EFFECTS OF INTEGRATED SOIL FERTILITY MANAGEMENT AND TIED-RIDGING ON MAIZE-SOYBEAN YIELDS AND SELECTED SOIL PROPERTIES IN THARAKA-NITHI COUNTY, KENYA

Sibomana Jean Damascene (BSc.)

A148EA/20759/2012

A Thesis Submitted in partial Fulfillment of the Requirements for the Award of Degree of Master of Science in Integrated Soil Fertility Management in the School of Agriculture and Enterprise Development of Kenyatta University

August 2016

DECLARATION

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

Sibomana Jean Damascene **Date**

A148EA/20759/2012

Supervisors Approval

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors.

Dr. Jayne Njeri Mugwe **Date**

Department of Agricultural Resource Management
School of Agriculture and Enterprise development
Kenyatta University, Kenya

Dr. Ngetich Kipchirchir Felix **Date**

Department of Land and Water Management
School of Agriculture
University of Embu, Kenya

DEDICATION

At the onset, I wish to dedicate this work to the Almighty God who gave me sufficient grace to complete the study on time. I also dedicate it to my late father Karemera Modeste and to my family and my late friend Fabrice Musoni. Finally, it is dedicated to all those who contributed towards my recovery from a fatal road accident that I was involved in while undertaking my Master's degree programme at Kenyatta University, Kenya.

ACKNOWLEDGEMENT

I appreciate my supervisors, Dr Jayne Mugwe and Dr Felix Ngetich for their reliable guidance during proposal development, fieldwork and thesis writing. Their valuable suggestions for the improvement of earlier drafts of this thesis are greatly appreciated.

It is my pleasure to thank University of Rwanda, College of Agriculture through Coltan Environment Management Project, for their financial support for my studies at Kenyatta University, Kenya. I am grateful to Prof Francois Naramabuye for his guidance and moral support.

I also thank Soybean and Climbing Beans Scaling up Project (SoCo project -SHP 014) funded by Alliance for Green Revolution in Africa (AGRA) for the financial support to conduct my research work in Tharaka-Nithi County, Kenya. I am very grateful to the entire SoCo project team namely; Dr Jayne Mugwe, Prof Daniel Mugendi, Dr Felix Ngetich, Dr Monicah Mucheru-Muna, Dr Eric Bett, Dr Salome Muriuki, Rebecca Githaika, Evelyn Wambui, Samuel Mutuma, Esther Wanjue, Frank Mutesa and field coordinator Joseph Macharia for the field support they provided. It was a pleasure and a privilege working under your strict guidance, hence my gratitude and appreciation. I am also grateful to the field technician, Jotham Mwiti.

I extend my sincere gratitude to the Chairperson and Lecturers from the Department of Agricultural Resource Management for imparting the necessary knowledge and skills during my course work, which strengthened my insight in carrying out this research. I express my thanks to my classmates for their friendship and sharing during my studies in Kenyatta University.

Finally, I wish to thank my parents and siblings, family of Twagirayezu Emmanuel and Celestin Rushyanuka, for their patience, love, support and endless encouragement, without which this work would not have been successfully accomplished.

GOD BLESSES YOU ALL

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	**-**	Analysis of Variance
ASL	-	Above Sea Level
BNF	**-**	Biological Nitrogen Fixation
C	**-**	Conventional Tillage
CEC	**-**	Cation Exchange Capacity
FAO	-	Food and Agriculture Organization
GDP	**-**	Gross Domestic Product
ICRAF	**-**	International Council for Research in Agroforestry
KARI	-	Kenya Agricultural Research Institute
LR	**-**	Long Rain
LSD	**-**	Least significant Difference
SAS	-	Statistical Analysis Software
SOC	**-**	Soil Organic Carbon
SOM	-	Soil Organic Matter
SR	**-**	Short Rain
SSA	-	Sub-Saharan Africa
SWC	-	Soil and water conservation
TR	-	Tied Ridging

ABSTRACT

Constraints to soil productivity include reduction in soil fertility and lack of adequate soil water conservation techniques due to erratic rainfall in central highlands of Kenya. This study evaluated effects of combining integrated soil fertility management options and tied-ridging on maize-soybean yields and selected soil properties during short rains in 2014 and long rains in 2015 seasons. The study was carried out in Kigogo primary school in Tharaka-Nithi County. The experimental layout was a randomized complete block design replicated 4 times. The treatments were: manure+fertilizer, tithonia+fertilizer, inorganic fertilizer, sole and control under tied ridging or conventional tillage. To evaluate effect of rotation on maize grain yield, 2 test crops: maize and soybean were alternated every season except sole maize treatment which was maintained throughout the trial period. Soil was sampled at 0-20 cm and 20-40 cm depths at the start and end of the study, and analyzed for soil pH, total N, available P, organic C and exchangeable bases. The data was subjected to analysis of variance using Genstat program and means were separated using Fishers' LSD at $p=0.05$. Integrated soil fertility management technologies under soil water conservation tillage significantly increased both maize and soybean grain yields during short rains in 2014 ($p \leq 0.037$ and $p \leq 0.039$ respectively) and only maize grain yield during long rains in 2015 ($p \leq 0.005$). Further, tithonia+fertilizer and manure+fertilizer treatments under tied ridging significantly increased maize grain yields and soybean grain yields by 34.8% and 43.5% respectively compared to the control in long rains in 2015. Only tithonia+fertilizer under tied ridging increased significantly soybean grain yields by 57.1% over control in short rains in 2014. Maize grain yield also has increased under maize-soybean rotation by 35.5% over sole maize. The results showed significant decrease in soil pH, available P and total N in mineral fertilizer under tied ridging ($p<0.05$). Soil exchangeable K^+, Ca^{2+} and Mg^{2+}generally increased in most treatments. This study recommends use of combination of either tithonia biomass or manure with inorganic fertilizer under conventional tillage as well as crop rotation to enhance soil fertility and maize-soybean yields in the region.

CHAPTER ONE
INTRODUCTION

1.1 Background of the study

Agriculture is by far the world's dominating land use (Welch *et al*., 2010). It accounts for more than 25% of the gross domestic product (GDP) of most African countries, and is the main source of income and employment for at least 65% of Africa's population of about 750 million. Agriculture provides 70% of employment and 35% of Sub-Saharan Africa's (SSA) gross domestic product (World Bank, 2000). Thus, agricultural development is vital to Africa's economic growth, food security and poverty alleviation. Moreover, in Eastern African countries, agriculture is the main source of livelihood for about 80% of the population and contributes to about 38% of the gross domestic product (GDP) (Mateete *et al*., 2010). Specifically in Kenya, agriculture accounts for approximately 27% of Kenya's GDP and it is the main source of livelihoods to about 80% of the population in rural areas (MoA, 2009).

The farmlands of Africa have progressively reduced crop production due to continuous farming without replenishing soil nutrients. The production constraints include physical soil loss due to erosion, nutrient deficiency, low organic matter, aluminum and iron toxicity, increased acidity, crusting and moisture stress (Oldeman *et al*., 1991). Furthermore, FAO (1995) estimated that Africa is losing large quantities of soil nutrients, for example 4.4 million tons of N, 0.5 million tons of P, and 3 million tons of K every year from its cultivated land due to erosion, leaching, and crop harvests. Besides these constraints, limited use of nutrient inputs among smallholder farmers exacerbates soil nutrient deficiency. Nutrient losses are several times higher than Africa's annual fertilizer consumption of 0.8

million tons of N, 0.26 million tons of P, and 0.2 million tons of K. Low soil fertility, limited availability of resources to farmers, nutrient mining, and frequent droughts are the main causes for low agricultural productivity in Sub-Saharan Africa (McCann, 2005). In the Central Highlands of Kenya, the major factor contributing to the problem of reduced crop yields is low soil fertility caused mainly by continuous cropping with inadequate addition of fertilizers and/or manures, and rampant soil erosion on steep slopes (Mugwe *et al.,* 2004).

One of the options proposed by several authors for addressing these land production constraints is use of integrated soil fertility management (ISFM) approaches (Vanlauwe *et al.*, 2010; Wang *et al.,* 2004). Integrated soil fertility management approaches comprises technologies which combine the use of organic soil amendments (biomass, manure, agroforestry trees and any other organic matter material), phosphate, lime and inorganic (chemical) fertilizers. Indeed, the ISFM paradigm acknowledges the need for both organic and mineral inputs to sustain soil health and crop production due to positive interactions and complementarities between them (Buresh *et al.,* 1997; Vanlauwe *et al.,* 2002). As highlighted by Breman, (2001), ISFM technologies should be promoted, improved, implemented and validated in regions where fertilizer use, though attractive, is beyond the reach of the resource poor farmers.

In addition, drought is one of the main causes for low agricultural productivity in SSA (McCann, 2005). The impact of drought stress on crop productivity is severe when farmers do not practise soil moisture management mechanisms (FAO, 2002). Soil water conservation technologies such as tied-ridging, mulching, contour ploughing among others can play an important role in soil moisture conservation. Tied-ridging, a physical soil and water conservation (SWC) technology is reported to be beneficial for increasing crop yields

(Ngetich *et al*., 2014). It is one of the rainwater harvesting techniques which reduces drought risks and promotes root growth and development, reduces runoff and improves water infiltration (Prentice *et al.*, 1946; Macartney *et al.*, 1971; Fournier, 1967; Kowal, 1970).

The crop rotation of a legume to the succeeding cereal crop benefits the cereal crop in terms of yield relative to a cereal-cereal rotation. It is important to seek a balanced approach to improving soil fertility as the rotation with legume crop which improves the soil fertility through BNF (Byerlee *et al.*, 1993). Rotation of maize and legume is often preferred to continuous cropping system because the rotation produces greater grain yield for both crops (Varvel, 1994; West *et al.*, 1996). Further, input costs are often less with rotation (Foltz *et al.*, 1995), with less N fertilizer needed for maize–soybean rotation compared with continuous maize. A maize–soybean rotation is also more effective in preventing deep leaching of nitrate N than continuous maize (Katupitiya *et al.*, 1997; Varvel and Peterson, 1990). Reduced stress from pests may be one of the reasons for improved yield with crop rotations (Boosalis and Doupnik, 1976). Therefore, there is need to study the interactive effects of ISFM technologies and tied-ridging under crop rotation farming system in the study site.

1.2 Problem Statement

Soil fertility in Tharaka-Nithi County has declined over time, with a depletion rate of 30 kg N ha^{-1} per year without inadequate soil nutrient replenishment (Smaling, 1993). However, the use of local available organic fertilizers is limited by their low quality and quantity (Bationo and Waswa, 2011). The utilization of inorganic fertilizers is also low and less than

20 kg N ha^{-1} and 10 kg P ha^{-1}, which is inadequate for recommended rates of 60 kg N ha^{-1} and 60 kg P ha^{-1} to meet the crop nutritional requirements for optimum crop yields in the region (Adiel, 2004). Moreover, majority of smallholder farmers in Tharaka-Nithi depend on rain-fed agriculture (Mugwe *et al.*, 2009) while water stress is also a limiting factor to crop production. Low soil fertility and the associated nutrient limitations for crop growth, limited availability of resources to farmers, nutrient mining, and frequent droughts have been acknowledged as pervasive constraints in smallholder farming systems in Tharaka-Nithi County in Kenya. Therefore, it is important for farmers to have options that increase soil fertility and conserve soil water as well as to stabilize crop yield of smallholder rain-fed farming in the region. So far, inadequate knowledge on these aspects exists because little research has been conducted that combines soil fertility replenishment options and soil water conservation.

1.3 Objectives of the study

The general objective of the study was to evaluate the effect of integrated soil fertility management options and tied ridging, on maize-soybean yields and selected soil properties in Tharaka-Nithi County. The specific objectives were:

i. To determine the effect of ISFM technologies and tied-ridging on maize and soybean yields.
ii. To evaluate the effect of maize-soybean rotation on maize grain yield.
iii. To assess the effect of ISFM technologies and tied-ridging on soil pH, organic carbon, total N, available P and exchangeable bases.

1.4 Research Hypotheses

The hypotheses tested in this study were:

i. A combination of ISFM technologies and tied-ridging significantly increases maize and soybean yields.
ii. A maize-soybean rotation significantly increases maize grain yields.
iii. A combination of ISFM technologies and tied-ridging significantly increases soil pH, soil organic carbon, soil total N, available P and soil exchangeable bases.

1.5 Justification of the study

Population pressures have prevented fallow opportunities, thus continuous cultivation which has led to the depletion of soil organic matter, soil nutrients, and low inherent water storage by soils. At the same time, rainfall in the area is low and unreliable which requires improving soil moisture content (Smaling, 1993). Although some studies have been done which focused on the potential of organic inputs, mineral fertilizers, and soil water conservation techniques and cropping practices in improving agricultural productivity in the study area, not much has changed. While the current study does compliment the previous studies, it however mostly focuses on the interactive effects of ISFM technologies and tied-ridging on maize-soybean yields and soil properties and some farming systems like maize-soybean rotation on maize grain yield under climatic variability in the region.

Another viewpoint of this study is that because maize is a very important staple food in Kenya, it means that ISFM technologies which increase maize yields are of a high consideration. Soybeans were also introduced to people in the region not only by its nitrogen supply into soil through biological N-fixation but also its relatively high content of oil and protein in its seeds and high nutritional quality for food consumer (Hoff *et al*., 1982).

1.6 Significance of the study

This research generates additional knowledge and recommends the best combination practices of ISFM technologies and tied-ridging on maize-soybean grain yields and soil properties in the study region. Due to the poor agricultural production, the results of this study are to help farmers to take the necessary measures of soil fertility management to improve crop yields for ensuring food security. The findings of this study also can be utilized by policy makers, extension service providers and stakeholders in planning for policies, programs and projects. This can facilitate adoption of combined ISFM and soil water conservation techniques and maize-soybean rotation systems in improving soil productivity, maize and soybean production.

1.7 Conceptual Framework

The primary problem in the study area is soil fertility decline, land degradation, runoff and low investment in soil water management technologies (Figure 1). Soil fertility depletion grossly limits agricultural productivity. It required therefore using ISFM technologies, soil water conservation through tied-ridging and crop rotation farming system.

