NUTRIENT MANAGEMENT OPTIONS FOR ENHANCING PRODUCTIVITY OF MAIZE AND BEANS UNDER CONSERVATION AND CONVENTIONAL TILLAGE SYSTEMS

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A THESIS SUBMITTED TO GRADUDUATE SCHOOL IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE

DEGREE IN AGRONOMY

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

DECLARATION

I declare that this is my original work and has not been presented for an award of a degree in any other university.

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DEDICATION

To my parents Jeremiah Otieno and Serfina Atieno

for the price they paid to

take me to school.

ACKNOWLEDGEMENTS

I am thankful to my supervisors Prof. George N. Chemining'wa, and Prof. Charles K. Gachene of the University of Nairobi and Dr. Shamie Zingore of the International Plant Nutrition Institute (IPNI) for their priceless support and guidance throughout this study period. Special thanks to International Plant Nutrition Institute (IPNI) for offering me a scholarship to pursue a Master of Science degree in Agronomy. I also thank the International Maize and Wheat Improvement Center (CIMMYT) and IPNI for jointly funding the project to its successful completion. I also wish to extend my deepest gratitude to the Kenya Agricultural and Livestock Research Organization (KALRO) staff in Alupe and Embu for their technical and logistical support, especially to Dr. Alfred Micheni and Mr. Nelson Kirimi who dedicated their time to ensure good progress all through.

I wish to appreciate my uncle John Omuga Kitoto for laying down this great foundation in my life. Last but not least, my brothers, sisters and friends for standing with me during my down moments.

Above all, I give my deepest gratitude to The Almighty God for His grace in every step I made throughout my study period.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ACSAD	Arab Centre for the Studies of Arid Zones and Dry Lands
AEZ	Agro-Ecological Zone
AFD	French Agency for Development
CA-SARD	Conservation Agriculture for Sustainable Agriculture and Rural Department
CFU	Conservation Farming Unit
CIMMYT	International Maize and Wheat Improvement Center
ECAF	European Conservation Agriculture Federation
FAO	Food and Agriculture Organization of United Nations
FURP	Fertilizer Use Research Project.
GAIN	Global Agricultural Information Network
GFAR	Global Forum on Agricultural Research
GHGs	Greenhouse Gases
GOK	Government of Kenya
GTZ	German Technical Cooperation
Ha	Hectare
ICRAF	International Center for Research in Agroforestry
IDM	Integrated Disease Management
IFDC	International Center for Soil Fertility and Agricultural Development
IFRI	International Food Policy Research Institute
IPNI	International Plant Nutrition Institute
KAMPAP	Kenya Agricultural Monitoring and Policy Analysis Project
KALRO	Kenya Agricultural and Livestock Research Organization

KARI	Kenya Agricultural Research Institute
KTI	Kirinyaga Technical Institute
MOA	Ministry of Agriculture
NCPB	National Cereals and Produce Board
NGO	Non-Governmental Organization
NMFA	Norwegian Ministry of Foreign Affairs
SCC-Vi	Swedish Co-operative Centre and Vi Agroforestry
SOC	Soil organic carbon
SOM	Soil organic matter
SSA	Sub-Saharan Africa
WARDA	West Africa Rice Development Association

GENERAL ABSTRACT

Maize (*Zea mays* L.) and dry bean (*Phaseolus vulgaris* L.) are considered the most important food crops in Kenya. However, their productivity has remained low due to climatic, soil and economic constraints. Utilization of no-till with crop residue management, a conservation agriculture practice, has the potential to ameliorate these constraints. A study to develop cost-effective best nutrient management options for enhancing productivity of maize and beans was set up in Busia, Embu and Kirinyaga counties during 2014-2015 growing periods. Experiments were carried out in a maize-bean rotation system under two tillage methods, no-till with crop residues retention (NT+CR) and conventional tillage with no residues retention (CT-CR), and fertilizer regimes (NK, NP, PK, NPK and NPK+CaMgZnBS). The N, P, K, Ca, Mg, Zn, B and S nutrients were applied at the rates of 120, 40, 40, 10, 10, 5 and 26.3 kg/ha respectively. The experiments were laid out in a split plot design with tillage method as the main plot and fertilizer regime as the subplots. Maize was planted in the long rains and subjected to the tillage and fertilizer treatments while dry bean was planted in the short rains in plots from which maize had been harvested. Partial budget analysis was done using production inputs and output cost to compare the profitability of various treatment combination under maize-bean rotation system.

The long rains results showed significantly higher leaf area index (LAI), plant height, aboveground biomass at 30, 60 and 90 days after emergence (DAE), and crop growth rate (CGR) of maize under CT-CR system than under NT+CR system at Alupe and Kirinyaga site. Maize yield under NT+CR was 400 kg/ha higher than under CT-CR in Embu. However, CT-CR produced 300 kg/ha and 600 kg/ha higher grain yields than NT+CR at Alupe and Kirinyaga, respectively. Application of PK and NPK+ZnBMgCaS fertilizer regimes resulted in significantly lower and higher, respectively, dry biomass, LAI, CGR, plant height and maize grain yield than other treatments in both sites. Application of NPK+ZnBMgCaS fertilizer regime had 500 kg/ha significantly higher grain yield than NPK fertilizer regime at Embu.

