shows that, maize mono crop with FYM 5 t/ha + 20 kg N/ha under tied ridging increased yields more than maize cowpeas intercrop with FYM 5 t/ha + 20 kg N/ha under flat bed (Table 4.14). Treatment W1xF2xC1 had significantly higher values for stover, grain and biomass yields compared to treatment W1xF1xC1. This means that, maize mono crop with FYM 5 t/ha under flat bed led to more increased yields than maize mono crop without farm yard manure under flat bed (Table 4.14).

4.6.3 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on yields and yield components of maize (Short rains 2015)

During short rains 2015, the interaction between tied ridges, fertilizers and cropping systems was highly significant ($P < 0.001$) on cobs weight, ears weight, grain yield and biomass. Generally, treatments with maize mono crop under tied ridging registered significantly higher values for all the yields and yield components compared to those with maize cowpeas intercrop under flat bed. Treatment with flat bed plus farm yard manure 5 t/ha + 20 kg N/ha in maize cowpeas intercrop (W1xF2xC2) had the highest values for all the yield and yield components. The highest mean value for cobs weight was 0.85t/ha, an increase of 123.68% above the control (W1xF1xC1) (0.38 t/ ha). The highest value for ears weight was 4.6 t/ha, an increase of 165.90% above the control (W1xF1xC1) (1.73 t/ha). Treatment W1xF2xC2 (3.13 t/ha) recorded the highest value for stover yield. This was 86.3%

increase above the control W1xF1xC1 (1.68 t/ha). The lowest value for stover yield was observed from the control (W1xF1xC1) (Table 4.15).

Table 4.15 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on yield and yield components of maize (Short rains 2015)

Treatments	Cobs weight (t/ha)	Ears weight (t /ha)	No. of ears/ha	Stover yield (t/ha)	Grain yield (t/ha)	Biomass yield (t/ha)	Harvest index
W1xF2xC2	0.85a	4.60a	61342	3.13a	3.59a	7.73a	0.46
W1xF3xC1	0.71abc	3.59abc	53819	3.02a	2.86abc	6.60abc	0.42
W2xF1xC1	0.77ab	3.90ab	58159	2.63ab	3.12ab	6.53abc	0.48
W2xF4xC1	0.61bcd	2.91bcd	53819	2.60ab	2.27bcd	5.50bcd	0.42
W2xF2xC1	0.74abc	3.46bc	56423	2.73ab	2.71bc	6.18abc	0.43
W2xF3xC2	0.75abc	3.87ab	64236	3.14a	2.95abc	7.01ab	0.43
W1xF2xC1	0.69abc	3.42bc	59895	2.66ab	2.71bc	6.08abc	0.43
W1xF4xC2	0.55bcd	2.65bcd	46875	2.49abc	2.09bcd	5.15bcde	0.4
W2xF2xC2	0.57bcd	2.71bcd	50347	2.13bc	2.29bcd	4.84cde	0.46
W2xF4xC2	0.59bcd	2.90bcd	53819	2.35abc	2.29bcd	5.25bcde	0.43
W2xF3xC1	0.54bcd	2.58cd	50347	2.40abc	2.05cd	4.98cde	0.43
W1xF3xC2	0.52cd	2.66cd	55555	2.09bc	2.11cd	4.74cde	0.45
W2xF1xC2	0.43d	1.94d	44271	1.93bc	1.54d	3.88de	0.4
W1xF1xC2	0.40d	1.89d	52083	1.87bc	1.53d	3.78de	0.39
W1xF1xC1	0.38d	1.73d	51215	1.68c	1.35d	3.42e	0.4
W1xF4xC1	0.40d	1.79d	58159	2.12bc	1.39d	3.90de	0.35
P value	< 0.001	< 0.001	0.119	0.008	< 0.001	< 0.001	0.176
s.e.d	0.142	0.703	6981	0.5022	0.5587	1.101	0.0457

*Means with the same letter in each column are not significantly different at P < 0.05

***W1:** Flat bed planting, **W2:** Tied ridges, **F1:** Farm yard manure 0t /ha, **F2:** Farm yard manure 5 t/ha, **F3:** 20 kg nitrogen fertilizer /ha, **F4:** Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha, **C1:** Maize mono crop, **C2:** Maize – cowpea intercrop.*

The highest value for grain yield was from treatment ((W1xF2xC2) (3.59 t/ha), an increase of 165.93% above the control (W1xF1xC1) (1.35t/ha). The lowest grain value was recorded by the control (W1xF1xC1) (1.35t/ha). Treatment W1xF3xC1 (2.86 t/ha) significantly (P < 0.05) increased grain yield more than treatment W1xF1xC2 (1.53 t/ha). Also treatment W2xF3xC2 significantly led to higher increased grain yields more than treatment W1xF4xC1 (1.398) (2.95) (Table 4.15).

Treatment W1xF2xC2 (7.73 t/ha) had the highest value for biomass yield, an increase of 141.46% above the control (W1xF1xC1) (3.42 t/ha). The lowest value for biomass yield was recorded by the control. Treatment W1xF3xC1 (6.60 t/ha) significantly ($P < 0.05$) increased the biomass yield more than treatment Wx1F1xC2 (3.78 t /ha). In addition, treatment W2xF3xC2 (7.01 t /ha) had significantly higher values for biomass yield, than treatment W1xF3xC2 (4.74 t/ha) (Table 4.15). Treatment combinations of W1xF2xC2 during the SR 2015 had significantly higher values for stover, grain and biomass yields compared to treatment W2xF2xC2. This means that, maize cowpeas intercrop with FYM 5 t/ha under flat bed planting increased the yields more than maize cowpeas inter crop with FYM 5 t/ha under tied ridging (Table 4.15). The increased yields could probably be due to high soil moisture content in these plots which in turn improved the yields. This improved soil moisture content ensured adequate moisture for growth which increased the yields in treatments under flat bed planting. Higher moisture status increases root profile ration and enhances availability of nutrients to crop roots improving yields (Sarkar, 2005).

Treatment with the highest grain yield values during the SR 2015 was flat bed plus farm yard manure 5t/ha in maize cowpeas intercrop (W1xF2xC2) in addition to increased soil moisture content (Table 4.15 and Table 4.3). The soil moisture content enables nitrogen mineralization and availability of nutrients ions in soil which in turn influences nutrient uptake and maize yields (Heluf et al., 2004). This is because most of the plant elements are in elemental form whereas plants take them up in ionic form. The soil moisture dissolves the plant nutrients to enable uptake by the plants. Therefore, this explains why treatments with higher moisture content had higher yields. The low yields from treatments under tied ridges could be associated with the reduced soil moisture content observed. This is because plants have problems in absorbing nutrients in dry soils and this leads to yield reduction (Jones *et al.,* 2011).