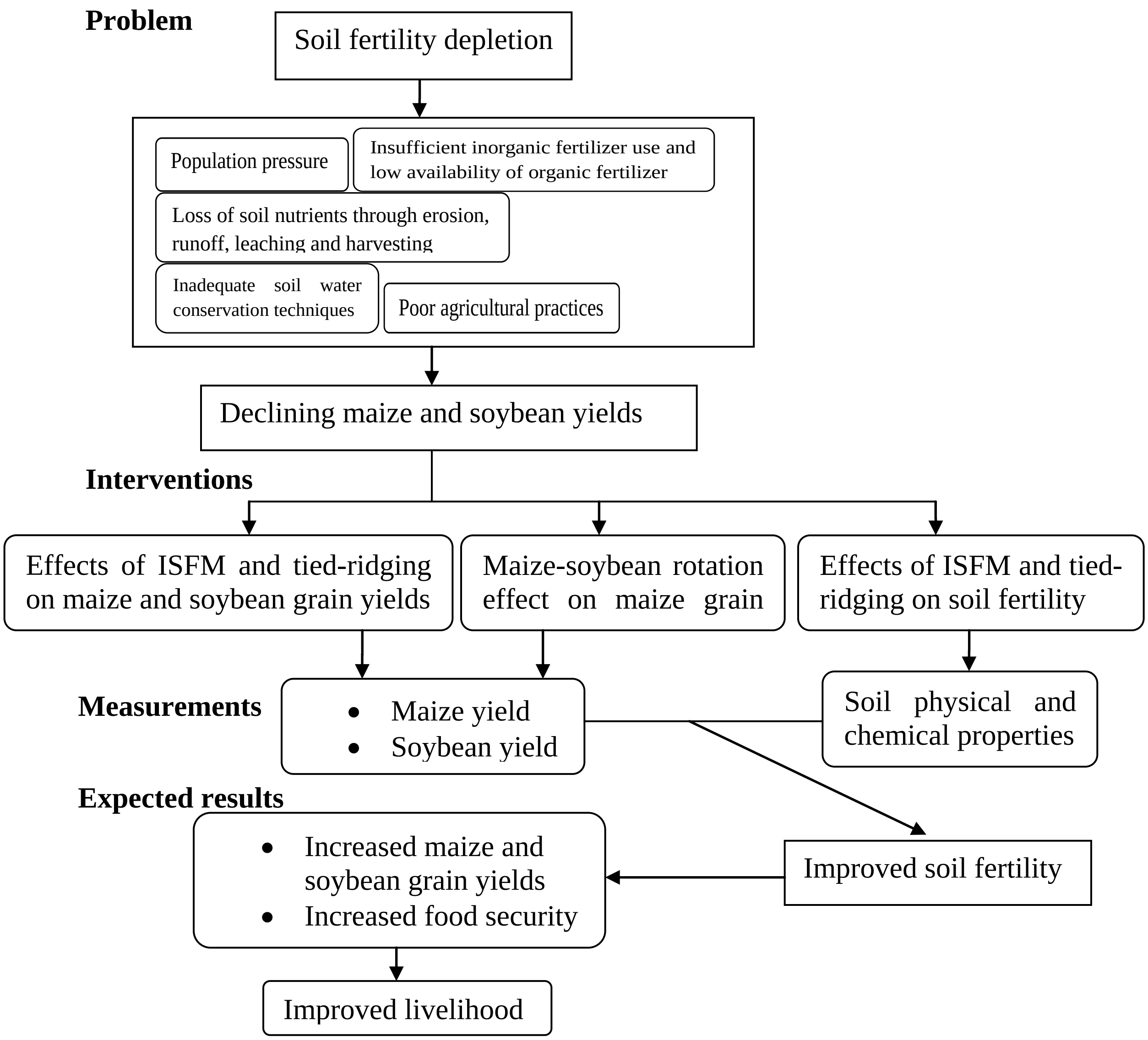

Figure 1. Conceptual diagram links the variables of the study

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview

Soil nutrient management practices are the key challenges for global food production (Powlson *et al.,* 2011). It has long been recognized that loss of plant nutrients due to land degradation through soil erosion, runoff, and continuous cultivation without soil nutrients replenishment is a principal cause of low agricultural productivity and food insecurity in Africa (Sanchez, 2002). Additionally, population increases and land scarcity indicate that Sub-Saharan African's food needs cannot be met through the low input systems that are based largely on traditional practices, instead much more will be required from farmers in terms of labor, knowledge, and skills (Borlaug and Dowswell, 1995). Apart from the lack of soil fertility management practices, water deficit especially at the plant root zone is a significant factor that hinders crop productivity (Bossio *et al*., 2010).

Water scarcity is more pronounced in semi-arid regions of Sub-Saharan Africa where agriculture is rain-fed and faces threat from frequent dry spells and droughts (Rockstrom *et al.,* 2003). Increased soil moisture storage at root zone through rainwater conservation technologies reduces runoff and soil loss (Ngigi *et al*., 2006). Similarly, legume crops, trees and shrubs add significant amounts of N by biological N_2-fixation, and deep-rooting trees recycle to the soil surface nutrients taken up from below the rooting depth of annual crop plants. Thus, this study is of interest to address some ISFM technologies and farming practice i.e maize-soybean rotation which help to manage soil fertility thereby enhancing maize and soybean productivity in the study area where farmers often experience a decline of crop yields.

2.2 Integrated Soil Fertility Management

Integrated soil fertility management is a collection of soil fertility management practices that inevitably include the use of fertilizer, organic inputs and improved germplasm combined with ways these practices can adapt to local conditions. It aims to maximize the agronomic use efficiency of applied nutrients and to improve crop productivity (Vanlauwe *et al*., 2006). However, soil nutrients and soil organic matter are usually depleted because of cultivation (Wang *et al.*, 2004). Nutrients losses are not only costly and wasteful, but they can be a source of environmental contamination when they reach lakes, rivers, and groundwater. There exist different forms of nutrients losses that cause nutrients to become unavailable for plant uptake. Nutrient losses occur through runoff, erosion, and leaching, gaseous losses to the atmosphere (primarily losses of different N forms) through volatilization and denitrification, and crop removal as plant uptake and removal of nutrients from the field in harvested products. A study by Okoba *et al*., (2007) in Meru south and Mbeere south sub-counties of Kenya indicates that, there is a high likelihood of maize yield decline below the optimal levels of 3.5 t ha^{-1} if soil erosion is not checked.

In many African countries, nutrient depletion of agricultural soils is so high that agricultural land use is not sustainable (Craswell *et al.*, 2004). 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). Use of fertilizers to replenish soil nutrients are therefore one of the major ways of counterbalancing this low soil fertility, and on soil nutrient management practices. There are also a host of other management practices that are vitally important to overall soil fertility, including soil conservation and tillage techniques, weed management practices, and cropping strategies themselves. 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.

Important soil parameters that affect nutrient cycling include soil pH, potentially mineralizable nitrogen and microbial biomass, which are often considered as indicators of soil quality (Karlen *et al*., 2006; Sparling, 1997). Nitrogen and phosphorus are the most limiting nutrients to crop production and high costs of these inorganic fertilizers limit their sufficient use by majority of the smallholder farmers in Sub-Saharan Africa (Mugwe *et al*., 2004). Crop yields in large parts of Kenya are low due to declining soil fertility as a result of soils impoverishment in organic matter content and low reserves of nitrogen, phosphorus and some trace elements (Ayuke *et al.*, 2004).

Therefore, integrated soil fertility management involves using of different types of farming practices and technologies like crop rotation, timely application of chemical and organic fertilizers mixed with soil and water conservation practices for the purpose of improving soil fertility and crop yield to enhance food security and the economy of the country. By making effective use of resources, ISFM options maximize the profitability of investments in soil fertility. Plants however require sufficient nutrients, organic matter, moisture and favorable weather conditions for food production.

2.3 Effect of ISFM on Selected Soil Properties

2.3.1 Soil pH

Soil pH is the negative logarithm of the hydrogen ion (H^+) concentration in soil solution. The neutral level is seven. Less than seven means acidic soil, more than seven means alkaline or basic soil. Soil acidity affects more than 1.5 billion ha of land worldwide (Graham and Vance, 2000). In acidic soils, the availability of the major plant nutrients nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum is reduced and may be insufficient. However, low soil pH (below 5.0) brings with it many potential associated problems, such as H^+, Al^{3+}, and Mn^{2+} toxicity, Ca^{2+} deficiency, low CEC, P fixation, and low microbial activity (eg: nitrification, N-fixation). As the soil pH decreases, most desirable crop nutrients become less available while others, often undesirable, become more available and can reach toxic levels. Hartemink (2006) defined soil fertility decline to include acidification by decline in soil pH and an increase in toxic elements such as aluminum and manganese. Some ISFM practices have been influencing soil pH to an extent that they can cause the acidity as Mugendi *et al.* (1999) reported a decrease of soil pH after application of mineral fertilizer and organic fertilizer in central Kenya. They can also reduce acidity in different soil conditions such as application of manure, which increased soil pH as reported by Adeniyan *et al.* (2005) in a research trial in Nigeria.

2.3.2 Soil Organic Carbon

Organic carbon can be added in soil through organic inputs such as tithonia biomass, composts and animal manures which are important source of nutrients for the growth of plants. Soil organic matter plays an important role in maintaining physical, chemical and biological properties of the soil, and therefore enhances the crop productivity (Micheni *et al.*, 2004). However, the addition of nutrients such as N, P and S into soil is after organic decomposition and releasing nutrients through mineralization process.

Manure is an excellent soil amendment, providing both organic matter and nutrients. However, the nutrient contents in manure vary enormously depending on the source, method of processing, application and storage. Organic manure alone produces an effect that is proportional to its nutrient content and to the quantities applied (Bouldin *et al.,* 1984; Merillo *et al.,* 1995). Soil organic compounds from humus such as fulvic and humic acids do form complexes (chelates) with cations like Al^{3+}, Fe^{2+}, Cu^{2+}, Zn^{2+} and Mn^{2+} present in the soil solution (Hue *et al.*, 1984). These results in a decrease of the levels of toxic cations to plants, and the chelates formed increase the availability of phosphorus previously fixed by the Al^{3+}, Fe^{2+} and Ca^{2+} cations (Tan, 1993). The exclusive use of organic inputs as external nutrient sources has been recommended as a logical alternative to expensive fertilizers in Africa (Reijntjes *et al.,* 1992). According to Heisey and Mwangi (1996), manures accounted for <10% of N inputs in Africa, or about 1 kg N ha^{-1} yr^{-1}. In Kenya, Omiti *et al.,* (1999) found that between 86% and 91% of farmers used manure in semi-arid and semi-humid zones east of Kenya.

In the last decade, *Tithonia diversifolia* has attracted substantial research attention because of their relatively high nutrient concentrations that are found in its biomass and its ability to extract high amounts of nutrients from the soil. Naturally growing wild stands along the roads are more efficient in absorbing nutrients (Liasu *et al,* 2008). Tithonia biomass is also high in nutrients other than N, P and K. Olabode *et al.* (2007) determined tithonia's N concentration as 1.76% (comparable to those of poultry and swine manure), P, 0.82% (compared to cattle manure 0.52%), K, 3.92% (compared to poultry and cattle manure: 1.8 and 0.95%, respectively). Besides, tithonia has low content of lignin (6.5%) and polyphenols (1.6%). Little and Hills, (1978) reported rapid decomposition of *Tithonia diversifolia* after soil incorporation. The green biomass of tithonia has been recognized to be high in nutrients and effective as a nutrient source for lowland rice (Nagarajah and Nizar, 1982). Studies in the highlands of western Kenya identified green biomass of tithonia as an effective source of nutrients for maize (Gachengo, 1996; Niang *et al.*, 1996).

2.3.3 Soil Nitrogen

Nitrogen is the most limiting element in agricultural production and its deficiency reduces the productivity of crops. However, short term fallows of leguminous trees and herbaceous cover crops provide a practical means of N replenishment via BNF when grown in rotation with cereal crops. Plants deficient in N become stunted and yellow (chlorotic) in appearance. Since N is mobile in plant tissues, therefore plants can remobilize N from older tissue to provide N to younger tissue, chlorosis usually appears on the lower leaves first while the upper leaves remain green (Werner *et al*., 1997). Excess N may cause plants to remain in a vegetative growth stage for longer time, hence delay initiation of flowering or fruiting, resulting in lowered yields of some crops. Excess N can also encourage tender, succulent plant growth that may be more susceptible to certain plant diseases. Palm et al. (2001), Umoetok *et al*. (2007) and Chiezey and Odunze, (2009), however, showed that application of manure either alone or combined with fertilizer had a significant effect by increasing soil mineral N. This increase may be due to supply of N content in manure through mineralization associated to the improvement of soil conditions for microorganism’s development and activity as reported by Kihanda *et al*. (2004).

2.3.4 Available P

Phosphorus is unique among the anions in that it has low mobility and availability in soils. It is difficult to manage because it reacts so strongly with both solution and solid phases of the soil. Phosphorus fixation is often high in Oxisols and Ultisols because they are most likely to have P-fixing clay minerals (amorphous and crystalline hydrous oxides of Fe and Al), high Fe and Al, and low pH, all of which are conducive to P fixation (Fox *et al.* 1971; Fox 1988). If amounts of P fertilizer have been applied over several years to satisfy both actual crop demand (crop uptake of P is usually much lower than that of N and K) and a soil's fixation capacity, many tropical soils are now known to be able to return this capital investment by releasing the P which was fixed in past years for use of present-day or future crops this amending the soil pH (Fox 1988).

Surface-applied P will be available to plants only when the soil surface is moist enough to permit both root growth and interception of P and P solubility. However, organic fertilizers like manure and tithonia biomass are excellent sources of major plant nutrients includes P and also it supplies many of the secondary nutrients that plants require. In a study conducted by Liang *et al.* (2011), they found an increase in soil available P resulting from manure application in the field.

2.3.5 Soil Exchangeable Bases

Soil exchangeable bases such as K^+, Ca^{2+}, Mg^{2+} and Na^+ are released through manure or tithonia biomass decomposition. Rahman *et al.* (2002) found an increase in the available Mg in the soil as a result of applied manure either alone or combined with mineral fertilizer. Elsewhere, Caire *et al*. (2006) reported significant increase of exchangeable Ca after application of manure alone or combined with lime and P fertilizer. Similarly, Awodun *et al*. (2007), Phengsouvana *et al*. (2009) and Odedina *et al*. (2011) also found significant increase in soil exchangeable Ca with application of manure and fertilizer or their combination.

2.4 Effect of ISFM on maize yields

Fertilizers are able to increase crop yields and additionally produce enough residues for soil fertility management, while organic sources are able to rehabilitate less responsive soils and make them responsive to fertilizers (Vanlauwe *et al.*, 2010). The combined application of organic resources and fertilizers is increasingly gaining recognition as one of the appropriate ways of addressing soil fertility depletion, especially in low-external input systems in SSA and forms an integral part of ISFM (Vanlauwe *et al*., 2010, 2002). Zhao *et al*. (2009) reported that farmyard manure combined with chemical fertilizer management resulted in a higher increase in maize yield, soil organic matter, available N and available P because of high contents of soil nutrients compared with those found under straw manure combined with chemical fertilizer management. Kimani *et al*. (2004) reported a 92% increase in maize grain yields after applying manure and fertilizer compared to the control. Other studies have reported more than 50% increase in maize grain yields above the no-input treatment following application of *Tithonia diversifolia* in the soil compared to the control (Jama *et al*., 2000; Nziguheba and Mutuo 2000; Mucheru-Muna *et al*., 2007). Furthermore, Mugendi *et al.* (1999) reported that the application of *Calliandra calothyrsus* green biomass increased maize grain yield by 32% and 48% above the control (Kimetu *et al*., 2004). Also Mutuo *et al*. (2000) reported that treatments that had received tithonia biomass had a high residual effect of 50% yield increase above the control in western Kenya.

2.5 Effect of ISFM on soybean yields

Soybean is an important foodstuff in the world especially in the tropical and subtropical regions (Gowda *et al*., 2000). The most important beneficial attribute of this legume is its contribution to the soil nitrogen status through symbiotic nitrogen fixation of the atmospheric N, thereby enhancing soil fertility and reducing the need for N-fertilizer application (Martins *et al*., 2003).

Fertilizer N is frequently unavailable to subsistence farmers, leaving them dependent on N_2 fixation by legumes or other N_2-fixing organisms. Maximum benefits from N_2 fixation depend on soil P availability (Kennedy and Cocking, 1997), with 33% of the world's arable land limited in P (Sanchez and Euhara, 1980). Acid soil conditions of the tropics and subtropics that are prone to P deficiency can particularly affect nodulation and N fixation and survival of rhizobia in soil (Holford, 1997). Perhaps, of greater concern, reserves of rock phosphate could be depleted in only 60 to 90 years (Abelson, 1999). Alternative sources of N such as the use of BNF technology may supplement or replace chemical fertilizer-N.

Many studies have reported no yield increase of soybean grain when N fertilizers are applied and they assumed that the crop simply substitutes the N it ordinarily would have derived from BNF with N from fertilizer (Deibert *et al*., 1979, Schmitt *et al*., 2001, Gan *et al*., 2003; and Barker and Sawyer, 2005). Javaid and Mahmood (2010) in Pakistan, found significant effect of farm yard manure on soybean pod number. In Nigeria, application of P fertilizer at the rate of 30 kg P_2O_5 ha^{-1} significantly decreased soybean grain yield in acid soil (Mahamood *et al*., 2009). In South Africa Mabapa *et al*., (2010) reported an increase in above ground biomass and grain yields of soybean following application of 60 kg P_2O_5 ha^{-1}. Increased soybean grain yield and components have also been reported after application of P fertilizers in Nigeria (Kamara *et al*., 2007; 2008; 2011). Combined organic and inorganic fertilizers have also been reported to increase soybean yield by 12.9% in India (Maheshbabu *et al*., 2008) and 19% in Indonesia (Yamika & Ikawati, 2012) relative to sole application of inorganic fertilizer.

2.6 Effect of tied ridges on soil moisture content and crop yields

Water availability; its effective storage in soil and efficient use, are the most important determinants of agriculture in all countries. Moisture conservation practices such as tied-ridging, mulching and tillage, significantly reduce runoff and evaporation, increase water infiltration and retention, and increased crop yields (Ngetich, 2012). 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).