In the 2014/2015 short rains, dry bean (a rotation crop) produced higher biomass at 60 DAE, stover, number of pods per plant, number of seeds per pod and 1000-seed weight under NT+CR than under CT-CR in Embu and Kirinyaga. The NT+CR significantly out-yielded CT-CR at Embu and Kirinyaga sites by 200 kg/ha and 140 kg/ha, respectively. In all sites, NPK+ZnBMgCaS and PK residual fertilizer effects yielded significantly the highest and lowest, respectively, dry bean biomass at 60 DAE, number of seeds per pod, 1000-seed weight and grain yields. Both NPK+ZnBMgCaS and NPK residual fertilizer effects out-yielded PK residual fertilizer effect by 600 kg/ha and 370 kg/ha, respectively, in Embu. At Kirinyaga, the former two treatments out-yielded PK residual fertilizer by 710 kg/ha and 330 kg/ha, respectively. Strong and positive relationships were recorded between grain yield and biomass at 60 DAE, number of pods per plant, number of seeds per pod, 1000-seed weight and harvest index. An economic analysis of the maize-bean rotation system showed a generally lower cost of production and higher profits under NT+CR than under CT-CR. In the two sites, the cost of production ranged from Ksh. 55,553 to Ksh. 68,096 for maize and Ksh. 21,425 to Ksh. 31,600 for dry bean. The profits ranged from Ksh. 148,841 under CT-CR to Ksh. 178,410 under NT+CR. Higher benefit to cost ratios of 4.00 and 3.34 under NT+CR than 2.72 and 2.67 under CT-CR at Embu and Kirinyaga, respectively, were recorded under maize-bean rotation system. Based on this study, application of NK fertilizer regime under NT+CR system is more profiting than other treatments, hence could be considered for adoption.

CHAPTER ONE: INTRODUCTION

1.1. Background information

In Kenya, maize (*Zea mays* L.) is of great importance as it provides food, foreign exchange, employment and raw materials for other industrial products (Mbithi and Huylenbroeck, 2000; FAO, 2011a). However, its productivity has remained low with average yields ranging from 1-2 t/ha over decades to date (FAOSTAT, 2014). This low productivity is majorly due to biotic, abiotic and socio-economic constraints.

Soil infertility characterised by high nutrient depletion rates of more than 40 kg of nitrogen, 6.6 kg of phosphorus and 33.2 kg of potassium per hectare per year have been reported in Central, Rift Valley, Eastern and Western parts of Kenya (Sanchez, 1997; Jaetzold *et al.,* 2006; Okalebo *et al.,* 2007). This is attributed to intensification of food crop production to meet the ever-increasing population needs without adequate fertilizer application (Henao and Baanante, 2006). On the other hand, low and erratic rainfall has resulted in soil moisture deficits that limit maize production (Hengsdijk and Langeveld, 2009). This situation is aggravated further by climate change due to global warming, which is partly caused by agricultural inefficiencies (Tubiello, 2012).

The prevalence of food insecurity in Kenya due to soil infertility and limiting soil moisture calls for development and adoption of feasible and effective methods of production which are sustainable and protect the environment. To manage these production constraints for improved food situation in Kenya, conservation agriculture is recommended for soil, moisture and nutrients management. Conservation agriculture offers benefits such as increased soil moisture conservation, soil erosion control, increased water infiltration (Derpsch, 2008), improved soil ecology and nutrient cycling (African Conservation Tillage Network, 2008; Blank, 2008), environmentally safe natural control of crop plant pests and diseases (Saturnino and Landers, 2002) and weed control (Marongwe *et al.*, 2011). These benefits are through four key principles namely: Crop rotation, minimal soil disturbance, crop surface residue retention (ACT, 2002; Erenstein *et al.*, 2008; FAO, 2011) and appropriate fertilizer use (Vanlauwe *et al.*, 2014). These attributes make conservation agriculture a mitigation and adaptive measure for agricultural crop production under climate change. Hence, the current promotion of conservation agriculture by local and international organizations (for example, United Nations Food and Agriculture Organization (FAO), German Technical Cooperation (GTZ), Global Forum on Agricultural Research (GFAR), European Conservation Agriculture Federation (ECAF), International Maize and Wheat Improvement Centre (CIMMYT) and French Agency for Development (AFD)) in Kenya.