Also treatment with flat bed plus farm yard manure in maize cowpeas intercrop (W1xF2xC2) recorded higher values for the yields than flat bed with farm yard manure 5 t/ha + 20 kg N/ha in maize mono crop (W1xF4xC1). This implies that, maize cowpeas inter crop with FYM 5 t/ha under flat bed increased yields more than maize mono crop with FYM 5 t/ha + 20 kg N/ha crop under flat bed. This improvement in yields could be probably due to the benefits of intercropping in increasing yields. This is because environmental resources like water, light and nutrients are more effectively used as compared to monocropping (Tadesse *et al.,* (2012). Intercropping also increases light interception and the shading effect reduces the rate of water evaporation; hence improving the yields (Ahmed *et al.,* 2010). Application of farm yard manure increases the benefits of intercropping. This could probably be the reason why treatments with farm yard manure and maize cowpeas inter crop performed better as opposed to those without FYM under maize mono crop (Undie *et al.,* 2012).

The high yields in treatment with flat bed, farm yard manure 5t/ha with maize cowpeas intercrop (W1xF2xC2) during the SR 2015 could also be attributed to efficient use of the environmental resources such as water, light and nutrients (Liu *et al.,* 2006). When crops are intercropped, there is better environmental resource use since crops utilize growth resources differently (Tadesse *et al.,* 2012). Therefore, when crops are grown together; they complement each other improving the yields (Vandermeer 1989 as cited by Karuma *et al.,* 2014). In addition, the greater canopy cover provided by maize cowpea intercrop helped to minimize evaporation. It also regulated the soil temperature, improved water infiltration consequently improving the yields (Steiner, 2002).

Application of FYM 5 t/ha led to increased yields because FYM plays an important role in improving the soil fertility in maize production (Muhammad and Khattak, 2009). In addition, application of FYM improves the physical conditions and biological activity of the soil increasing the nutrient levels resulting to higher yields (Atreya *et al.,* 2005). Cowpeas has the ability to bring nitrogen into the farming system through biological fixation as well as smothering weeds like striga improving yields (Clark, 2007; Ayana *et al.,* 2013; Agza et al., 2012). The maize cowpea intercrop increased the amount of nitrogen, phosphorus and potassium contents which in turn mighty have contributed to the increased yields (Dahmardel *et al.,* 2010). When legumes are used in intercropping, they maintain soil nitrogen through nitrogen fixation (Adigbo *et al.,* 2013; Ghanbari *et al.,* 2010).

Incorporation of FYM into the soil improves nutrients availability and soil moisture for crop uptake (Muhammad and Khattak, 2009). This could explain why treatments with FYM 5 t/ha had increased yields as compared to those without. Also, organic inputs improve soil water holding capacity and facilitate release of other soil nutrient to the crops (Akande *et al.,* 2005). Addition of FYM enhances soil microbial activities leading to release of nutrients after decomposition which in turn increases crop yields (Belay *et al.,* 2001). The high and positive response of crop yields to fertilizer application was reflected in treatments where farm yard manure was used. These findings agree with the studies done by Marschner *et al.,* (2011) who reported improved yields due to application of farm yard manure to the soil. Shiraniet *et al.* (2002) and Kepkemboi (2012) also reported increased yields as a result of FYM application. Similar findings were reported by Innocent (2014) who observed increased yields due to use of farm yard manure.

4.6.4 Effect of tied ridges, farm yard manure, nitrogen fertilizers and cropping systems on yields and yield components of maize (Long rains 2016)

The interaction effect between tied ridges, fertilizers and cropping systems was highly significant ($P < 0.001$) on stover, grain, biomass yields and harvest index during the LR 2016. The highest value for stover yield was recorded by treatment W2xF2xC1 (1.41 t/ha), an increase of 46.88% above the control (W1xF1xC1) (0.96 t/ha). The lowest value for stover yield was obtained from treatment W1xF3xC2 (0.78 t/ha), a decrease 18.75% below the control. Treatment W1xF3xC1 (1.31 t/ha) significantly ($P < 0.05$) increased the stover yield more than treatment W2xF1xC2 (0.87 t/ha). Also treatment W2xF3xC2 (1.24 t/ha) led to significantly higher values for stover yield than treatment W1xF3xC2 (0.78 t/ha) (Table 4.16).

Treatment W2xF3xC1 (0.67 t/ha) recorded the highest value for grain yield, an increase of 458 which is 33% above the control (W1xF1xC1) (0.12 t/ha). The lowest grain mean value was recorded by treatment W1xF3xC2 which had no grains. Treatment W2xF2xC1 (0.56 t/ha) significantly ($P < 0.05$) increased grain yield compared to treatment W2xF4xC2 (0.09 t/ha). In addition, treatment W2xFx4C1 (0.59 t/ha) significantly had higher grain value compared to treatment W2xF3xC2 (0.06t/ha). Treatment W1xF2xC1 (0.36 t/ha) significantly increased grain yield more than treatment W2xF1xC2 (0.03 t/ha) (Table 4.16).

The highest value for biomass yield was recorded by treatment W2xF3xC1 (2.18 t/ha), an increase of 134.41% above the control (W1xF1xC1) (1.12 t/ha). The lowest value for biomass yield was obtained from treatment W1xF3xC2 (0.78 t/ha), a decrease of 43.59% below the control. Treatment W2xF2xC1 (2.13 t/ha) significantly (P < 0.05) increased biomass yield more than treatment W2xF1xC2 (0.03 t/ha). Also treatment W2xF1xC1 (0.13 t/ha) significantly increased the biomass yield compared to treatment W1xF3xC2 (0.78 t/ha) (Table 4.16).