Using tied-ridges significantly increase the grain yield of sorghum, maize, and beans compared to the practice of flat seedbeds, particularly in drier seasons (Mitiku and Fassil, 1996). According to Jensen *et al.,* (2003) maize yield with tied-ridging in years with dry to near normal rainfall was improved by 42% compared to control 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. Tied ridging increased maize yields without fertilizer by approximately 10 percent, with fertilizer this increase ranged from 15 percent to over 250 percent (Ruthenberg, 1980). However, the substantial labor costs and yield gaps observed under farmers' conditions throw doubt on the extensive use of this approach.

The significant increase of the soil water in the root zone using tied ridging tillage has been observed. In a study by Miriti *et al.*, (2012), using tied-ridge tillage treatments they contributed to greatest soil water content due to the capture and storage of rainfall by ridge basins and yielded more grains than the other tillage systems. Ridges take longer to get wet after a dry spell, and germination of a crop planted on ridges is quite often observed to be slower than a crop planted on flat land.

In Kenya, Pereira *et al.* (1967) demonstrated the importance of tied ridges in controlling erosion and runoff. No attention has however been given to the synergetic implications of combining it with ISFM technologies under crop rotation system on soil properties and crop yields in the study area.

2.7 Effect of maize-soybean rotation on crop yields

Crop rotation is one of the best cropping practices for successful integrated soil fertility management. Additionally, cultivation of leguminous crops like soybean in rotation with other food crops such as cereals like maize is recognized as one of beneficial ways by which farmers can maintain sustainably the soil fertility. Cereal crop typically produces greater yields when following a legume, than as a monoculture or following another cereal crop (Varvel, 2000). Similarly, maize produced higher yield when grown in rotation with a soybean crop than when grown in continuous maize monoculture. Crop rotation improved soil structure (Raimbault and Vyn, 1991) increased soil organic matter levels (Campbell and Zentner, 1993; Bremer *et al.,* 2008), increased water use efficiency (Roder *et al.,* 1989; Varvel, 1994; Tanaka *et al.,* 2005), enhance mycorrhizae associations (Johnson *et al.,* 1992), improved grain quality (Kaye *et al.,* 2007), and reduced grain yield variability. Crop rotations also provide better weed control, interrupt insect and disease cycles, and improve crop nutrient use efficiency (Karlen *et al.,* 1994).

Soybean is a legume crop capable of symbiotic N_2 fixation with *Rhizobium* spp. Plants grown in N-free sand or gravel culture can form in excess of 150 mg of nodule dry weight and accumulate between 200 and 400 mg N per plant solely from BNF. Positive legume rotation effects on subsequent cereal yields have been reported by several scientists (Kaleem, 1993; Carsky *et al.,* 1997). These beneficial effects have been attributed to the availability of extra nitrogen (N) through biological nitrogen fixation (BNF) and other rotation effects (Sanginga *et al.,* 2002). Maize plants require 9–11 kg N to produce 1 tons of biomass (Anuar *et al.,* 1995). Studies have shown that the optimum rate of N applied for cereal crop production is lower following soybean than following other crops, leading to the assumption that soybean contributes N to subsequent cereal crops. When grown in rotation, maize grain yield can increase by 10 to 17% compared to monoculture (Mannering and Griffith, 1981; Dick *et al.,* 1986; Higgs *et al.,* 1990). Further, Bationo *et al.* (2011) also reported that soybean yields reached 2.5 t of grain ha^{-1} with N-fixation, contributing about 50 kg N ha^{-1}. The maize following soybean had 75% greater yields than maize following maize. Fertilizer utilization by maize was improved by 100% because applying soybean residues and 45 kg N ha^{-1} resulted in maize yields equal to those obtained by applying the 90 kg of fertilizer N ha^{-1} without soybean. Although crop rotation as series of different crops planted in the same field has long been known to increase crop yields, there exists inadequate information on its performance when ISFM and SWC technologies are combined.

2.8 Summary and Research Gaps

This chapter reviewed the information about concerns and benefits of Integrated Soil Fertility Management (ISFM) and discussed its application under soil water conservation practice. Various ISFM options have been developed and adopted by farmers in the study area. However, many studies have focused on nutrient replenishment through use of organic and inorganic inputs. The runoff and erosion studies in the area have not given attention to the potential of tied- ridging and maize-soybean rotation as important options for land management in the region. This study was therefore set up with an objective of evaluating the effects of integrated soil fertility management options and tied-ridging, on maize-soybean yields and selected soil properties.

CHAPTER THREE
MATERIALS AND METHODS

3.1 The Study Area

The study was carried out at Kigogo Primary School in Meru South Sub-county of Tharaka Nithi County in the Central Highlands of Kenya (Figure 3.2). Kigogo primary school site is situated in the Upper Midland Agro-ecological Zone (UM2-UM3), coordinates (00^o 23” S, 37^o 38” E) (Jaetzold *et al.*, 2007). It is located on the eastern slopes of Mount Kenya at an altitude of about 1,500m above sea level (a.s.l.), with annual mean temperature of 20^oC and total annual rainfall ranging from 1200 to 1400 mm. The rainfall is bi-modal with short rains (SR) falling between October, November and December (ONM) and long rains (LR) which fall between March, April and May (MAM). Soils in the study area are predominantly humic Nitisols, a typical deep and weathered soil with moderate to high inherent fertility (Jaetzold *et al.*, 2007). Agriculture in the area 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 such as dairy and beef cattle, goats, sheep, poultry and pigs (Shisanya *et al.*, 2009). It is a predominantly maize growing zone with small holdings ranging from 0.1 to 2 hectare with an average of 1.2 hectare per household (Shisanya *et al.*, 2009).

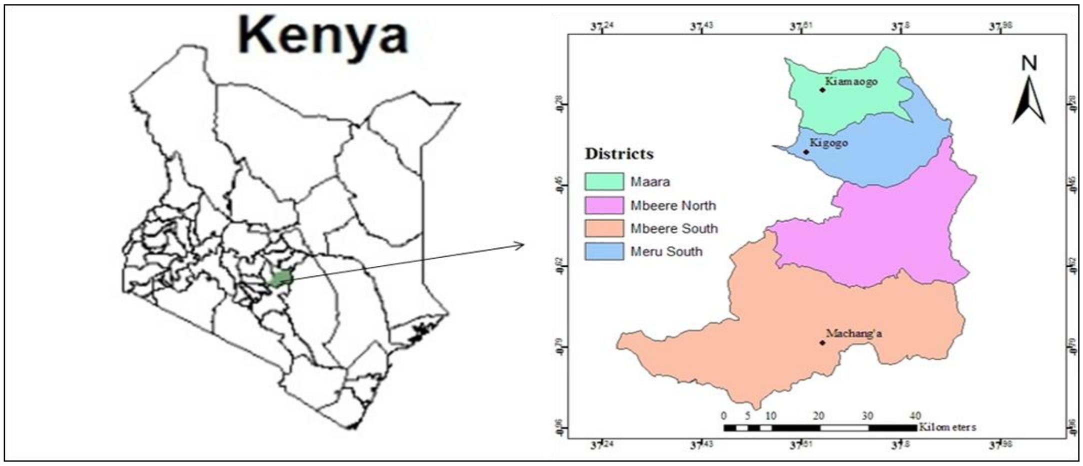

Figure 2. Map of study area in blue (Source: Ngetich, 2012)

3.2 Experimental Design and Treatments

The experiment was laid out as a randomized complete block design (RCBD) replicated four times. There were nine treatments where ISFM (manure+fertilizer, tithonia+fertilizer, inorganic fertilizer, and control) technologies were combined with soil and water conservation technology (either tied ridged or conventional).

To evaluate maize-soybean rotation effect on maize grain yield, rotation cropping system was applied and sole treatment (continuous maize cropping without rotation as control) was set up with inputs: manure+fertilizer under conventional tillage. The considered rotation treatment was the treatment with the same inputs as the sole treatment. The treatments are shown in Table 3.1

Table 1. Treatments combination at the study site at Kigogo primary school, Tharaka-Nithi County, Kenya

No	SWC	ISFM	Treatment combination	Fertilizer application
1	Tied ridging	Manure+fertilizer	TR+M+IF	5t M ha^{-1}+30kg F ha^{-1}
2	Tied ridging	Tithonia+fertilizer	TR+T+IF	5t T ha^{-1}+30kg F ha^{-1}
3	Tied ridging	Inorganic fertilizer	TR+IF	60kg F ha^{-1}
4	Tied ridging	Control	TR+Con	No inputs
5	Conventional	Manure+fertilizer	C+M+IF	5t M ha^{-1}+30kgF ha^{-1}
6	Conventional	Tithonia+fertilizer	C+T+IF	5t T ha^{-1}+30kg F ha^{-1}
7	Conventional	Inorganic fertilizer	C+IF	60kg F ha^{-1}
8	Conventional	Control	C+Con	No inputs
9	Conventional	Manure+fertilizer	Sole+M+IF	5t M ha^{-1}+30kgF ha^{-1}
10	Conventional	Manure+fertilizer	Rotation+M+IF	5t M ha^{-1}+30kgF ha^{-1}

3.3 Trials Management

The test crops were maize (*Zea mays, L.*) and soybean (*Glycine max,L.*) where maize variety DH515 and soybean variety gazelle were used, 3 seeds were planted per hill to ensure successful establishment and maximum population and thinned to 2 per hill after germination. The plot size was 4.5 m × 6 m and the spacing was 0.75 m between rows by 0.50 m within rows for maize crop while for soybean crop, was 0.50 m by 0.10 m.

Both NPK 23-23-0 and TSP 46% P_2O_5 inorganic fertilizers were applied at planting on maize and soybean plots respectively at a full rate of 60 kg N ha^{-1} and 60 kg P ha^{-1}, at half rate of 30 kg N ha^{-1} and 30 kg P ha^{-1} on required plots. Cattle manure and *Tithonia diversifolia* were applied as organic fertilizers 2 weeks before planting both at full rate of 10 t ha^{-1} and half rate of 5 t ha^{-1} (plate 1).

(a) **(b)**

Plate 1. Incorporation of cattle manure (a) and tithonia biomass (b) at Kigogo site

Soybean seeds were inoculated with *Rhizobial* biofix inoculum just before planting to facilitate effective nitrogen fixation. Conventional tillage was done by hand hoeing to a depth of about 15 cm in all plots. For tied-ridging technology, ridges were constructed at the beginning of each season on selected plots and maintained throughout the season. Maintenance involved reconstruction of any ties and ridges that might have collapsed during rainfall. The height of ties was 15 cm high and distance between them was alternated at 50 cm while the height of the ridges was 20 cm (plate 2).

(a) **(b)**

Plate 2. Construction of tied ridges (a) and a tied plot (b) at Kigogo site

Weeding was done using hoe as necessary so as to keep the plots clean throughout the season. Using rotation cropping system, the two test crops (maize and soybean) were alternated every season except on sole treatments for sole maize and sole soybeans which were maintained throughout the trial period.

3.4 Data Collection

3.4.1 Rainfall Data Collection

Daily rainfall measurement during experimental period was taken at Kigogo site using an automatic rain gauge to measure the amount of rainfall over a period for each of the two seasons (SR14 and LR15) in millimeter as unit of measurement. The rain gauge was mounted on a distance of 20 m away from trials, in an open air area, to avoid obstruction of rain pattern. The rain gauge was placed on a level position, clear of overhead structure and the stand on which it was mounted on was free from vibration. Status of rain gauge was regularly checked to ensure proper functioning and accurate recordings of rainfall during the study period.

3.4.2 Soil sampling

Soil sampling was done in each plot using Zigzag method for two depths i.e 0-20 cm and 20-40 cm from each block using soil auger. Soil samples were taken before and after experiment to evaluate the effect of treatments on selected soil properties. Seventy six (76) soil samples were collected per each sampling activity for laboratory soil analysis (plate 3).

(a) (b)

Plate 3. Soil sampling before (a) and after experimental period (b)

3.4.3 Laboratory soil analyses

Soil samples were analysed for soil pH water and KCl, soil texture, soil organic carbon, total N, available P and exchangeable bases. The methods employed the standard methods of soil analysis described by Ryan *et al.*,(2001) and Okalebo *et al*., (2002).

3.4.3.1 Soil pH

Soil pH_{water} was measured in a 1:2.5 soil water ratio (Ryan *et al.*, 2001) that is adding 25 ml of distilled water to 10 g of soil in a 50 ml beaker, the mixture was stirred for 10 minutes and allowed to stand for 30 minutes and stirred again for 2 minutes. The pH_{water} value was then measured using a glass electrode PT 100 for 30 to 60 seconds until the value remained constant (Okalebo *et al*., 2002), electrode was then removed from the bottle, rinsed with distilled water before introducing it to the next sample. Similar process was used to measure soil $pH_{KCl;}$ it was measured in a suspension of soil and 1M KCI in a 1:2.5 soil solution ratio (Ryan *et al.*, 2001; Okalebo *et al.*, 2002).

3.4.3.2 Soil texture

Soil texture was determined by the hydrometer method (Okalebo *et al.,* 2002). A sample of 50 g of air-dry soil (2 mm sieve) was weighed and put into a plastic beaker of 500 mL, and then 125 mL of distilled water added. The mixture was stirred to wet the soil, carefully 20 mL of hydrogen peroxide was added to froth in the beaker, put it into hot water bath at 85 to 90^0C and agitated until frothing ceases indicating complete destruction of organic matter. The mixture was cooled and 10 ml of 10% calgon solution was added to it and allowed to stand for 10 minutes, the sample was transferred to the dispersing cup and mixed for 2 minutes with electric high speed stirrer. The suspension was transferred into a 1000 ml graduated cylinder using distilled water to wash all soil particles and filled it with distilled water, the cylinder was covered and mixed the suspension by inverting the cylinder carefully 10 times. 2 to 3 drops of amyl alcohol were added to the soil suspension in order to remove froth. After 20 sec, the hydrometer was gently placed in the suspension and at 40 sec hydrometer reading was taken and measured the temperature of the suspension. Repeat the mixing of soil suspension 10 times and after 2 hours of undisturbed standing of cylinder, both hydrometer and temperature readings were recorded. The percentage of sand, silt and clay were then calculated as described by Okalebo *et al*., (2002) and used the textural triangle diagram to determine the textural class of the soil.

3.4.3.3 Soil Organic Carbon and total Nitrogen

Both total N and C in the soil were determined using the flash combustion method using the CN Elemental Analyzer (Krotz *et al*., 2013). Fifteen grams of soil was weighed in a tin capsule. This was done twice: first after filling the tin capsule and second after folding the tin capsule.

The weight of each sample was recorded in the sample table which is contained in the Eager Experience Software which calculates and records the data as obtained from the CN analyzer. The flash elemental analyzer system completely oxidizes the sample with a catalyst through combustion. It is then further reduced to CO_2, N_2 and H_2O under high temperature reactor chambers. The solid sample was wrapped inside a tin capsule and placed into a steel column through an auto sampler. The tin capsule containing the sample was burned in a pure oxygen environment. The carbon in the sample was converted into carbon dioxide, nitrogen into free air or oxides and hydrogen to water. A stream of helium gas carried those gases into a quartz column (which carries the reduction processes) filled with copper that reduced the nitrogen oxides to nitrogen and removes excess oxygen. The gas stream then flowed through a magnesium perchlorate trap (adsorption filter) which removed water before CO_2 and N_2 went into a gas chromatograph (GC) column at room temperature. N_2 then flowed through the gas chromatograph column first (retention time -110 seconds) then CO_2 (retention time- 190s) and the thermal detector (TD) was used to give the quantitative data. Helium is used as a carrier gas because it is chemically inert. For soil organic matter was calculated using the equation 1.

$$\%\,Soil\ Organic\ Matter\ =\ 1.724\ \times \%\,Soil\ Organic\ Carbon \qquad \text{Equation 1}$$

3.4.3.4 Soil Phosphorus

Soil available P was determined using 5 g of soil (2 mm sieve) which was weighed and placed into a 50 mL Erlenmeyer flask, tapping the scoop on flask to remove all of soil from scoop. A 25 mL of extracting solution (reagent-grade ammonium fluoride (NH_4F)) mixed with distilled water and 250 mL of previously standardized 1M HCl were added to each flask and shaken at 200 rpm or more for 5 minutes at a room temperature (24 to 27^{o}C). Extracts were filtered using Whatman No. 42 filter paper. Phosphorus was then analyzed by colorimetric using a blank and standards prepared in Mehlich P-1 extracting solution (Mehlich, 1953). Five milliliters of working standard series, soil extract and blank were pipetted into test tubes. One milliliter of ammonium vanadate-molybdate mixture was added and mixed well and its optical density read on the UV-Visible spectrophotometer after one hour at 430nm. To obtain the concentration of P in the soil (ppm), the ppm in solution obtained from the UV-Visible spectrophotometer was multiplied by the dilution factor, which is the ratio of soil sample in grams to the extracting solution which in this case was the ratio 1:5 obtained from 5g of soil sample in 25ml extracting solution.