1.2.Problem statement and justification

Maize is the leading crop in Kenya that provides a wide range of uses ranging from food to income generation (Mbithi and Huylenbroeck, 2000). However, intensive tilling of land with little or no nutrient replenishment from either organic or inorganic sources has resulted to high levels of nutrient mining which has caused low maize production (Sanchez, 1997). For instance, current fertilizer consumption in Kenya is at 27 kg/ha against the global level of 138 kg/ha (World Bank, 2014). Fertilizers applied in Kenya are majorly NPK-based sources with no attention given to other essential nutrients like Mg, Ca, Zn, B and S. This is despite several researches which have demonstrated significant contributions of Zn (Yerokun and Chirwa, 2014), S and Mg (Szulc *et al.* 2008), Ca (Fageria *et al.*, 2010) and B (Ahmad *et al.*, 2009) to maize grain yields. Hence, the need to supply secondary nutrients and micronutrients for plant growth. Despite current levels of nutrient depletion, farmers still apply low quantities of fertilizers that do not appreciably raise soil nutrient levels. Besides, such low quantities are often utilized with high inefficiencies because of poor agronomic practices that do not conserve soil and nutrients (Vanlauwe *et al.,* 2010). In addition, farmers who are capable of supplying adequate nutrients to maize crops often use fertilizer recommendations that are obsolete under conservation tillage practices for maize production. This demands adjustments in fertilizer application to fit the change in soil fertility status and new conservation tillage systems. According to Zingore and Johnston, (2013) for increased agronomic use efficiency of fertilizers, the recommended fertilizer application rates should be site-specific based on 4R (right source, right rate, right time and right placement) principles which take care of both conventional and conservation tillage practises.

Agriculture consumes about 75% of the total fresh water quantity available (UNESCO 2001). However, this available fresh water is under threat due to climate change that negatively impacts food crop production, especially of the tropical cereal crops (Porter *et al.*, 2014). For instance, maize crop production is predicted, on average, to decrease by 5-10% due to climate change if no action is taken by the end of 21st Century (Ramirez-Villegas and Thornton, 2015). Currently, augmentation of rainfall through irrigation is faced by the poverty challenge among Kenya farmers (Neubert *et al.*, 2007). Hence there is an urgent call for strategies based on science and technology and agronomic practices to adapt maize crop production to this climate change. These strategies must be effective and financially feasible and at the same time conserve and preserve the environment.

Conservation agriculture is potentially an effective, cheap and financially sustainable method of production that may not only improve maize yields but also conserve the environment. Hence, it may offer a solution to soil infertility, water inadequacy and high cost of production currently facing maize and dry bean production in Kenya. Addressing nutrients deficiencies alone could lead to closing maize yield gaps, with yield variation due to soil fertility management ranging from 1.8 to 3.2 tons/ ha (Wopereis *et al.*, 2006), to 50% of the attainable yield in SSA (Mueller *et al.,* 2012). Therefore addressing soil infertility through application of inorganic fertilizers is important in realizing increased maize production in Kenya. Conservation agriculture is based on crop rotation, crop residue retention, no-till and appropriate fertilizer application principles. These principles in synergy offer farmers an opportunity to reverse land degradation and support sustainable intensification of crop production (Fowler and Rockstrom, 2001) due to their potential to enhance physical, biological and chemical properties of the soil (Madari *et al.,* 2005). In Kenya, adoption of conservation agriculture is low and only under promotion by various local and international organizations such as International Maize and Wheat Improvement Centre, European Conservation Agriculture Federation, Food and Agriculture Organization and Kenya Agricultural and Livestock Research Organization (Maina *et al.,* 2013). Several factors have been cited to reduce adoption and effectiveness of conservation agriculture in Kenya and Sub-Sahara Africa (Knowler and Bradshaw, 2007; Mlamba, 2010; González, 2012; Mazvimavi and Twomlow, 2009). The resultant reduction in production cost under conservation agriculture as a result of reduced labour requirement for weed control and reduced fertilizer application rates, in the long run, may help to relieve resource-constrained farmers of the burden of costly commercial inorganic fertilizers. No-till and crop residue retention minimise soil water lose, erosion and encourage water infiltration. A maize-bean rotation system provides an integrated system of soil fertility management and pest and disease control. Based on this background, this study was therefore conducted to develop economically efficient nutrient management options for both conservation and conventional tillage systems.

1.3. Objectives

1.3.1. Main objective

To develop nutrient management options for sustainable production of maize and bean under conservation agriculture and conventional tillage system in Kenya.

1.3.2. Specific objectives

i. To assess the effects of tillage method and inorganic fertilizers regimes on growth and yield of maize.
ii. To evaluate the effects of tillage method and residual inorganic fertilizer nutrients on shoot biomass and grain yield of dry bean.
iii. To determine the economic returns of a maize-bean rotation system under different tillage systems and nutrient management regimes.

1.4. Hypotheses

i. No-till and inorganic fertilizer application increase growth and yield of maize.
ii. No-till and residual fertilizer nutrients increase shoot biomass and yield of dry bean.
iii. A maize-bean rotation system has higher economic returns under no-till than under conventional tillage.

CHAPTER TWO: LITERATURE REVIEW

2.1. Maize production in Kenya

Maize is one of the most important cereal crops in the world with a current production of about 872 million metric tons (FAO, 2012a). The United States of America is the world's largest producer of maize (40%) followed by China (20%), Brazil (7%), Mexico (3%) and Argentina (3%) (USDA, 2015). Sub-Saharan Africa and Latin America consume 30% of the global maize production but only produce 6.5% of it (http://www.iita.org/maize). In Kenya, the crop is ranked the most important staple food feeding more than 33 million people (Wambugu and Muthamia, 2009). As a result of its dominance, national food security is always described based on maize availability and sufficiency in meeting household demand. Ruto (1992) estimated maize to contribute more than 20, 25, 78, 44 and 32 percent of total agricultural production, agricultural employment, cereal consumption, food energy needs and protein requirement in the country, respectively.

