EFFECTS OF SOIL AND WATER CONSERVATION TECHNOLOGIES ON SEDIMENT AND MAIZE YIELD IN THARAKA-NITHI AND EMBU COUNTIES OF KENYA

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DECLARATION

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

Signed_____ Date_____

I/We confirm that the work reported in this thesis was carried out by the candidate under my/our supervision.

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DEDICATION

This thesis is a dedication to my dear mum, Mrs. Anne Okeyo, for her encouragement, unending support and value towards my education.

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ACRONYMS AND ABBREVIATIONS

ANOVA	-	Analysis of Variance
AR4	-	Assessment Report Four
ASL	-	Above Sea Level
C	-	Carbon
CA	-	Conservation Agriculture
CEC	-	Cation Exchange Capacity
CO_2	-	Carbon-dioxide
CT	-	Conventional Tillage
ENSO	-	El Niño/Southern Oscillation
ETo	-	Reference Evapotranspiration
FAO	-	Food and Agriculture Organization
GDP		Gross Domestic Product
IL	-	Inner Lowland
IPCC	-	Intergovernmental Panel on Climate Change
K	-	Potassium
KARI	-	Kenya Agricultural Research Institute
KMDET	-	Kenya Meteorological Department
LR	-	Long Rains
LSD	-	Least significant Differences
MBILI	-	Managing Beneficial Interactions in Legume Intercrops
MC	-	Mulching
MI	-	MBILI Intercrop
MT	-	Minimum Tillage
N	-	Nitrogen

NARL	-	National Agricultural Laboratory
P	-	Phosphorus
RMPs	-	Recommended Management Practices
SAS	-	Statistical Analysis Software
SOC	-	Soil Organic Carbon
SOM	-	Soil Organic Matter
SR	-	Short Rains
SSA	-	Sub-Saharan Africa
SWC	-	Soil and water conservation
TR	-	Tied Ridging
UNESCO	-	United Nations Educational Scientific and Cultural Organization

ABSTRACT

Decline in crop yields in Tharaka-Nithi and Embu counties is linked to poor agricultural practices and climate variability. Research has reported positive results from implementation of mulching, tied ridging, minimum tillage and intercropping. This study was set up to: i) determine effect of soil and water conservation technologies on runoff ii) evaluate effect of the technologies on sediment and nutrient loss iii) investigate effect of the technologies on maize yield, and iv) analyze economic implications of the technologies. The study was conducted in Meru South and Mbeere South sub-counties for two consecutive cropping seasons; Long rains 2011 and short rains 2011. A randomized complete block design was adopted with 3 replicates. Treatments were Mulching, MBILI intercrop and conventional in both sites, minimum tillage in Meru south and tied ridges in Mbeere south. Conventional tillage was the control treatment. Key variables measured were runoff, sediment yield, nutrient concentration in sediment, grain yields, economic and weather data. Data was subjected to Analysis of Variance using SAS 9.1.3. Mean separation was done using Fisher's LSD at 5% level of significance. Compared with control results showed that in Meru South, mulching and MBILI intercrop reduced runoff by 26% (p=0.04) during short rains 2011; sediment yield was reduced by 41 and 12% under mulching and MBILI intercrop respectively, during long rains 2011 (p=0.03) and by 71, 61 and 68% (p=0.01) under mulching, MBILI intercrop and minimum tillage respectively, during short rains 2011; Mulching and MBILI intercrop reduced N concentration by 29 and 35% respectively, during long rains 2011 (p=0.02). During short rains 2011, mulching, MBILI intercrop and minimum tillage reduced N concentration by 61, 33 and 46% respectively (p=0.01). Potassium concentration was reduced by 55, 40 and 44% under mulching, MBILI intercrop and minimum tillage respectively, during short rains 2011 (p=0.02). Organic carbon concentration was reduced by 54, 30 and 46% during long rains 2011 (p=0.01) and by 54, 33 and 39% during the short rains 2011 (p=0.01) under mulching, MBILI intercrop and minimum tillage respectively. Maize yield was increased by 5, 40 and 7% under mulching, MBILI intercrop and minimum tillage respectively (p=0.001) during long rains 2011. Net benefits under mulching, MBILI intercrop and minimum tillage were increased by 11, 75 and 16% respectively, during long rain 2011 (p=0.001). Benefit cost ratio increased by 27, 77 and 54% during long rains 2011 (p=0.004) and by 33, 44 and 89% during short rains 2011 (p=0.02) under mulching, MBILI intercrop and minimum respectively. In mbeere south, runoff was reduced by 52% and 49% during long rains 2011 and by 51% and 30% during short rains 2011under tied ridging and mulching, respectively. Mulching, MBILI intercrop and tied ridging reduced sediment yield by 78, 50 and 71% during long rains 2011 (p=0.01) and by 53, 29 and 64% during short rains 2011. Potassium concentration was reduced by 53, 19 and 47% during long rains 2011 and by 33, 13 and 54% during short rains 2011 under mulching, MBILI intercrop and tied ridging respectively. Organic carbon concentration was reduced by 54, 22 and 50% under mulching, MBILI intercrop and tied ridging respectively, during long rains 2011. Mulching reduced organic carbon concentration by 58% during short rains 2011. Total crop failure occurred during long rains 2011 due to erratic rainfall. During short rains 2011 tied ridging and mulching increased maize yield by 94 and 75% respectively. Tied ridging, mulching and MBILI intercrop increased net benefits by 228, 205 and 127% (p=0.01) and BCR by 280, 260 and 120% (p=0.004) respectively. The soil and water conservation technologies performed better than the control in all parameters evaluated.

CHAPTER 1

INTRODUCTION

1.1 Background to the Study

Agriculture is by far the world's dominating land use (Welch *et al*., 2010). From a global perspective, its productivity is low in areas under rainfed farming systems (Temesgen *et al.,* 2009). Sub-Saharan Africa (SSA) is highly dependent on the agricultural sector for its livelihood which contributes 10-70% to their gross domestic product (GDP) (Biazin *et al*., 2012). Per capita food availability in SSA has however decreased over time and the region suffers from food insecurity (Beintema and Stads, 2006). Over 80% of agriculture in SSA is rainfed, of which the bulk is under smallholder farming (Rockström, 2000). The farmers are faced with challenges of increasing population pressure, food insecurity, very low levels of agricultural productivity and rapid natural resource degradation associated with nutrient depletion through soil erosion, and excessive runoff (Rockstrom, 2000). Majority of small-holder farmers in Meru south and Mbeere south subcounties depend on rainfed agriculture (Mugwe *et al.,* 2009). Apart from soil nutrient loss, water stress is also a limiting factor to food production in rainfed farming systems. Farmers often experience food shortages due to water stress induced crop failure. Therefore, the challenge of solving the problem of food insecurity is to a large extent a question of addressing soil nutrient loss and water deficit by ensuring maximum harvest from a drop of rain in the region.

As a result of soil loss from agricultural land, plant nutrients are removed; soil texture is changed; structure deteriorates subsequently reducing the productive capacity of land (Atreya *et al.,* 2005). Erosion by water is the major cause of soil, nutrient and

soil water loss in Meru south and Mbeere south subcounties. Xin-hu *et al.* (2011) have pointed out that traditional farming practices and unsustainable utilization on sloping lands have induced tremendous soil loss. This is because erosion is more rampant when the soil is bare than when covered with crop residues. Therefore, soil and water conservation technologies like mulching and tied ridges present good options for reversing soil nutrient and water loss through erosion. According to Al-Kaisi (2008), the impact of millions of raindrops hitting bare soil surface can be incredible, dislodging soil particles and splashing them far away.

Mulch reduces erosion by reducing kinetic energy of raindrops and hydrodynamic power of flowing water (Pan *et al*., 2006). Studies by Adekalu *et al*. (2007) and Smets *et al*. (2008) reported effectiveness of mulching in conserving water and soil through reduced surface runoff, increased water infiltration into the soil and retarded soil erosion. Grismer and Hogan (2005) found that application of mulch covers dramatically decreased sediment yields and concentrations in comparison to conventional practice. According to Prats *et al*. (2012) mulching can be highly effective in reducing runoff coefficient from 26 to 15% and sediment losses from 5.41 to 0.74 Mega grams per hectare (Mg ha^{-1}) compared with conventional tillage.

The significant role of tied-ridges in improving water and crop productivity in arid and semi-arid regions has been widely reported (Araya and Stroosnijder, 2010; Jensen *et al.*, 2003; McHugh *et al.*, 2007; Motsi *et al.,* 2004). Biazin and Stroosnijder (2012) reported an increase of 26% in maize grain yield under tied ridging as compared to conventional tillage in the Central Rift Valley of Ethiopia around Langano, which has similar environmental conditions as Mbeere south sub-county of Kenya where this study was

carried out. Araya and Stroosnijder (2010) and Walker *et al.* (2005) have stated that single interventions through water conservation could improve crop yields by up to 50% in arid and semi- arid regions of sub-Saharan Africa. The combined use of tied-ridges and nutrient inputs has resulted in two-fold to six-fold crop yields as compared to conventional farming practices without fertiliser use according to Jensen *et al.* (2003) and Zougmore *et al.* (2003).

Benefits of minimum tillage on soil health and improved crop yield have been well documented (Franzluebbers, 2004; Magdoff and Weil, 2004; Weil and Magdoff, 2004). According to Castellini and Ventrella (2012), continual soil inversion can in some situations lead to a degradation of soil structure, decrease in available soil water, depletion of soil organic carbon, and increasing greenhouse gases emissions into the atmosphere. A study by Kong *et al.* (2009) reported greater potential for nitrogen (N) nutrient stabilization and higher grain yield under minimum tillage in comparison to conventional tillage.

Intercropping cereals with legumes such as beans and cowpea provide an important pathway to alleviate constraints related to nutrients especially N limitations in soil and improve crop productivity (Rusinamhodzi *et al.,* 2012). The potential of intercropping systems in biological nitrogen fixation and improving crop productivity has widely been reported in literature (Mucheru-Muna *et al.,* 2010; Zhang *et al.,* 2010; Gao *et al.,* 2006; Woomer *et al.,* 2004). The soil cover provided by legumes also protects soil surface from the destructive effect of rain drops.

1.2 Problem Statement and Justification

Farmers in Meru south and Mbeere south sub-counties have experienced declining crop yields in recent decades. The main factor contributing to this decline is soil impoverishment caused by continuous cropping without addition of adequate fertilizers and manures and nutrient loss through crop harvest, soil erosion and leaching. This problem is exacerbated by rapidly growing population, low water availability, caused by low and unreliable rainfall, low inherent water storage by soils and poor water harvesting techniques. High variability in rainfall has been partly attributed to El-Niño/Southern Oscillation (ENSO) which causes abnormally wet or dry short periods (Camberlin *et al.,* 2001). A number of Integrated Soil Fertility Management (ISFM) options have been developed and adopted by farmers in the two sub-counties. Few studies however, have focused on the potential of soil and water conservation technologies in improving agricultural productivity in the area. To further increase crop yield, and moreover reduce production risks, a better use of rainfall through SWC technologies is required, especially since rainfall is very erratic in the region. The study therefore aimed at evaluating agricultural production technologies that reduce soil erosion and nutrient stresses under erratic rainfall. The strategy involved reducing runoff losses (water conservation) by surface management (tied ridging, mulching and minimum tillage), preventing sediment and nutrient loss (soil conservation) and using infiltrated water more efficiently (water-use efficiency, WUE) by intercropping with drought-resistant grain legumes.

1.3 Research Questions

The study sought to address the following questions:

i. What is the effect of mulching, MBILI intercrop, minimum tillage and tied ridging on runoff in maize fields?
ii. To what extent do mulching, MBILI intercrop, minimum tillage and tied ridging affect sediment, nutrient and soil organic matter loss?
iii. Among mulching, MBILI intercrop, minimum tillage and tied ridging, which technology has significant effect on maize yields?
iv. What is the economic implication of mulching, MBILI intercrop, minimum tillage and tied ridging technologies?

1.4 Objectives

The broad objective of the study was to investigate the effects of selected soil and water conservation technologies on runoff, sediment, soil nutrient and maize yields in Meru south and Mbeere south. The specific objectives are

i. To assess effects mulching, MBILI intercrop, minimum tillage and tied ridging on runoff in maize fields.
ii. To determine the effect of mulching, MBILI intercrop, minimum tillage and tied ridging on sediment, soil nutrient and organic matter loss in Meru south and Mbeere south sub-counties
iii. To evaluate performance of mulching, MBILI intercrop, minimum tillage and tied ridging on maize yield.
iv. To examine the economic implications of mulching, MBILI intercrop, minimum tillage and tied ridging technologies.

1.5 Hypotheses

The study sought to test the following hypotheses:

i. Mulching, MBILI intercrop, minimum tillage and tied ridging technologies significantly influence runoff in maize fields
ii. Mulching, MBILI intercrop, minimum tillage and tied ridging have significant effect on sediment, soil nutrient and organic matter loss in Meru south and Mbeere south sub-counties.
iii. Mulching, MBILI intercrop, minimum tillage and tied ridging improve maize yield.
iv. Mulching, MBILI intercrop, minimum tillage and tied ridging are economically feasible.

1.6 Significance of the study

The research is expected to contribute and recommend suitable, sustainable and cost effective soil and water management options aimed at improving maize productivity for the two study sub-counties, contribute scientific knowledge and suggest viable coping mechanisms for future climate variability for farmers in the study area as well as to contribute additional knowledge to research. The targeted beneficiaries were farmers, policy makers, researchers in soil science and the student/researcher.

1.7 Conceptual Framework

The major problem in the study area is soil fertility decline caused by poor farming practices, lack of soil and water conservation measures and worsened by climate variability (Figure 1.1). Climate variability affects rainfall intensity, frequency, spatial

and temporal distributions which may in-turn accelerate soil erosion and consequent soil nutrient loss. High temperatures attributed to climate variability increases oxidation of organic matter hence affecting soil aggregate stability. Reduced soil aggregate stability renders soil highly susceptible to soil erosion and consequent nutrient loss.

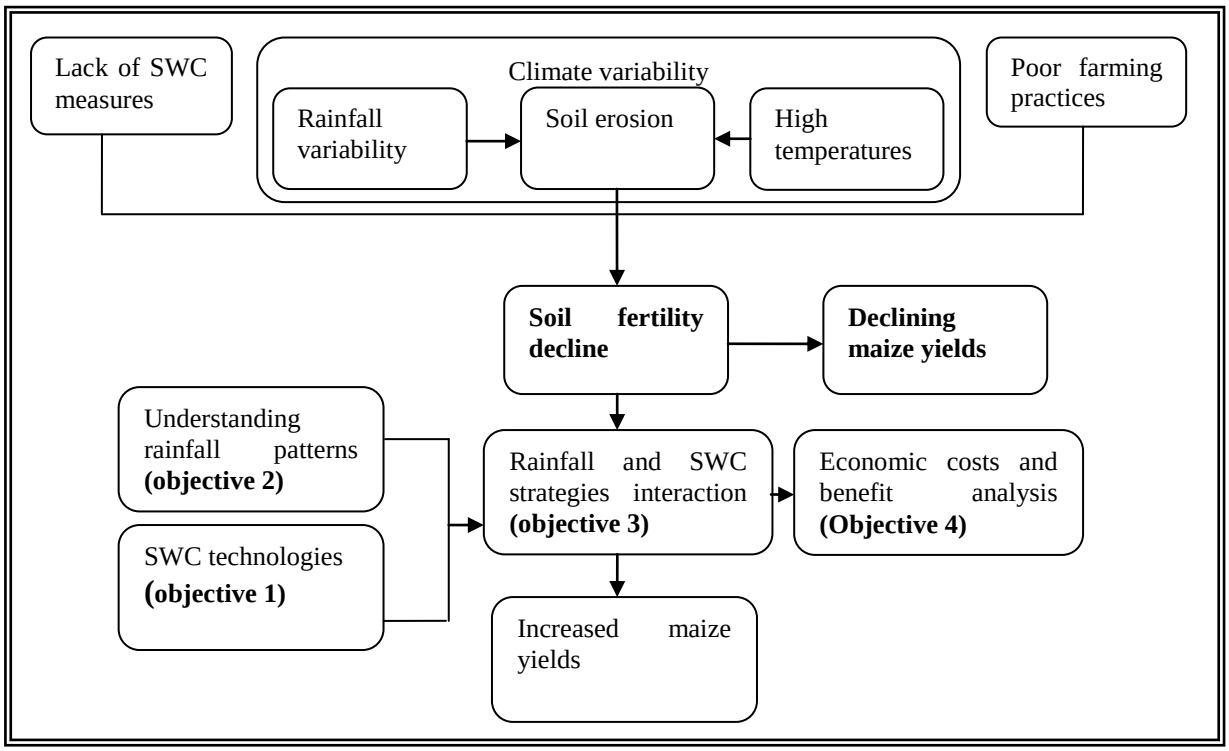

Figure 1.1: link between the study problem and objectives

These factors work together to suppress agricultural productivity in the study area. Farms in Meru south and Mbeere south are characterized by widespread failure to make sufficient soil fertility replenishment investments, resulting in declining soil fertility. Reversing these trends call for a proper understanding of rainfall patterns, adoption of sound soil and water conservation practices based on their interactions with the rainfall. Cost benefit analysis is necessary to establish the affordable technology for adoption by the farmers.