3.4.3.5 Exchangeable cations

Exchangeable cations (K, Ca, Mg, and Na) were measured by weighing 5 g of air-dry soil (2 mm sieve) into a clean plastic bottle with a stopper, and 30 mL of 1M NH_4OAc neutral solution was added, closed and shaken for 2 hours with a mechanical shaker. Solution was centrifuged for 15 minutes with a rotating apparatus (2000 r.p.m) and filtered through Whatman filter paper No.2 into a 100 mL flask. An addition of 30 mL 1M NH_4OAc solution into a plastic bottle was done and shaken for 30 minutes, centrifuged for 15 minutes and transferred the filtrate into the same flask. The above steps were repeated and filled to 100 mL flask mark containing filtrate with NH_4OAc solution. This soil extract was used for the determination of Na, K, Ca and Mg using atomic absorption spectrophotometer (Okalebo *et al.*, 2002). The concentration measurement was calculated using equation 2.

$$Exchangeable\ cations\ (Mgkg^{-1})\ soil = \frac{((a-b)\times v \times f \times 1000)}{1000 \times w} \qquad \text{Equation 2}$$

Where: a is Exchangeable cations are concentrations of K, Na, Ca, and Mg in the sample extract; b is concentration of the element in the blank extract; v is volume of the extract solution; w is weight of the soil sample; and f is dilution factor.

3.4.4 Maize measurements

Maize stover and grains were harvested at maturity from a net plot of 21m^2 after leaving 2 rows, one in upper and another in lower parts, and first and last plants in each row of a plot to minimize edge effect. The number of plants harvested at each net plot was recorded, and cobs were removed from plants, counted and their numbers and fresh weights were recorded. The fresh weights and dry weights of above ground biomass (stover), dry weights of cobs, and dry weights of grain after hand shelling were weighed using a balance in kg/net plot and converted in t ha^{-1}. Moisture content % for grain after 2 weeks of air drying period for each net plot was determined.

3.4.5 Soybean measurements

Soybeans were harvested two weeks before maize harvesting; the above ground biomass weights and weights of grains were measured at physiological maturity stage from a net plot of 19.80 m^2, the size of plots were reduced to net plots to minimize the effect of edge. The size was reduced by leaving 2 rows, one in upper and another in lower parts and 50 cm in both sides of a plot. The following data were taken while harvesting activity of soybeans at each net plot: number of plants harvested, number of pods, weights of pods, weights of grains after hand threshing from pods, plants were cut at the ground level, fallen leaves were collected and fresh weights of above ground biomass were recorded and moisture contents % for grain were taken. Fresh weights of sub samples of haulms and husks were recorded and they were dried in air for a period of 2 weeks, after which their dry weights and dry weights of above biomass were determined. The weights were measured by using a balance in kg/net plot after which unit of measurement was converted into t ha^{-1}.

Therefore, all yields data (biomass and grains) for maize and soybean in t ha^{-1} were calculated and adjusted to 12.5% standard moisture content for maize and 12% standard moisture content for soybean using equations 3 and 4.

$$\text{Yield (t ha}^{-1}) = \left(\frac{10{,}000\ \text{m}^2 \times \text{observed yield}}{\text{net plot area (m}^2)}\right)/1000 \qquad Equation 3$$

$$MA\ yield(t\ ha^{-1}) = Yield \times \frac{\%\ standardmoisturecontent\ (12.5\%)}{\%\ moisturecontentatharvesting} \qquad Equation\ 4$$

Where MA yield is the moisture adjusted yield.

3.5 Statistical Data Analysis

All data were recorded and managed in Microsoft excel. Maize and soybean above ground biomass and grain yields and selected soil properties data were subjected to analysis of variance (ANOVA) using Genstat software (GenStat, 2007). Means were separated using

Least Significant Difference (LSD). Pair-wise comparison of the initial and final soil properties parameters were subjected *to student t*-test. All analyses were done at $p = 0.05$.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Rainfall Patterns during Experimental Period

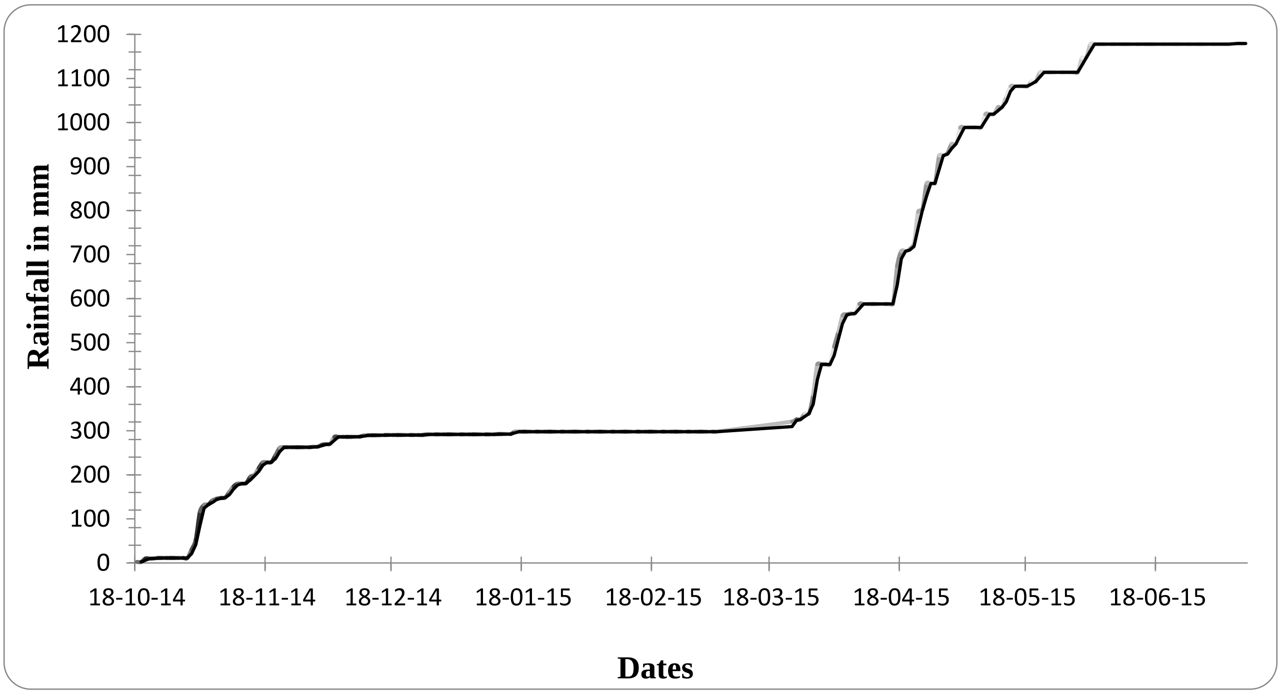

Figure 3. Cumulative rainfall during short rains and long rains seasons

There was a significant difference in total rainfall amounts received and rainfall distribution between the two cropping seasons during experimental activity. However, there was a higher amount of rainfall in long rains season compared to short rains season. The cumulative rainfall amounts received for long rains season in 2015 and short rains season in 2014 seasons were 882 mm and 298 mm respectively (Figure 3). The rainfall performance was not good throughout the short rains season and there was intra-seasonal rainfall variation and the dry spells were observed in different stages of crop growth. For example 7 days immediately after planting, 9 days on tussling and flowering periods and 16 days on development of cobs and pods. While during long rains season, runoff and soil erosion occurred and destroyed ridges at critical crop phenological development stages. It was due to heavy rains like for example 2 days after emergence stage and 2 days in the period of flowering. Similarly, dry spells were reported in long rains 2015 (8 days and 9 days during flowering and podding stages respectively).

4.2 Maize and Soybean Yields

4.2.1 Effects of ISFM Technologies and Tied-Ridging on maize yields

Maize stover and grain yields were significantly affected by combination of ISFM and tied ridging treatments during short rains season 2014 ($p \leq 0.05$) and long rains season 2015 ($p \leq 0.05$) (Table 2). During short rains season 2014, ISFM technologies under tied ridging treatments recorded higher stover yields and a slight increase in grain yields over the control under tied ridging treatment. On the other hand, during long rains season 2015, all treatments under tied ridging significantly increased stover yields over the control under tied ridging treatment. Manure+fertilizer and tithonia+fertilizer treatments increased yields by 34.8% and 43.5% over the control under tied ridging treatment.

Manure+fertilizer and tithonia+fertilizer under conventional treatments increased maize grain yields by 86.7% and 100%, respectively over the control under conventional treatment during short rains season 2014. Similarly, in long rainy season of 2015, both stover and grain yields were influenced by ISFM and conventional treatments. Grain yields from inorganic fertilizer, manure+fertilizer and tithonia+fertilizer under conventional treatments were increased by 63.6%, 54.5% and 54.5%, respectively over the control under conventional treatment.

Table 2. Maize stover and grain yields under various treatments during short 2014 and long rains seasons 2015

	SR14	**LR15**
Treatment	**Stover (t ha^{-1})**	**Stover (t ha^{-1})**
Tied ridging+No inputs	4.7^{b}	4.5^{b}
Tied ridging+Fertilizer	6.6^{a}	7.4^{a}
Tied ridging+Manure+Fertilizer	6.8^{a}	7.5^{a}
Tied ridging+Tithonia+Fertilizer	6.8^{a}	7.4^{a}
Conventional+No inputs (control)	4.1^{b}	4.0^{b}
Conventional+Fertilizer	8.0^{a}	8.3^{a}
Conventional+Manure+Fertilizer	6.8^{a}	8.7^{a}
Conventional+Tithonia+Fertilizer	7.5^{a}	8.3^{a}
p-value	0.002*	<.001**
LSD	1.7	1.9
	SR14	**LR15**
Treatment	**Grain (t ha^{-1})**	**Grain (t ha^{-1})**
Tied ridging+No inputs	1.7^{bc}	2.3^{bc}
Tied ridging+Fertilizer	2.0^{ab}	3.0^{ab}
Tied ridging+Manure+Fertilizer	2.3^{ab}	3.1^{a}
Tied ridging+Tithonia+Fertilizer	2.1^{ab}	3.3^{a}
Conventional+No inputs (control)	1.5^{c}	2.2^{c}
Conventional+Fertilizer	2.4^{abc}	3.6^{ab}
Conventional+Manure+Fertilizer	2.8^{a}	3.4^{a}
Conventional+Tithonia+Fertilizer	3.0^{a}	3.4^{a}
p-value	0.037*	0.005*
LSD	1.0	0.7

Note: *significant at $p \leq 0.05$. Means with the same superscript letters in the same column indicate no significant difference between treatments.

Tithonia biomass in combination with mineral fertilizer under soil water conservation (tied ridging and conventional tillage) gave good results in terms of yields than the control treatment. However, the explanation for the observed trends is that tithonia biomass provided soil nutrients, because its biomass is relatively high in N, P and K nutrients and other nutrients, for example Ca and Mg than other green manure (Gachengo *et al.* 1999). The nutrients are released through organic matter mineralization into soil solution and made available for plant uptake hence increasing crop growth. This corroborates observation by

Niang *et al.*, (1996) who found high maize yield following incorporation of tithonia biomass than biomass of other common shrubs and trees in western Kenya. Gachengo (1996) also demonstrated increased maize yield following incorporation of fresh tithonia biomass at the equivalent of 5 t dry matter ha^{-1} on a site deficient in N, P and K in western Kenya. Furthermore, NPK fertilizer used in the treatments in combination with tithonia similarly contributed to crop growth and maize yields. Other studies have also demonstrated that the combined use of organic and inorganic inputs enhance use efficiency of chemical fertilizers (Mucheru *et al*., 2007; Mugwe *et al*., 2007). However, availability of tithonia biomass growing near smallholder agricultural fields is not sufficient to supply all the nutrients required to eliminate nutrient deficiencies over large areas of the fields. Integration of tithonia biomass and mineral fertilizer is consequently essential for the supply of sufficient soil nutrients and enhance crop yields.

Several other authors like Gachengo, (1996) and Niang et al., (1996) have reported increased yield performance with integration of organics with inorganic fertilizer. Kimani *et al.* (2004) reported 101%, 112% and 196% increase with maize grain yield in central Kenya with an additional of mineral fertilizer to tithonia biomass at 2 t ha^{-1}, 4 t ha^{-1} and 10 t ha^{-1}, respectively. Other researchers in central Kenya have also observed higher maize grain yields as a result of applying tithonia with combination of mineral fertilizers compared with sole application of mineral fertilizers (Mugendi *et al.,* 1999; Mutuo *et al.,* 2000; Nziguheba *et al*., 2000; Kimetu *et al.,* 2004; Mucheru-Muna *et al*., 2007). Gikonyo *et al.* (2010) also reported positive results of combined tithonia and fertilizer in increasing maize yields.

In this study, manure in combination with mineral fertilizer also recorded higher performance in maize yields during both SR14 and LR15 seasons, respectively. This could be attributed to manure supplying nutrients for plant growth. Similar results were reported by Nziguheba *et al.,* (1998). According to Nziguheba *et al.,* (1998), manure has the advantage of supplying essential plant nutrients either directly or indirectly by alleviating aluminum toxicity or by producing organic acids which complex with aluminum, thereby increasing nutrient availability. Thus, in this study, the use of combined manure and mineral fertilizer inputs could have sustained soil health resulting to high crop production. Similarly, Ahmad *et al*., (2008) also reported better crop yield in manure plus mineral fertilizers treatment. According to Palm *et al.* (1997) a combination of manure and mineral fertilizer has synergistic effects and improved synchronization of nutrient release and uptake by crop leading to higher yields. This is especially so when the levels of mineral fertilizers used are relatively low as it is the case in most smallholder farms of central Kenya (Kapkiyai *et al.* 1998). This result is also in agreement with earlier studies by other researchers as (Adeniyan and Ojeniyi, 2005) who reported that application of chemical fertilizer and organic manure improved maize grain yield.

4.2.2 Effects of ISFM Technologies and Tied-Ridging on soybean yields

In short rains season 2014, soybean biomass and grain yields were significantly influenced by the treatments ($p \leq 0.05$). In long rains season 2015, soybean biomass and grain yields were not significantly affected by the treatments ($p > 0.05$) (Table 3). However, during short rains season 2014, Tithonia+Fertilizer under tied-ridging treatment were significant recorded higher soybean grain yield of 1.1 t ha^{-1} and with an increase of 57.1% over control under tied-ridging treatment. On the other hand, Tithonia+Fertilizer and Manure+Fertilizer plus conventional tillage treatments significantly recorded higher soybean grain yields of 1.1 t ha^{-1} and 1.0 t ha^{-1}, respectively and by an increase of 66.7% and 83.3%, respectively over control under conventional tillage treatment.

Table 3. Soybean biomass and grain yields in different treatments during short rains 2014 and long rains 2015 seasons

	SR14	**LR15**
Treatment	**Biomass_ t ha^{-1}**	
Tied ridging+No inputs	1.8^{bc}	1.9^{a}
Tied ridging+Fertilizer	2.0^{bc}	2.1^{a}
Tied ridging+Manure+Fertilizer	2.8^{abc}	2.8^{a}
Tied ridging+Tithonia+Fertilizer	2.6^{abc}	2.4^{a}
Conventional+No inputs (control)	1.7^{c}	2.2^{a}
Conventional+Fertilizer	2.6^{abc}	2.7^{a}
Conventional+Manure+Fertilizer	2.9^{ab}	2.6^{a}
Conventional+Tithonia+Fertilizer	3.3^{a}	3.1^{a}
p-value	0.028*	0.386^{ns}
LSD	0.959	1.034
	SR14	**LR15**
Treatment	**Grain_ t ha^{-1}**	
Tied ridging+No inputs	0.7^{bc}	1.0^{a}
Tied ridging+Fertilizer	0.8^{abc}	1.0^{a}
Tied ridging+Manure+Fertilizer	0.9^{abc}	1.5^{a}
Tied ridging+Tithonia+Fertilizer	1.1^{a}	1.1^{a}
Conventional+No inputs (control)	0.6^{c}	1.2^{a}
Conventional+Fertilizer	0.8^{abc}	1.5^{a}
Conventional+Manure+Fertilizer	1.0^{ab}	1.8^{a}
Conventional+Tithonia+Fertilizer	1.1^{a}	1.9^{a}
p-value	0.039*	0.158^{ns}
LSD	0.331	0.832

Note: ns: not significant, *_significant at $p \leq 0.05$. Means with the same superscript letters in the same column indicate no significant difference between treatments.