Maize production in Kenya lacks uniformity both in agronomic and cultural practices due to socio-economic differences. Both traditional and improved hybrid maize varieties are produced, though hybrids are preferred to traditional varieties because of their abilities to yield higher (Musandu and Njul, 1999). According to FAO (2011a), 90% of rural households grow maize and this accounts for 75% of the total maize produced nationally. Maize production in Kenya is carried out virtually in all altitudes ranging from coastal regions to highlands of 1600 m above sea level (FAO, 2011a) with a wide temperature range (Mbithi and Huylenbroeck, 2000). The bimodal seasons experienced in Kenya offer two growing seasons, especially in medium and low altitudes. Maize is produced under conventional tillage system in Kenya, which is marked by high rates of nutrient mining (Argwings-Kodhek *et al.,* 1998) with less nutrient replenishment through organic and/or inorganic sources (Smaling *et al.,* 1997). Acreage under maize production increased from 1.7 million hectares in 2008 to 2.1 million hectares in 2013 (FAOSTAT, 2012b). Expansion of land under maize is expected to continue because of high population growth rate estimated at 2.9% per annum (FAO, 2011a). Maize is normally intercropped with legumes such as green and black gram, soybean, cowpea and dry bean in various parts of Kenya. This polycultural practice ensures food diversification and improved soil fertility (Mbithi and Huylenbroeck, 2000), increase in maize grain output (Snapp and Silim, 2002) and general improvement of economic returns (Zingore, 2011). Maize production is low in Kenya, as farmers achieve an average of 1.5 t ha^{-1} compared to potential yields of 7-8 t ha^{-1} (Musandu and Njul 1999; Makokha *et al.*, 2001). Maize production also varies regionally, a fact that can be linked to different prevailing agro-ecological conditions and population level in Kenya (Table 2.1 and 2.2).

Maize is a very sensitive crop to both biotic (e.g. weeds, diseases and insect pests) and abiotic (e.g. soil acidity, soil degradation and drought) constraints, leading to its frequent temporal and spatial fluctuations in production. This explains the maize yield gap level that vary between 0.5 and 4 t/ha per season (Tittonell *et al.,* 2008), despite over-reliance by Kenyans on maize as a key source of livelihood. Global analysis of yield trends and yield gaps of major crops has revealed that limited water availability, limited nutrient availability, inadequate crop protection, insufficient or inadequate use of labour or mechanization, and deficiencies in knowledge are the key constraints leading to the current yield gaps of such crops like maize, wheat and rice (Hengsdijk and Langeveld, 2009).

Table 2. 1 Average maize production in Kenya (2006-2013)

	Years							
	2006	2007	2008	2009	2010	2011	2012	2013
Area harvested (Mha)	1.888	1.615	1.700	1.884	2.008	2.132	2.159	2.100
Yield (kg/ ha)	1720	1813	1393	1294	1725	1584	1667	1615
Production (Million tons)	3.2	2.9	2.4	2.4	3.5	3.4	3.6	3.4

Source: FAOSTAT, 2013. Mha = Million hectares

Table 2. 2: Average maize production versus human population per province from 2005-2009.

Province	Area under crop (ha)	Production (90 kg/bag)	Yield (bags/ha)	Population[a]
Rift Valley	644,895	13,225,039	20.5	10,066,805
Nyanza	262,453	3,711,215	14.1	5,442,711
Eastern	462,401	3,903,141	8.4	5,668,123
Western	225,302	4,163,878	18.5	4,334,282
Coast	129,379	1,079,383	8.3	3,325,307
Central	157,063	1,047,879	6.7	4,383,743
North Eastern	2,525	5,520	2.2	2,310,757
Nairobi	1,053	6,420	14.4	3,138,369

Source: GOK Economic Review of Agriculture 2010 and [a]Kenya Population and Housing Census 2009.

2.2.Constraints to maize production in Kenya

The major constraints to maize production in Kenya include soil acidity, low soil fertility, inadequate soil moisture, weed infestation, pests and disease attack.

2.2.1. Soil acidity

Soil acidity is a major constraint in any crop production, as it affects the availability of essential crop nutrients and causes impaired growth of plants (Yamoah *et al.,* 1996). About 20% of Kenyan soils are acidic due to the original nature of the rock forming the soils (FURP, 1987). For instance, Ferralsols and Acrisols are by nature acidic and are the main soil types of western Kenya (Musandu and Njul, 1999; Kanyanjua *et al.,* 2002). Areas with acidic soils lie within humid zones which form the food basket of the economy (Kanyanjua *et al.,* 2002). For instance about74, 58 and 68 % of farms in Busia, Embu and Kirinyaga counties, respectively, have pH less than 5.5 (Aslund, 2012; MOA, 2014). Such acidic soils make macronutrients unavailable while micronutrients may become toxic for maize growth. Low soil pH is associated with high levels of Al^{3+} ions which complex with the plant available form of P ($H_2PO_4^-$), making it fixed and unavailable for plant uptake. In addition, very low pHs hinder survival of soil fauna which are effective in improving soil health.