Table 4.16 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on yield and yield components of maize (Long rains 2016)

Treatments	Cobs weight (t/ha)	Ears weight (t /ha)	No. of ears/ha	Stover yield (t/ha)	Grain yield (t/ha)	Biomass yield (t/ha)	Harvest index
W1xF2xC2	0.01c	0.03d	1157ef	0.87ef	0.02d	0.89f	0.02de
W1xF3xC1	0.03bc	0.12cd	6076def	1.31ab	0.08d	1.43bcdef	0.04de
W2xF1xC1	0.07b	0.46abcd	11285cd	1.20abcd	0.35bc	1.66abcde	0.13bc
W2xF4xC1	0.18a	0.79ab	24300ab	1.30ab	0.59ab	2.10abc	0.26a
W2xF2xC1	0.15a	0.72abc	17361bc	1.41a	0.56ab	2.13ab	0.21ab
W2xF3xC2	0.03bc	0.14cd	7812def	1.24abc	0.06d	1.39cdef	0.07cde
W1xF2xC1	0.04bc	0.18bcd	7812def	1.20abcd	0.35bc	1.38cdef	0.06cde
W1xF4xC2	0.03bc	0.04bcd	1736def	0.96bcdef	0.03d	1.00ef	0.03de
W2xF2xC2	0.02bc	0.12cd	5208def	1.12abcde	0.10d	1.23ef	0.26a
W2xF4xC2	0.03bc	0.97a	8681de	1.01bcdef	0.09d	2.00abcd	0.06cde
W2xF3xC1	0.19a	0.87a	27778a	1.31ab	0.67a	2.18a	0.28a
W1xF3xC2	0.00c	0.00d	0f	0.78f	0.00d	0.78f	0.00e
W2xF1xC2	0.01bc	0.04d	3472def	0.87ef	0.03d	0.92f	0.03de
W1xF1xC2	0.06c	0.03d	2604ef	0.90def	0.03d	0.93f	0.03de
W1xF1xC1	0.03bc	0.15bcd	7812def	0.96cdef	0.12cd	1.12ef	0.09cd
W1xF4xC1	0.03bc	0.14cd	7812def	1.22ab	0.10d	1.36def	0.07cde
P value	< 0.001	0.013	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
s.e.d	0.038	0.381	4905	0.176	0.14	0.423	0.052

*Means with the same letter in each column are not significantly different at P < 0.05

***W1:** Flat bed planting, **W2:** Tied ridges, **F1:** Farm yard manure 0 t /ha, **F2:** Farm yard manure 5 t/ha, **F3:** 20kg nitrogen fertilizer /ha, **F4:** Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha, **C1:** Maize mono crop, **C2:** Maize-cowpea intercrop.*

Treatments with maize mono crop under tied ridging during the LR 2016 had higher harvest index compared to those with maize cowpeas intercrop under flat bed. Treatment combination of W2xF3xC1 (0.28) had the highest value for harvest index, an increase of 211.11% above the control (W1xF1xC1) (0.09). The lowest value for harvest index was recorded by treatment W1xF3xC2 which had no harvest index because it had no grains. Treatment in W2xF2xC1 (0.21) significantly ($P < 0.05$) increased the harvest index more than treatment W1xF1xC2 (0.03). Also treatment W2xF1xC1 (0.13) significantly had higher values for harvest index compared to treatment W2xF1xC2 (0.03) (Table 4.16).

During the LR 2016, treatment with tied ridging plus 20 kg N/ha in maize mono crop (W2xF3xC1) gave significantly ($P < 0.05$) higher yields compared to flat bed with 20 kg N/ha in cowpeas intercrop (W1xF3xC2). This means that, maize mono crop with 20 kg N/ha under tied ridging increased the yields more than maize cowpeas intercrop with 20 kg N/ha under flat bed (Table 4.16). The increased yields could have been as a result of high soil moisture content in tied ridges during the long rains. Tied ridges have the ability to retain surface run-off near the cropped area. This in turn could have reduced the risk of erosion and increased water holding capacity of the soil which improved the yields. These results agree with the work done by Hailemariam (2016) who reported that, tied ridges increased sorghum yield by 34.5% compared to rain- fed treatment due to increased soil moisture content.

Similar observations were made by Uwizzeyimana *et al.* (2018) who also reported significant increase of yields as a result of increased soil moisture. This is because water plays a key role in crop development. Water shortage in crops limit cell division and proliferation which lead to either lower grain yield or crop failure (Muhammed *et al.*, 2015). When there is water shortage, germination percentage decreases significantly lowering the crop yields (Karasu *et al.,* 2015). During the LR 2016, the total rainfall amount was low (96.0 mm) but the tied ridges effectively conserved the little rain received increasing the yields.

In addition, Tekle *et al.* (2014), reported higher yield and yield components of pearl millet and rabi sorghum in treatments with higher moisture which improved the plant growth. They attributed this to adequate available soil moisture for crop use. Karasu *et al.* (2015), also stated that supplementary irrigation resulted to positive significant differences in grain and yield components due to increased soil moisture. In related studies in Rwanda, NISR (2007) observed 1.52 t/ha yield under rain -fed as opposed to 3.3 t/ha under irrigation. He attributed this to the increased soil moisture in treatments under supplementary irrigation. Higher soil moisture also improves availability of nutrients to crops increasing the yields (Sarkar, 2005 as cited by Okeyo *et al.* (2014). Tied ridges can improve response of crops to rainfall and fertilizer soil supply of available N. This leads to increased yields and the harvest index (Nuti *et al.,* 2009 as cited by Okeyo *et al.,* 2014).

Treatment with W2xF3xC1 had significantly ($P < 0.05$) higher yields than treatment W1xF1xC1 for yield and yield components. This indicates that, maize mono crop with 20 kg N/ha under tied ridging resulted to more increased yields as compared to maize mono crop with FYM 0 t/ha under flat bed (Table 4.16). Similarly, treatment W2xF4xC1 recorded significantly higher yields than treatment W1xF1xC2. This shows that, maize mono crop with FYM 5 t/ha + 20 kg N/ha under tied ridges led to more increased yields than maize cowpeas inter crop with FYM 0 t/ha under flat bed.

The increased yields in treatments with maize mono crop compared to those with maize cowpeas intercrop could probably be due to low plant density in mono cropped plots, reducing competition for the little water available in the soil hence the yields increase. The low yields from maize cowpeas intercropped plots could have been as a result of high plant density which led to increased water demand for growth. However, the available water was not adequate to meet this demand which consequently reduced the yields. These findings are in line with work done by Karasu *et al.* (2015) who also observed reduced yields as a result of increased plant density (Table 4.16).

During LR 2015 and 2016, treatments with application of farm yard manure had very low yields (Table 4.14 and 4.16). This is because the soils were quite dry for any ionization to take place. The little moisture available in the soil was also used up by the micro- organisms present in the manure lowering the soil moisture which in turn reduced the yields (Mansouri *et al.*, 2010). The higher yields in treatments under tied ridges and 20 kg N/ha during the LR 2016 agrees with studies done by Gichagi *et al.* (2003) who worked in the highland areas of Central Kenya and reported that, tied ridging increased both maize and bean yields. Similar findings were also observed by Miriti (2010) who worked in semi-arid region of Eastern Kenya and reported higher maize grain yield under tied ridges in comparison to the control. Araya and Stroosnider (2010) reported that, maize yield under tied ridges could be increased by 44% over the control. This usually occurs during those years when the rainfall is below average. Tied ridges and mulching increased yield by at least 65% with exceptional amounts of rainfall of about 549mm (Enfors *et al.* (2011).