Treatments having tithonia biomass in combination with inorganic fertilizer under both tied ridging and conventional tillage performed better than other treatments. The explanation of the good performance from tithonia plus inorganic fertilizer could be due to the beneficial effects of tithonia as a source of nutrients. The inorganic fertilizer, on the other hand, is an important source of phosphorus, an important element in soybean establishment. Several other researchers have reported significant increase on soybean grain yield with application of tithonia biomass and mineral fertilizer (Mekki & Ahmed, 2005; Tagoe *et al*., 2008; Javaid and Mahmood, 2010). In addition, application of manure+fertilizer under no-tied ridging tillage also provided highest grain yield in SR2014 (1.0 t ha^{-1}) over fertilizer alone and control treatments. Danga *et al*., (2009) reported that manure when combined with P-mineral fertilizer contributed to improved soil physical conditions and nutrient use efficiency and soybean yields. Similarly, significant increase in soybean yields when manure was applied in combination with mineral fertilizers than mineral fertilizers alone have been successfully reported by Zingore & Giller (2012) and Peter & Ayolagha (2012). Similar results were reported by Kimani *et al.* (2004) who observed greater improvement in soybean yields in treatments with cattle manure and mineral fertilizer than when the inputs were applied separately. Therefore, the findings from this study confirmed the advantage of integrated approach.

Use of ISFM technologies under conventional tillage was more beneficial in both maize and soybean grain yields than in ISFM technologies under tied ridging during experimental period (Table 4). For instance, during short rains season, tithonia+fertilizer plus conventional tillage treatment increased maize grain yield by 42.9% increase compared to tithonia+fertilizer under tied ridging treatment. During long rains season, mineral fertilizer and tithonia+fertilizer under conventional tillage treatments significantly increased soybean grain yields by 50% and 81.8%, respectively over inorganic fertilizer and tithonia+fertilizer under tied ridging treatments while those of maize grain yield increased by 20% and 3%, respectively.

Table 4. Maize and soybean grain yields under tied ridging and conventional tillage during short and long rains seasons

Maize						
	SR14			LR15		
ISFM	Tied ridging	conventional	Difference	Tied ridging	conventional	Difference
No inputs	1.7^{a}	1.5^{b}	+0.2	2.3^{b}	2.2^{b}	+0.1
Fertilizer	2.0^{a}	2.4^{a}	–0.4	3.0^{ab}	3.6^{a}	–0.6
Manure+Fert.	2.3^{a}	2.8^{a}	–0.5	3.1^{ab}	3.4^{a}	–0.3
Tithonia+Fert.	2.1^{a}	3.0^{a}	–0.9	3.3^{a}	3.4^{a}	–0.1
p-value	0.039^{ns}	0.007^{*}		0.115^{ns}	0.013^{*}	
LSD	1.248	0.778		0.842	0.835	

Soybean						
	SR14			LR15		
ISFM	Tied ridging	conventional	Difference	Tied ridging	conventional	Difference
No inputs	0.7^{b}	0.6^{b}	+0.1	1.0^{a}	1.2^{a}	–0.2
Fertilizer	0.8^{ab}	0.8^{ab}	0.0	1.0^{a}	1.5^{a}	–0.5
Manure+Fert.	0.9^{ab}	1.0^{a}	–0.1	1.5^{a}	1.8^{a}	–0.3
Tithonia+Fert.	1.1^{a}	1.1^{a}	0.0	1.1^{a}	1.9^{a}	–0.8
p-value	0.031^{*}	0.036^{*}		0.149^{ns}	0.228^{ns}	
LSD	0.325	0.356		0.719	1.114	

Note: ns_not significant, *_significant at $p \leq 0.05$. Means with the same superscript letters in the same column indicate no significant difference between treatments.

It was observed that treatments with tied ridging produced lower maize and soybean grain yields than treatments with conventional tillage during short and long rains seasons. Poor performance of crop and low yields from treatments with tied ridges may be as a result of low rainfall amounts, poor rainfall distribution and dry spells that occurred during short rains season 2014. This may have caused increased soil temperature, shallow penetration of moisture into the soil compared to that of conventional tillage and dryness of the ridges. Moreover, the treatments with tied ridges also gave significant low maize and soybean grain yields during long rains season 2015. Heavy rainfall may have caused runoff and soil loss through erosion which destroyed ridges, exposed roots to the air and they were spoiled.

These results are in agreement with Videnović *et al*. (2011) who observed higher maize yield in conventional tillage plots in comparison with zero-tillage and tied ridging plots. However, majority of the studies reported had high yields with tied ridging and effective in reducing run-off and soil loss. But most common reports of success were focused when study areas received low rainfall. For example, the findings of McCarthey *et al.* (1971) indicated that in low rainfall condition, tied ridging resulted in higher maize yields in Tanzania. Similarly, the findings by Ngetich, (2012) in on-station experiment in Mbeere South sub-county noted that tied ridging had the highest positive effect on maize yields (1.23 t ha^{-1}) than mulching and control even when the total rainfall amounts were below average. Accordingly, the results of this study indicate that tied ridging technique for soil water conservation could not respond to crop yields thus more trials need to be done for the confirmation and for other methods in Meru South.

4.3 Effect of maize-soybean rotation on maize grain yield

There was no significant difference between continuous maize cropping and maize-soybean rotation on maize grain yield during experiment ($p<0.05$) (Table 5). Maize grain yield increased by 45.8% and by 10.3% for maize-soybean rotation and continuous maize cropping, respectively, during the period of this study.

Table 5. Means for maize grain yield under maize-soybean rotation and continuous maize cropping during experiment

Treatment	SR14	LR15	% increased
	Maize (grain_ t ha^{-1})	Maize (grain_ t ha^{-1})	
Maize-soybean rotation	2.4^{a}	3.5^{a}	45.8
Continuous maize cropping	2.9^{a}	3.2^{a}	10.3
p-value	0.416ns	0.231ns	
LSD	1.765	1.544	

Note: ns_not significant, *_significant at $p \leq 0.05$. Means with the same superscript letters in the same column indicate no significant difference between treatments

In the two seasons of this study, the results showed that crop rotation had an advantage in increasing maize grain yield relative to continuous maize cropping system. The difference in performance increasing maize grain yield for maize-soybean rotation was 35.5% over maize-maize rotation. This positive result of soybean on grain yield of the following maize was remarkable in the field because of rotation farming practice. Therefore integration of legumes in the cropping systems in the rotational system, results in positive improvements in subsequent cereal yields. It is likely to be due to legume N-fixation benefits thus improving the N supplies in soil (Kamara *et al.*, 2008). The benefit grain yield of legume rotation on a subsequent maize crop has also been reported by other researchers. Sanginga *et al.* (2003) reported maize yield increases by 14% due to soybean grown in rotation with maize. Osunde and Bala (2005) reported an increase of maize yield by at least 25% following the soybean as a preceding crop in rotation. In this study, the yield for continuous maize cropping system was low, as confirmed by others (Meese *et al.*, 1991; Crookston *et al.*, 1991) who reported lower yields for monocropped maize than for maize-soybean rotation. Therefore, farmers in Meru South should be encouraged to use the rotation cropping system of soybean and maize to enhance their maize yields.

4.4 Effects of ISFM technologies and tied ridging on selected soil properties

4.4.1 Soil status of study site before experiment

The initial soil characterization at the study area (Table 6) indicated that soil was medium acidic with a mean value of 5.5. Soils were moderated in organic carbon and organic matter with mean values of 1.9% and 3.3% respectively. Also in study area, soil total nitrogen content and available phosphorus were adequate with mean values of 0.2% and 35.8 ppm, respectively. The mean soil exchangeable bases: K, Ca, Mg and Na were 0.6 cmol kg^{-1}, 3.7 cmol kg^{-1}, 1.4 cmol kg^{-1}, and 0.4 cmol kg^{-1}, respectively.

Table 6. Soil chemical and physical properties at beginning of experiment (October 2014)

Soil properties	Baseline value
Chemical properties	
pH_{water}	5.5
Organic C (%)	1.9
Organic matter (%)	3.3
Total N (%)	0.2
Available P (ppm)	35.8
Exchangeable K^+ (C mol kg^{-1})	0.6
Exchangeable Ca^{2+} (C mol kg^{-1})	3.7
Exchangeable Mg^{2+} (C mol kg^{-1})	1.4
Exchangeable Na^+ (C mol kg^{-1})	0.4
Physical properties	
Bulk density (g/cm^3)	0.95
Sand %	7.5
Silt %	9.5
Clay %	83
Texture class	clay

4.4.2 Effects of ISFM technologies and tied ridging on soil pH and available P

4.4.2.1 Soil pH

Soil pH varied significantly among the treatments before and after the experimental period ($p<0.05$). In overall, ISFM under conventional tillage increased soil pH. This implies that soil acidity was reduced. On the other hand, ISFM under tied ridging caused an increase in soil acidity (Table 7). In both seasons, application of mineral fertilizers under tied ridging treatment caused significant decrease of soil pH water (t-test, $p=0.022$) with a negative change of 4.4% over baseline. Mineral fertilizers under conventional tillage treatment caused significant increase of soil pH water than other treatments (t-test, $p=0.015$) with a positive increase of 8.7% over initial value. However, application of mineral fertilizers under conventional tillage significantly increased soil pH values by releasing cations such as $NH4^+$, Ca^{2+}, Mg^{2+},… in soil solution by dissolution process. The cations replaced H^+ and Al^{3+}ions; hence they reduced soil acidity at the study area. McCauley *et al.* (2009) observed that soil pH is affected by mineral fertilizer application. Reduction of soil pH in mineral fertilizer under tied ridges treatment could be that the ridges caused fertilizer to reject N in form of NH_4^+ which in oxidation process releases H^+ ions. This is in agreement with the findings of Darusman *et al.* (1991) and Hati *et al.* (2008) who also reported a significant decline in soil pH with the application of N-fertilizer under tied ridging in vertisols of semi-arid tropics. On the other hand use of manure+fertilizer under both tied- and no-tied ridges recorded a slight increase of soil pH although not significant (t-test, $p=0.121$ and 0.679 respectively). This is probably because manure combined with mineral fertilizer in soil solution has an ability to absorb hydrogen ions (H^+) in its complex humic forms which consequently reduce soil acidity. These results are in agreement with the finding of Mugwe *et al.,* (2009) who reported an increase of soil pH in treatments that received manure after four years of experimentation. Mugendi *et al*., (1999) also, reported a general reduction in soil acidity after organic and mineral fertilizers application.

Table 7. Soil pH$_{water}$ at beginning and end of the experiment under different treatments

		Soil pH (water)		
Treatment	baseline	final	change	t-test, *p*
Tied ridging+No inputs	5.60^{ab}	5.58^{abcd}	-0.02	0.88ns
Tied ridging+Fertilizer	5.48^{bc}	5.25^{d}	-0.23	0.02*
Tied ridging+Manure+Fertilizer	5.45^{bc}	5.63^{abc}	+0.18	0.12ns
Tied ridging+Tithonia+Fertilizer	5.56^{abc}	5.38^{cd}	-0.18	0.06ns
Conventional+No inputs (control)	5.38^{c}	5.38^{cd}	0.00	0.98ns
Conventional+Fertilizer	5.39^{c}	5.86^{bc}	+0.47	0.02*
Conventional+Manure+Fertilizer	5.69^{a}	5.75^{ab}	+0.06	0.68ns
Conventional+Tithonia+Fertilizer	5.54^{abc}	5.56^{abcd}	+0.02	0.92ns
p-value	0.031*	0.023*		
LSD	0.1882	0.3439		

Note: ns_not significant, *_significant at $p \leq 0.05$. Means with the same superscript letters in the same column indicate no significant difference between treatments.

4.4.2.2 Soil available P

There was a decline in soil available P in all treatments (Table 4.8). Soil available phosphorus decreased significantly under mineral fertilizer and tithonia+fertilizer under tied ridging treatments (t-test, p=0.015 and 0.006, respectively). The decrease was 27.4% and 46.5%, respectively, over baseline values. Further, P also declined significantly in manure+fertilizer and tithonia+fertilizer under conventional tillage treatments (43.2% and 42.3% respectively over initial values).

The reduction of soil P could be due to the increase of soil acidity observed in this study and crop uptake. In acidic soils, P reacts with Fe and Al to produce insoluble Fe and Al phosphates that are not readily available for plant uptake. Nurlaeny *et al.* (1996) reported that, acidic soils are naturally deficient in available P because significant portions of applied P are immobilized and precipitated as insoluble Al phosphates. The soils in this region are Nitisols that highly fix P because the soils are highly which favour P fixation. The other explanation of decrease in P from soil is due to P uptake by the crops which eventually were harvested.

Table 8. Soil available P at beginning and end of the experiment period under various treatments

	Avail. P in ppm			
Treatment	baseline	final	Change	t-test, *p*
Tied ridging+No inputs	36.25^{ab}	30.00^{a}	-6.25	0.37ns
Tied ridging+Fertilizer	26.25^{c}	20.60^{a}	-5.65	0.02^{*}
Tied ridging+Manure+Fertilizer	31.25^{bc}	27.50^{a}	-3.75	0.15ns
Tied ridging+Tithonia+Fertilizer	37.50^{ab}	25.60^{a}	-11.9	0.01^{*}
Conventional+No inputs (control)	41.25^{a}	36.20^{a}	-5.05	0.52ns
Conventional+Fertilizer	31.25^{a}	27.50^{a}	-3.75	0.18ns
Conventional+Manure+Fertilizer	41.25^{a}	28.80^{a}	-12.45	0.02^{*}
Conventional+Tithonia+Fertilizer	40.00^{a}	28.10^{a}	-11.9	0.001^{*}
p-value	$<.001^{**}$	0.115ns		
LSD	7.351	11.14		

Note: ns_not significant, *_significant at $p \leq 0.05$. Means with the same superscript letters in the same column indicate no significant difference between treatments.

4.4.3 Effects of ISFM technologies on soil total N and soil organic carbon

4.4.3.1 Soil total N

Initially, soil total N values were significantly different among the treatments (p=0.005) but at the end of the experiment, treatments were not significantly different (p=0.476) (Table 9). There was a decrease of soil total N in all treatments. Treatments with sole mineral fertilizers inputs under both tied ridging and conventional tillage recorded a significant decline in soil total N (t-test, p=<0.001 and 0.044, respectively) at the end of the trial period.

Manure+fertilizer under tied ridging and tithonia+fertilizer under no-tied ridging treatments significantly reduced soil total N. (t-test, p=0.002 and 0.005, respectively).

The reduction of soil total N could be attributed to soil nitrogen leaching in the site that was caused by heavy rains in LR15 season and N immobilization (Figure 3). Kamoni *et al.* (2000) also observed a decreasing trend in total soil N content during the growth period of maize which they concluded to be due to immobilization of N. Another study by Van Straaten (2002) observed and confirmed that with the treatment that received mineral fertilizer and manure, the decline in soil total N could have been caused by high nitrates leaching. The other explanation for decrease in total N could be high rates of mineralization within this tropical environment. In the tropics the high humidity and temperatures are responsible for high rates of decomposition in the soil resulting in decrease of total N (Mugwe *et al.*, 2009 and Six et al., 2008).