1.8 Definition of terms

Agricultural drought: When there is not enough plant available soil moisture in the root zone.

Climate Variability: Fluctuations in elements of climate such as rainfall, temperature, air pressure, wind flow patterns and ocean currents, and may be caused by either natural processes or anthropogenic activities

Dry spell: Two-four weeks long days without rainfall during the cropping period

Long rains 2011 Cropping season in the study area which occurs between mid March to mid June 2011 in Mbeere South and early March to July 2011 in Meru South

Meteorological drought: When the amount of overall rainfall is below the minimum required to generate fundamental ecosystem services from nature, especially food.

Runoff: The portion of rainwater not infiltrated into the soil after a rainfall event

Sediment: Solid material that settles at the bottom of runoff, especially soil and rock pieces resulting from erosion

Short rains Cropping season in the study area which occurs between late October and mid June in Mbeere South and early March to July in Meru South

Soil nutrients: Elements required by soil for quality plant growth and productivity and determines the level of soil fertility.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Soil nutrient management is a key challenge for global food production (Powlson *et al.*, 2011). According to Nyssen *et al.* (2009), nearly all tropical highlands suffer from land degradation, especially medium to very high water erosion. It has long been recognized that lack of plant nutrients due to land degradation is a principal cause for low agricultural productivity and food insecurity in Africa (Sanchez, 2002) where rainfed farming is dominant. Failure by smallholder farmers to intensify agricultural production in a manner that maintains soil productivity is the main cause of land degradation in sub-Saharan Africa (SSA). Soil erosion is the major cause of nutrient loss, particularly where agronomic inputs are low, vegetation cover is poor, soils are not resilient and where intense rainfall sometimes occur (Powlson *et al.*, 2011). According to Stolte *et al.* (2009), soil erosion has direct negative effects on the productivity of land by loss of soil, water and nutrients. Soil impoverishment in Meru south and Mbeere south sub-counties is attributed to poor farming practices and high costs of commercial inorganic fertilizers by majority of farmers (Shisanya *et al.*, 2009). As a result, soil fertility has continued to decline and the productivity of the land has declined drastically.

Apart from soil nutrient loss, water deficit especially at the plant root zone is a significant factor that hinders crop productivity (Bossio et al., 2010). Increased soil moisture storage at the root zone, called *in situ* rainwater conservation technology, reduces runoff and soil loss (Ngigi *et al.*, 2006). Water scarcity is more pronounced in semi arid regions of Sub Saharan Africa where agriculture is rainfed and faces threat from frequent dry spells and droughts (Rockstrom *et al.*, 2003). Mbeere south sub-

county is such an area. There is therefore an urgent need to increase nutrient and water availability to crops grown by smallholder farmers in developing countries.

Literature highlights mutual relationships among soil, nutrient and water conservation, hence the need to address all concurrently. Studies by Barron (2004), Fofana *et al.* (2003) and Snyman (2003) have revealed that benefits of soil moisture conservation are more visible where soil fertility improvement measures are considered and incorporated. According to Bossio *et al.* (2010), soil erosion, nutrient depletion and other forms of land degradation reduce water productivity, nutrient use efficiency and hence agricultural productivity. Stroosnijder (2009) emphasizes that plant production suffers because water is not available due to deteriorated physical properties of soil. Araya *et al.* (2012) has linked imbalanced soil hydrology in the central highlands of Ethiopia to physical deterioration of soil quality and absence of effective *in situ* soil and water conservation measures. Rockström and Barron (2007) suggested that yield response to rain was only achieved through proper soil fertility management.

Despite the substantial knowledge accumulated on different approaches to manage soil fertility in smallholder farms in Africa, there is laxity in adoption, widespread testing and experimentation by farmers (Giller *et al.*, 2006). This is a major concern where farmers perceive the technologies to be expensive and technical. According to Mateete *et al.* (2010), smallholder farmers are at the center of soil fertility restoration processes and their decisions to utilize technologies and to improve soil fertility are guided by the overall benefits that will accrue from production. Adoption of simple

and cost effective soil and water technologies is hence a pertinent step towards reversing maize crop decline in Meru south and Mbeere south sub-counties.

2.2 Runoff

Runoff is the portion of rain water that is not infiltrated into the soil for crop uptake but carried away out of reach by plants. Runoff generation is a key point in soil erosion processes as it determines the duration and volume of water running off the soil surface, and controls soil detachment rates and sediment transport (Lozano-garcía *et al.,* 2011). Factors influencing runoff at plot scale include vegetation, soil types, slope, rainfall characteristics (storm duration and intensity) and surface management practices (Reaney *et al.,* 2007). Floor (2000) highlighted that when rainfall intensity exceeds soil infiltration capacity, runoff is generated which can accelerate transportation detached soil particles. According to Stolte *et al.* (2009), the loss of nutrients through runoff adversely affects agricultural production. García-Ruiz (2010) states that land use changes, climate, scarce and torrential rainfall, steep slopes and the fragility of soil (low levels of organic matter, aggregate stability and nutrients) makes a region very prone to surface sealing, runoff generation and water erosion.

There is however, remedy to reduce runoff in agricultural fields. Runoff mitigation can be solved by infiltrability improvement of soil profile and limitation of surface structural degradation (Armand *et al.,* 2009). On-site, conservation of plant-available water is an important issue for agricultural production (Rockström *et al.,* 2010) and may be a more important concern than soil loss, particularly in areas where water is a key resource (Maetens *et al.,* 2012). Sustainable cultivation practices can enhance infiltration of rainfall and delay drainage of soil moisture in some soil types (FAO,

2008). The objective of *in situ* rainwater conservation technology is to minimize water losses by runoff, deep percolation and evaporation; and maximize water storage in the root-zone (Hensley and Bennie, 2003). Agronomic practices under *in situ* water conservation include mulching and tied ridging. For instance, mulching improves runoff storage which also delays runoff transfer (Ngigi *et al.,* 2006). Xin-hu *et al.* (2011) explain that interception of precipitation by mulch not only reduces the volume of runoff, but also protects detached soil particles from being transported.

Long term application of conservation agriculture practices such as minimum tillage and mulching has significantly reduced runoff in different soil types (Zhang *et al.,* 2007). Non-inversion tillage systems reduce water erosion compared to conventional tillage systems where soil is exposed to runoff (Morrison and Sanabria, 2002). In a few cases, however, conservation tillage reduces runoff much less than the erosion. For instance, Wilson *et al.* (2004) observed higher runoff amounts in minimum tillage than in conventional tillage based on plough use. This may be attributed to the fact that in cultivated fields, soil surface crusts partly control runoff rates by reducing infiltrability (Armand *et al.,* 2009).

Runoff studies in Meru south and Mbeere south have focussed more on water catchment rather than plot scale. There is hence the need to document knowledge on runoff management at farm level in reference to various soil and water conservation technologies so as to buffer against soil water deficit in agricultural productivity. This study can further guide on modelling impacts of the technologies over longer time periods.

2.3 Soil and Nutrient loss

Soil fertility depletion is seen as the most important process in land degradation equation and a primary constraint to improving food security in developing countries (Drechsel *et al.,* 2004). Plants require sufficient nutrients, organic matter, moisture and favourable weather conditions for food production. Some of essential nutrients are nitrogen (N), phosphorus (P), potassium (K), soil organic carbon (SOC), iron (Fe), calcium (Ca), magnesium, manganese (Mn), copper (Cu) and zinc (Zn) (Mugendi *et al.,* 2006). Soil nutrients and soil organic matter (SOM) are usually depleted after cultivation (Wang *et al.,* 2004). Bossio *et al.* (2010) state that on a global scale, only half of the nutrients that crops take from soil are replaced. In many African countries, nutrient depletion of agricultural soils is so high that agricultural land use is not sustainable (Craswell *et al.,* 2004).

Although there exists other forms and causes of nutrient loss, soil erosion is the most visible form involving movement of soil particles downhill by forces of gravity, water or wind (Floor, 2000). Soil erosion is also considered a serious environmental problem globally (Pimentel, 2006) with on-site-effects mainly through its impacts on soil quality and crop yield (Putte *et al.,* 2010). For long, it has been appreciated that the effect of soil erosion is lowering soil fertility through removal of organic matter and nutrients in the eroded sediments (Young, 1989).

Concern on soil erosion is great in every agricultural region of the world due to its long-term negative effects on soil productivity (Liu *et al.,* 2011). Studies of soil nutrient balance across Africa indicate evidence of widespread depletion of soil resource within smallholder farming sector, as organic matter and nutrient source is

not replenished (Briggs and Twomlow, 2002). Annual net nutrient depletion exceeds 30 kg N ha^{-1} and 20 kg K ha^{-1} for arable land, for example, in Kenya (Smaling and Fresco, 1993). World Atlas of Desertification (UNEP, 2006) based on surveys carried out by International Soil Reference and Information Centre (ISRIC) and the Winrand Staring Centre approximated the area affected by soil degradation in arid, semi-arid and dry sub- humid agro-ecological zones alone at 332 million hectares, or 25.8% of the surface of Africa. Mateete *et al.* (2010) indicate average annual depletion rates of 22 kg N ha^{-1}, 2.5 kg P ha^{-1}, and 15 kg K ha^{-1} at continental level. Intensively cultivated highlands in East Africa lose an estimated 36 kg N ha^{-1} yr^{-1}, 5 kg P ha^{-1} yr^{-1}, and 25 kg K ha^{-1} yr^{-1} while croplands in Sahel decline by 10, 2, and 8 kg ha^{-1} (Africa Fertilizer Summit, 2006).

Rates of nutrient depletion are particularly high in areas with favourable climates for crop production and high population densities (Briggs and Twomlow, 2002); Meru south subcounty in Meru south and Mbeere south is such an area. Bakker *et al.* (2004) state that in intensive agricultural systems, the effects of erosion on crop yields mainly occur due to reduction of the amount of water the soil can store and avail to plants. The resultant decrease in soil fertility affects soil productivity and results in degradation of soil physical and chemical properties (Schiettecatte, 2006). Further, Angima *et al.* (2003) approximates productive top soil loss through water erosion to lakes and oceans of about 5000 kg ha^{-1} each year in Africa. A study by Okoba *et al.* (2007) in Meru south and Mbeere south sub-counties has indicated high likelihood of maize yield decline below the optimal levels (3.5 t ha^{-1}) in East Africa if soil erosion is not checked.

A direct link between soil nutrient depletion and food insecurity has been suggested, by noting evidence of declining global trends in the rate of yield improvements for some major food crops (Gruhn *et al.,* 2000). A study by Mortimore and Harris (2005) however, contradict the belief that soil fertility decline automatically leads to decline in soil productivity and advises that the concept of soil fertility be viewed at a broader perspective than implied in the nutrient depletion scenarios.

Soil fertility depletion can be mitigated if proper practices are adopted (Lal, 2004). Mateete *et al.* (2010), state that Sub-Sahara Africa can overcome the soil fertility depletion that has resulted from decades of nutrient mining and threatens the region's food security. With the goal of reducing soil degradation and ameliorating subsequent problems, several research efforts have been focused on developing sustainable soil management technologies, which protect the soil resource base while enhancing food production (Das and Bauer, 2012). Giller *et al.* (2006) state that soil erosion control is perhaps the clearest benefit of conservation agriculture. This is further emphasized by Putte *et al.* (2010) who point to conservation agriculture as one of the many strategies to combat soil degradation through erosion and compaction on agricultural fields. Stolte *et al.* (2009) has indicated that soil particle erosion is the driving force of N and P losses from fields, therefore, *in situ* interception of early runoff flows, for instance through biological barriers, could effectively control and prevent nutrient losses.

There are several technical solutions to soil fertility restoration, many with similar fundamental principles, but their success depends upon practical relevance, efficiency of application, and acceptance by the farmer (Mateete *et al.*, 2010). Soil conservation technologies can play a significant role in reversing the current soil and nutrient loss

in the study area. For instance, maize legume intercrop contributes to the soil N-budget through biological N_2-fixation and this is especially important in low-input farming systems (Rusinamhodzi *et al.,* 2012) such as those that prevail in Meru south and Mbeere south. Legumes used for intercropping systems further provide soil cover which protects the soil from the splash effect of rainfall. Nitrogen fixation by indigenous and introduced legumes combined with improved agronomic practices has shown potential for kick-starting self-multiplying improvements in soil productivity (Mateete *et al.,* 2010).

Minimum tillage is another soil and water conservation technology that can reverse soil loss in the study area. A study by Das and Bauer (2012) reported that minimum tillage is effective in reducing a substantial rate of soil erosion prevailing in the conventional system of maize cultivation. The main benefit of minimum tillage according to Kertesz (2004) is to preserve the soil in semi-natural conditions as soil disturbance is minimized and physicochemical degradation is reduced.

However, little attention has been paid to investments in soil and water conservation (SWC) and local soil fertility amendments in Mbeere South and Meru south sub-counties. Limited attention is attributed in part to the low income levels and inadequate operational knowledge on the technologies. In the drylands, like Machang'a, restoring soil fertility can be better optimized using support technologies that target water capture and practiced in conjunction with other technologies such as the use of crop residue and ridges (Mateete *et al.,* 2010).

2.4 Water scarcity

Water scarcity and a large variation in inter-annual and intra-annual rainfall are the main constraints to crop production, leading to variable crop production and low crop water use (Wang *et al.*, 2011). Globally, a country is categorized 'water scarce' if its renewable freshwater supplies are less than 1,000 cubic meters per capita per annum (m^3 cap^{-1} $year^{-1}$) (UN water, 2006). According to International Water Management Institute, Kenya falls among the water scarce countries. Agriculture sector consumes freshwater of an estimated 1300m^3 cap^{-1} $year^{-1}$ in order to produce an adequate diet (Falkenmark and Rockström, 2004). Rainfed farming system utilizes more water than the irrigation systems and hence is likely to suffer most from water scarcity. From a scenario analysis, approximately 7100 km^3 $year^{-1}$ are consumed globally to produce food, of which 5500 km^3 $year^{-1}$ are used in rainfed agriculture and 1600 km^3 $year^{-1}$ in irrigated agriculture (de Fraiture *et al.*, 2007).