2.2.2. Soil infertility

Soil infertility hinders maize and general crop productivity in many parts of the country and developing nations (FAO, 1990). Continuous cultivation and cropping of cereal crops extracts more nutrients from the soil than cash crops such as tea and coffee (Argwings-Kodhek *et al.,* 1998) leading to high soil nutrient depletion in Kenya’s soils. Estimates indicate that more than 40 kg N, 6.6 kg P and 33.2 kg K per hectare per year are depleted from Kenyan soils (Smaling *et al.,* 1997). The depletion occurs because plants use nutrients for growth and development which are later removed from the farm through burning and feeding of animals (Valbuena *et al.,* 2012), soil erosion and leaching (KARI, 1998). However, replenishment of these lost nutrients is low leading to negative nutrient balances. As reported by FAO (1998 and 1999) fertilizer consumption among SSA countries is very low at 8.2 kg ha^{-1} compared to 97.7 kg ha^{-1} in developed countries. This worsens the agricultural productivity potential for the region (Smaling *et al.*, 1997). African soils are low in available P nutrient thus seriously limiting crop production (Buresh *et al.,* 1998). Drechsel *et al.* (2001) explains that about 70, 90 and 100 percent of all N, K and P nutrients, respectively, are lost due to erosion and plant extraction.

Addressing nutrients deficiencies alone could lead to closing maize yield gaps to 50% of the attainable yield in SSA (Mueller *et al.*, 2012). Wopereis *et al.* (2006) also revealed variations in average yield due to soil fertility management range from 1.8 to 3.2 tons/ ha. Therefore addressing soil infertility is important in realizing increased maize production in Kenya. This constraint may be addressed through the use of inorganic and organic fertilizers reduced tillage, and crop rotation (Kumwenda *et al.* 1996).

2.2.3. Inadequate soil moisture

Soil moisture greatly influences crop production (Hengsdijk and Langeveld, 2009) because of its functions in plants including nutrient absorption, maintenance of cell turgidity and general transport. Sub-Saharan Africa lies within the region experiencing water shortage due to the low, erratic and unreliable rainfall, which is exacerbated by the effects of climate change. Kenya has recorded about 28 severe droughts in the last 100 years, three of them in the last decade, and the frequency seemed to be increasing leading to low production of maize (Huho and Mugalavai, 2010). According to MoA, farmers are currently abandoning maize cultivation in favor of roots and tubers that are better adapted to climate change. Such cultural and climatic changes have caused high variations in maize production across the country. For instance, Hansen and Indeje (2004) reported a maize yield prediction with 28-33% variance in Machakos region. Therefore, effective soil moisture conservation is necessary to reduce farmers' vulnerability to drought. Though shifting from rain-fed agriculture to irrigated agriculture could provide the solution by enabling 16% of underachieving areas in SSA to close the yield gap by 25% (Mueller *et al.*, 2012), poverty among farmers hinders their purchasing power hence failure to adopt the technology. Conservation agriculture, through soil surface cover by live and/or dead crop residues (Uri, 1999) and reduced tilling of land, as an alternative measure which could help conserve the limiting moisture and reduce maize production cost in Kenya (Maina *et al.*, 2013).

2.2.4. Weed infestation

Weeds are a major constraint to maize production in Kenya. Witch weed (*Striga* spp.) is one of the most serious parasitic weeds pausing technical and economic challenges to maize farmers in SSA, including Kenya. In Western and Nyanza regions, striga weed infestation is a challenge and its proper management is required for increased maize production (MOA, 2012). Weeds are efficient in consuming plant nutrients applied through fertilizer, thus a weed-free field is a prerequisite for fertilizer application. Weeds have been reported to cause serious yield losses. Gressel *et al.* (2004) reported that striga weed infestation can lead to up to 50% yield loss in cereals such as maize, sorghum and millet. Research on breeding maize for striga resistance has been conducted since early 1980s but no much progress has been made. Therefore weed control must be timely and effectively done especially in annual crops to reduce yield gap. Other control measures include crop rotation and crop residue mulch which have been found to be efficient in reducing weed infestation in the field (Mazvimavi and Twomlow, 2009; Mashingaidze *et al.*, 2012; Davis *et al.*, 2012).

2.2.5. Pests and diseases

Hot, wet and humid climatic conditions prevailing across the tropics encourage the proliferation of an array of damaging insect pests and diseases which cause high maize yield losses. For example, the stem borer can cause yield losses of 20-40 percent in maize and sorghum (Gressel *et al.*, 2004). Disease causing pathogens (viruses, bacteria, fungi and protozoa) cause yield losses in maize if left uncontrolled (Oerke, 2006). Maize lethal necrosis disease which has been reported in South Rift, Nyamira County, Central Rift and parts of Western (Teso sub-county) has caused great losses in maize production (MOA, 2012). Other diseases such as maize streak and head smut have also been reported to cause maize losses. Currently, there are no maize varieties that offer meaningful resistance to diseases such as MLND. Crop rotation could offer an environmentally safe way of reducing pest and disease levels below the action threshold, a benefit well offered through conservation agriculture and crop rotation system (Cook, 2001).