Table 9. Soil total N at beginning and end of the experiment in relation to treatments

	Total soil N in %			
Treatment	**baseline**	**final**	**change**	**t-test**
Tied ridging+No inputs	0.20^{ab}	0.17^{a}	-0.03	0.043^{*}
Tied ridging+Fertilizer	0.20^{ab}	0.17^{a}	-0.03	$<0.001^{**}$
Tied ridging+Manure+Fertilizer	0.22^{a}	0.19^{a}	-0.03	0.002^{*}
Tied ridging+Tithonia+Fertilizer	0.19^{bcd}	0.17^{a}	-0.02	0.058ns
Conventional+No inputs (control)	0.19^{cd}	0.17^{a}	-0.02	0.120ns
Conventional+Fertilizer	0.20^{bcd}	0.17^{a}	-0.03	0.044^{*}
Conventional+Manure+Fertilizer	0.20^{bc}	0.19^{a}	-0.01	0.138ns
Conventional+Tithonia+Fertilizer	0.20^{bc}	0.17^{a}	-0.03	0.005^{*}
p-value	0.005^{*}	0.476ns		
LSD	0.0143	0.0264		

Note: ns_not significant, *_significant at $p \leq 0.05$. Means with the same superscript letters in the same column indicate no significant difference between treatments.

4.4.3.2 Soil organic carbon

At the start of the experiment, soil organic carbon was significantly different among the treatments (p=0.002) but the changes were not significant at end of experiment (2 seasons) (p=0.421). However, there was slight increase of soil organic carbon in the treatment of manure+fertilizer under tied ridging and conventional tillage, respectively (Table 10). McDonagh *et al*., (2001) also observed an improvement of soil organic carbon by combining organic and inorganic fertilizers treatment in an experiment. This treatment could significantly increase organic matter in the long term not in one or two seasons.

Table 10. Soil Organic Carbon at beginning and end of the experiment activity under treatments

	SOC in %			
Treatment	baseline	final	change	t-test
Tied ridging+No inputs	1.95^{bc}	1.95^{a}	0.00	0.982ns
Tied ridging+Fertilizer	1.99^{ab}	1.90^{a}	-0.09	0.209ns
Tied ridging+Manure+Fertilizer	2.14^{a}	2.14^{a}	0.00	0.987ns
Tied ridging+Tithonia+Fertilizer	1.86^{bcd}	1.89^{a}	+0.03	0.770ns
Conventional+No inputs (control)	1.80^{cd}	1.88^{a}	+0.08	0.612ns
Conventional+Fertilizer	1.92^{bcd}	1.89^{a}	-0.03	0.849ns
Conventional+Manure+Fertilizer	1.92^{bcd}	2.13^{a}	+0.21	0.064ns
Conventional+Tithonia+Fertilizer	1.91^{bcd}	1.85^{a}	-0.06	0.655ns
p-value	0.002^{*}	0.421ns		
LSD	0.1631	0.3245		

Note: ns = not significant, * = significant at $p \leq 0.05$. Means with the same superscript letters in the same column indicate no significant difference between treatments.

4.4.4 Effects of ISFM technologies on soil exchangeable K, Ca and Mg

At the initial soil sampling, K^+ values were not significantly different among the treatments (p=0.133) and the values ranged between 0.57 cmol kg^{-1} and 0.67 cmol kg^{-1}. After harvesting, there were significant increased of K^+ in soil (p=<.001), with significant positive changes in manure+fertilizer under both tied ridging and no-tied ridging treatments, of

101.7%, 102.9% over initial values. Mineral fertilizer alone under no-tied ridging treatment showed a positive increment of 55.9% over initial value (Table 11).

In case of soil exchangeable Ca^{2+}, the changes were significantly affected by the treatments before and after planting ($p=<.001$ and $p=0.010$, respectively) during experimental undertaking. There were positive changes and significant increases of soil Ca^{2+} after application of manure+fertilizer under both tied ridging and conventional treatments by 50.7% and 52.9% respectively over initial values.

Soil exchangeable Mg^{2+} values were significantly different between treatments at the beginning ($p=0.045$) but at the end of experiment there were no significant differences ($p=0.073$). However, mineral fertilizer, manure+fertilizer and tithonia+fertilizer under tied ridging treatments significantly increased soil exchangeable Mg^{2+} by 43%, 77.4% and 51.1%, respectively over initial values. Similarly, mineral fertilizer and manure+fertilizer under conventional treatments significantly increased soil exchangeable Mg^{2+} by 98.4% and 38.3%, respectively, over baseline values.

The increase of soil exchangeable bases in the study was due to release of nutrients from organic materials (K^+, Ca^{2+} and Mg^{2+}) into the soil solution. This is because decomposition of organic materials releases nutrients into soil through mineralization process. This is confirmed by Rahman et al., (2002) who found an increase of exchangeable K, Ca and Mg in the soil as a result of applied manure either alone or combined with fertilizer .

Table 11. Soil exchangeable K^{+}, Ca^{2+} and Mg^{2+}at beginning and end of the experiment activity under treatments

	K^{+} in cmol kg^{-1}			
Treatment	**Baseline**	**Final**	**Change**	**t-test**
Tied ridging+No inputs	0.67^{a}	0.86^{cd}	+0.19	0.166ns
Tied ridging+Fertilizer	0.64^{a}	0.57^{f}	-0.07	0.216ns
Tied ridging+Manure+Fertilizer	0.60^{a}	1.21^{ab}	+0.61	$<0.001^{**}$
Tied ridging+Tithonia+Fertilizer	0.66^{a}	0.84^{cd}	+0.18	0.062ns
Conventional+No inputs (control)	0.56^{a}	0.79^{df}	+0.23	0.071ns
Conventional+Fertilizer	0.59^{a}	0.92^{cd}	+0.33	0.013^{*}
Conventional+Manure+Fertilizer	0.67^{a}	1.36^{a}	+0.69	$<0.001^{**}$
Conventional+Tithonia+Fertilizer	0.63^{a}	0.88^{cd}	+0.25	0.060ns
p-value	0.133ns	$<.001^{**}$		
LSD	0.086	0.2615		
	Ca^{2+}in cmol kg^{-1}			
Tied ridging+No inputs	4.35^{a}	4.86^{ab}	+0.51	0.527ns
Tied ridging+Fertilizer	3.65^{b}	3.08^{c}	-0.57	0.097ns
Tied ridging+Manure+Fertilizer	3.65^{b}	5.50^{a}	+1.85	0.004^{*}
Tied ridging+Tithonia+Fertilizer	3.75^{b}	3.77^{bc}	+0.02	0.925ns
Conventional+No inputs (control)	3.05^{c}	3.48^{c}	+0.43	0.404ns
Conventional+Fertilizer	3.30^{bc}	5.38^{a}	+2.08	0.064ns
Conventional+Manure+Fertilizer	3.40^{a}	5.20^{ab}	+1.80	0.016^{*}
Conventional+Tithonia+Fertilizer	3.75^{b}	4.50^{abc}	+0.75	0.398ns
p-value	$<.001^{**}$	0.010^{*}		
LSD	0.536	1.483		
	Mg^{2+} in cmol kg^{-1}			
Tied ridging+No inputs	1.38^{abc}	2.16^{a}	+0.78	0.006^{*}
Tied ridging+Fertilizer	1.37^{abc}	1.96^{a}	+0.59	0.043^{*}
Tied ridging+Manure+Fertilizer	1.37^{abc}	2.43^{a}	+1.06	0.004^{*}
Tied ridging+Tithonia+Fertilizer	1.37^{abc}	2.07^{a}	+0.70	0.002^{*}
Conventional+No inputs (control)	1.23a	1.74^{c}	+0.51	0.010^{*}
Conventional+Fertilizer	1.28a	2.54^{c}	+1.26	$<0.001^{**}$
Conventional+Manure+Fertilizer	1.54a	2.13^{a}	+0.59	0.028^{*}
Conventional+Tithonia+Fertilizer	1.46^{ab}	2.24^{a}	+0.78	0.064ns
p-value	0.045^{*}	0.073ns		
LSD	0.179	0.5536		

Note: ns_not significant, *_significant at $p \leq 0.05$. Means with the same superscript letters in the same column indicate no significant difference between treatments.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The first objective of this study was to determine the effect of ISFM technologies and tied ridging on maize and soybean yields. Results showed that a combination of tithonia biomass and fertilizer under tied ridging increased yields during the two seasons under study. Soybean increased by 57.1% and 10% in short rain 2014 and long rain 2015 seasons, respectively, while maize increased by 23.5% and 43.5%, respectively, compared to the control. The second best treatment was a combination of manure plus fertilizer under tied ridging which increased maize and soybean grain yields by 35.3% and 28.6%, respectively, in short rain season 2014 and 34.8% and 50%, respectively in long rain season 2015. The findings of this study showed good performance of maize and soybean under ISFM technologies with no-tied ridging (conventional) than ISFM technologies under tied ridging.

The second objective was to evaluate maize-soybean rotation effect on maize yield. The findings revealed that, rotational cropping system is the best agricultural practice than continuous of mono-cropping system. It significantly increased maize grain yield by 35.5% over maize sole crop. The increase was attributed to improved soil fertility by soybean through biological nitrogen fixation.

The third objective was to assess the effect of ISFM technologies and tied ridging on soil pH, available P, total N, soil organic carbon and soil exchangeable bases. The results of this study showed that ISFM technology under tied ridging increased soil acidity, for example: mineral fertilizer under tied ridging treatment reduced soil pH by 4.4% over baseline value (t-test, p=0.022). Generally, soil available phosphorus decreased after the two seasons; eg in mineral fertilizer and tithonia+fertilizer under tied-ridging treatments recorded a decrease of 27.4% and 46.7%, respectively over the baseline values. Soil total nitrogen also reduced across the treatments. In mineral fertilizer and manure+fertilizer under tied ridging treatments, the reduction was significant ($p<0.001$ and $p=0.002$, respectively) with a reduction of 43.2% and 42.3%, respectively over baseline values. Soil organic matter also generally decreased in all treatments. Finally, soil exchangeable bases generally increased in treatments with ISFM technologies under tied ridging treatments. Soil exchangeable K^+, Ca^{2+} and Mg^{2+} significantly increased in manure+fertilizer under tied ridging treatment ($p<0.001$, $p=0.004$ and $p=0.004$, respectively) with a positive increase of 101.7%, 50.7% and 77.4% over initial values.

Findings from this research showed that organic fertilizers such as tithonia biomass and cattle manure combined with mineral fertilizers under tied ridging and conventional method were the most successfully ISFM technologies for increasing both maize and soybean grain yields in Tharaka-Nithi County. Further, the study results showed that tied ridging was not suitable for improving soil fertility and enhancing maize-soybean yields in the study area. Finally, the study highlighted the benefits of maize-soybean rotation on maize grain yields.

5.2 Recommendations

Based on the findings from this research, the following recommendations were suggested:

1. To improve maize and soybean yields, use of combination of either tithonia biomass or manure with inorganic fertilizer without tied ridging is recommended for farmers.

2. To increase maize grain yield and to assist farmers to get double categories of crops per each season, maize-soybean rotational farming practice is recommended as the best farming practice for adoption by the farmers.
3. The ISFM technologies under tied ridging are not the best technologies to improve soil fertility, therefore they are not recommended for using by farmers in the study area. Further research is needed for other technologies.
4. Further research on rotational farming system should be conducted to find out its long term effects on maize yield, soil fertility and economic implications for smallholder farmers.

REFERENCES

Abelson PH (1999). A potential phosphate crisis. *Science 283*: 2015.

Adams, F. (1984). Soil acidity and liming, *Agronomy Monograph No. 12, 2nd edn.*, pp. 349-368.

Adeniyan, O.N. and Ojeniyi. S.O. (2005). Effect of poultry manure, NPK 15-15-15 and combination of their reduced levels on maize growth and soil chemical properties. *NigeriaJournalSoil Science*, 15: 34-41.

Adiel RK (2004) Assessment of on-farm adoption potential of nutrient management strategies in Chuka division, Meru south, Kenya. *MSc Thesis*, Kenyatta University, Kenya

Ahmad, R., M. Naveed, M. Aslam, Z.A. Zahir and M. Arshad. (2008). Economizing the use of nitrogen fertilizer in wheat production through enriched compost. *Renewable Agric. Food Syst.*, 23: 243- 249.

Anuar, A.R., Shamsuddin, Z.H., Yaacob, O., 1995. Contribution of legume-N by nodulated groundnut for growth of maize on an acid soil. *Soil Biology and Biochemistry* 27, 595–601.

Awodun, M. A., Omonijo, L. I. & Ojeniyi, S. O. (2007). Effects of goat dung and NPK fertilizer on soil and leaf nutrient content, growth and yield of pepper. *International Journal of Soil Science, 2* (2): 142-127.

Barker DW, Sawyer JE (2005). Nitrogen application to soybean at early reproductive development. *Agronomic Journal*, 97: 615-619

Bationo, A., Kimetu, J., Vanlauwe, B., Bagayoko, M., Koala, S., and Mukwunye, A. U. (2011). Comparative analysis of the current and potential role of legumes in integrated soil fertility management in West and Central Africa. In A. W. Bationo, *Fighting poverty in Sub Saharan Africa: The multiple role of legumes in integrated soil fertility management* (pp. 117 - 150). Springer science + Business media.

Bationo, A. and Waswa, B. S. (2011). New challenges and opportunities for integrated soil fertility management in Africa. In *Innovation as Key to the Green Revolution in Africa. Exploring the Scientific Facts*, Vol 1 (Eds A. Bationo, B. Waswa, J. M. Okeyo, F. Maina and J. Kihara). New York, NY: Springer.

Borlaug, N. E., & Dowswell, C. R. (1995). Mobilising science and technology to get agriculture moving in Africa. *Development Policy Review, 13*(2), 115-129.

Boosalis, M.G., and B. Doupnik. 1976. Management of crop diseases in reduced tillage systems. *Bull. Entomol. Soc. Am.* 22:300–302.

Bossio, D., Geheb, K., & Critchley, W. (2010). Managing water by managing land: addressing land degradation to improve water productivity and rural livelihoods. *Agricultural Water Management, 97*(4), 536-542.

Bouldin DL., Klausner SW., Right WS. (1984). Use of nitrogen from manure. In Hauck RD. Nitrogen in crop production. *Madison, Wisconsin,* USA: ASA/CSSA/SSSA.

Bremer, E., H.H. Janzen, B.H. Ellert, and R.H. McKenzie. 2008. Soil organic carbon after twelve years of various crop rotations in an Aridic Boroll. *Soil Sci. Soc. Am. J.* 72:970–974.

Buresh, R. J., Smithson, P. C., & Hellums, D. T. (1997). Building soil phosphorus capital in Africa. *Replenishing soil fertility in Africa* (replenishingsoi), 111-149.

Byerlee, D. and Heisey, P. 1993. Strategies for technical change in small-farm agriculture, with particular reference to sub-Saharan Africa. In: Policy Options for Agricultural Development in Sub-Saharan Africa. Russell, N. and Dowswell, C. (Eds.). *CASIN/SAA/Global 2000*, Mexico, OF, Mexico.

Caires, E. F., Churka, S., Garbuio, F. J., Ferrari, R. A. & Morgano, M. A. (2006). Soybean yield and quality as function of lime and gypsum application. *Scientia Agricola (Piracicaba, Brazil), 63* (4): 370 – 379.

Campbell, C.A., and R.P. Zentner. 1993. Soil organic matter as influenced by crop rotations and fertilization. Soil Sci. Soc. Am. J. 57:1034–1040.

Carsky, R.J., Abaidoo, R., Dashiell, K.E., Sanginga, N., 1997. Effect of soybean on subsequent maize grain yield in Guinea savanna of West Africa. *Afr. Crop Sci. J.* 5, 31–39.

Chiezey UF and Odunze AC (2009), Soybean response to application of poultry manure and phosphorus fertilizer in the Sub-humid Savanna of Nigeria. *J. Ecol. Nat. Environ.,* 1(2): 025-031.

Craswell, E. T., Grote, U., Henao, J., & Vlek, P. L. (2004). Nutrient flows in agricultural production and international trade: Ecological and policy issues*: ZEF Discussion Papers on Development Policy*.

Crookston, R.K., J.E. Kurle, P.J. Copeland, J.H. Ford, and W.E. Lueschen. (1991). Rotational cropping sequence aff ects yield of corn and soybean. *Agron. J.* 83:108–113.