Resource poor farming communities in water scarce countries who entirely rely on rainfed agriculture are subject to various hydrological constraints (De Winnaar *et al.*, 2007). Water scarcity experienced in semi-arid areas can be attributed to poor rainfall partitioning and frequent occurrence of mid season dry spells that consequently result in poor soil water availability during the growing season (Rockström, 2000). Mortimore and Harris (2005) report that frequent droughts depress nutrient uptake by plants and crop yields. According to Love *et al.* (2006) short dry spells are often the major cause of low yields in sub-Saharan Africa. Future climate change may further undermine attempts to mobilize the necessary water resources, due to observed reductions in rainfall in the lower tropical latitudes (Zhang *et al.*, 2007). Soil degradation and vegetative change that result in evaporation and convection changes

can also have detrimental impacts on local precipitation patterns and water availability (Ryszkowski and Kedziora, 2008). Rockström and Barron (2007) suggested that mitigation of seasonal dry spells was a key to improving water productivity for rainfed agriculture. In Kenya, agriculture sector is constrained by among others the erratic nature of the rainfall and the ever increasing population (UN water, 2006).

2.5 Soil organic matter loss

Organic matter is the key to soil fertility and productivity in agricultural systems where there is no use of inorganic fertilizers (Briggs and Twomlow, 2002). The remains of plant material and soil organisms in various stages of decomposition and synthesis constitute SOM (Ryan *et al.,* 2001). Poor soil fertility is regarded as the underlying factor limiting productivity in African agriculture (Giller *et al.,* 2006). The significance of SOM in agricultural soil has long been recognized. For instance, Quiroga *et al.* (1998) showed that soils with higher levels of organic matter had lower susceptibility to compaction and greater aggregate stability. Holland (2004) has indicated that SOM influences many of the physical, biological and chemical properties of soil such as soil structure, soil stability, buffering capacity, moisture retention, biological activity, nutrient reserve and its availability and ultimately determines the risk of erosion. Soil organic matter is also integral to managing water cycles in ecosystems (Bossio *et al.,* 2010). Pinheiro *et al.* (2004) attribute part of the aggregate size variation and the aggregation indices in tropical soils to variations in SOM.

Soils low in organic matter and nutrients exhibit increased susceptibility to degradation upon cultivation especially if management of the soils is inappropriate (Burt *et al.,* 2001). For instance, rates of decline in SOM when land is converted from forest or grassland to agriculture are rapid, with up to 50% of the SOM being lost within 10-15 years (Diels *et al.,* 2004). According to Lal (2004), depletion of soil organic Carbon (SOC) pool has contributed 78 Petagram (Pg) of C to the atmosphere. Some cultivated soils have lost one-half to two-thirds of the original SOC pool with a cumulative loss of 30-40 Mg C ha^{-1}.

Quantity and quality of SOM and its major component, humus, is largely influenced by management practices. This was earlier recognized by Quiroga *et al.* (1998) and is further emphasized by Lal (2004) who states that the depletion of soil C is accentuated by soil degradation and exacerbated by land misuse and soil mismanagement. Maintenance of productivity on smallholder farms through the improved use and management of organic resources within the farming system has become a priority for research in past times (Briggs and Twomlow, 2002). Thus, adoption of a restorative land use and recommended management practices on agricultural soils can reduce the rate of enrichment of atmospheric CO_2 while having positive impacts on food security, agro-industries, water quality and the environment (Temesgen *et al.,* 2009). Adoption of conservation tillage with cover crops and crop residue mulch, nutrient cycling and other systems of sustainable management of soil and water resources can help restore a considerable part of the depleted SOC pool (Rockström *et al.,* 2009).

Giller *et al.* (2009) and Kong *et al.* (2009) have demonstrated the potential of minimum tillage and mulch in enhancing accumulation of SOM, mitigating CO_2 emissions and partly addressing the mounting environmental problems associated with modern agricultural practices. Implementation of soil and water conservation technologies such as mulching, minimum tillage, intercropping and tied ridging would therefore provide a partial solution to the deteriorating quality of SOM in rainfed farming systems. According to Limon-Ortega *et al.* (2006), conservation agriculture also improves soil physical properties such as infiltration rate, available water content, aggregate stability and hydraulic conductivity. In the study, organic matter is lower in soils in Mbeere South sub-county compared with Meru South sub-county, as reflected on the soil characteristics (Jaetzold et al., 2007). Limited studies in Meru south and Mbeere south have focused on the implications of conservation practices on organic matter loss from runoff plots. Organic matter loss in the study area was approximated from organic carbon concentration in the sediment suspended in runoff.

2.6 Rainfall variability

Rainfed subsistence farming systems in SSA generally obtain low crop yields as a result of highly erratic rainfall seasons (Makurira, 2011). In systems reliant on rainfall as the sole source of moisture for crop or pasture growth, seasonal rainfall variability is inevitably mirrored in both highly variable production levels, risk-averse livelihood and coping strategies that have emerged over time (Cooper *et al.*, 2008). In the semi-arid and dry sub-humid zone, the limiting factor of production is the extreme variability of rainfall, with high rainfall intensities, few rain events and poor spatial and temporal distribution of rainfall, while in arid zone, crop water needs often

exceed total rainfall causing absolute water scarcity (Rockström *et al.*, 2010). According to FAO (2008), the day-to-day variability of rainfall associated with weather is the major risk factor for most forms of agriculture. Further, Soil moisture deficits, crop damage and crop diseases are all driven by rainfall and associated humidity. The variability in rainfall intensity and duration makes the performance of agricultural systems in relation to long-term climate trends very difficult to anticipate, particularly the case for rainfed production (Brouder and Volenec, 2008). Long-term rainfall records from Eastern and Southern Africa indicate that inherent replenishment of soil moisture storage may occur as a result of rainfall (Cooper *et al.*, 2008).

Climate change is likely to worsen rainfall variability (Cooper *et al.*, 2008). According to Lobell and Field (2007) changes in climate have already decreased crop yields in several regions and are estimated to have reduced global maize production by 12 Megatonnes (Mt) $year^{-1}$ between 1981 and 2002. Holland (2004) reports that climate may affect relative yields under conservation tillage due to its significant effect on the overall water balance and the availability of soil water to the plants. The Assessment Report Four (AR4) states that the ability of agricultural communities in SSA to cope better with current climate variability and adapt to future climate change must therefore be enhanced (IPCC, 2007). Regions and systems which currently undertake adequate nutrients' management stand a good chance of continued optimization under a changed climate (Brouder and Volenec, 2008). There was therefore the need to study and document the potential of selected soil and water conservation technologies which could help buffer against the rainfall variability experienced in the study area.

2.7 Soil and water conservation technologies

Soil water shortage due to water loss by surface run-off particularly on steep-sloping arable land intensified by severe dry spells within the season constrains crop production (Jaetzold *et al.*, 2007). Improved soil and water conservation measures are therefore paramount. The value of soil nutrients in plant growth and agricultural output is closely related to water availability and likewise, agricultural water productivity is in large part determined by nutrient supplies (Drechsel *et al.*, 2004), hence the need to conserve both soil and water. The threat of increasing dry spell occurrences suggest an urgent need to change from the traditional cultivation practices in SSA to more efficient and robust approaches (Rockström, 2003). The approaches should promote soil and nutrient conservation while channelling more water to the root zone where they have high potential for attaining improved yields. Various soil and water conservation technologies have been demonstrated in literature. In the study areas, tied ridging, mulching, minimum tillage and cereal-legume intercrop were the selected soil and water conservation technologies as will be discussed.

2.7.1 Tied Ridging

Tied ridging technology involves growing of crops on small ridges established on the contour while blocking the furrows with cross-ties to retain rain water (Twomlow and Bruneau, 2000). It is a commonly used physical conservation practice that when aligned parallel to the contour lines has the dual purpose of erosion control and surface drainage (FAO, 2008). The significant role of tied-ridges in conserving soil moisture and increasing crop productivity in arid and semi-arid regions has been reported (Jensen *et al.*, 2003; Motsi *et al.*, 2004; McHugh *et al.*, 2007; Araya and

Stroosnijder, 2010). There has been a long experience of tied ridging in Eastern Africa (Gebreegziabher *et al.,* 2009). In Kenya, the importance of tied ridges in controlling erosion and runoff was demonstrated by Pereira *et al.* (1967), no attention was however given to its economic implications. In Ethiopia, a traditional ridging practice is done 4-6 weeks after sowing of maize as a means of breaking the soil surface crusts and enhancing infiltration (Biazin *et al.,* 2011). A tied-ridge system has been practised successfully in parts of Tanzania for many years in areas of marginal rainfall where water conservation was essential (Dagg and MacCartney, 1968).

As a soil and water conservation measure, tied ridging can substantially improve crop productivity. According to Jensen *et al.* (2003) maize yield with tied ridging in years with dry to near normal rainfall was improved by 42% even without any nutrient inputs while the seasonal average runoff was between 5-9% in the plots with water conservation and 16-30% in the plots without water conservation. Similar studies by McHugh *et al.* (2007) in semi-arid Ethiopia have indicated that tied ridging on slopes less than 3% reduced runoff by more than 75% compared with control practice. It is more advantageous with less steep terrain and more permeable soil.

Tied-ridging can also improve capture and infiltration of water (Giller *et al.,* 2006). According to Biazin and Stroosnijder (2012), tied ridging has potential benefit of rainwater harvesting and improved soil fertility on maize productivity. Fournier (1972) reported a 7 to 13-fold decrease in erosion and runoff in parts of West Africa due to ridging. Generally, for small landholders with only hand implements or animal traction and low-value subsistence crops, the ridge-furrow system used along the

contour is a satisfactory method of enhancing infiltration and reducing runoff (FAO, 2008).

Ridge-tying is a quite effective soil and water conservation system especially in arid and semi-arid regions, such as the ones that prevail in Machang'a. Araya and Stroosnijder (2010) indicated that tying ridges or mounds to allow more rainwater to infiltrate was an effective system in drier areas (< 1000 mm annual rainfall) on gentle slopes (< 7%) but not in wet years or more humid areas. The effectiveness of tied-ridges however, depends on soil type, slope, rainfall and design characteristics. On clay soils, it may induce water logging which may be followed by mass movement (Gray and Brenner, 1970). In severe storms, poorly designed ridge-furrow systems may fail as the row catchments can over-top and water flow unimpeded down slope with danger of it accumulating enough energy to scour and transport soil (McHugh *et al.,* 2007). These factors should therefore be taken into consideration before its selecting tied ridging as a soil and water conservation technology in any given area. Despite the adequate knowledge accumulated from literature on the potential of tied ridging in improving maize productivity, little attention has been given to it in the study area.

2.7.2 Minimum tillage

Minimum tillage is a non-inversion practice which aims at maximizing soil infiltration and soil productivity, and minimizing water losses while conserving energy and labour (Rockström *et al.,* 2002). Minimum tillage has been proposed by Giacomini et al. (2010) as a major component of conservation agriculture (CA) that help to protect the soil against erosion and favour carbon sequestration and soil

biological activity. Improved agricultural productivity using minimum tillage systems based on non-inversion tillage methods have predominantly originated from farming systems in sub-humid to humid regions where water is not a key limiting factor for crop growth (Rockström *et al.,* 2009). Minimum tillage technology package offers several advantages such as increased organic matter on the soil surface, soil erosion prevention and in the long run, restoration of soil fertility (Giller *et al.,* 2009). It has been found to increase soil moisture retention by improving water infiltration and diminishing soil erosion (Lopez-Bellido *et al.,* 2000).

Relative magnitude of tillage-induced differences in soil chemical properties depends on the soil type, climate, and cropping system (Lal, 1997). In some soils and climate, the new equilibrium in soil properties by conversion from plough-till to minimum-till or change in land use from natural vegetation to agricultural land may be attained over a period of l0 to 20 years (Kern and Johnson, 1993) while in others it may take as long as 130 years (Powlson and Johnston, 1994). A comparative study conducted on normal cultivation and minimum tillage for eight years in western Nigeria with monoculture maize revealed that, cultivation resulted in degradation of soil physical and chemical properties and that degradation was less for minimum tillage with mulch than for plough based methods of seed bed preparation (Lal, 1997).

Farmers can reduce labour costs, save time and expand the size of the cultivated area at little cost with minimum tillage (Giller *et al.,* 2009). It is profitable even when using inputs such as herbicides, improved seed varieties and fertilizers (Rockström *et al.,* 2008). Examples from sub-Saharan Africa show that converting from ploughing to minimum tillage results in yield improvements ranging between 20% and 120%

with water productivity improving from 10% to 40% (Rockström *et al.,* 2009; Smith *et al.,* 2011). Across sets of experiments in semi-arid and dry sub-humid locations in East and Southern Africa, Rockström *et al.* (2008) reported increased water productivity and crop yields with minimum-tillage practices and attributed this to its water-harvesting potential.

However, potential disadvantages of minimum tillage include higher costs of pest and weed control, cost of acquiring new management skills and investments in new planting equipment (Rockström *et al.,* 2008). As a result, the approach is quite important for upgrading rainfed agriculture which often is constrained by lack of investment capital. According to Enfors *et al.* (2010), while there is ample evidence to show that minimum tillage can promote soil health, it has recently been suggested that the main benefit in semi-arid farming systems may in fact be on *in situ* water harvesting effect.

Nhamo (2007) reported more abundance and activity of soil biota under maize-based minimum tillage cropping systems than with conventional practice in the sandy soils of Zimbabwe. Other successful minimum tillage systems where crop yields have been significantly increased, soil erosion reduced and conservation of water improved, can be found in several countries in SSA, e.g., Ghana, Nigeria, Zimbabwe, Tanzania and South Africa. However, little work has been done on minimum tillage in Meru South and Mbeere south sub-counties of Kenya.

2.7.3 Mulching

Mulch is any material placed on a soil surface for the purpose of reducing erosion, evaporation or controlling weeds (Armand et al., 2009). Mulches act as barriers to movement of moisture out of the soil, prevent soil crusting and enhances infiltration by protecting the soil surface from raindrops impact (Araya and Stroosnijder, 2010). Mulching has been widely used with the intention of conserving soil water (Sarkar and Singh, 2007; Chakraborty *et al.,* 2008). The maintenance of SOM and thus soil nutrient status through the supply of organic residues is an essential component in the management of tropical soils (Briggs and Twomlow, 2002).

A strong relationship exists between retention of mulch and reduction of runoff and soil losses by erosion (Erenstein, 2002). Given that erosion rates are greatest under high rainfall intensity, on steep slopes and on more erodible soils, it seems likely that these are precisely the conditions where mulching can have the greatest benefits (Roose and Barthes, 2001). Giller (2001) reported that mulching can improve the capture and efficient use of rain water in the short term and improve soil physical properties through increasing SOM contents in the long-term. In semi-arid regions, mulching is shown to be effective in reducing the risk of crop failure at field level due to better capture and use of rainfall (Bationo *et al.,* 2007). Mulumba and Lal (2008) found that wheat straw mulch significantly increased available water capacity and soil moisture content at field capacity. Mahboubi *et al.* (1993) reported higher available water capacity under mulching. Similar observations were made by Duiker and Lal (1999).

In few cases, mulching is less effective where the rainfall amounts are low (Zhang *et al.,* 2007; Stolte *et al.,* 2009). Jalota and Prihar (1998) reviewed the effects of mulch on soil moisture content and found that mulch may be detrimental in low rainfall periods because the mulch can intercept moisture from light rains before it reaches the soil and also wick moisture from the soil into the air thereby increasing evaporation. Jalota and Prihar (1990) determined that with evaporation rates of 15.4 mm per day, non-mulched soil conserved more moisture than mulched soil.