2.2.6. Other constraints

Other important constraints to maize crop production in Kenya have been listed by MOA (2012). Use of uncertified seeds causes reduction in maize yield. About 15 to 30% of farmers are reported to use recycled seeds leading to reduced yields due to genetic segregation. Sometimes prolonged rains experienced during harvest time contribute to higher post-harvest losses especially in central and parts of western Kenya. Lack of ready markets resulting from inability of the National Cereal and Produce Board (NCPB) to purchase large quantities of maize has led to exploitation of farmers by middlemen. This reduces the motivation of farmers to produce maize. Poverty among the farmers who are major producers (Musandu and Njul, 1999) reduces their ability to utilize farm inputs such as inorganic fertilizers.

2.3.Conservation agriculture

2.3.1. Introduction

Conservation agriculture dates to about 70 years ago in Edward Faulkner's "Ploughman's Folly" (1945) writing. Conservation agriculture has its origin from conservation tillage which was meant to counter the effect of wind and rain water (as erosion agents) on agricultural crop productivity, which later led to minimum tillage and to zero tillage currently (ACSAD, 2007). According to FAO (2011), conservation agriculture is defined as "a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. This concept is pillared on four key principles: permanent organic soil cover, crop rotation (Hobbs *et al.*, 2008; Erenstein, *et al.*, 2008), use of appropriate fertilizers (Vanlauwe *et al.*, 2014) and minimum mechanical soil disturbances (Banites, 2008).

Conservation agriculture is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. The concept of conservation agriculture has gained popularity and is increasingly being promoted as a key option for mitigating food insecurity (FAO, 2011b) especially among farmers in Sub-Saharan Africa. This helps farmers to increase productivity, reduce vulnerability to drought and address issues of draft power ownership levels and mitigate increasing levels of land degradation (FAO Conservation Agriculture Website: http://www.fao.org/ag/ca/). Adoption of conservation agriculture is low and accounts for about 8% of arable and permanent cropped land, globally (Friedrich *et al.*, 2011). It is reported to be practiced in over 106 million hectares (Derpsch and Friendrich, 2011) (Table 2.3). Only South

Africa has a significant acreage under conservation in Africa. Kenya's practice and adoption of conservation agriculture is still low and negligible on global ranking (Table 2.3). This low adoption in Africa has stimulated creation and promotion of several researches and extension programmes which are currently being implemented and sponsored by major international initiatives such as Food and Agriculture Organization of United Nations, German Technical Cooperation, Global Forum on Agricultural Research, European Conservation Agriculture Federation, International Maize and Wheat Improvement Center and French Agency for Development (Maina *et at*., 2013).

Conventional tillage systems face a serious problem of land degradation, which together with high temperatures and erratic and unreliable rainfall affect rain-fed agriculture (Met Office, 2005; FAO, 2007). As reported by Ragab and Prudhomme (2002), agriculture consumes more than 75% of the global water use and has been predicted to exceed the existing blue water available by 2050. This may not only be due to increased water use but also careless management of water as a natural resource. Adoption of conservation agriculture, involving reduced soil disturbances and permanent ground cover by crop residues, has the potential to conserve moisture by reducing evaporation and run off.

Conservation agriculture sponsorship programs have mainly boosted its adoption among large-scale farmers but not among small-scale farmers. For instance, it is reported that 75% of the large scale farmers in Zimbabwe practised some forms of conservation agriculture (minimum tillage, residue farming, mixed cropping, and crop rotations) by 1995 (FAO, 2002b).

About 20% of Africa's agricultural lands are reported to be severely degraded because of direct agricultural activities (McNeely *et al.,* 2001) such as intensive land tilling, poor residue management and continuous cropping without external nutrient replenishment leading to nutrient mining (Sunchez *et al.*, 1997)

Table 2. 3: Extent of no-tillage adoption worldwide

Country	Area under no-till (Mha) 2007/2008
USA	26.593
Brazil	25.502
Argentina	19.719
Canada	13.481
Australia	12.00
Paraguay	2.400
China	1.330
Kazakhstan	1.200
Bolivia	0.706
Uruguay	0.672
Spain	0.650
South Africa	0.368
Venezuela	0.300
France	0.200
Finland	0.200
Chile	0.180
New Zealand	0.162
Colombia	0.100
Ukraine	0.100
Others	0.100
Total	105.863

Source: Derpsch and Friedrich, 2011.

In Kenya, only areas which have Conservation Agriculture for Sustainable Agriculture and Rural Department (CA-SARD), International Center for Research in Agro-forestry (ICRAF), Swedish Co-operative Centre and Vi Agroforestry (SCC-Vi), Millennium Development and Kenya Agricultural and Livestock Research Organization (KALRO) project trials have been reported to practice some levels of conservation agriculture including reduced tillage, crop rotation and crop residue management (K'Owino, 2010).