The crop failure during the LR 2015 and 2016 could be associated with the severe meteorological drought experienced during the crop growing period. The initiation of the ear and grain filling was greatly affected by the poor rainfall distribution in the two seasons. When drought occurs at the grain filling stage of maize, it reduces photosynthetic rate and impairs assimilate translocation in kernel resulting to decreased maize yields (Passioura and Angus 2010). These findings concur with the studies done by Muhammed *et al.* (2015) who reported that, water deficit and drought decreased both grain yield and biomass production.

Similar observations were also made by Ngigi *et al.* 2006 as cited by Okeyo *et al.* (2014) who reported that, in a semi-arid context especially where the soils are coarse textured with low moisture storage, *in-situ* water conservation may offer no guarantee against poor rainfall distribution. This means that, the risk of crop failure is only slightly lower than that without any measures. Intra-seasonal and inter-seasonal changes in temperature and precipitation affect yields of cereal crops (Rowhanil *et al*, 2011).

The potential yield of maize is 6 t/ha (NEMA, 2013). However, this was not achieved in this study. This could be attributed to the amount of rainfall received in each season which affected the grain filling reducing the yields (Rockstrom *et al.*, 2010). The differences in yields in the seasons were as a result of variations in the amount of rainfall received. In addition, the differences in maize grain yield under different treatments could be attributed to water availability and fertility status of the soil as influenced by the treatments.

During the SR 2015, the total amount of rainfall was 574.6 mm with 65 rainy days while during the LR 2016 the rainfall was only 96.0 mm with 20 rainy days (Table 4.2). This high and well distributed rainfall resulted in higher yields during SR 2015 as compared to the low yields in SR 2014, LR 2015 and LR 2016 seasons. The maize stover yield was higher than the grain yield during the seasons when rainfall was low. This reflected that, the available soil moisture was only adequate to positively enhance maize stover production but not enough for grain formation. However, during SR 2015, the grain yield was more than the stover yield since the rainfall was high. Similar observations were also made by Passioura and Angus (2010).

The harvest index was significantly ($P < 0.05$) affected by the interaction between tied ridges, fertilizers and cropping systems during the LR 2015 and 2016 as opposed to SR 2014 and 2015 (Tables 4.14, 4.15 and 4.16). This could have probably been brought about by the differences in the seasonal rainfall. Although the magnitude of the harvest index is heritable, it varies with season, management and the environment. The optimum harvest index for most crops is 0.4 (Passioura and Angus (2010). This was achieved during SR 2015 where the highest mean was 0.48 (Table 4.15). The harvest index for both SR 2014 and LR 2015 was below the world average mean (0.3-0.5). This could probably be as a result of the low amount of rainfall received during these two seasons (Table 4.1) which reduced the biomass yield as well as the grain yield. Contrary, during the SR 2015 when the amount of rainfall was high (Table 4.2), the harvest index ranged between 0.35-0.46 (Table 4.15) which was within the world range because the biomass and grain yields were high.

This could be probably due to variations in rainfall amount. Crops that have good water supply during grain filling are able to produce a large biomass which matches with a good harvest index and this explains why treatments with more moisture content had a higher harvest index. In this study, the harvest index matched with the grain yield. When there is presence of good partitioning of dry matter to grain yield is indicated by high harvest index (Passioura and Angus, 2010).

4.7 Effect of Tied Ridges, Farm Yard Manure, Nitrogen Fertilizer and Cropping Systems on Maize Profitability

The variable cost, gross benefit, net profit, gross margin, return to labor and cost benefit ratio were significantly (P < 0.05) affected by the interaction between tied ridges, fertilizers and cropping systems (Tables 4.17 and 4.18). In both SR 2015 and LR 2016, treatment combinations with maize mono crop generally exhibited higher values for gross benefit, net profit, gross margin, return to labor and cost benefit ratio than those with maize cowpeas intercrop. However, in both seasons, treatments with maize cowpeas intercrop had increased variable cost in comparison to those with maize mono crop. Also treatments with FYM 5 t/ha + 20 kg N/ha registered increased variable cost as compared to treatments without fertilizer application. The gross benefit, net profit, gross margin return to labor and cost benefit ratio was higher during the SR 2015 compared to LR 2016. The cost benefit ratio during the SR 2015 showed positive returns because the numbers were greater than 1, while during the LR 2016 the returns were negative (the values were less than 1) (Tables 4.17 and 4.18).

4.7.1 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize profitability (Short rains 2015)

During the SR 2015, the highest value for variable cost was observed from treatment in maize cowpeas intercrop with an addition of FYM 5 t/ha under tied ridges (W2xF2xC2) (63,837 Ksh/ha), an increase of 41.78% above the control (W1xF1xC1) (45,062 Ksh/ha). The lowest value for variable cost was registered by the control (W1xF1xC1) (45,062 Ksh/ha. Treatment W2xF4xC2 (63,837 Ksh.) had significantly (P <0.05) higher variable cost than treatment combination of

W1xF4xC2 (62,294 Ksh.). This means that, maize cowpeas intercrop with FYM 5 t/ha + 20 kg N/ha under tied ridging increased the variable cost more than maize cowpeas intercrop with an addition of FYM 5 t/ha + 20 kg N/ha under flat bed (Table 4.17). This could be probably due to the additional labor cost incurred in preparing the tied ridges.