The availability of mulch material despite high demand as fodder in the study area and its simplicity as a SWC technology makes it a viable option for adoption by the farmers. Paucity of information however exists on comparative effects of mulch on soil nutrient in agriculturally high and low potential regions such as the ones found in Meru south and Mbeere south sub-counties. There is therefore the need to test the effectiveness of mulching on runoff, sediment and soil nutrient loss and maize yield before recommending it for farmers in the study area.

2.7.4 Intercropping

Legume-cereal intercropping, especially maize-beans intercropping is common throughout East and Southern Africa (Giller, 2001). Smallholder farmers in East-Africa commonly intercrop maize (*Zea mays* L.) with grain legumes to maximize utilization of land and labour and to attain larger crop yields (Mucheru-Muna *et al.,* 2010). Intercropping provides several environmental benefits such as mitigation of runoff and erosion, improvement of soil properties, increase in biodiversity and

reduction of herbicide use (Celette *et al.,* 2010). In drier areas, common beans are often replaced by cowpea or groundnut (Mucheru-Muna *et al.,* 2010).

Many intercropping systems have proved to be better than sole crops in terms of yields (Zhang *et al.,* 2007). Intercropping makes better use of one or more agricultural resources both in time and in space (Rodrigo *et al.,* 2001). Yield advantages of intercropping systems could be attributed to both above and below-ground interactions between intercropped species (Li *et al.,* 2006). Crop growth and final yield of an intercropping system are also closely related to the spread of roots, which determines the uptake and utilization of water and nutrients (Gao *et al.,* 2010). Zhang *et al.* (2002) indicated that, the growth stages of wheat and faba bean when root weight is maximum did not overlap, which reduced the competition between the two crops for water and nutrients and resulted in higher yields of both.

In this study, a modified intercropping system; MBILI intercrop whereby two legume rows were alternated with two cereal rows was adopted. MBILI is a Swahili word meaning two and an acronym for Managing Beneficial Interactions in Legume Intercrop. A previous study conducted in Mbeere South sub-county to evaluate the potential of MBILI intercrop on crop yields revealed that when combined with adjusted nutrient inputs, the technology resulted in superior and robust improvements in crop yields and economic benefits relative to the conventional intercropping system (Mucheru-Muna *et al.,* 2010). The system allows more light penetration for under-storey legume component without changing the plant densities and has proven successful in western Kenya (Woomer *et al.,* 2004; Woomer, 2007). A study by Woomer *et al.* (2004) found that superior crop yields in the MBILI system were

related to more than 50% higher light penetration, additional advantages in root distribution and reduced below ground competition.

There is however, paucity of information on the effectiveness of MBILI intercrop on reducing runoff, sediment yield and nutrient concentration in sediment, improving maize yield and economic benefits in comparison to other soil and water conservation technologies in the study area.

2. 8 Cost benefit analysis

The integration of economic benefits in soil and water conservation practices is a rather unexploited field of research (Basso *et al.,* 2011). The limitations of soil and water conservation technologies in terms of costs, adaptability and effectiveness determine the level of adoption by farmers (Babalola, 2007). True value of relative benefits and costs of various agricultural land and water management options can be measured and accurately assessed through combined and balanced consideration of operational costs and return from produce (Drechsel *et al.,* 2004).

Viable recommendations for improving soil fertility management practices which are both economically suitable to the farmer and appropriate for resources available can only be made if current sources, whereabouts and uses of organic materials and nutrients within smallholder farming system have been identified (Nandwa and Bekunda, 1998). The main objective of sustainable agriculture is to obtain crops which are highly productive, healthy and high quality by means of preserving sustainability of soil and environment (Barut *et al.*, 2011).

The few studies on soil and water conservation previously conducted in the study area have often ignored the economic dimension of the technologies. There was hence the need to carry out a cost benefit analysis on the selected SWC technologies in order to establish technologies that will be most appropriate to be recommended for adoption by the farmers.

2.9 Study gaps

Various Integrated Soil Fertility Management (ISFM) options have been developed and adopted by farmers in the study area. Many studies have focused on nutrient replenishment through use of organic and inorganic inputs, *ex-situ* rain water harvesting, investment into supplementary irrigation and agricultural extensification. Soil erosion has been addressed from a perspective of environmental degradation, principally focussing on downstream pollution rather than plot scale. The few runoff and erosion studies in the area have given inadequate attention to the potential of tied ridging, mulching, minimum tillage and cereal- legume intercrop as worthy options for the region. Furthermore, integrating economic analysis provides a better understanding of evaluating soil conservation technologies from the farmers' point of view and therefore, impacting viability and the widespread adoption of these technologies. This study was therefore set up with an objective of investigating the effects of selected soil and water conservation technologies on runoff, sediment, soil nutrient loss, maize yields and their economic implications. It was expected to give solution to the dwindling maize yield production in Meru south and Mbeere south sub-counties.

CHAPTER 3

METHODOLOGY

3.1 Study area

The study was conducted in Meru South sub-county in Tharaka-Nithi County and Mbeere South sub-county in Embu County (Figure 3.1). The two sites have contrasting soil fertility and highly variable rainfall patterns (Shisanya *et al.,* 2009). In Meru South, experimental site was Kigogo primary school, Magumoni Division (00^{o} 23’ S, 37^{o} 38’E) while in Mbeere, the trial was set up at Machang’a Secondary school (00°47’26.8’’S; 37°39’45.3’’E). The schools being public places are accessible to many farmers who wish to learn about the technologies.

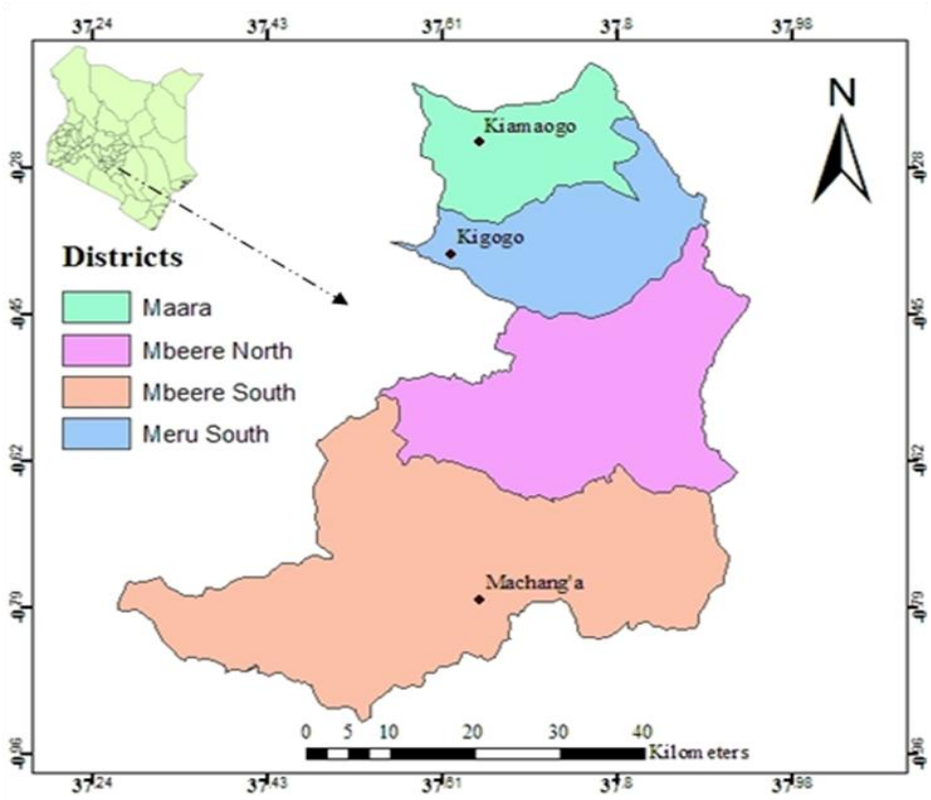

Figure 3.1: Map of the study area and the two research sites where the field trials were installed (Source: Author)

Kigogo is situated in the Upper Midland Agro-ecological Zone (UM2-UM3) (Jaetzold *et al.,* 2007) on the eastern slopes of Mount Kenya at an altitude of about 1500 m above sea level (a.s.l.), annual mean temperature of 20^{o}C and total annual rainfall ranging from 1200 to 1400 mm. Rainfall is bimodal with long rains (LR) falling from March through June and short rains (SR) beginning from October to December. The soils are predominantly humic Nitisols, a typical deep and weathered soil with moderate to high inherent fertility (Jaetzold *et al.,* 2007). It is a predominantly maize growing zone with small holdings ranging from 0.1 to 2 ha with an average of 1.2 ha per household (Shisanya *et al.,* 2009). Population pressure in the high potential area has forced people to migrate to marginal areas like Mbeere South sub-county (Mucheru-Muna *et al.,* 2010). Agriculture is characterized by smallholder mixed farming activities, which include cash crops (coffee, tea and horticultural crops), food crops (maize, beans, bananas, and Irish potatoes) trees and livestock (dairy and beef cattle, goats, sheep poultry and pigs) (Shisanya *et al.,* 2009).

Machang'a is located in the Lower Midland (LM) Agro-ecological Zones 3, 4 and 5 and Inner Lowland 5 (IL) on the eastern slopes of Mount Kenya at an altitude of between 700 to 1200 m a.s.l (Jaetzold *et al.,* 2007). Mean annual temperature ranges from 20.7 to 22.5^{o}C with high evapotranspiration rates. Average annual rainfall is between 700 to 900 mm and farmers primarily rely on small-scale rainfed farming system, which is mostly non-mechanized and involves little use of external inputs. The rainfall is bimodal with long rains falling (LR) from mid March to June and short rains (SR) from late October to December, hence two cropping seasons per year. The soil of the experimental site is predominantly plinthic Cambisols according to classification by FAO (1988). These are brown soils with cambic B horizons as a

major feature; layers change characteristically due to their relatively "young" age. Cambisols are less weathered than most of the other soils of the humid tropics. Cropping systems in Mbeere are predominantly maize-based, with beans as the preferred legume for intercrop, although cowpea, groundnut and green grams are gaining importance. Rapid population growth has resulted to expansion of fragile area and low-potential lands being taken under cultivation, reduced fallow periods and systematic degradation (Mucheru-Muna *et al.,* 2010).

3.2 Soil characteristics

Selected soil characteristics at 15cm depth for the study region are shown on Table 3.1. Soils of Machang'a are deficient in major nutrients necessary for crop growth and development; N (0.01%), C (0.2%), P (25.5 ppm) and K (0.4%). Soil pH (H_2O) is about 5.7, a description of slightly acidic soils which have a great impact on nutrient uptake by plants and on biological activities. The texture of soils in Machang'a is sandy clay loam while that for Kigogo is clay. Generally, soils at Kigogo site are more fertile than those for Machang'a (Table 3.1) hence favouring high crop productivity.

Table 3.1: Soil chemical properties at Kigogo and Machang'a experimental sites

Parameter	**Kigogo**	**Machang'a**
pH	4.9	5.7
Exchangeable Ca (cmol/kg)	4.7	2.1
Exchangeable Mg (cmol/kg)	1.7	0.8
Exchangeable K (cmol/kg)	0.5	0.4
Organic C (g/kg)	1.5	0.4
Total N (g/kg)	0.2	0.1
Total P (g/kg)	0.1	0.01

3.3 Experimental design

The experiments adopted a randomized complete block design (RCBD) with four treatments replicated thrice giving a total of twelve plots per site (Appendix 1, Appendix 2). The experiment was implemented in the runoff plots. Trials were run for two consecutive cropping seasons, Long rains 2011 and Short rains 2011. Treatments in Kigogo were minimum tillage, MBILI intercrop and mulching evaluated against conventional tillage. In Machang'a, the treatments were the same as Kigogo except minimum tillage was replaced with tied ridging.

a) b)

Plate 3.1: Runoff plot with dry maize stover sample for mulching (a) and MBILI intercrop treatment (b)

Slope for the experimental units in Kigogo was between 9.5 to 12% and between 4 and 5 % in Machang'a. The test crop was maize (*Zea mays,* L.). Maize variety DH04 (a short-duration seed with maturity between 85 to 100 days recommended for drylands) was used in Machang'a while H513 (with longer growing period, 120-150 days recommended for high-potential areas) was used in Kigogo. The legumes used were common beans (*Phaseolus vulgaris*) in Kigogo and cowpea (*Vigna unguiculata*) in Machang'a. Tillage was done by hand hoeing to a depth of about 0.15 m in all plots

except the plots where minimum inversion of land was maintained. Two maize seeds were planted per hill with a spacing of 0.9 m between maize rows and 0.6 m within rows in Machang'a and 0.75 m between maize rows and 0.50 m within the rows in Kigogo. Nitrogen fertilizer was spot applied as Nitrogen, Phosphorus, and Potassium (NPK) 23:23:0 at planting at a rate of 60 kg ha^{-1}, and phosphorous as Triple Super Phosphate (TSP) to give a total of 90 kg P ha^{-1}, the recommended rates (FURP, 1987).

Legumes were planted two weeks after maize planting. The MBILI treatment was a maize-legume intercrop whereby two rows of maize are alternated with two rows of legumes, following a recommendation from a previous study in the area. Inter-row space between cowpeas was 0.4 m while between maize and cowpeas rows was 0.25 m. Inter-row space between beans was 0.4 m and between maize and beans rows was 0.175 m.

Weeding was done whenever necessary to ensure clean fields throughout the seasons following conventional best practices. Dry maize Stover was used for mulching and applied at a rate of 5 tonnes ha^{-1}. For tied ridging technology, ridges were constructed at the beginning of first cropping season and any damages repaired accordingly during the following season. Distance between ties alternated at 0.5 m, 1.5 m and 1.0 m while the height of the ridges was 0.15 m.

3.4 Data collection

3.4.1 Runoff collection

Runoff plots measuring 3 m wide by 12 m long (along the slope) were bounded on three sides with a galvanized metal sheet buried at least 25 cm in the ground and 25

cm left above the ground surface (Plate 3.2). Plots on same blocks were separated by a distance of 1 m. At the bottom end of the plot, a gutter designed to slope towards end of the drainage tube was installed to collect and convey runoff into a 200 litres storage tank via a 7.6 cm diameter drain pipe. Given the limited storage capacity, the tank was modified so that in cases of high rainfall, excess runoff that would lead to storage tank overflow was accounted for. The tanks were perforated using 8.4328 mm drill bits at a constant height from the bottom so that all the holes were on same plane. One of the holes was fitted with hose pipe that drained to a 20 litres container (Plate 3.2). Volume of runoff water was determined in each drum and later converted to depth (mm) of water. The tanks were fitted with tight lids to minimize external effects. Runoff tanks and iron sheets were regularly checked and any damage repaired accordingly.

(a) (b)

Plate 3.2: Runoff plot and collection tank (a) and an automatic rain gauge (b)

Total runoff in storage tank was measured before thoroughly mixing and sampling for sediment concentration determination in the laboratory. In case of excess runoff,

overflow volume was determined and sampled separately for laboratory sediment amount determinations.

Sediment samples were oven-dried at 105^{o}C until constant weight. Sediment yield data from storage tank overflow just like in accounting for overflow were rescaled by multiplying with the number of holes per tank and summed up with main storage tank sediment to give total sediment yield per rainfall. Runoff coefficient (Rc) was expressed in percentage (%) as per Equation 1 (Appendix 3).

3.4.2 Sediment extraction

At the laboratory, runoff samples were placed in aluminium metal bowls. After thoroughly shaking and mixing, the suspension was poured into bowls and oven dried at a temperature of 105^{o}C. All information on labels, volume of suspension in the runoff bottles, can weight, weight of can+soil (after oven drying) was carefully recorded. Sediment yield was calculated using total volume of suspension in the major drum. Sediment weight (g) was then divided by the total runoff volume from each plot to obtain sediment concentration (g/l) as indicated by Equation 2 (Appendix 3). Sediment yield gave an estimate of total soil loss from each runoff plot.