2.3.2. Constraints and challenges to adoption and utilization of conservation agriculture

Adoption and sustainable utilization of conservation agriculture is characterized by serious confusion as the extent seems to vary depending on the stage of the trial. That is, very active during the initial phases of the technology introduction and promotion to farmers by research organizations then declines after the end of the project (Giller *et al.,* 2009). For instance, most farmers have been found to adopt conservation agriculture concept as a means to acquire farm inputs from the research projects but not for sustainable production (Haggblade and Tembo, 2003). This phenomenon has been reported in Mali, Nigeria, Ethiopia, and Uganda (Ito *et al.*, 2007), in South Africa (Bolliger, 2007), Zambia, Tanzania and Ghana (Gowing and Palmer, 2008). In Zimbabwe, adoption of conservation agriculture is limited despite about two decades of its promotion by several projects and extension programs (Mashingaidze *et al.,* 2012). The low adoption of this concept at a global scale is caused by several factors which may be said to vary from one continent to the next, country to country and farmer to farmer. Like any form of crop production, any factor affecting farmers' ability to produce efficiently affects conservation agriculture. Some of the inhibitors to adoption of conservation agriculture are limited access to inputs (e.g. fertilizers, herbicides and cover crop seeds) and labour challenges (Shetto and Owenya, 2007; Kaumbutho and Kienzle, 2007). High weed intensity, especially in the first growing season and under low crop residue cover, has been reported in conservation agriculture (Muliokela *et al.,* 2001; Baudron *et al.*, 2007). Some other hindrances reported are lack of appropriate farm machinery and implements (e.g. seed drillers, rippers and sub-soilers), insufficiency of appropriate technical information and competition for crop residue in mixed crop–livestock systems (Nyanga, 2012).

2.4. Effects of conservation agriculture and conventional tillage practices on maize productivity

Adoption of conservation agriculture leads to improved soil health as a result of the interactions between conservation agriculture principles- crop rotation, residues management, fertilizer application and reduced tilling of land (Derpsch *et al.,* 2010). According to Benites (2008), 'healthy soil' ensures decomposition of organic matter into humus, retains N and other plant nutrients, increases soil aggregate stability and soil porosity, protects roots from diseases and parasites, makes nutrients available to plants and produces hormones that help plants to grow. This healthy soil improves maize growth and productivity. Under conventional tillage, removal of crop residues from soil surfaces leave soil vulnerable to soil erosion which encourages detrimental processes such as increased soil erosion, depletion of soil organic matter and nutrients, and reduced water infiltration which together impact negatively on maize crop productivity (Hobbs *et al.* (2008; Gowing and Palmer, 2008).

Under conservation agriculture, crop residues are left as organic mulches which impede surface run-off resulting in reduced loss of N and other nutrients for healthy crop growth. Improved water infiltration and storage under no-till with crop residue cover, increase the amount of biomass produced by maize per unit volume of water consumed (Mzezewa and Van Rensburg, 2011; Giller *et al.,* 2011). Retention of crop residue under conservation agriculture has also been found to help in weed control, hence the reduction in weed-maize plant competition for growth factors and early labour requirement for maize production (FAO, 2010; Hobbs *et al*., 2008). Three mechanisms have been cited to be behind weed control by crop residues under maize production; reduction in the amount of light required by weed seeds to germinate and grow (Hobbs *et al.*, 2008); allelopathic effects on germination of surface weed seeds (Jung *et al.*, 2004); and encouragement of soil microbial growth which suppresses weeds (Kennedy, 1999).

Minimum tillage aspect has been reported to encourage soil aggregation which reduces surface crusting under conservation tillage compared to conventional tillage (Thierfelder *et al.*, 2005; Marongwe *et al.*, 2011). These conditions encourage proper developments of maize roots, water percolation and nutrient movements for increased efficiency and productivity. Conservation agriculture practices have been proved to encourage and promote survival of beneficial soil micro and macro organisms. For example, mycorrhizal hyphae create micro and macro soil pores which encourage water, nutrients and aeration within the soil volume thereby promoting maize root development for anchorage and nutrient absorption (McGonigle and Miller, 1996).

In general, conservation agriculture practices synergistically blend up to cause yield improvement as reported by most researchers. For instance, Lal (1998) reported that maize grown under conventional practices was out yielded by maize grown under conservation agriculture. Rockstrom *et al*. (2007) reported a yield increase of 20-120 % in maize productivity in Ethiopia, Kenya, Tanzania and Zimbabwe under conservation agriculture relative to conventional tillage practices. In Brazil, maize grain yield increased by 67.2 million tons under conservation agriculture in 15 years, which translates to additional 10 billion dollars accrued as a result of conservation agriculture adoption (Derpsch, 2005). Zimbabwe also showed increases in maize productivity from an average of 970 kg/ha under conventional tillage to 1546 kg/ha under conservation tillage (Mazvimavi *et al.*, 2010).

2.5. Nutrient management for maize production under conservation agriculture and conventional tillage systems

Conservation agriculture is a multi-principled concept that ensures improved soil fertility for sustainable production. According to Kassam and Friendrich (2009), any nutrient management strategy has to address soil acidity, biological processes, biomass production and Biological Nitrogen Fixation (BNF) and access to all nutrients by plant. Conservation agriculture achieves its benefits in crop production through the synergy among its principles (Shaxson *et al.,* 2008). Minimum soil disturbance as provided by no-till enhance nutrient accumulation in maize rhizosphere under conservation agriculture, while intensive tilling of soil with disc and chisel distributes these nutrients in the soil volume under conventional tillage system (Karlen *et al.,* 1991). This distribution of soil nutrients within the soil hastens their losses through water erosion and leaching, hence losses and low maize productivity. Reduced tilling of land together with crop rotation and fertilizer application enhance soil nutrient status and organic carbon (Liu *et al.,* 2005); with attainable qualities of up to 0.36 Mg C per hectare per year (Wagen *et al*., 2005) particularly within 0-5 cm depth of top soil (Peigne *et al.,* 2007). This soil organic carbon is found to be lost easily due to soil erosion agents and disintegration by soil micro-organisms under conventional tillage system (McGechan *et al.,* 2005). In the pasture land, 55% of this soil organic carbon has been found to be lost within 2 years of cultivation (Torbert *et al.,* 2004). Unlike under conservation agriculture with improved micro-aggregation, this organic matter is protected from microbial disintegration (six *et al.,* 2002; Blanco-Canqui and Lal, 2004).