Table 4.17 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize profitability (Short rains 2015)

Treatments	Total variable cost (Ksh/ha)	Gross benefit (Ksh/ha)	Net profit (Ksh/ha)	Gross margin (%)	Return to labor	Cost benefit ratio
W2xF4xC2	63,837a	115,837bcd	53,543def	38.34cdefg	1.13def	1.86de
W1xF4xC2	62,294b	112,476bcde	48,638cdef	40.41abcdef	1.13def	1.76de
W1xF2xC2	61,231c	170,243a	109,012a	59.61ab	2.63a	2.79abc
W1xF3xC2	60,288d	105,078cde	44,790ef	34.42defgh	1.04ef	1.74e
W2xF3xC2	60,858d	151,484ab	91,196abcd	55.48abcd	2.05abcde	2.52abcd
W2xF2xC2	58,385e	11,127bcde	52,742def	38.12cdefg	1.15def	1.90de
W2xF1xC2	57,922e	84,898de	26,976f	24.00efgh	0.58f	1.47e
W1xF1xC2	56,379f	83,319de	26,941f	15.88fh	0.61f	1.48e
W2xF4xC1	54,064g	120,399bcd	66,335bcdef	46.30abcd	1.61bcdef	2.23bcde
W1xF4xC1	52,512h	83,694de	31,174f	34.42defgh	0.73f	1.60e
W2xF3xC1	50,874i	109,439cde	58,925bcdef	41.2bcde	1.42cdef	2.12cde
W2xF2xC1	50,514i	135,668abc	85,514abcde	61.38ab	2.11abcd	2.71abc
W1xF3xC1	48,971j	146,056abc	97,084abc	63.92a	2.51ab	2.98ab
W1xF2xC1	48,611j	134,479abc	85,868abcde	57.92abc	2.21abc	2.77abc
W2xF1xC1	46,605k	146,078abc	99,473ab	65.2a	2.47ab	3.13a
W1xF1xC1	45,062l	74,102e	29,041f	36.11cdefgh	0.67f	1.64e
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
s.e.d		17.03	17,094	9.15	o.43	

*Means with the same letter in each column are not significantly different at P < 0.05

***W1:** *Flat bed planting*, **W2:** *Tied ridges*, **F1:** *Farm yard manure 0 t/ha*, **F2:** *Farm yard manure 5 t/ha*, **F3:** *20 kg nitrogen fertilizer /ha*, **F4:** *Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha*, **C1:** *Maize mono crop*, **C2:** *Maize-cowpea intercrop*.

Also treatment combination of W2xF3xC2 (60,858 Ksh.) recorded significantly higher (P < 0.05) variable cost compared to treatment W1xF3xC1 (48,971 Ksh.). This indicates that, maize cowpeas intercrop with 20 kg N/ha under tied ridging had more increased variable cost than maize mono crop with 20 kg N/ha under flat bed (Table 4.17). The significantly higher variable cost could be due to extra cost incurred in buying cowpeas seeds in the intercrop in addition to maize seeds in comparison to the mono crop where only maize seeds were bought. In addition, there was increased labor cost in preparing the tied ridges and harvesting the maize cowpeas intercrop as compared to maize mono crop under flat bed.

The highest value for gross benefit was recorded by treatment with maize cowpeas intercrop with FYM 5 t/ha under flat bed (W1xF2xC2) (170, 243 Ksh/ha), which is an increase of 129.74% above the control (W1xF1xC1) (74, 102 Ksh/ha). This was followed by maize mono crop with 20 kg N/ha under tied ridging (W2xF3xC1) (151, 484 Ksh/ha), representing an increase of 104.43% higher than the control (Table 4.17).

The highest value for net profit was recorded by treatment with maize cowpea intercrop with FYM 5 t/ha under flat bed (W1xF2xC2) (109,012 Ksh/ha), an increase of 275.37% over the control treatment (maize mono crop without fertilizer under flat bed) (W1xF1xC1) (29,041 Ksh/ha). This was followed by treatment with maize mono crop without fertilizer under tied ridging (W2xF1xC1) (99, 473 Ksh/ha), showing an increase of 242.53% above the control. However, the lowest value for net profit was registered by treatment with maize cowpeas intercrop without fertilizer under flat bed (W1xF1xC2) (26,941 Ksh/ha), a decrease of 7.23% below the control (29,041 Ksh/ha) (Table 4.17).

The highest value for the gross margin during the SR 2015 was recorded by treatment with maize mono crop without fertilizer under tied ridging (W2xF1xC1) (65.2%), a percentage increase of 80.56% above the control (W1xF1xC1) (36.11%). This was followed by treatment in maize mono crop with an addition of 20 kg N/ha under flat bed (W1xF3xC1) (63.92%), indicating a percentage increase of 77.01% over the control. The lowest value for gross margin was recorded by treatment in maize cowpeas intercrop without fertilizer under flat bed (W1xF1xC2) (15.88%), a percentage decline of 56.02% below the control (36.11%) (Table 4.17).

During the SR 2015, treatment with W1xF2xC2 recorded significantly ($P < 0.05$) higher values for gross benefit (105,078 Ksh.), net profit (109,012 Ksh.) and gross margin (59.61% Ksh.) compared to treatment W2xF1xC2 (Table 4.17). This means that, maize cowpeas intercrop with FYM 5 t/ha under flat bed led to more increased gross benefit, net profit and gross margin than maize mono crop without fertilizers under tied ridging. The significant increase could be probably due to the higher grain and stover yields in treatment with flat bed plus FYM 5 t/ha in maize cowpeas intercrop (W1xF2xC2) compared to tied ridging without fertilizer in maize cowpeas intercrop (W2xF1xC2) which increased the profit. These findings agree with work done by Barut et al. (2011) who reported increased gross benefit due to high net profit (Table 4.17).

Similarly, treatment combination of treatment W1xF2xC2 had significantly ($P < 0.05$) higher gross benefit, net profit and gross margin compared to treatment W1xF1xC2 (Table 4.17). This increase could probably be due to the increased yields in treatment with flat bed plus FYM 5 t/ha in maize cowpeas intercrop (W1xF2xC2) which led to increased income compared to flat bed without fertilizer in maize cowpeas intercrop (W1xF1xC2); where yields were low with reduced gross benefit, net profit and gross margin. This reflects the yield advantage of the two crops compared to the mono crop (Dahmardeh et al., 2010).

Generally, the return to labor during SR 2015 was higher in treatment combinations with maize mono crop than those with maize cowpeas intercrop.

Treatment combination of W1xF3xC1 had significantly ($P < 0.05$) higher return to labor than treatment W1xF3xC2. This means that, maize mono crop with 20 kg N/ha under flat bed led to more increased return to labor than maize cowpeas intercrop with 20 kg N/ha under flat bed (Table 4.17).

Also treatment in W2xF1xC1 recorded significantly ($P < 0.05$) higher return to labor than treatment W2xF4xC2. This shows that, maize mono crop without fertilizer under tied ridging resulted to more increased return to labor than maize cowpeas intercrop with FYM 5 t/ha + 20 kg N/ha under tied ridging. The increased return to labor in treatments with maize mono crop as opposed to those with maize cowpeas intercrop could be probably as a result of the extra labor cost incurred in planting, weeding, spraying and harvesting in the maize cowpeas intercrop as compared with the maize mono crop (Dahmardeh *et al.*, 2010).