3.4.3 Analysis for nutrient concentration

Sediments were analyzed to determine concentration of N, P, K and organic carbon using standard methods described by Ryan *et al.* (2001). Nitrogen was analyzed by Kjeldahl method, total phosphorus by Olsen method, Potassium by flame photometer and Organic carbon by Walkley and Black method.

3.4.3.1 Total Nitrogen

Nitrogen was obtained through Kjeldahl method (Ryan *et al.,* 2001). The procedure involved digestion and distillation. Nitrate N (NO_{3-N}) fraction in the soil was reduced and subsequently distilled. Finely ground soil sample (15 mm) was uniformly mixed and spread in a thin layer on a sheet of paper. A representative sample containing about 3 g of N was taken by withdrawing 10 small portions from the sample. The sample was weighed into 0.01 g, placed into a 250 ml calibrated digestion tube and10 ml distilled water added to each tube and thoroughly swirled to wet the soil and let to stand for 30 minutes.

A blank digest was prepared and 0.1 g EDTA standard digest accurately weighed to 0.1 gm with each batch. About 10 ml potassium permanganate solution was added and swirled well, left to stand for 30 seconds, and the digestion tube held at 45^{o} angle while 20 ml 50% sulfuric acid was slowly and carefully added so that it washed down material adhering to the tube neck. It was left to stand for 15 minutes then swirled. A few pumice boiling granules was added to the blank, EDTA, and sample digest tubes. 2.5 g reduced iron was added through a long-stem funnel and a 5cm (internal diameter) glass funnel (with stem removed) immediately placed in tube neck, and swirled. Excessive frothing at this stage was halted by pouring 5 ml distilled water through the 5 cm glass funnel. The tubes were allowed to stand overnight.

The samples were pre-digested by placing them on the cold block and heating at 100°C for an hour. Samples were swirled at 45 minutes after removing from block-digester and left to cool. About 5 g catalyst mixture was added through a long stem funnel and 25 ml concentrated sulfuric acid added to each tube, and swirled. Tubes

were placed back on the block-digester and pre-heated to 100°C, and block temperature setting increased to 240°C, and funnels removed. Funnels were systematically arranged so as to be placed afterwards into the same digestion tube. Boiling off the water was continued for 1 hour after reaching 240°C. After water had been removed, funnels were replaced and the temperature raised to 380°C. The timer was set on the block-digester, and digested for 4 hours at same temperature. The tubes were removed from the block-digester, about 50 ml DI water added, and mixed using a vortex mixture. Solid precipitate remains in the tubes, were broken up with a glass rod. After cooling, DI water was added to the 250 ml mark.

For the distillation procedure, the digestion tube was shaken to mix thoroughly its contents prior to distillation and 50 ml immediately pipetted into a 250 ml distillation flask. Acid digests were distilled with excess NaOH. One ml saturated boric acid solution and 1 ml distilled water were dispensed into a 100-ml Pyrex evaporating dish and placed underneath the condenser tip with the tip touching the solution surface. Appropriate volume of 10 N NaOH was then carefully dispensed down the side of the flask, while holding the distillation flask containing the digest at a 50° angle. The flask was immediately attached to the distillation unit with a clamp, distillation started, and continued for 3 minutes. The dish was lowered and distillate let to drain freely into the dish.

After 4 minutes, when about 35 ml distillate was collected, steam supply was turned off and tip of the condenser washed into the evaporating dish with a small amount of DI water. The distillate was titrated to pH 5.0 with standardized 0.01 N H_2SO_4 using the Auto-Titrator. After titration, the Teflon-coated magnetic stirring bar, the burette

tip and the combined electrode were washed into the dish. Distillations between different samples were steamed out. Distillation flasks containing the digest sample and NaOH were disconnected, a 100-ml empty distillation flask attached to distillation unit, and a 100 ml empty beaker placed underneath the condenser tip, cooling water supply turned off and steamed out for 90 seconds. Each distillation contained at least two standards and two blanks. Percentage N was then calculated using Equation 4 and Equation 5 (Appendix 3).

3.4.3.2 Total Phosphorus

The method followed Olsen and Sommers (1982). Determination of Total P involved digestion of soil sample with a strong acid and the dissolution of all insoluble inorganic minerals and organic P forms.. In the digestion chamber, 2 g air-dry soil (0.15 mm) was weighed into a 250 ml calibrated digestion tube, 30 ml 60% perchloric acid and a few pumice-boiling granules were added and mixed well. Tubes rack was placed in the block-digester and gently heated to about 100°C. Block-digester temperature was slowly increased to 180°C and the samples digested until dense white fumes of acid appeared. An extra perchloric acid was used to wash down the sides of the digestion tube as necessary. Heating continued at the boiling temperature for 15 minutes longer. At this stage the insoluble material became like white sand. The total digestion with perchloric acid required about 40 minutes.

The mixture was cooled and distilled water added to obtain a volume of 250 ml, contents mixed and filtered through Whatman No. 1 filter paper. About 5 ml of the sample digest was pipetted into a 50 ml volumetric flask, 10 ml ammonium-vanadomolybdate reagent added, and diluted to volume with DI water. A standard

curve was then prepared by pipetting 5 ml (2 – 10 ppm) and preceded as for the samples. A blank was made with 10 ml ammonium-vanadomolybdate reagent, and preceded as for the samples. Absorbance of blank, standards, and samples were read after 10 minutes. A calibration curve was prepared for standards, plotting absorbance against the respective P concentrations. P concentration was read in the unknown samples from the calibration curve and calculated from Equation 6 (Appendix 3).

3. 4.3.3 Extractable Potassium

The method used was flame photometer (Ryan *et al*., 2001) whereby a neutral salt solution replaced cations present on the soil exchange complex. Air-dry 5 g soil (< 2 mm) was weighed into a 50 ml centrifuge tube, 33 ml ammonium acetate solution added, and shaken for 5 minutes on a shaker. The tubes were fitted with a clean rubber stopper and centrifuged until the supernatant liquid was clear and the extract collected in a 100 ml volumetric flask through a filter paper to exclude any soil particles. The process was repeated two more times and extract collected each time. The combined ammonium acetate extracts was diluted to 100 ml with 1 N ammonium acetate solution. A series of suitable potassium standards were run and a calibration curve drawn. The samples (soil extracts) were measured and emission readings taken on a Flame Photometer at 767 nm wavelength as per Equation 7 (Appendix 3).

3. 4.3.4 Organic carbon

Organic carbon content was determined using modified Walkley and Black wet oxidation procedure described by Ryan *et al.* (2001). Half a gram of air dried soil passed through 0.5 mm sieve were weighed into 500 ml wide mouth conical flasks

and 10 ml of 1 N potassium dichromate added into the flasks using a burette. In a fume cupboard, 15 ml concentrated sulphuric acid was rapidly added directing the stream into the suspension. The flasks were swirled gently at first until all soil and reagents mixed and then more vigorously for about one minute. They were then allowed to stand for exactly 30 minutes. About 150 ml of distilled water was added and allowed to cool, after which 10 ml 85% orthophosphoric acid and finally 10 drops diphenylamine indicator were added. The solutions were titrated with 0.5 N ammonium ferrous sulphate. Organic carbon was then calculated as per the equation 8 and Equation 9 (Appendix 3).

3.4.4 Rainfall and ETo

Daily rainfall measurements were taken using an automatic rain gauge with a 0.2 mm resolution (Plate 3.2). The rain gauge was mounted on a mast 20 m away from runoff plots in an open area so that there was no obstruction of rain pattern. It was ensured that it was on a level position, clear of overhead structures and the stand on which it was mounted on was free from vibration. Data logger in the rain gauge was launched, read out using HOBO ware Pro Version 3.2.2 and data exported to excel worksheets for further processing. Data recorded were tipping count, time of tip and air temperature at an interval of 15 minutes throughout the study period.

Status of the rain gauge was regularly checked to ensure proper functioning. Exhausted batteries were replaced to ensure constant and accurate record of rainfall and air temperature data throughout the experimental period. Reference

evapotranspiration (ETo) for was determined using FAO Penman-Monteith equation given by Equation 3 (Allen *et al.,* 1998) (Appendix 3).

3.4.5 Crop harvesting

Maize grain and stover were harvested at maturity from a net area of $21m^2$ and $18m^2$ in Kigogo and Machang'a, respectively, after leaving out guard rows and the first and last maize plants in each row to minimize edge effect. Cobs were air dried to 12.5% moisture content, separated from stover and fresh weight determined. Maize grain was separated from cobs by hand shelling and weighed to give net grain weight. Maize stover was cut at ground level and total above ground fresh weight determined. Dry stover was obtained by air drying at 12.5% moisture content and weight determined. Stover and grain were measured in Mg ha^{-1} and valued at prevailing market price at harvest. Beans and cowpea in respective sites were harvested a month before maize harvesting.

3.4.6 Economic analysis

Table 3.2: Parameters used in the economic analysis of the selected soil and water conservation technologies

Parameter	Actual values
Price of maize seed (USD kg^{-1})	2.5
Price of TSP fertilizer (USD $(kg\ p)^{-1}$)	1.25
Price of NPK fertilizer (USD kg^{-1})	0.93
Price of CAN fertilizer (USD kg^{-1})	0.75
Labour cost (USD day^{-1})	3.13
Price of bean grains (USD kg^{-1})	0.88
Price of cowpea grains (USD kg^{-1})	0.63
Price of maize grains (USD kg^{-1})	0.5
Price of maize stover (USD t^{-1})	56.25

Exchange rate Ksh 80=1 USD (official rate in February, 2012 at end the trial period).

Cost benefit analysis in the study considered the cost of farm inputs; seeds, fertilizer, pesticide and herbicide purchased, operations costs and returns from sale of produce. Time taken to perform every activity was carefully recorded (Appendix 4) and labour valued at local wage of KShs. 250 (USD 3.13) per day (eight hours) (Table 3.2).

Returns were based on prevailing market price for maize grain and legume grain. Maize stover is commonly used as cattle feed in the area (with a market value of USD 56.25 $t^{-1}$and thus accounted for as an additional benefit. Average costs were used for operations unaffected by technologies such as land acquisition and fertilization. Where operations were affected by different technologies, for instance sowing, stover cutting and application in mulching, making and repair of ties and ridges, harvesting of legumes in intercrop plots, costing was worked out per technology.

Cost of farm inputs (NPK, TSP, CAN, seeds and pesticides) were based on retail prices as per agro-input stockists around the study sites. Other operations with no market price such as making of ties and ridges were valued in terms of labour involved in their making. Maize yields on air dry basis (12.5% moisture content) were used for the economic analysis. A benefit cost ratio (BCR) of 2 was used so that for each US$ invested, a farmer gains US$ 2 in return. This followed a recommendation by Srivastava *et al.* (2004).

The following assumptions were made during cost-benefit analysis; (i) that maize stover is locally available in farmers' fields, (ii) differences between costs of production for a single tilled plot are due to adoption of a tillage strategy, cost of other agronomic practices (e.g., fertilization, crop protection, etc.) and use of materials

(e.g., fertilizers) were same for all treatments, (iii) difference between cost of post-emergence herbicide application in minimum tillage and that for weeding in control, mulching and MBILI intercrop was not statistically significant, (iv) cost due to adoption of variable tillage arose from cost of tillage practices usually performed by the farmer i.e., fixed and variable costs for inputs and equipment. Other input and output prices, derived from farm gate prices in the area, and values used in economic analysis are presented in Table 3.2. Economic analysis was performed on cumulated costs and benefits over 2 seasons in Kigogo and one season in Machang'a (short rains 2011) since there were no grain yields in Machang'a during the long rains 2011 season.

3.5 Statistical analysis

Runoff data across different technologies, sediment, nutrient concentration, maize yield data, net benefits and benefit cost ratio for the experimental period were subjected to analysis of variance (ANOVA) using SAS 9.1.3 (SAS Institute Inc., 2003), to test levels of significance due to treatments. Significantly different means were separated using least significance difference test (L.S.D.) at $P=0.05$.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Weather

4.1.1 Evapotranspiration

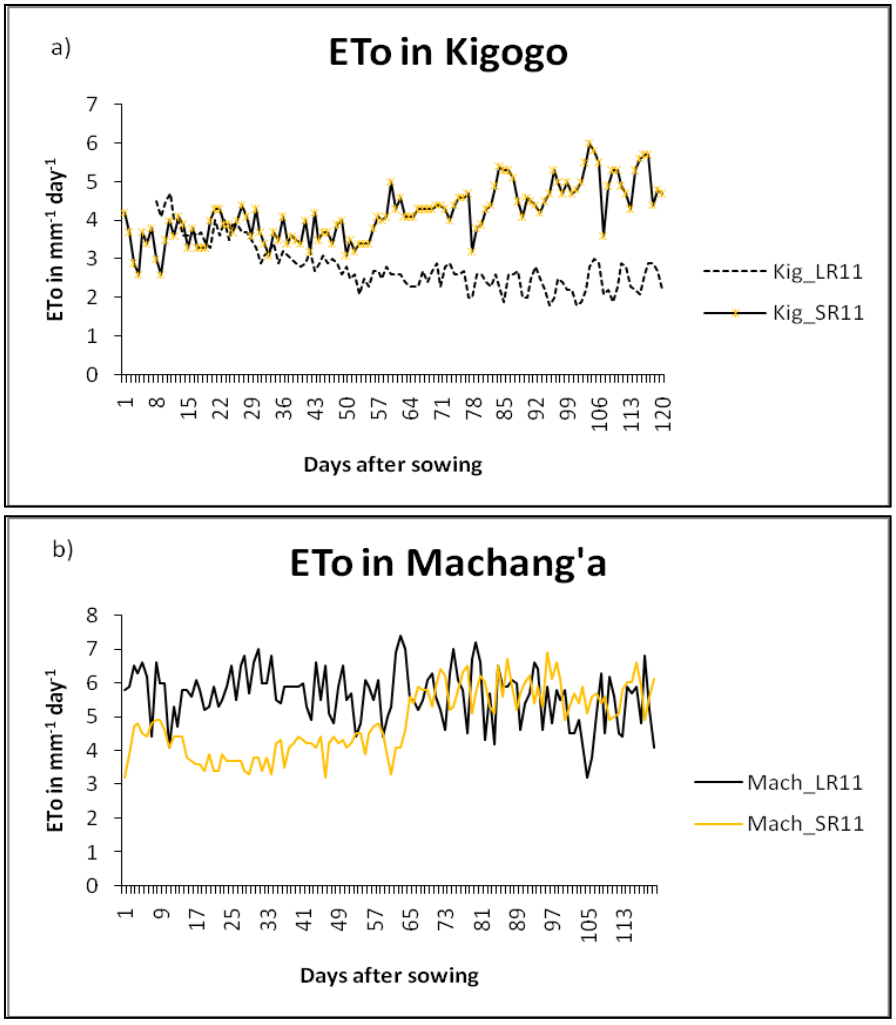

Figure 4.1: Daily evapotratranspiration rates at Kigogo (a) and Machang'a (b) during long rains 2011 (LR11) and short rains 2011 (SR11) seasons

The ETo in Kigogo ranged between 1.8 and 4.7 during long rains 2011 season and between 2.6 and 6 during short rains 2011 season (Fig 4.1). In Machang'a, ETo was between 4.1 and 7.4 during long rains 2011 and 3.2 and 6.9 during short rains 2011.