Danga, B. O., Ouma, J. P., Wakindiki. I. I. C. & Bar-Tal, A. (2009). Legume–Wheat rotation effects on residual soil moisture, nitrogen and wheat yield in tropical regions. In D. L.Sparks (Eds). *Advances in Agronomy* Vol. 101. Burlington: Academic Press, pp.315-349.

Darusman, L.R., Stone, D.A., Janssen, K.A.and Long, J.H., (1991). Soil properties after twenty years of fertilizers with different nitrogen sources. *Soil Sci. Soc. Am. J.* 55, 1097–1100.

Deibert EJ, Bijeriego M, Olson RA (1979). Utilization of 15N fertilizer by nodulating and non-nodulating soybean isolines. *Agron. J.,* 71: 717–723.

Dick, W.A., D.M. Van Doren, G.N. Triplett, and J.E. Henry. 1986. Influence of long-term tillage and rotation combinations on crop yields and selected soil parameters. *Res. Bull. (Sun Chiwawitthaya thang Thale Phuket) Bull. 1180 Ohio Agric. Res. And Dev. Ctr.,* Ohio State Univ.,Wooster.

Drechsel, P., Giordano, M., & Gyiele, L. (2004). *Valuing nutrients in soil and water: concepts and techniques with examples from IWMI studies in the developing world* (Vol. 82): Iwmi.

FAO. (1995). World Agriculture: Towards 2010. *A FAO Study*. Rome. Italy. pp. 1–481.

FAO. (2002). Conservation agriculture: Case studies in Latin America and Africa. *FAO Soils Bulletin 78,* FAO, Rome. pp 70.

Fournier, F. (1967). Research on soil erosion and soil conservation in Africa. *African Soils, 12*(1), 53-96.

Fox, R.L, Hasan, S.M., and Iones, R.C. 1971. Phosphate and sulfate sorption by latosols. *Proceedings of an International Symposium on Soil Fertility Evaluation*. New Delhi, 1, 857-864.

Fox, R.L. 1988. Phosphorus- a basic nutrient for soil improvement. In: *Proceedings of an International Conference in the Management and Fertilization of Upland Soils in the Tropics and Subtropics*.

Gachengo C.N. (1996): Phosphorus release and availability on addition of organic materials to phosphorus fixing soils. *MSc thesis.* Moi University, Eldoret, Kenya.

Gan Y, Stulen I, Van Keulen H, and Kuiper PJC (2003). Effect of N fertilizer top-dressing at various reproductive stages on growth, N2 fixation and yield of three soybean (Glycine max (L.) Merr.) Genotypes. *Field Crops Res., 80*: 147–155.

GenStat, (2007). GenStat Discovery Edition 3: Lawes Agricultural Trust, Rothamsted Experimental Station Hertfordshire, United Kingdom.

Gikonyo, E. W., Zaharah, A. R., Hanafi, M. M., and Anuar, A. R. (2010). Extractable Bray - 1 phosphorus and crop yields as influenced by addition of phosphatic fertilizers of various solubilities integrated with manure in an acid soil. *Nutr Cycl Agroecosyst 88* , 79 - 90.

Gowda BS, Miller JL, Rubin SS, Sharma DL, Timko MP (2000). Isolation, sequencing and mapping of resistance gene analogs from cowpea (*Vigna unguiculata* L. Walp). In: Fatokun CA, Tarawali SA, Singh BB, Kormawa PM, Tawo (eds). Challenges and opportunites for enhancing sustainable cowpea production. *Proceeding of the world cowpea conference III, Int. Inst. Trop. Agric.* Ibadan, Nig. 4-8 Sept. 2000 pp. 167-184.

Graham, P.H., Vance, C.P., 2000. Nitrogen fixation in perspective: an overview of research and extension needs. *Field Crops Res*. 65, 93–106.

Hartemink, A. E. 2006. Assessing soil fertility decline in the tropics using soil chemical data. *Elsevier, Advances in Agronomy,* volume 89. 47 pages.

Hati, K.M., Swarup, A., Mishra, B., Manna, M.C., Wanjari, R.H., Mandal, K.G., Misra, A.K., 2008. Impact of long-term application of fertilizer, manure and lime under intensive cropping on physical properties and organic carbon content of an Alfisol. *Geoderma 148*, 173–179.

Heisey, P.W., and W. Mwangi. 1996. Fertilizer use and maize production in sub-Saharan Africa. *Econ.Work. Pap.* 96-01. CIMMYT, Mexico City.

Higgs, R.L., A.E. Peterson, and W.H. Paulson. 1990. Crop rotation: Sustainable and profitable. *J. Soil Water Conserv.* 45:68–70.

Hoff, J.E., Howe, J.M., and Mitchell, C.A. (1982), Nutritional and cultural aspects of plant species selection for a regenerative life support system, *NASA Contract Report 166324, Moffet Field*, California.

Holford, I.C.R. 1997. Soil phosphorus: Its measurement, and its uptake by plants. *Aust. J. Soil Res.* 35:227-239.

Hue NV., Craddock GR., Adams F. (1986). Effect of organic acids on aluminium toxicity in subsoils. *SoilSci. Soc. Am. J.*50, p. 28–34.

Jaetzold, R., Schmidt, H., Hornet, Z. B., and Shisanya, C. A. (2007). Farm Management Handbook of Kenya. Natural Conditions and Farm Information. 2n*d Edition. Vol.11/ C. Eastern Province. Ministry of Agriculture/GTZ*, Nairobi, Kenya.

Javaid, A. & Mahmood, N. (2010). Growth, nodulation and yield response of soybean to biofertilizers and organic manures. *Pakistan Journal of Botany, 42* (2): 863 - 871.

Jama, B., Palm,C. A., Buresh,R. J., Niang, A.,Gachengo, C.,Nziguheba,G. and Amadalo, B. (2000). *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: a review. *Agroforestry Systems* 49:201–221.

Kaleem, F.Z., 1993. Assessment of N benefit from legumes to following maize crop. 1989 *Annual Report of Nyakpala Agricultural Experimental Station.* Tamale, Ghana, GTZ, Eschborn, Germany, pp. 109–113.

Kamara, A. Y., Abaidoo, R., Kwari, J. & Omoigui, L. (2007). Influence of phosphorus application on growth and yield of soybean genotypes in the tropical savannas of northeast Nigeria. *Archives of Agronomy and Soil Science, 53* (5): 539 – 552.

Kamara, A. Y., Kwari, J., Ekeleme, F., Omoigui, L. & Abaidoo, R. (2008) Effect of phosphorus application and soybean cultivar on grain and dry matter yield of subsequent maize in the tropical savannas of north-eastern Nigeria. *African Journal of Biotechnology, 7* (15): 2593-2599.

Kamara, A. Y., Ekeleme, F., Omoigui, L. O. & Ajeigbe, H. A. (2011) Phosphorus and nitrogen fertilization of soybean in the nigerian savanna. *Experimental Agriculture Available on Cambridge Journals Online. doi:10.1017/S0014479711000512*.

Kamoni, P.T., Mburu, M.W.K and Gachene, C.K.K (2000). Influence of irrigation on maize growth, grain yield and nitrogen uptake in a semi-arid environment in Kenya. *Paper presented to Soil Science Society of East Africa (SSSEA)* conference held in Mombasa, Kenya, 27 November.1 December 2000. SSSEA/ KARI, Nairobi.

Kapkiyai, J., Karanja, N., Woomer, P., & Qureshi, J. (1998). Soil Organic Carbon Fractions In A Long-term Experiment And The Potential For Their Use As A Diagnostic Assay In Highland Farming Systems Of Central Kenya Highlands.

Karlen, D.L., G.E. Varvel, D.G. Bullock, and R.M. Cruse. 1994. Crop rotations for the 21st century. *Adv. Agron.* 53:1–44.

Karlen, D.L., E.G. Hurley, S.S. Andrews, C.A. Cambardella, D.W. Meek, M.D. Duff y, and A.P. Mallarino. 2006. Crop rotation effects on soil quality at three Northern Corn/Soybean Belt locations. *Agron. J.* 98:484–495.

Katupitiya, A., D.E. Eisenhauer, R.B. Ferguson, R.F. Spalding, F.W. Roeth, andM.W. Bobier. 1997. Long-term tillage and crop rotation effects on residual nitrate in the crop root zone and nitrate accumulation in the intermediate vadose zone. *Trans.ASAE* 40:1321–1327.

Kennedy IR, Cocking EC, eds (1997) Biological Nitrogen Fixation: The Global Challenge and Future Needs. *Rockefeller Foundation Bellagio Conference Proceedings. SUN Fix Press*, University of Sydney, Sydney, p 83.

Kihanda FM, Warren GP, Atwal SS (2004). The Influence of Goat Manure Application on Crop Yield and Soil Nitrate Variations in Semi-Arid Eastern Kenya. In Bationo A (eds) Managing nutrient cycles to sustain soil fertility in Sub-Saharan Africa. *Academy Science Publishers (ASP)*. Nairobi. Kenya.

Kimani, S. K., Macharia, J. M., Gachengo C., Palm, C. A. & Delve, R.J.2004. Maize production on the central highlands of Kenya using cattle manures combines with modest amounts of mineral fertiliser. *Uganda Journal of Agricultural sciences* 9:480–490.

Kimetu, J. M., Mugendi, D. N., Palm, C. A., Mutuo, P. K., Gachengo, C. N., Bationo, A., Nandwa, S. and Kung'u, J. B. (2004). Nitrogen fertilizer equivalencies of organics of differing quality and optimum combination with inorganic nitrogen source in central Kenya. *Nutrient Cycling in Agroecosystems* 68:127–135.

Kowal, J. (1970). The hydrology of a small catchment basin at Samaru, Nigeria. 3. Assessment of surface run-off under varied land management and vegetation cover. *Nigerian Agricultural Journal, 7*(2), 120-133.

Krotz, L. Ragaglia, L., and Giazzi, G. 2013. Quick, accurate nitrogen, total carbon and total organic carbon determination in soils by elemental analysis. Strada, Rivoltana, Italy.

Liang W, Wu X, Zhang S, Xing Y, Wang R (2011). Effect of organic amendments on soil water storage in the aeolian sandy land of northeast China. *Proceedings of the Electrical and Control E Engineering (ICECE), International Conference o*n 16th – 18th Sept. 2011. pp. 1538-1540.

Liasu, M. O., Ogundare, A. O. and Ologunde, M. O. 2008. Effect of soil supplementation with fortified Tithonia mulch and directly applied inorganic fertilizer on growth and development of potted okra plants. *American-Eurasian Journal of sustainable Agriculture.* 2(3), 264-270, 2008.

Little, T.M. and F.J. Hills, 1978. Agricultural Experimentation. Design and Analysis, *pp: 350, John Willey & Sons Inc.,* New York.

Mabapa, P. M., Ogola, J. B. O., Odhiambo, J. J. O., Whitbread, A. & Hargreaves, J. (2010). Effect of phosphorus fertilizer rates on growth and yield of three soybean (*Glycine max*) cultivars in Limpopo Province. *African Journal of Agricultural Research, 5* (19): 2653 - 2660.

Mahamood, J., Abayomi, Y. A. & Aduloju, M. O. (2009). Comparative growth and grain yield responses of soybean genotypes to phosphorous fertilizer application. *African Journal of Biotechnology, 8* (6): 1030 - 1036.

Maheshbabu, H. M., Hunje, R., Patil, N. K. B. & Babalad, H. B. (2008). Effect of organic manures on plant growth, seed yield and quality of soybean. *Karnataka Journal of Agricultural Science, 21* (2): 219 - 221.

Mannering, J.V., and D.R. Griffi th. 1981. Value of crop rotation under various tillage systems. *Agron. Guide AY-230. Coop. Ext. Serv., Purdue Univ.,* West Lafayette, IN.

Martins LMV, Xavier GR, Rangel FW, Ribeiro JRA, Neves MCP, Morgado LB, Rumjalek, NG (2003). Contribution of biological nitrogen fixation to cowpea : a strategy for improving grains yield in the semi-arid regions of brasil. *Biol. Fertil. Soils 38*: 333-339.

Mateete, B., Nteranya, S., and L, W. P. (2010). Restoring Soil Fertility in Sub-Sahara Africa. *Advances in Agronomy, 108,* 183-236.

McCann, J. (2005). *Maize and grace*: Harvard University Press.

McCauley, A., Clain, J., and Jacobsen, J. (2009). *Commercial fertilizers and soil amendments. Nutrient management, a self-study course from MSU extension continuing education series.* Montana state, USA: Montana state university.

McDonagh, J.F., Thomsen, T. B. and Magid, J. 2001. Soil organic matter decline and compositional change associated with cereal cropping in southern Tanzania. *John Wiley & Sons, Ltd*, Land Degrad. Develop. 12: 13±26.

Meese, B.G., P.R. Carter, E.S. Oplinger, and J.W. Pendleton. 1991. Corn/ soybean rotation eff ect as influenced by tillage, nitrogen, and hybrid/ cultivar. *J. Prod. Agric.* 4:74–80.

Mehlich, A. (1953) Determination of P, Ca, Mg, K, Na, NH4. Short test methods used in soil testing division, *Department of Agriculture, Raleigh, North Carolina. S.T.D.P.* No. 1- 53.

Mekki, B. B. & Ahmed, A. G. (2005). Growth, yield and seed quality of soybean (*Glycine max* L.) as affected by organic, biofertilizer and yeast application. *Research Journal of Agriculture and Biological Sciences, 1* (4): 320 - 324.

Merillo JM., Lopez R., Cabrera F., Martin-Olmedo P. (1995). Testing a low quality urban compost as a fertilizer for arable farming. *Soil Use Manage.* **11**, p. 127–131.

Micheni, A. N., Kihanda, F. M., Warren, G. P., and Probert, M. E., (2004). Testing the APSIM Model with Experiment Data from the Long Term Manure Experiment at Machang'a (Embu), Kenya. Canberra: *Australian Center for International Agricultural Research* (ACIAR).

Ministry of Agriculture (MoA), 2009. Strategic Plan 2008-2012. Nairobi: *Kenya Ministry of Agriculture*.

Miriti, J. M., Kironchi, G., Esilaba, A. O., Heng, L. K., Gachene, C. K. K., and Mwangi, D. M. (2012). Yield and water use efficiencies of maize and cowpea as affected by tillage and cropping systems in semi-arid Meru south and Mbeere south. *Agricultural Water Management*, 115, 148-155.

Mitiku, H., and K. Fassil. 1996. Soil and moisture conservation in semi-arid areas of Ethiopia. Pages 60–66 *in* T. Yizengaw, E. Mekonnen, and M. Behailu (eds.). Soils Information and database: The basis for improved agricultural productivity and sustainable land resources management. 1996. *Proceedingsof the third conference of the Ethiopian Society of Soil Science*.

Mucheru-Muna, M. W., Mugendi, D., Kungu, J., Mugwe, J. and Bationo, A. (2007). Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. *Agroforestry Systems* 69:189–197.

Mugendi, D. N., Nair, P. K. R., Mugwe, J. N., O'Neill, M. K. and Woomer, P. L. (1999). Calliandra and Leucaena alley cropped with maize. Part 1: soil fertility changes and maize production in the sub-humid highlands of Kenya. *Agroforestry Systems* 46:39–50.

Mugwe, J., Mugendi, D., Mucheru-Muna, M., Merckx, R., Chianu, J., & Vanlauwe, B. (2009). Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya. *Experimental agriculture, 45*(01), 61-75.

Mugwe, J.N., Mugendi, D., Kungu, J.B., Mucheru, M.M. (2007). Effects of plant biomass, manure and inorganic fertilizer on maize yield in the central highlands of Kenya. *African Crop Science Journal*, Vol 15, No. 3,pp 111-126.

Mugwe, J., Mugendi, D., Okoba, B., Tuwei, P. & O'Neill, M. (2004). Soil conservation and fertility improvement using leguminous shrubs in central highlands of Kenya: NARFP case study. In: Bationo, A. (Ed.), Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. *Academy Science Publishers*, Nairobi, pp. 277–297.

Mutuo PK, Mukalama JP, Agunda J (2000): On-farm testing of organic and inorganic phosphorous source on maize in Western Kenya. In: The biology and fertility of tropical soils, *TSBF report*, p 22.

Nagarajah S and Nizar BM (1982) Wild sunflower as a green manure for rice in the mid-country west zone. *Tropical Agriculturalist 138*: 69–78.