The highest value for cost benefit ratio during the SR 2015 was registered by treatment in tied ridges without farm yard manure in maize mono crop (W2xF1xC1) (3.13), an increase of 90.85% over flat bed without farm yard manure in maize mono crop (W1xF1xC1) (1.64). The lowest value for cost benefit ratio was recorded by treatment of tied ridging without farm yard manure in maize cowpeas intercrop (W2xF1xC2) (1.46), a decline of 18% below the control (W1xF1xC1) (1.64). Treatment with W2xF1xC1 (3.13) had significantly ($P < 0.05$) higher value for cost benefit ratio compared treatment W2xF1xC2. This indicates that, maize mono crop without farm yard manure under tied ridging had increased cost benefit ratio compared to maize cowpeas intercrop without farm yard manure under tied ridging (Table 4.17).

4.7.2 Effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize profitability (Long rains 2016)

During LR 2016, treatment combinations in maize mono crop had higher values for gross benefit, net profit and return to labor (Table 4.18). In addition, the gross benefit was quite low compared to that of SR 2015 (Table 4.17). This is because there was crop failure during the LR 2016 as a result of very low rainfall (96.0 mm). Most of the treatments had no grains hence it is only the stover yield which was used to calculate the gross benefit. The variable costs for all the treatments during the LR 2016 were higher than the gross benefit. Consequently, this resulted to loss in net profit (Table 4.18). This implies that, reduced grain yields lowered the gross benefit and net profit.

The highest value for the gross benefit was observed from treatment with maize mono crop with FYM 5 t/ha under tied ridging (W2xF2xC1) (723.80 Ksh/ha). This shows an increase of 46.73% above the control W1xF1xC1) (493.4 Ksh/ha). The lowest gross benefit was recorded by treatment in maize cowpeas intercrop with 20 kg N/ha under flat bed (W1xF3xC2) (401.0 Ksh/ha). This was a decrease of 18.73% below the control (W1xF1xC1) (Table 4.18).

Table 4.18 Interaction effect of tied ridges, farm yard manure, nitrogen fertilizer and cropping systems on maize profitability (Long rains 2016)

Treatments	Total variable cost (Ksh/ha)	Gross benefit (Ksh/ha)	Net profit (Ksh/ha)	Gross margin (%)	Return to labor	Cost benefit ratio
W2xF4xC2	63,837a	521.1bcdef	-66,917p	-13.423	-0.57n	0.007ef
W1xF4xC2	62,294b	494.8bcdef	-65,400o	-13.617	-0.6o	0.007ef
W1xF2xC2	61,231c	445.3ef	-6,1540k	-14.900	-0.50k	0.007ef
W1xF3xC2	60,288d	401.0f	-61,944l	-17.084	-0.51l	0.006f
W2xF3xC2	60,858d	639.9abc	-63,249n	-11.108	-0.48i	0.010cde
W2xF2xC2	58,385e	569.8abcde	-62,959m	-11.413	-0.47h	0.08def
W2xF1xC2	57,922e	449.8ef	-59,529j	-35.725	-0.39d	0.007ef
W1xF1xC2	56,379f	461.7def	-57,974i	-13.257	-0.41f	0.007ef
W2xF4xC1	54,064g	669.8ab	-57,509h	-8.820	-0.49j	0.011abcd
W1xF4xC1	52,512h	626.0abc	-56,009g	-9.254	-0.52m	0.011abcd
W2xF3xC1	50,874i	671.6ab	-53,958f	-8.257	-0.40e	0.012abc
W2xF2xC1	50,514i	723.8a	-53,545e	-8.097	-0.38c	0.013a
W1xF3xC1	48,971j	676.0ab	-52,410d	-8.263	-0.42g	0.012abc
W1xF2xC1	48,611j	615.3abcd	-5,211c	-8.849	-0.41f	0.011abcd
W2xF1xC1	46,605k	615.3abcd	-50,105b	-8.809	-0.3a	0.012abc
W1xF1xC1	45,062l	493.4cdef	-48,683a	-10.734	-0.31b	0.01bcde
P value	< 0.001	< 0.001	< 0.001	0.229	< 0.001	< 0.001
s.e.d		493.4	-64.1	-6.89	0.002	

*Means with the same letter in each column are not significantly different at P < 0.05

W1:** Flat bed planting**, W2:** Tied ridges, **F1:** Farm yard manure 0 t/ha, **F2:** Farm yard manure 5 t/ha, **F3:** 20kg nitrogen fertilizer /ha, **F4:** Farm yard manure 5 t/ha + 20 kg nitrogen fertilizer /ha, **C1:** Maize mono crop, **C2:** Maize-cowpea intercrop**.

Treatment with maize mono crop plus FYM 5t/ha under tied ridges (W2xF2xC1) had significantly (P < 0.05) a higher value for gross benefit compared to maize cowpeas intercrop without fertilizer input under tied ridging (W2xF1xC2) during LR 2016. This means that, maize mono crop with FYM 5 t/ha under tied ridging decreased gross benefit more than maize cowpeas intercrop without fertilizer input under tied ridging. Also treatment in maize mono crop without fertilizer input under flat bed (W1xF1xC1) registered significantly higher net profit than maize cowpeas intercrop with FYM 5 t/ha + 20 kg N/ha under tied ridging (W2xF4xC2).

This implies that, maize mono crop without fertilizer under flat bed reduced the net profit more than maize cowpeas intercrop with FYM 5 t/ha + 20 kg N/ha under tied ridging. Similarly, treatment combination of W2xF1xC1 recorded significantly ($P < 0.05$) higher return to labor than treatment W1xF4xC2. This shows that, maize mono crop without fertilizer under tied ridging led to decreased return to labor more than maize cowpeas intercrop with FYM 5 t/ha + 20 kg N/ha under flat bed (Table 4.18).