High evapotranspiration rates affect crop productivity. Welch *et al.* (2010) has indicated that extreme daily temperatures above a certain threshold may have

damaging consequences on crop yields. Evapotranspiration in the study area was relatively high particularly in the low potential area, Machang'a, posing great challenge to crop productivity given the erratic rainfall received.

4.1.2 Rainfall

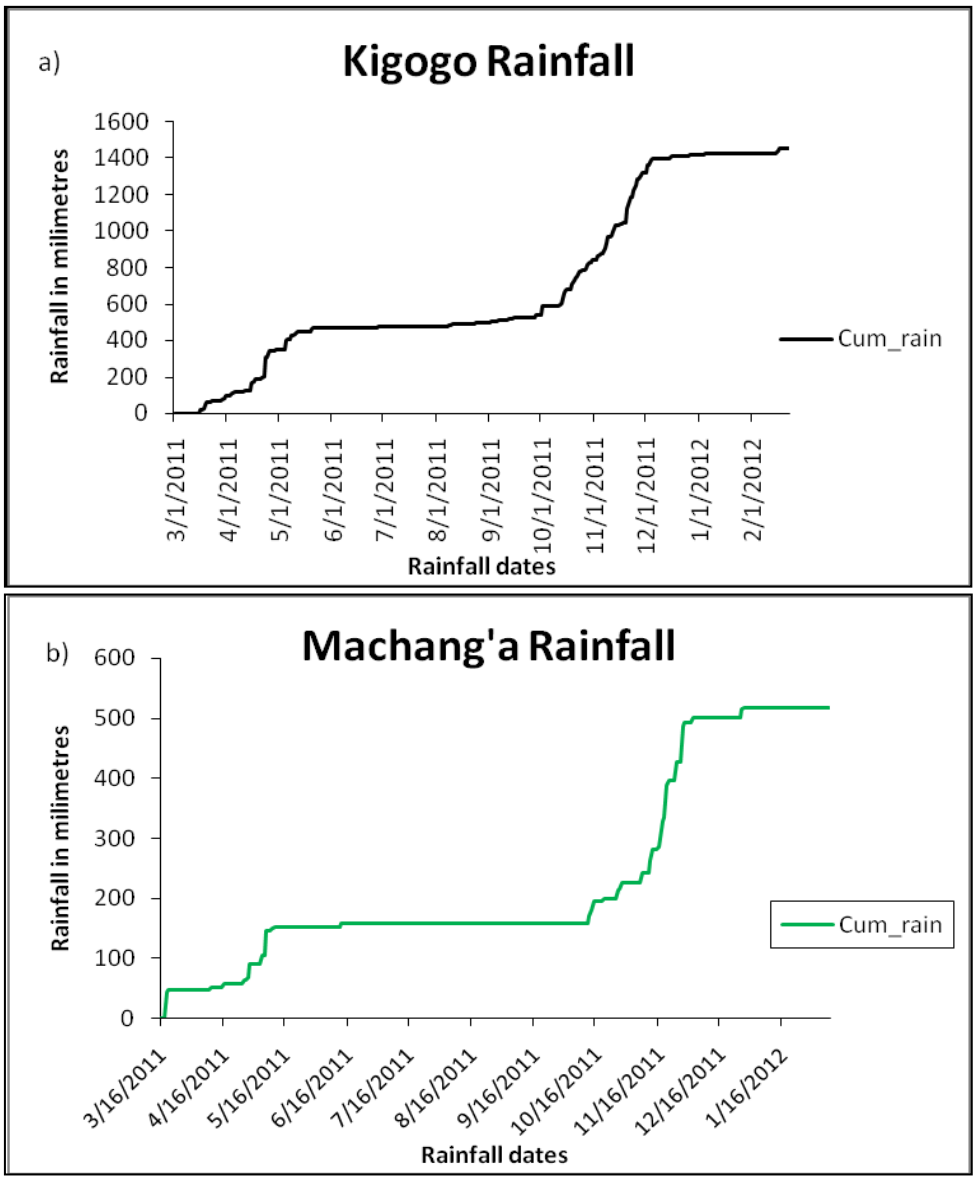

Figure 4.2: Cumulative rainfall at Kigogo a) and Machang'a b) experimental sites during long rains 2011 and short rains 2011 seasons

Total rainfall and distribution showed large differences between seasons in both sites (Figure 4.2). Cumulative rainfall received at Kigogo during the experimental period was 1451 mm whereby; 476 mm was received during long rains 2011, 910 mm during short rains 2011 and 65 mm during the off season. The rainfall was distributed among 36 and 71 rainfall events during long rains 2011 and short rains 2011 seasons, respectively.

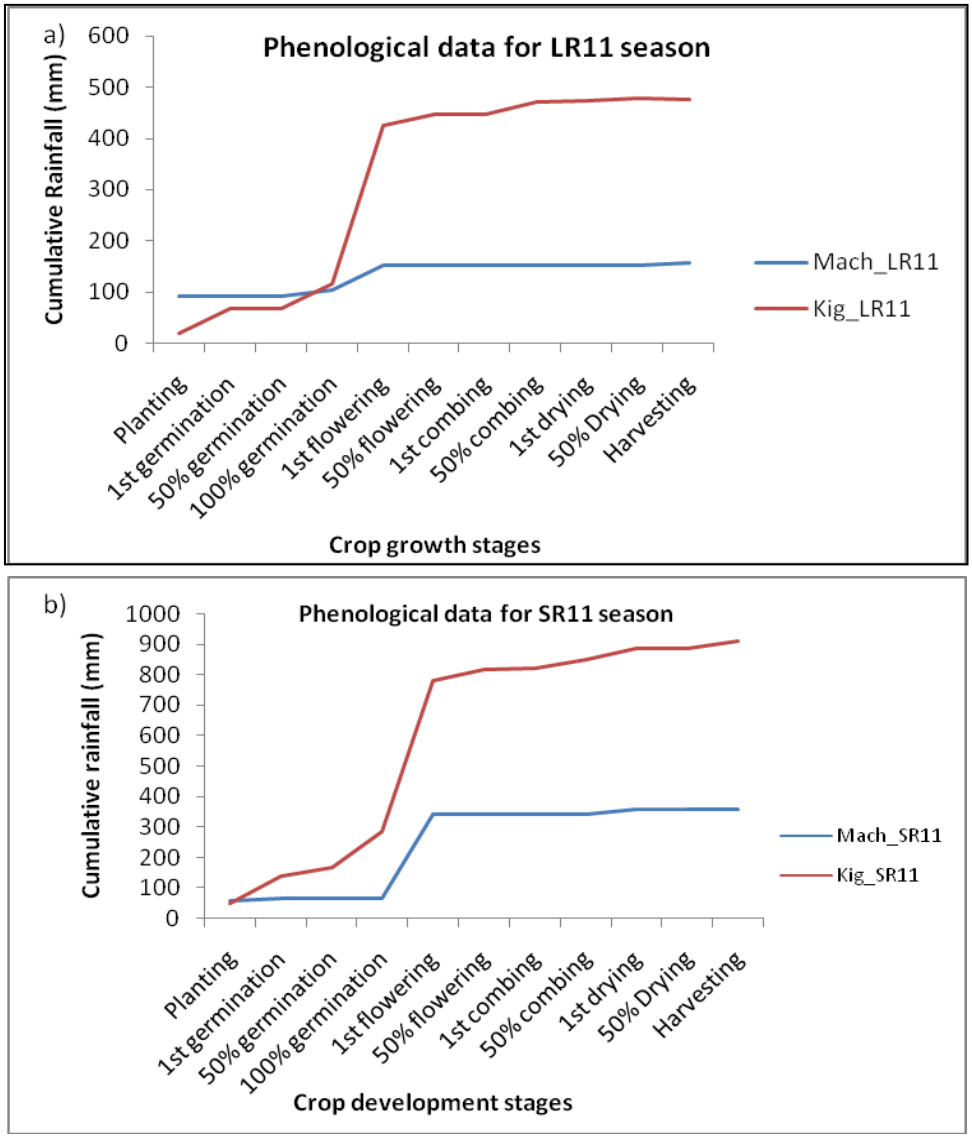

Figure 4.3: Crop growth stages and rainfall distribution during the experimental period

In Machang'a, cumulative rainfall amounted to 516 mm with 157 mm for long rains 2011 and 359mm for short rains 2011 distributed among 11 and 26 rainfall events, respectively. There were variational intra-seasonal dry-spells at different crop growth stages in both sites. In this study, dry spells were considered to be periods ranging between 10-28 days without rainfall while meteorological drought was the absence of rainfall for a period above four weeks during the growing season. This followed definitions given by Rockström *et al.* (2002). According to Barron *et al.* (2003), short, 2-4 week long dry spells are almost seasonal occurrences in semi-arid tropical farming systems in East Africa. Long rains 2011 season in Kigogo had three dry spells of 18, 15 and 20 days occurring immediately after first flowering, continued during flowering stage and recurring after 50% combing through to harvest. Short rains 2011 season in Kigogo had two major dry spells of 10 and 24 days occurring at late stages of the maize cycle; after combing and at drying.

In Machang'a, long rains 2011 season encountered a severe meteorological drought which coincided with sensitive crop flowering stage (figure 4.3). It occurred immediately after full germination and lasted for 32 days consequently leading to total crop failure. Rockström (2003) states that if a dry spell hits during water stress sensitive flowering phase, it may result in complete crop failure. During short rains 2011 season, a major dry spell of 23 days was experienced immediately after first flowering through to 50% combing. A meteorological drought of 38 days later occurred during drying period but this was not detrimental as the crop had almost reached maturity. Total rainfall in all seasons was much lower than average (over 31 years from 1972 to 2006) mean seasonal rainfall of 237 mm and 363 mm expected in the long rain and short rains seasons, respectively. Seasonal variations in rainfall

reflect what is typical for given hydro-climatological conditions. Even though short rains 2011 received higher rainfall than long rains 2011 in both sites, substantial amount of water was lost through runoff (Table 4.3).

4.1.3 Rainfall variability

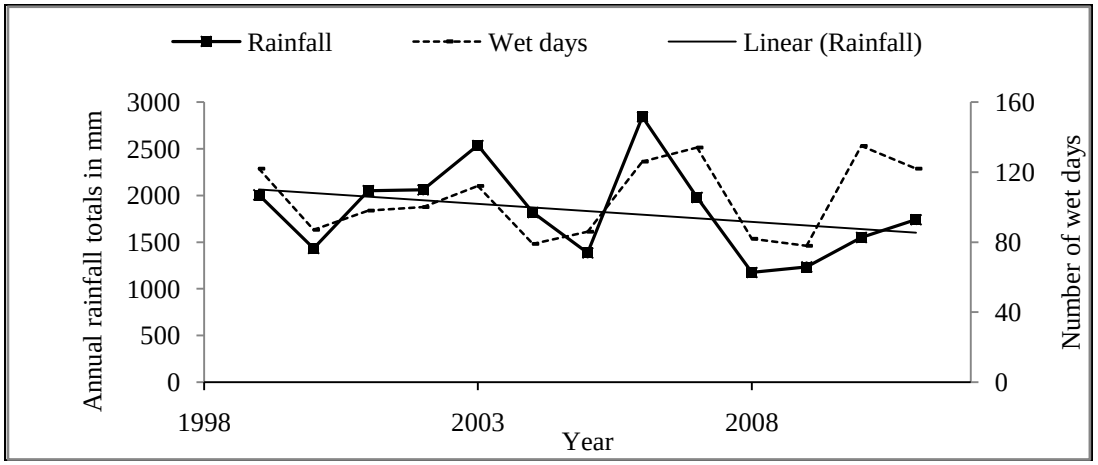

Figure 4.4: Rainfall variability at Kigogo

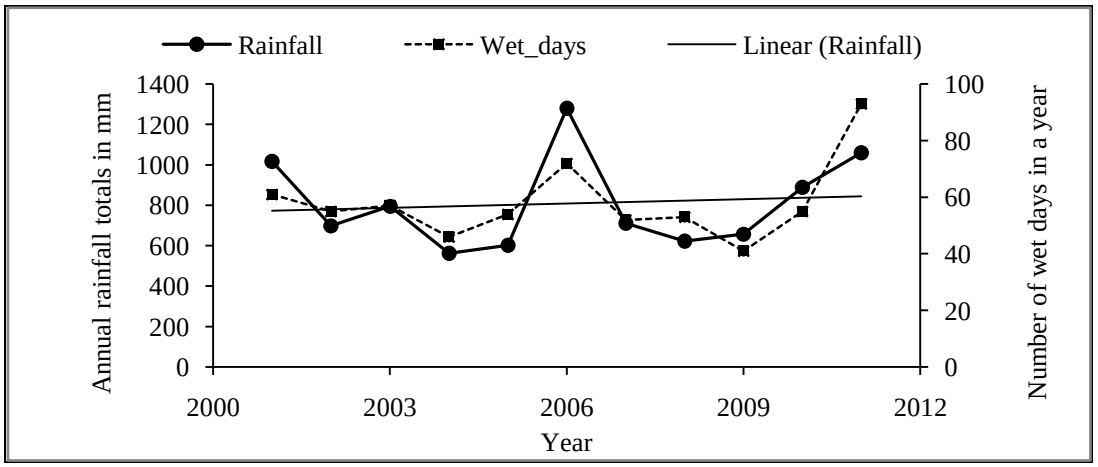

Figure 4.5: Rainfall variability at Machang'a

Fluctuations in rainfall pattern in the study area were assessed from long term rainfall data obtained from Kenya Meteorological Department, Embu branch. Rainfall variability is relatively high in the region (Figure 4.4 and Figure 4.5).

Total annual rainfall in Kigogo ranged between 1176-2843 mm (Figure 4.4). In general, the rains fluctuate in amount and distribution. Relatively wet years with rainfall above 2000 mm; were 1999, 2001, 2002, 2003 and 2006. Rainfall since 2007 has remained below average rainfall requirement for crop production in the area. In Machang'a, total annual rainfall from 2001 to 2011 ranges between 562-1279 mm (Figure 4.4). Wet years with rainfall above 700 mm; were 2001, 2003, 2006, 2007 and 2010. Rainfall variability is less pronounced in the sub-humid region (Kigogo) as compared to the semi arid region of Machang'a. According to Chikozho (2010) impacts of rainfall variability are more magnified in marginal rainfed agricultural areas characterized by low and erratic precipitation leading to low and unpredictable levels of crop production. This is the case with Machang'a site.

4.2 Runoff

Table 4.1: Runoff coefficients in Kigogo and Machang'a during the experimental period

Treatment	**Runoff coefficient in %**			
	Kigogo		**Machang'a**	
	Long rains 2011	**Short rains 2011**	**long rains 2011**	**Short rains 2011**
CT	2.7^{ba}	2.3^{ba}	14.9^{a}	10.5^{a}
MC	2.2^{b}	1.7^{b}	7.6^{b}	7.4^{b}
MI	2.8^{ba}	1.7^{b}	14.9^{a}	9.9^{a}
MT	3.4^{a}	2.7^{a}	-	-
TR	-	-	7.2^{b}	5.1^{c}
p	0.09	0.04	0.001	0.001
LSD	0.9	0.8	4.5	1.9

(CT= Conventional tillage; MC= Mulching; MI= MBILI Intercrop; MT= Minimum tillage; TR= Tied ridging). Same superscript letters in same column denote no significant difference between treatments

In Kigogo runoff was not influenced by SWC treatments during long rains 2011 season. During short rains 2011 season, mulching and MBILI intercrop reduced runoff by 26% (p=0.04) while minimum tillage increased runoff by 17% compared with control. In Machang'a, runoff was reduced by 49 and 52% during long rains 2011 season and by 30 and 51% during short rains 2011 season under mulching and tied ridging respectively, compared with control. There was no difference between runoff from control and MBILI intercrop plots.