Ngetich, K. F. (2012). Enhancing farmers' agricultural productivity through improved field management practices in the central highlands of Kenya. *Ph.D Thesis,* Kenyatta University, Kenya. Pp 42-159.

Ngetich, K. F., Mucheru-Muna, M., Mugwe, J. N., Shisanya, C. A, Diels, J. & Mugendi, D. N. (2014)Length of growing season, rainfall temporal distribution, onset and cessation dates in the Kenyan highlands. *Agricultural and Forest Meteorology* 188, 24-32.

Ngigi, S. N., Rockström, J., & Savenije, H. H. (2006). Assessment of rainwater retention in agricultural land and crop yield increase due to conservation tillage in Ewaso Ng'iro river basin, Kenya. *Physics and Chemistry of the Earth, Parts A/B/C, 31*(15), 910-918.

Niang A, Amadalo B, Gathumbi S and Obonyo CO (1996). Maize yield response to green manure application from selected shrubs and tree species in western Kenya: a preliminary assessment. In: Mugah JO (ed) *Proceedings of the First Kenya Agroforestry Conference on People and Institutional Participation in Agroforestry for Sustainable Development,* pp 350–358.

Nurlaeny, N., Marschner, H. and George, E. (1996). Effects of liming and mycorrhizal colonization on soil phosphate depletion and phosphate uptake by maize (Zea Mays L.) and soybean (Glycine max L.) grown in two tropical acid soils. *Plant Soil*, 275-285.

Nziguheba, G. andMutuo, P. K. (2000). Integration of *Tithonia diversifolia* and inorganic fertilizer for maize production. In *The Biology and Fertility of Tropical Soils,* TSBF Report, 23 pp.

Nziguheba G, Palm CA, Buresh RJ, Smithson PC (1998) Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. In*: The biology and fertility of tropical soils, TSBF report,* p 22.

Odedina, J. N., Odedina, S. A. & Ojeniyi, S. O. (2011). Effect of types of manure on growth and yield of cassava (*Manihot esculenta*, Crantz). *Researcher, 3* (5): 1 – 8.

Okalebo, J.R., Kenneth, W.G. and Woomer, P.L. (2002). Laboratory method of soil and plant analysis. Second edition, SACRED Office Nairobi. 128p.

Okoba, B., Tenge, A., Sterk, G., & Stroosnijder, L. (2007). Participatory soil and water conservation planning using an erosion mapping tool in the central highlands of Kenya. *Land Degradation & Development, 18*(3), 303-319.

Olabode, O. S., Ogunyemi S., Akambi, W. B., Adesina, G. O., and Babajide, P.A. 2007. Evaluation of Tithonia diversifolia (Hemsl. A. Grey) for soil improvement. *World Journal of Agricultural Sciences.* 3(4), 503-507.

Omiti JM, Freeman HA, Kaguongo W, Bett C (1999). Soil fertility maintenance in Eastern Kenya: Current practices, constraints and opportunities. *CARMASAK Working Paper* No. 1.KARI/ICRISAT, Kenya.

Osunde, A. O., and Bala, A. (2005). Nitrogen derived from promiscuous soybean in maize - based cropping systems in the moist savanna of Nigeria. *Nigerian Journal of Soil Science 15* , 109 - 115.

Palm CA, Gachengo CN, Delve RG, Candisch G, Giller K (2001) Organic inputs for soil fertility management in tropical agroecosystem: application of organic resource database. *Agric Ecosyst Environ 83*:27–42

Palm, C., Myers, R., & Nandwa, S. (1997). Organic-inorganic nutrient interactions in soil fertility replenishment. *Replenishing soil fertility in Africa. Soil Science Society of America special publication, 51*, 193-218.

Peter, K. D. & Ayolagha, G. A. (2012). Effects of remediation on growth parameters, grain and dry matter yield of soybean (*Glycine max*) in crude oil polluted soils in Ogoni land, South Eastern Nigeria. *Asian Journal of Crop Science, 4* (3): 113-121.

Phengsouvana,V., Attanandana, T. & Yost, R. S. (2009). Lime application to two acidic upland soils for soybean production in Champasak Province, Lao PDR. *Kasetsart Journal (Natural Sciences), 43*: 19 – 27.

Powlson, D., Gregory, P., Whalley, W., Quinton, J., Hopkins, D., Whitmore, A., . . . Goulding, K. (2011). Soil management in relation to sustainable agriculture and ecosystem services. *Food Policy, 36*, S72-S87.

Prentice, a.n. 1946. *Tied-ridging*. East AI Agric. 1. 12. 101-108.

Rahman MA, Meisner CA, Duxbury JM, Lauren J, Hossain ABS (2002). Yield response and change in soil nutrient availability by application of lime, fertilizer and micronutrients in an acidic soil in a rice-wheat cropping system. *Paper presented in 17th WCSS, 14th-21st August 2002*. Thailand.

Raimbault, B.A., and T.J. Vyn. 1991. Crop rotation and tillage eff ects on corn growth and soil structural stability. *Agron. J.* 83:979–985.

Rockström, J. (2003). Resilience building and water demand management for drought mitigation. *Physics and Chemistry of the Earth, Parts A/B/C, 28*(20), 869-877.

Roder, W., S.C. Mason, M.D. Clegg, and K.R. Kneip. 1989. Yield-soil water relationships in sorghum-soybean cropping systems with different fertilizer regimes. *Agron. J.* 81:470–475.

Ruthenberg, H. (1981). *Farming systems in the tropics*: Oxford University Press.

Ryan, J., George, E., and Rashid, A. (2001). Soil and Plant Analysis Laboratory Manual. Second edition. *Jointly published by international Center for Agricultural Research in the dry areas (ICARDA) and the National Agricultural Research Centre (NARC),* pp 46-48.

Sanchez PA, Euhara G (1980) Management considerations for acid soils with high phosphorus fixation capacity. *In* FE Khasawneh, EC Sample, EJ Kamprath, eds, The Role of Phosphorus in Agriculture. *American Society of Agronomy, Madison, WI*, pp 471–514

Sanchez, P. A. (2002). Soil fertility and hunger in Africa. *Science(Washington), 295*(5562), 2019-2020.

Sanginga, N., Okogun, J., Vanlauwe, B., Dashiell, K., 2002. The contribution of nitrogen by promiscuous soybeans to maize based cropping in the moist savanna of Nigeria. *Plant Soil 251*, 1–9.

Sanginga, N., Dashiell, K. E., Diels, J., Vanlauwe, B., Lyasse, O., Carsky, R. J., Tarawali, S., Menkir, A., Schulz, S., Singh, B. B., Chikoye, D., Keatinge, D., and Ortiz, R. (2003). Sustainable resource management coupled to resilient germplasm to provide new intensive cereal-grain-legume-livestock systems in the dry savanna . *Agric. Ecosyst. Environ. 100* , 305 - 314.

Schmitt MA, Lamb JA, Randall GW, Orf JH, Rehm GW (2001). In-season fertilizer nitrogen applications for soybean in Minnesota. *Agron. J.,* 93: 983-988.

Shisanya, C. A., Mucheru, M. W., Mugendi, D. N., & Kung'u, J. B. (2009). Effect of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in central highlands of Kenya. *Soil and Tillage Research, 103*(2), 239-246.

Six J, Gentile R, Vanlauwe B, Chivenge P (2008) Interactive effects from combining fertilizer and organic residueinputs on nitrogen transformations. *Soil Biol Biochem* 40:2375–2384.

Smaling, E. M. (1993). *An agro-ecological framework for integrated nutrient management with special reference to Kenya.* Landbouwuniversiteit te Wageningen.

Sparling, G.P.(1997). Soil microbial biomass activity and nutrient cycling as indicators of soil health. In: Biological Indicators of soil Health,(C.E.. Pankhurst, B.M. Double and V.V.S.R. Gupta, eds*). CAB International, Wallingford*, UK. Pp. 97-119.

Tagoe, S. T., Horiuchi, T. & Matsui, T. (2008). Preliminary evaluation of the effects of carbonized chicken manure, refuse derived fuel and K fertilizer application on the growth, nodulation, yield, N and P contents of soybean and cowpea in the greenhouse. *African Journal of Agricultural Research, 3* (11): 759 – 774.

Tanaka, D.L., R.L. Anderson, and S.C. Rao. 2005. Crop sequencing to improve use of precipitation and synergize crop growth. *Agron. J.* 97:385–390.

Twomlow, S., & Bruneau, P. (2000). The influence of tillage on semi-arid soil–water regimes in Zimbabwe. *Geoderma, 95*(1), 33-51.

Umoetok SBA, Uko AE, Archibong BE, Ukeh DA, Udo IA (2007). Effect of application of inorganic fertilizer and poultry manure on insect pests and yield of soybean (*Glycine max* L.) in the rain forest zone of Nigeria. *J. Food Agric. Environ.,* 5(2): 149-152.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., & Six, J. (2011). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and soil, 339*(1-2), 35-50.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., Shepherd, K. D. (2010). Integrated soil fertility management operational definition and consequences for implementation and dissemination. *Outlook on agriculture, 39*(1), 17-24.

Vanlauwe, B., Tittonell, P., and Mukalama, J. (2006). Within-farm soil fertility gradients affect response of maize to fertilizer application in Western Kenya. *Nutrient Cycling in Agroecosystems 76* , 171 - 182.

Vanlauwe, B., Diels, J., Sanginga, N., Merckx, R., 2002. Integrated Plant Nutrient Management in sub-Saharan Africa: *From Concept to Practice. CABI,* Wallingford, UK, (352 pp).

Van Straaten, P. (2002). Rocks for Crops – Agrominerals of sub-Sahara Africa. Online available:URL:http://www.uoguelph.ca/%7Egeology/rocks_for_ crops/, 12/09/2015.

Varvel, G.E., and T.A. Peterson. 1990. Residual soil nitrogen as affected by continuous, two-year, and four-year crop rotation systems. *Agron. J*. 82:958–962.

Varvel, G.E., 1994. Rotation and nitrogen fertilization effects on changes in soil carbon and nitrogen. *Agron. J*. 86, 319±325.

Varvel, G.E. 2000. Crop rotation and nitrogen effects on normalized grain yields in a long-term study. *Agron. J*. 92:938–941.

Videnović, Ž., Simić, M., Srdić, J. and umanović, Z. (2011). Long term effects of different soil tillage systems on maize (Zea mays L.) yields, *Plant, Soil and Environment. 57* (4): 186–192.

Wang, G., Eltahir, E., Foley, J., Pollard, D., & Levis, S. (2004). Decadal variability of rainfall in the Sahel: results from the coupled GENESIS-IBIS atmosphere-biosphere model. *Climate Dynamics, 22*(6-7), 625-637.

Welch, J. R., Vincent, J. R., Auffhammer, M., Moya, P. F., Dobermann, A., &Dawe, D. (2010). Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. *Proceedings of the National Academy of Sciences, 107*(33), 14562-14567.

West, T.D., D.R. Griffith, G.C. Steinhardt, E.J. Kladivko, and S.D.Parsons. 1996. Effect of tillage and rotation on agronomic performance of corn and soybean: Twenty-year study on dark silty clay loam soil. *J. Prod. Agric.* 9:241–248.

World Bank. (2000). Spurring Agricultural and Rural Development. Can Africa Claim the 21st Century? *World Bank*, Washington, DC, USA, pp. 170–207.

Yamika, W. S. D. & Ikawati, K. R. (2012). Combination inorganic and organic fertilizer increased yield production of soybean in rain-field Malang, Indonesia. *American-Eurasian Journal of Sustainable Agriculture, 6* (1): 14 – 17.

Zhao, Y., Wang, P., Li, J., Chen, Y., Ying, X., & Liu, S. (2009). The effects of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat–maize cropping system. *European Journal of Agronomy, 31*(1), 36-42.

Zingore, S. & Giller, K. E. (2012). Optimizing phosphorus and manure application in Maize-Soybean rotations in Zimbabwe. *Better Crops, 96* (2): 23 – 25.

APPENDICES

Appendix 1: Experimental layout

	Block1				**Block2**				**Block3**				**Block4**		
	maize		soya		maize		soya		maize		Soya		maize		soya
	4.5	1	4.5	2	4.5	1	4.5	2	4.5	1	4.5	2	4.5	1	4.5
6	1A C+TF		1B C+TF		10A TR+IF		10B TR+IF		19A TR+MF		19B TR+MF		28A TR+MF		28B TR+MF
1															
6	2A TR+TF		2B TR+TF		11A C+Con		11B C+Con		20A TR+Con		20B TR+Con		29A TR+IF		29B TR+IF
1															
6	3A C+Con		3B C+Con		12A TR+TF		12B TR+TF		21A C+MF		21B C+MF		30A C+MF		30B C+MF
1															
6	4A TR+Con		4B TR+Con		13A C+IF		13B C+IF		22A C+TF		22B C+TF		31A TR+Con		31B TR+Con
1															
6	5A C+MF		5B C+MF		14A TR+MF		14B TR+MF		23A TR+IF		23B TR+IF		32A TR+TF		32B TR+TF
1															
6	6A TR+MF		6B TR+MF		15A C+TF		15B C+TF		24A C+IF		24B C+IF		33A C+IF		33B C+IF
1															
6	7A C+IF		7B C+IF		16A TR+Con		16B TR+Con		25A TR+TF		25B TR+TF		34A C+TF		34B C+TF
1															
6	8A TR+IF		8B TR+IF		17A C+MF		17B C+MF		26A C+Con		26B C+Con		35A C+Con		35B C+Con
1															
6	9A Sole		9B Sole		18A Sole		18B Sole		27A Sole		27B Sole		36A Sole		36B Sole

Appendix 2: Anova tables

```
***** Analysis of variance *****

Variate: SR14 Maize yield_Yadj_grains_Mg_ha

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                3     0.9422     0.3141    0.64

Rep.*Units* stratum
SWC_ISFM                   7     9.0218     1.2888    2.61  0.042
Residual                  21    10.3566     0.4932

Total                     31    20.3206
```

```
***** Analysis of variance *****

Variate: SR14 Maize yield_Yadj_stover_Mg_ha

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                3      6.170      2.057    1.15

Rep.*Units* stratum
SWC_ISFM                   7     81.495     11.642    6.50  <.001
Residual                  21     37.607      1.791

Total                     31    125.272
```

```
***** Analysis of variance *****

Variate: SR14 Soybean yield_Yadj_grains_Mg_ha

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                3    1.48363    0.49454    9.77

Rep.*Units* stratum
SWC_ISFM                   7    0.94321    0.13474    2.66  0.039
Residual                  21    1.06341    0.05064

Total                     31    3.49025
```

```
***** Analysis of variance *****
Variate: SR14 Soybean yield_Yadj_biomass_Mg_ha
Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
Rep stratum                3     1.3116     0.4372    1.03
Rep.*Units* stratum
SWC_ISFM                   7     8.6225     1.2318    2.90  0.028
Residual                  21     8.9238     0.4249
Total                     31    18.8579
```

```
***** Analysis of variance *****
Variate: LR15 Maize yield_Adj_Stover in_Mg_ha
Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
Rep stratum                3      5.418      1.806    1.06
Rep.*Units* stratum
SWC_ISFM                   8     88.989     11.124    6.53  <.001
Residual                  24     40.853      1.702
Total                     35    135.260
```

```
***** Analysis of variance *****
Variate: LR15 Maize yield_Adj_Grain in_Mg_ha
Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
Rep stratum                3     0.2256     0.0752    0.29
Rep.*Units* stratum
SWC_ISFM                   8     8.0070     1.0009    3.87  0.005
Residual                  24     6.2035     0.2585
Total                     35    14.4361
```

```
***** Analysis of variance *****
Variate: LR15 Soybean yield_Yadj_grains_Mg_ha
Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
Rep stratum                3     1.6376     0.5459    1.70
Rep.*Units* stratum
SWC_ISFM                   8     6.3717     0.7965    2.49  0.040
Residual                  24     7.6845     0.3202
Total                     35    15.6938
```

```
***** Analysis of variance *****
Variate: LR15 Soybean yield_dry_biomass_Mg_ha
Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
Rep stratum                3     6.1803     2.0601    2.82
Rep.*Units* stratum
SWC_ISFM                   8     7.4132     0.9266    1.27  0.305
Residual                  24    17.5255     0.7302
Total                     35    31.1190
```