During the LR 2016, the highest value for the cost benefit ratio was recorded by treatment in tied ridging, FYM 5 t/ha in maize mono crop (W2xF2xC1) (0.013), an increase of 0.3% above the control (W1xF1xC1) (0.01). The lowest value for the cost benefit ratio was observed from treatments with flat bed plus 20 kg N/ha in maize cowpeas intercrop (W1xF3xC2) (0.006), a decrease of 0.36% below the control (W1xF1xC1) (0.01) (Table 4.18). Treatment with (W2xF2xC1) recorded significantly ($P < 0.05$) higher values for cost benefit ratio compared to treatment W1xF2xC2. This shows that, tied ridging plus FYM 5t/ha in maize mono crop increases the cost benefit ratio more than flat bed with FYM 5 t/ha in maize cowpea intercrop.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The interaction between tied ridges, fertilizers and cropping systems at 0-20 cm depth had a significant effect ($P < 0.001$) on the soil moisture content. At 0-20 cm depth, plant density affected the soil moisture content in this study. Applications of farm yard manure 5 t/ha improved soil moisture content. An important finding in this study is that, during the SR 2015, tied ridges were not effective in water harvesting when the rainfall amount was high hence, the effectiveness of tied ridges as a water conservation method in the study area was influenced by the amount of seasonal rainfall received and its distribution.

In both SR 2015 and LR 2016 seasons, the interaction between tied ridges, fertilizers and cropping systems had significant effect ($P < 0.001$) on plant height, plant leaf width and leaf area. Maize mono crop with an addition of 20 kg N/ha under flat bed recorded the highest values for all the growth parameters during SR 2015. However, during the LR 2016, the highest values for vegetative growth were recorded by treatment in maize mono crop, with an addition of 20 kg N/ha under tied ridging. This implies that, application of 20 kg N/ha promoted maize vegetative growth in both seasons. Also, low plant density in maize mono cropped plots resulted to increased vegetative growth.

A key finding in this study is that, tied ridging was more effective in promoting vegetative growth during the LR when the rainfall was low and poorly distributed, whereas flat bed planting was more effective during the SR as a result of high and well distributed rainfall. High soil moisture and high nutrient levels increased the maize vegetative growth. Therefore, in order to promote vegetative growth, there is need to apply nitrogen fertilizer in addition to improving soil moisture content.

The interaction between fertilizers and cropping systems had significant effect ($P < 0.05$) on the final soil pH. The highest value for the soil pH value was recorded by treatment with FYM 5 t/ha in maize cowpeas intercrops (6.32). Therefore, it may be concluded that, application of FYM 5 t/ha resulted to increased soil pH. Also, treatment with FYM 5 t/ha in maize cowpeas intercrop (6.32) resulted to optimum pH value for growing maize which ranges from 6-7.2.

The percentage N content in maize stovers and grains was significantly ($P < 0.05$) affected by the interaction between fertilizers and cropping systems during the LR 2016 season. Treatments with maize mono crop had higher percentage of N content in both stovers and grains. Treatment combination of 20 kg N/ha in maize mono crop had the highest N content in both stovers and grains LR 2016 season. This could mean that, the percentage N content in both stovers and grains was affected by fertilizer application, cropping systems and rainfall variations within seasons.

The interactions between tied ridges, fertilizer and cropping systems had a highly significant effect ($P < 0.001$) on maize grain yield and yield components in the four seasons. This implies that, in maize production, fertilizer application and cropping systems are important aspects to be considered in order to improve maize yields. The grain yield was higher than stover yield during both SR 2014 and SR 2015 seasons. However, during the LR 2015 and LR 2016, the stover yield was higher than grain yields meaning that, the amount and distribution of rainfall plays a very key role in determining grain filling. The highest value for the grain yield in the four seasons was recorded during the SR 2015 (3.5 t/ha), by treatment with maize cowpeas intercrop with an addition of 5 t/ha FYM under flat bed. The grain yield was higher than what the farmers produce in the study area (0.5 t/ha). It may therefore be concluded that, integrating farm yard manure 5 t/ha with maize cowpeas intercrop during the seasons with rainfall above average even without use of tied ridges could improve yields in the study area.

The slightly improved yield in treatments with maize mono crop in seasons when the rainfall was low with poor distribution implies that, maize mono crop may be a better option for the farmers in the study area since the rainfall is unreliable in most of the seasons. Therefore, when choosing a cropping system to adopt in the study area, seasonal rainfall variation and distribution should be put into consideration.

The interaction between tied ridges, fertilizers and cropping system significantly ($P < 0.05$) affected variable cost, gross benefit, net profit, gross margin, return to labour and cost benefit ratio during SR 2015 and LR 2016 seasons. Treatments with maize mono crop resulted to increased gross benefit, net profit, gross margin, return to labor and cost benefit ratio in both seasons while treatments with maize cowpeas intercrop had increased labour cost. Application of FYM 5 t/ha + 20 kg N/ha led to increased variable costs.

The most economical treatment combination was maize cowpeas intercrop with application of 5 t/ha FYM under flat bed planting during the SR 2015 season. During the LR 2016 season, the variable costs were higher than the gross benefit which was a loss meaning that, any technology where the variable costs are higher than the gross benefit lowers the net profit and consequently the gross margin.

5.2 Recommendations

During the seasons when the rainfall amount is adequate and reliable, farmers may adopt maize cowpeas intercrop with application of 5 t/ha FYM under flat bed because this combination was the most economical combination in the four seasons. However, during the seasons when the rainfall is low, farmers in the study area may consider adopting maize mono crop with application of 20 kg N/ha under tied ridges. The use of tied ridging in the study area should be restricted to only during the seasons of low rainfall since they are less profitable in seasons with high rainfall. The choice of a cropping system to adopt in this study area should be based on the seasonal rainfall variations.

The amount of soil organic carbon in the soil should be maintained at optimum levels because it raises the soil pH. Application of farm yard manure could be restricted to seasons of high rainfall since when the rainfall is low, the soil moisture is too low for mineralization to take place. The farmers in the study area could consider application of nitrogen fertilizer only during seasons of low rain fall since the nutrients are readily available for plant use.

Increased vegetative growth yields in treatments of maize could be used as forage for livestock feeding and also mulching to increase humus in the soil. Therefore, there is need to integrate various soil and water management practices since adopting a single technology does not exploit its potential as well as incorporating farm yard manure in the soil. However, variations in seasonal rainfall should be put into consideration while choosing the treatment combinations to adopt. This is because the success of different technologies in soil and water conservation varies with the seasonal rainfall.

Farmers in Machakos County may have to consider using supplementary irrigation during low rainfall seasons to avoid crop failure. In addition, mulching or crop residues could also be incorporated with the supplementary irrigation so as to minimize water losses through evapotranspiration during the dry spell to improve the yields.