Runoff coefficient was generally higher in Machang'a than in Kigogo (Table 4.3). This could be attributed in part to the fact that runoff is limited on soils with a high infiltration and water retention capacity such as the nitisols of Kigogo in comparison to the cambisols of Machang'a which are more susceptible to erosion.

Reduced runoff under SWC technologies means an improvement in soil water status in the root zone and a reduction in soil loss, which in turn leads to reduced land degradation and reduced crop water stress (Rockstrom *et al.,* 2002; Stroosnijder, 2009; Temesgen *et al.,* 2009). Runoff mitigation can be explained by infiltrability improvement of soil profile and limitation of surface structural degradation (Armand *et al.,* 2009).

Effectiveness of mulching might be attributed to the improved infiltration capacity and soil transmission characteristics (Cairns *et al.,* 2012). Lal (2007) indicated that beneficial effects of mulching arise from protection of soil surface against raindrop impact, decrease in flow velocity by imparting roughness on soil surface and improved infiltration capacity. Consequently, transmission of water through soil

profile is improved, surface crusting, and runoff reduced and soil moisture storage in root zone enhanced. According to Uwah and Iwo (2011), mulch provides a better soil environment, moderates soil temperature and increases soil porosity during intensive rain thus controlling runoff and erosion. These effects have been widely reported (McHugh *et al.*, 2007; Araya and stroosnijder, 2010; Nuti *et al.,* 2011; Cairns *et al.,* 2012). Roose and Barthès (2006) reported drastic reductions in runoff and erosion from a mulched pineapple field on a 20% slope. Wilson *et al.* (2004) observed higher amounts of runoff in absence of mulch in an experiment set out to test different mulch managements and their consequences on runoff generation.

Effectiveness and efficacy of mulch on runoff was also demonstrated by Kwaad *et al.* (1998). Quantity of mulch required for maintenance of favourable infiltration capacity and structural stability however, depends on the rate of residue decomposition, climate, soil properties, relief and rainfall characteristics (FAO, 2008). Babalola *et al.* (2007) suggests that about 70% of soil surface must be covered by mulch for effectiveness.

Effectiveness of tied ridging in reducing runoff in might be attributed to water harvesting effect of bunds under tied ridging technology in increasing water infiltration, improving soil physical properties, thereby decreasing runoff and erosion. These findings are consistent with those of Araya and Stroosnijder (2010) who indicated that runoff in tied ridges in a wheat field were far lower than runoff in flat land. Similar studies in semi-arid Ethiopia by McHugh *et al.* (2007) have indicated that tied ridging reduced runoff by more than 75% compared with control practice. Patil and Sheelavantar (2004) reported reduced runoff with compartmental bunding

and ridges and furrows over flat land in a study set out to explore effectiveness of these technologies. Nuti *et al.* (2009) explained that reduced runoff under ridges led to water storage in profile available to the crop during various stages of crop growth and especially in moisture stress situations resulting in better crop growth with higher crop yields.

4.3 Sediment yield, soil nutrient and organic matter loss

4.3.1 Sediment Yield

Table 4.2: Sediment yield under different soil and water conservation treatments at Kigogo and Machang'a during the experimental period

Sediment in Kg ha^{-1} Season^{-1}				
Treatment	**Kigogo**		**Machang'a**	
	Long rains 2011	**Short rains 2011**	**Long rains 2011**	**Short rains 2011**
CT	452^{a}	1020^{a}	959^{a}	500^{a}
MC	267^{b}	292^{b}	209^{b}	234^{b}
MI	397^{a}	397^{b}	477^{b}	354^{ab}
MT	482^{a}	323^{b}	-	-
TR	-	-	278^{b}	179^{b}
p	0.03	0.01	0.01	0.02
LSD	128	333	384	176

(CT= Conventional tillage; MC= Mulching; MI= MBILI Intercrop; MT= Minimum tillage; TR= Tied ridging). Same superscript letters in the same column denote no significant difference between the treatments

The soil and water conservation treatments significantly influenced sediment yield in both sites during the two seasons (Table 4.1). During long rains 2011 season in Kigogo, sediment yield was reduced by 41 and 12% under mulching and MBILI intercrop respectively, while minimum tillage increased sediment yield by 7% (p=0.03) in comparison to control. During short rains 2011 season, mulching, MBILI intercrop and minimum tillage reduced sediment yield by 71, 61 and 68% (p=0.01)

respectively, as compared to control. Mulching was the best (separate letters in superscript) in reducing sediment yield during the long rains 2011. In Machang'a, mulching, MBILI intercrop and tied ridging reduced sediment yield by 78, 50 and 71% during long rains 2011 season (p=0.01) and by 53, 29 and 64% during the short rains 2011 season (p=0.02), respectively, in comparison to control (Table 4.1).

From the results, sediment yield was lower under the soil and water conservation treatments as compared to control. High sediment yield under control treatment might be attributed to beating action of rain drops thereby causing breakdown of aggregates and clay dispersion. These subsequently lead to surface sealing with decreased infiltration and increased surface runoff and sediment yield (Biazin *et al*., 2010). Mulching has been demonstrated to be effective in reducing soil erosion below desirable threshold and greatly improving soil properties (Liu *et al.,* 2012). Effectiveness and efficacy of mulching in managing sediment yield arises from protection provided against rain-splash hence resulting to low sediment yield. Soil surface mulching effectively reduces surface runoff, increases the infiltration of water into the soil thereby slowing soil erosion (Wang *et al.,* 2009). Mulching further decreases soil crusting caused by rainfall impact and reduces erosion by absorbing kinetic energy of raindrops (Nyssen *et al.,* 2008). The results corroborate the findings of Liu *et al.* (2012) who reported significant decrease in sediment yield under straw mulch treatment by 18-22% in comparison to conventional tillage. Babalola *et al.* (2007) reported best performance with vetiver grass mulch in reducing soil, water and nutrient losses in Nigeria.

Minimum tillage resulted in higher sediment yield during the long rains 2011 season but reduced sediment by 68% during short rains 2011 compared with control. Initial high runoff in minimum tillage plots could be linked to the stabilization face of the experiment. Low sediment yield during short rains 2011 season might be attributed to compact soil surface that resisted erosion of soil as opposed to loose soil surface under control due to tillage. MBILI intercrop reduced sediment yield. This might be ascribed to the fact that legume crops protected soil surface from splash effect of rainfall and subsequent soil loss.

Effectiveness of tied ridging technology in reducing sediment yield in Machang'a might be linked to the reduced runoff resulting from improved infiltration (Araya and stroosnijder, 2010). The results highlight the importance of soil management to reduce sediment loss from agricultural fields.

4.3.2 Nutrient and carbon concentration in the sediment

Table 4.3: Nutrient and organic carbon concentration in the sediment in kg ha^{-1} at Kigogo and Machang'a during the experimental period

Nutrient and organic carbon concentration in kg ha^{-1}								
	long rains 2011 season				short rains 2011 season			
Nutrient	**N**	**P**	**K**	**Organic_C**	**N**	**P**	**K**	**Organic_C**
Treatment				**Kigogo**				
CT	1.7^{a}	8.0^{a}	3.7^{b}	195.2^{a}	17.8^{a}	9.6^{a}	53.9^{a}	175.1^{a}
MC	1.2^{b}	7.2^{a}	5.2^{a}	90.5^{d}	7.0^{c}	7.6^{a}	24.3^{b}	80.2^{d}
MI	1.1^{b}	7.8^{a}	4.0^{ba}	137.6^{b}	12.0^{b}	10.0^{a}	32.3^{b}	116.6^{b}
MT	1.4^{a}	6.7^{a}	4.9^{ba}	111.8^{c}	9.7^{cb}	7.8^{a}	30.1^{b}	106.1^{c}
p	0.02	0.5	0.14	<0.01	<0.01	0.23	0.02	<0.01
LSD	0. 4	2.2	1.5	27.9	2.8	3.1	17.0	10.0
				Machang'a				
CT	0.7^{a}	12.2^{a}	6.2^{a}	25.0^{a}	0.2^{a}	9.7^{a}	3.9^{a}	25.9^{a}
MC	0.3^{a}	5.6^{b}	2.9^{c}	11.6^{d}	0.1^{a}	7.5^{a}	2.6^{bc}	11.0^{b}
MI	0.3^{a}	9.1^{ba}	5.0^{b}	19.4^{b}	0.2^{a}	8.7^{a}	3.4^{ba}	0^{c}
TR	0.3^{a}	11.6^{a}	3.3^{c}	12.5^{c}	0.0^{a}	9.4^{a}	1.8^{c}	0^{c}
P	0.3	0.11	<0.01	<0.01	0.45	0.70	0.01	<0.01
LSD	0.6	5.8	1.1	10.0	0.3	4.8	1.1	10

(CT= Conventional tillage; MC= Mulching; MI= MBILI Intercrop; MT= Minimum tillage; TR= Tied ridging).Same superscript letters in same column denote no significant difference between treatments.

Sediment obtained from runoff water during the experimental period was analyzed for N, P, K and organic carbon (Table 4.2). In Kigogo, N concentration was reduced by 29, 35 and 18% during long rains 2011 season and by 61, 33 and 46% during short rains 2011 season under mulching, MBILI intercrop and minimum tillage, respectively, compared to control. Phosphorus concentration was not influenced by SWC treatments in Kigogo. Potassium concentration was reduced by 56, 41 and 44% during short rains 2011 season under mulching, MBILI intercrop and minimum tillage respectively, compared to control (p=0.02). Organic carbon concentration in the sediment was reduced by 54, 46 and 30% during the long rains 2011 and by 54, 39 and 33% during the short rains 2011 under mulching, minimum tillage and MBILI

intercrop, respectively in comparison to control. On average, mulching was the best in reducing nutrient concentration in the sediment in Kigogo site followed closely by minimum tillage. MBILI intercrop performed better than the control in reducing nutrient concentration.

In Machang'a, N and P concentration was not significantly influenced by SWC treatments across the seasons. Potassium concentration was reduced by 53, 19 and 47% during long rains 2011 season and by 33, 13 and 54% during short rains 2011 season under mulching, MBILI intercrop and tied ridging respectively, compared to control. Organic carbon concentration was reduced by 54, 22 and 50% under mulching, MBILI intercrop and tied ridging respectively, during long rains 2011 season. Mulching reduced organic carbon concentration by 58% in compared with control during short rains 2011 season. Sediment under tied ridging and MBILI intercrop was insufficient for analysis of organic carbon to be performed during short rains 2011 season. The amount of nutrient loss from the study was directly proportional to the amount of soil loss. The low nutrient concentrations were therefore justified by low runoff and low sediments under SWC technologies.

Reduced soil organic carbon yield under minimum tillage could be attributed to absence of the physical act of tillage which disrupts soil and causes increased decomposition of previously stable SOM. Organic matter, soil nutrients N, P and K undergo erosion due to the action of rainfall and runoff (Kothyari *et al.,* 2004). Puustinen *et al.* (2005) indicated the reduction of losses in soil and organic carbon (SOC) in conservation tillage practices such as minimum tillage. Evaluating two long-term (18 and 20 years old) tillage sites in Michigan, Senthilkumar *et al.* (2009) found

a greater loss of soil carbon (C) with conventional till (CT) as compared to minimum tillage, in some cases minimum tillage increased C concentration.

The effectiveness of intercrop could be linked to the improved uptake of the nutrients from the soil by the plants (Woomer *et al.*, 2004). The reduction varied markedly between seasons and treatments, and was more pronounced during dry seasons. This is attributed to low runoff generation during the dry period.

4.4 Maize grain yield

Table 4.4: Maize grain yield (Mg ha^{-1}) under SWC technologies at Kigogo and Machang'a during the experimental period

	Grain yield Mg ha^{-1}			
Treatment	**Kigogo**		**Machang'a**	
	long rains 2011	**short rains 2011**	**long rains 2011**	**short rains 2011**
CT	5.8^{b}	2.5^{a}	0.0	1.6^{b}
MC	6.1^{b}	2.6^{a}	0.0	2.8^{a}
MI	8.1^{a}	2.7^{a}	0.0	0.2^{c}
MT	6.2^{b}	2.3^{a}	-	-
TR	-	-	0.0	3.1^{a}
p	0.001	0.5	0.0	0.003
LSD	0.7	0.7	0.0	0.8

(CT= Conventional tillage; MC= Mulching; MI= MBILI Intercrop; MT= Minimum tillage; TR= Tied ridging). Same superscript letters in same column denote no significant difference between treatments

At Kigogo, maize yield was increased by 40, 7 and 5% during long rains 2011 season under MBILI intercrop, minimum tillage and mulching respectively, compared with control. Maize yield was not influenced by the SWC treatments during short rains 2011 season.

In the lower potential area, Machang'a, total crop failure occurred during long rains 2011 season. Maize development was adversely affected because of erratic rains at the time of planting which led to poor germination and a sudden cessation of rains at critical flowering stage of crop cycle, and a severe meteorological drought stress (Figure 4.2). During short rains 2011 season, mulching and tied ridging increased maize grain yield by 75 and 94%, respectively, in comparison with control. MBILI intercrop suppressed maize grain yield by 86%. Despite the dismal performance of MBILI Intercrop in terms of maize grain yield, it had legume yields which translate to additional benefits to the farmer.

Differences in maize grain yield under the various SWC treatments were due to a combination of water availability and fertility status of the soil as influenced by treatments. Although total rainfall received in short rains 2011 season was slightly higher, occurrence of prolonged dry spells within the season (Figure 4.2) affected final yields. Yields at Kigogo were higher than that of Machang'a. This is attributed to contrasting environmental conditions in the two experimental sites with regard to soil chemical and physical characteristics (Table 4.1), rainfall (Figure 4.2) and evapotranspiration rates (Figure 4.1). Kigogo is generally considered to be better than Machang'a in terms of agricultural potential.

Good maize yield under mulch and tied ridging technologies might be ascribed to conservation of soil moisture which ultimately influence grain yield (Araya and Stroosnijder, 2010). Higher moisture status increases root proliferation and enhances availability of nutrients to crop roots (Sarkar, 2005). Tied ridging can enhance response of crops to rainfall and fertilizer, soil supply of available N, positive effect

on yield and harvest index. The effectiveness of tied ridging in improving yields has been demonstrated by several scholars (Jensen *et al.,* 2003; McHugh *et al.,* 2007; Nuti *et al.,* 2009; Temesgen *et al.,* 2009). Araya and Stroosnijder (2010) reported that maize grain yield under tied ridging could be increased by at least 44% over control

(a) (b)

Plate 4.1: Runoff plot with dry maize stover sample for mulching (a) and MBILI intercrop treatment (b)

during below average rainfall years. Rainfall received during the one year experimental period in Machang'a was 515 mm (Figure 4.2). This is far much below expected annual rainfall totals of 700-1200 for the area (Jaetzold *et al.* 2007). Biazin and Stroosnijder (2012) suggest that in below average rainfall seasons, tied-ridges are more effective at improving crop yields than enhancing the fertility level of the soil. Enfors *et al.* (2010) indicated that conservation treatments such as tied ridging and mulching increase maize yield by at least 65%, with exceptional amounts of rainfall of about 549 mm. Miriti *et al.* (2012) found greater maize grain yields under tied-ridge tillage as compared to conventional tillage in semi arid region of Meru south and Mbeere south. High crop yields in ridge tillage have also been reported in Ghana

by Akinyemi *et al.* (2003) and in Kenya by Miriti *et al.* (2005). Rodriguez (1987) found that maize grain yield response to tied ridging was higher in comparison to conventional tillage.