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LIST OF APPENDICES

Appendix 1: Experimental plot lay out

Block I

W1xF3xC2	W1xF4xC2	W1xF2xC1	W2xF4xC1
W1xF3xC1	W1xF4xC1	W1xF2xC2	W2xF4xC2
W1xF1xC1	W2xF2xC1	W1xF1xC2	W2xF1xC2
W2xF1xC1	W2xF2xC2	W2xF3xC2	W2xF3xC1

Block II

W2xF1xC1	W2xF2xC1	W2xF3xC1	W2xF1xC2
W1xF1xC2	W2xF2xC2	W2xF3xC2	W1xF2xC1
W1xF1xC1	W2xF4xC2	W2xF4xC1	W1xF2xC2
W1xF4xC2	W1xF3xC2	W1xF3xC1	W1xF4xC1

Block III

W1xF1xC1	W1xF4xC1	W1xF2xC2	W2xF4xC1
W1xF1xC2	W1xF4xC2	W1xF2xC1	W2xF4xC2
W1xF3xC2	W2xF3xC1	W2xF2xC2	W2xF1xC2
W1xF3xC1	W2xF3xC2	W2xF2xC1	W2xF1xC1

Block IV

W2xF3xC1	W2xF1xC1	W1xF1xC2	W1xF4xC2
W2xF3xC2	W2xF1xC2	W1xF3xC2	W1xF1xC1
W2xF2xC1	W2xF4xC2	W1xF3xC1	W1xF4xC1
W2xF2xC2	W2xF4xC1	W1xF2xC2	W1xF2xC1

Appendix 2: Treatment combinations

W1xF1xC1	W1xF3xC1	W2xF1xC1	W2xF3xC1
W1xF1xC2	W1xF3xC2	W2xF1xC2	W2xF3xC2
W1xF2xC1	W1xF4xC1	W2xF2xC1	W2xF4xC1
W1xF2xC2	W1xF4xC2	W2xF2xC2	W2xF4xC2

***W1:** Flat bed planting**, W2:** Tied ridges, **F1:** Farm yard manure 0t /ha, **F2:** Farm yard manure 5t/ha, **F3:** 20kg nitrogen fertilizer /ha, **F4:** Farm yard manure 5t/ha + 20kg nitrogen fertilizer /ha**, C1:** Maize mono crop**, C2:** Maize – cowpea intercrop.*

Appendix 3: Determination of Nitrogen content in plant samples

For the determination of total N in plant tissues, 0.2g of oven dried (70^0C) samples were weighed into 250ml digestion flask. Then a scoop of mixed catalyzed (1g) and 8ml of concentrated sulphuric acid were added. The mixture was shaken gently for the acid and the contents to mix properly after which it was placed in a Kjeldahl digestion block and digestion commenced at low temperatures (120^0C) for one hour. The temperatures were then raised to 330^0C and heating continued until the solution became colorless. The contents were then allowed to cool. % N in plant tissue was calculated using equation 8:

% N in plant sample = (corrected ml of N/70 HCL x 0.2)/ weight of sample **___** Eq. 8.

About 25ml distilled water was added and mixed well until no more sediment dissolved. It was then allowed to cool and made into 50ml with water. The mixture was allowed to settle so that, a clear solution could be taken from the top for analysis. An aliquot of 10mls was taken into a Kjeldahl distillation flask and fixed into the distillation system. Then 10mls of 40% sodium hydroxide was quickly added through the ancillary mouth of the flask; after which distillation was started into the 2% boric acid containing 4 drops of the mixed indicator in a 250ml conical flask. The titrate contents were added sulphuric acid 0.01N which made it to turn into pink color from the green color. The same procedure was followed to determine the amount of total nitrogen in the soil samples during initial characterization as outlined by Ryan et al., (2001) (Equation 9).

% N is soil sample = (corrected ml of N/140 HCL x 0.1)/ weight of sample **__**Eq. 9.

Appendix 4: Determination of soil organic carbon

The soil organic carbon was determined using modified Walkley and Black wet oxidation procedure described by Ryan et al., (2001). Half gram of air-dried soil was passed through 0.5mm sieve and weighed into 500ml wide mouth conical flasks and 10ml of 1 N potassium dichromate added into the flasks using a burette. In a fume cupboard, 15ml concentrated sulphuric acid was rapidly added directing the stream into the suspension. This was followed by the flasks being swirled gently until all the soil and reagents mixed and thereafter more vigorously for about one minute. The contents were then allowed to stand for 30 minutes after which about 150ml of distilled water was added and the solution allowed to cool.

Then 10ml 85% orthophosphoric acid was added and finally 10 drops of diphenylamine indicator. The solutions were titrated with 0.5 N ammonium ferrous sulphate. Organic carbon was then calculated and expressed as a percentage using as using Equation 10:

% organic carbon = $\{(V\ blank - V\ sample) \times 3 \times 10^{-3} \times 100\}/\ Weight$____ Eq. 10.

Where: V blank = volume (ml) of ferrous ammonium sulphate solution required to titrate the blank.

Appendix 5: Determination of available Phosphorus in the soil

For the determination of available P in the soil, Mehlich l double acid extraction method was used (Sonon, 2008; Savoy, 2009). The dried soil was extracted in 1:5 ratios (W/V) with a mixture of 0.1N HCL and 0.025 NH_2SO_4 solutions. The hydrochloric acid was used to replace the bulk exchangeable metal cations. Five grams of dried soil was weighed in 50ml polyethylene bottle and 25ml of extracting solution was added. This was followed by shaking the suspension for one hour after which it was transferred into centrifuge tubes and centrifuged for 5 minutes. It was then filtered through Whatman No. 1 filter paper to give a clear filtrate.

Five milliliters of working standard series, soil extract and blank were pipetted in test tubes. One milli litre of ammonium vanadate-molybdate mixture was added and thoroughly mixed and its optical density recorded on the UV-visible spectrophotometer after an hour at 430nm. To get the concentration of P in the soil (ppm), the ppm in solution got from the UV-visible spectrophotometer was multiplied by the dilution factor, which is the ratio of soil sample in grams to the extracting solution (this was the ratio 1:5 gotten from 5g of soil sample in 25ml extracting solution).

Appendix 6: Determination of Calcium and Potassium in the soil

In order to determine calcium and potassium in the soil, Mehlichl double acid extraction method was used (Kissel and Sonon, 2008; Savoy, 2009). Five grams of soil sample was weighed and put into 50ml polyethylene bottle and 25ml extracting solution was added (0.1N HCL and 0.025 N H_2SO_4). The suspension was thoroughly shaken for one hour and then taken to centrifuge tubes where it was centrifuged for 5 minutes and then filtered through Whatman No. 1 filter paper to get a clear filtrate. The concentrations of the cations in the soil extract were measured using flame photometer. A calibration graph was obtained from the working standard series against elements (in me/100 g soil).