Good performance of MBILI intercrop crop in terms of maize yield might be attributed to the ability of intercrop to quickly cover the soil surface and reduce soil erosion, suppress weeds, biological N_2-fixation (Rusinamhodzi *et al.,* 2012) and larger quantities of better quality organic matter inputs produced in cereal-legume intercrop Doré *et al.* (2011) view cereal legume intercropping as a useful component of ecological intensification, an approach to produce more food per unit resource to achieve positive social outcomes without negative effects on the environment.

Rusinamhodzi *et al.* (2012) state that maize-legume intercropping reduces the risk of crop failure, improves productivity per unit area, improves profitability and can provide a pathway to food security in vulnerable production systems. High maize yield under intercrop can be associated with above-ground interactions between intercropped species, for instance, greater interception of sunlight or more efficient conversion of the intercepted radiation (Li *et al.,* 2006; Gao *et al.,* 2010). Zhang *et al.* (2002) indicated that the growth stages in an intercrop when root weight is maximum and does not overlap reduces competition between the two crops for water and nutrients and results in higher yields of both. The results agree with findings of Mucheru-Muna *et al.* (2010) whereby the MBILI system resulted in increased maize and legume yields in comparison to control. Woomer *et al.* (2004) reported that MBILI system increased both legume yields (by average 40%) and maize yields (by average 20%).

In Machang'a site however, MBILI intercrop performed dismally in terms of maize grain yield compared with control (Table 4.4). The poor productivity of maize under MBILI intercrop could be linked to long dry spells (Figure 4.2) which resulted in water stress and high competition between maize and cowpea for the limited water. These results are consistent with findings of Rusinamhodzi *et al.* (2012) who reported that intercropping resulted in significantly less maize yield than the sole maize. Tungani *et al.* (2002) demonstrated that MBILI arrangement mostly benefits legumes. Oswald *et al.* (2002) states that cereal crop yields are often significantly reduced in some cases in intercropping systems.

Increased maize yield under minimum tillage might be attributed to high aggregate stability and subsequent fertility at the top soil due to lack of soil disturbance. Yield under conventional cropping declined due to diminishing soil fertility caused by the loss of soil nutrients and organic matter over time.

Crop failure during long rains 2011 season at Machang'a' could be linked to a severe meteorological drought (32 days) experienced during the critical crop development stage (Figure 4.2); flowering and coupled with high evapotranspiration rates ranging between 4.1-7.4 (Figure 4.1). Rainfall distribution received during this season was quite erratic with a total of 157mm (Figure 4.2) distributed among eleven pentads. Two days after full germination of the crops; on May 5, 2011, a major rainfall event (41mm) occurred after which a meteorological drought (32 days) was experienced throughout the season.

This observation is consistent with the statement of Ngigi *et al.* (2006) that in a semi-arid context, especially in a coarse-textured soil with low moisture storage capacity, *in situ* conservation may offer little or no guarantee against the poor rainfall distribution. Thus the risk of crop failure is only slightly lower than that without any measures. Meteorological dry spells and droughts are an important cause for low yield levels (Rockstrom, 2002). The risk of drought in sub-Saharan Africa has also been linked to a lack of available water as a result of deteriorated soil physical characteristics (Stroosnijder and Slegers, 2008).

Studies by (Rockström, 2003; New *et al.,* 2006; Funk *et al.,* 2008; Shongwe *et al.,* 2009) have shown the importance of seasonal climatic variability affecting crop yield performance. A study by Rowhani *et al.* (2011), examining the relationships between seasonal climate and crop yields focusing on maize, sorghum and rice in Tanzania has indicated that both intra- and inter-seasonal changes in temperature and precipitation influence cereal yields. Negative impacts of climate variability on crop growth occur especially if it happens at specific crop development stages (Semenov and Porter, 1995). Previous studies (Rockström, 2003; Nuti *et al.,* 2009; Araya and Stroosnijder, 2010) have particularly pointed out to water shortage during critical crop development stages as a fundamental constraining factor to crop productivity.

4.5 Cost-Benefit Analysis

Table 4.5: Net benefit and benefit-cost ratio in Machang'a; and Kigogo during the experimental period

	Net Benefit (ha^{-1}) in US $			**Benefit-Cost Ratio**		
Treatment	**Kigogo**		**Machang'a**	**Kigogo**		**Machang'a**
	long rains 2011	**short rains 2011**	**short rains 2011**	**long rains 2011**	**short rains 2011**	**short rains 2011**
CT	2651^{b}	836^{b}	398^{b}	2.6^{c}	0.9^{b}	0.5^{b}
MC	2942^{b}	947^{ab}	1215^{a}	3.3^{bc}	1.2^{b}	1.8^{a}
MI	4631^{a}	1182^{a}	903^{a}	4.6^{a}	1.3^{a}	1.1^{b}
MT	3074^{b}	979^{ab}	-	4.0^{cb}	1.7^{a}	-
TR	-	-	1305^{a}	-	-	1.9^{a}
p	0.001	0.17	0.01	0.004	0.02	0.004
LSD	762.51	322.67	442.22	0.8695	0.40	0.64

(CT=control treatment; MC=Mulching; MI=MBILI intercrop; MT=Minimum tillage; TR=Tied ridging). Same superscript letters in the same column denote no significant difference between the treatments

During long rains 2011 in Kigogo, MBILI intercrop, minimum tillage and mulching increased net benefits by 75, 16 and 11% (p=0.001) and Benefit cost ratio (BCR) by 77, 54 and 27% (p=0.004) respectively, compared with control (Table 4.5). Benefit cost ratio in all treatments were above 2 during long rains 2011 season. During short rains 2011 season, BCR was increased by 89, 44 and 33% under minimum tillage, MBILI intercrop and mulching respectively, compared to control (0.02). Net benefit was not influenced by the treatments during short rains 2011 season.

In Machang'a, tied ridging, mulching and MBILI intercrop significantly increased net benefits by 228, 205 and 127% (p=0.01) and BCR by 280, 260 and 120% (p=0.004) respectively, compared with control (Table 4.5). Net benefit from tied ridging, MBILI intercrop and mulching were not significantly different from each other. Tied ridging was the best in increasing net benefits followed by mulching. Mulching and tied

ridging resulted in a BCR greater than 2 while MBILI intercrop and the control had BCR of less than 2.

High net benefits and BCR is often the case when assessing effectiveness of different soil fertility amendment technologies (Srivastava *et al.,* 2004). Several benefits have been linked to soil and water conservation technologies in literature (Srivastava *et al.,* 2004; Hobbs *et al.,* 2011; Olarinde *et al.,* 2012). Perhaps, the major source of benefits of these technologies arises from the increased grain yields compared to conventional practice (Table 4.4). A study by Hobbs *et al.* (2011) demonstrated that CA is a more sustainable and environmentally friendly management system for cultivating crops. For instance, the results indicate lower production costs under minimum tillage and mulching compared to control. Minimum tillage reduced costs of digging since a minimum inversion of the soil is maintained. According to Srivastava *et al.* (2004), minimum tillage unlike intensive tillage system reduces energy consumption, drudgery of labour and high cost of cultivation. Mulching on the other hand resulted to low costs on weeding which was associated with suppressed weeds under mulching technology. The higher net benefits under tied ridging technology arose from high maize yields compared with control.

Olarinde *et al.* (2012) highlight the need to economically examine adoption of soil and water management technology (SWMT) options to improve agricultural production in order to evaluate the impact of their uptake by the resource-poor African farmers. Zhou *et al.* (2009) found minimum tillage to be most efficient practice with highest net benefit of \$94.5 ha^{-1}compared with control. Das and Bauer

(2012) reported that minimum tillage was better than conventional system in providing positive economic returns for a longer period

CHAPTER 5

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Findings and conclusions

Mulching and MBILI intercrop reduced runoff by 26% in Kigogo compared with control. Tied ridging gave best results in terms of runoff in Machang'a site whereby it reduced runoff by 52% on average compared with control. Mulching was the best soil and water conservation technology in reducing sediment yield in Kigogo site by 56% on average, compared with control. Tied ridging was the most effective soil and water conservation technology in reducing sediment yield in Machang'a by 68% on average compared with control.

Mulching was the best in reducing nutrient and organic carbon concentration in Kigogo whereby it reduced N, P, K and organic carbon concentration by 45, 56 and 54% respectively, compared with control. Mulching was also the best in reducing organic carbon concentration in Machang'a site by 56% on average compared with control. Tied ridging was the best in reducing K concentration by 48% on average compared with control in Machang'a site.

In terms of maize yield MBILI intercrop was the best technology in Kigogo site whereby it increased maize yield 40% while tied ridging increased maize yield by 94% over control and was the best in Machang'a site. For the net benefits and BCR MBILI intercrop was the best technology in Kigogo site whereby increase in net benefit and BCR were 75 and 73% respectively, compared with control. In Machang'a site tied ridging increased net benefits and BCR by 228 and 280% respectively, compared with control and was rated the best.

From these results, mulching was the best technology in Kigogo site in terms of the parameters evaluated followed closely by MBILI intercrop. In the semi-arid region, Machang'a, tied ridging was the best technology on average. The study highlights the possibility of improving grain yields with the little available rainfall through implementation of technologies which promote water availability and retention within the field. The technologies can also contribute significantly to increasing household incomes in many poor regions as reflected on net benefits reported.

Emerging from the study is however, the difficulty in promoting SWC technologies in semi-arid lands such as Machang'a. For instance, total crop failure occurred during long rains 2011 season despite the implementation of soil and water conservation technologies. Small scale farmers in such environments are faced with difficult task of producing sufficient food for own consumption while generating cash income for their needs.

5.2 Recommendations

From the findings, the following recommendations were made:

- For reduction of runoff, sediment yield and nutrient loss, mulching is the best technology for adoption by farmers in the sub-humid region (Kigogo) while tied ridging be adopted by farmers in Machang'a.
- For high maize grain yields, net benefits and benefit cost ratios, MBILI intercrop offer the best option for farmers in Kigogo while tied ridging is the best for farmers in Machang'a

- With the emerging challenge of climate variability, tied ridging, mulching and MBILI intercrop are recommended as adaptation measures for enhanced food security in the study region

5.3 Areas for further research

Based on the findings of the research, the following areas for further research were identified;

- Future study to explore the potential of minimum tillage technology in the sub-humid region over a longer period of time
- A study to investigate capture and reuse of runoff in agricultural fields

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APPENDICES

Appendix 1: Experimental layout at Kigogo station

Block1			Block 2				Block 3			
Plot 1 Trt 1	Plot 2 Trt 2	Plot 3 Trt 3	Plot 4 Trt 4	Plot 5 Trt 4	Plot 6 Trt 3	Plot 7 Trt 1	Plot 8 Trt 2	Plot 9 Trt 4	Plot 10 Trt 1	Plot 11 Trt 2	Plot 12 Trt 3

Where: Treatment= Trt, 1=Minimum tillage, 2=Conventional tillage, 3=Intercrop and 4= Mulching

Appendix 2: Experimental layout at Machang'a station

Block1				Block 2				Block 3			
Plot 1 Trt 1	Plot 2 Trt 2	Plot 3 Trt 3	Plot 4 Trt 4	Plot 5 Trt 2	Plot 6 Trt 1	Plot 7 Trt 4	Plot 8 Trt 3	Plot 9 Trt 3	Plot 10 Trt 4	Plot 11 Trt 1	Plot 12 Trt 2

Where: Treatment=Trt, 1=Tied Ridging, 2= Intercrop, 3= Mulching and 4= Conventional tillage

Appendix 3: Calculations

Runoff Coefficient

$$Rc\% = \frac{Runoff\ (mm)}{Rainfall\ \ (mm)} * 100 \quad \text{Equation 1}$$

Where: *RC*=Runoff coefficient

Sediment yield

$$Total\ sediment\ loss\left(\frac{kg}{ha}\right) = \frac{sediment\ \ concentration\ \left(\frac{g}{l}\right) \times runoff\ \ volume\ (l)}{plot\ \ area\ (m^2) \times 10^{-1}} \quad \text{Equation 2}$$

Reference evapotranspiration (ETo)

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad \text{Equation 3}$$

Where: ET_o=Reference evapotranspiration [mm day^{-1}]

R_n=Net radiation at the crop surface [MJ m^{-2} day^{-1}]

G=soil heat flux density [MJ m^{-2} day^{-1}]

T=Mean daily air temperature at 2 m height [^oC]

U_2=Wind speed at 2 m height [m s^{-1}]

e_s=Saturation vapour pressure [kPa]

e_a=Actual vapour pressure [kPa]

e_s-e_a=Saturation vapour pressure deficit [kPa]

Δ=slope vapour pressure curve [kPa $^oC^{-1}$]

γ=Psychometric constant [kPa $^oC^{-1}$]

The value 0.408 converts the net radiation R_n expressed in MJ/m^2day to equivalent evaporation expressed in mm/day. Because soil heat flux is small compared to Rn, particularly when the surface is covered by vegetation and calculation time steps are 24 hours or longer, the estimation of G is ignored in the ETo calculation and assumed

to be zero. This corresponds with the assumptions reported in the FAO Irrigation and Drainage Paper No. 56 for daily and 10-daily time periods (Raes, 2009). Allen *et al.* (1989) state that the soil heat flux beneath the grass reference surface is relatively small for that time period.

Sediment samples

- **Total Nitrogen**

Percentage recovery of EDTA standard and Nitrogen (%) in soil

$$\%\ Recovery\ = \frac{(V-B)\times N\times R\times 186.1\times 100}{Wt_1\times 1000} \quad \text{Equation 4}$$

$$\%\ N = \frac{(V-B)\times N\times R\times 14.01\times 100}{Wt_2\times 1000} \quad \text{Equation 5}$$

Where: V=Volume of 0.01 N H_2SO_4 titrated for the sample (mL)

B=Digested blank titration volume (ml)

N=Normality of H2SO4 solution

14.01=Atomic weight of N

R=Ratio between total volume of the digest and the digest volume used for distillation

Wt1=Weight of EDTA (g)

Wt2=Weight of air-dry soil (g)

186.1=Equivalent weight of the EDTA

- **Total phosphorus**

$$TotalP(ppm) = ppmP(fromcalibrationcurve) * \frac{A}{Wt} * \frac{50}{V} \quad \text{Equation 6}$$

Where: A=Total volume of the digest (ml)

Wt=Weight of air-dry soil (g)

V=Volume of digest used for measurement (ml)

- **Extractable potassium**

Potassium (K) concentrations were calculated according to the calibration curve

$$ExtractableK\ (ppm) = ppmK\ (calibrationcurve)\ \times\ A/Wt \quad \text{Equation 7}$$

Where: A=Total volume of the extract (ml)
Wt=Weight of air-dry soil (g)

- **Organic carbon**

Percent oxidisable organic carbon

$$\%OrganicCarbon = \frac{V_{Blank}\ -V_{Sample}\ \times M\times 3\times 10^{-3}\times 100}{W_t} \quad \text{Equation 8}$$

Where: *VBlank*=Volume (ml) of ferrous ammonium sulphate solution required to titrate the blank

VSample=Volume (ml) of ferrous ammonium sulphate solution required to titrate the sample

Wt=*W*eight (g) of air-dry soil

3 x 10^{-3}=Equivalent weight of carbon

100=percentage

M=Molarity of ferrous ammonium sulphate solution (approximately 0.5M i.e. 10/Vblank).

The organic matter amount, a factor of organic carbon was derived using equation 9.

$$\%\ OrganicMatter\ (w/w) = 1.724 * \%\ TotalOrganicCarbon \quad \text{Equation 9}$$

Appendix 4: Labour data form

LABOUR DATA FORM

Experiment Title: _____ Site_____ Season_____

Plot No.	Rep	Treatments	Ploughing	planting	Surface mngt	1st weeding	Thinning	2nd weeding	Top dressing	Pests contrl	Harvesting	Other

Compiled by: Name_____ Signature_____ Date_____