Continuous cropping under no-till system increases C and surface residue of N, which are accumulated and immobilized, hence not easily lost through leaching and made available for maize use during mineralization (McKenney *et al*., 1995). In contrast, increased soil available N under conventional tillage is easily lost by erosion and leaching, hence unavailable for maize uptake (Halvorson *et al.*, 2006; Hobbs *et al.*, 2008). Increased soil mycorrhizal growths under conservation also ensure that large volumes of soils are exploited for relatively immobile nutrients such as P, Zn and Cu for required maize crop use (Habte, 2006). This ensures recycling of nutrients and availability for improved maize production under such system. Though intensive tilling of land leads to high losses of C as CO_2 gas and other nutrients by leaching (Busscher *et al.,* 2000), there is high oxidation that consequently improves mineralization process, hence faster release of immobilized nutrients from improved maize growth and productivity (Kumar and Goh, 1999).

2.6. Maize-bean rotation

The influence of crop rotation on soil health improvement is greatly linked to its design which is based on the crops included. Crop rotation is an effective tool under conservation agriculture that ensures that crops which are of different species are alternately grown on the same piece of land during different seasons. The most preferred crop under a rotation sequence is a nitrogen fixing legume (Shaxson *et al.,* 2008), which offers several benefits in terms of efficient use of soil water and nutrients, improved physical characteristics of the soil and reduced soil erosion (Reeves, 1997). Crop rotation has a great influence on soil health and fertility in any agro-ecological zone both in the short term and in long run. The system helps in soil and water conservation and minimizes salinity problems in arid and semi-arid lands (Turner, 2004). Weeds are effectively controlled under crop rotation since the system effectively changes the pattern of disturbances thereby diversifying selection pressure (Liebman *et al.* 1996). The mechanism of weed control is due to diversification as it reduces the proliferation of certain weeds which are ever in association with a given crop because of certain practices (Buhler, 2002). However, survival of weed plants is dependent on several biological behaviors such as competitiveness of the weed species and seed dispersal. Rotation also increases the microbial diversity thereby reducing the hazard of pests and diseases outbreak through constant check on the population of the pathogenic microbes (Leake, 2003). For instance, crop pathogens with narrow or specific host ranges such as nematodes have their populations easily checked by inclusion of non-host crops in the program (Peters *et al.,* 2003). Crop rotation plays a major role in soil fertility management especially when leguminous plants are included in the sequence (Watson *et al.*, 2002). This is made possible as it modifies soil structure which has substantial effects on soil nutrient cycling through changed physical and biological nature of the soil environment (Ladd *et al.,* 1993). Important interactions between soil physics and biology ensure availability of plant nutrients (Ball *et al.,* 2005). Such interactions increase soil nitrogen through BNF and soil organic matter through residues, which is more efficient and beneficial under conservation agriculture than under conventional tillage practices. According to Kihara *et al.* (2011), BNF was increased in legume soybean rotation under reduced tillage together with crop residue management than under conventional tillage. High quality dry bean residue with high protein content under a rotation system has been found to release nutrients more quickly than more fibrous cereal residues (Lu *et al.,* 2011). However, cereal residue (e.g. maize) have high stability and therefore are more important in soil and water conservation through reduced surface run off. Economically, BNF through N-fixing legume crops like dry bean helps farmers to supply soil N for the following cereal crops thus reducing the demand for commercial N-based inorganic fertilizers. This fixed N is always affected by the availability and colonization of right rhizobia bacteria in the soil (Mabood *et al.,* 2006) and the soil characteristics (Goss and Varennes, 2002). The soil chemical, physical and biological characteristics are influenced positively by conservation practices (Madari *et al.,* 2005).

Cumulative benefits of crop rotation, both above and below the soil, results in high yield, which is of importance to the farmers. Copeland and Crookston (1992) have revealed that crops grown in rotation normally have higher accumulation of biomass than when grown in monoculture. Kasasa *et al.* (1999) and Giller *et al*., (2001) have both reported double yields in the cereal crops that followed legume crops in a rotation system in the same field. However, legume-cereal rotation program is faced by challenges such as land availability among Kenyan farmers. For example, quite often crop rotation is only practiced in home fields (Zingore *et al.*, 2007) which are small and this might not benefit the farmer much. Also, during harvest farmers normally uproot the whole legume plant leaving no residues in the field to build up soil N content upon decay. Well defined and organized maize-bean rotation systems are not common in Kenya. However, dual purpose legumes which produce both food and feed such as groundnut, cowpea, pigeon pea and forage legumes (e.g. *Trifolium* spp and *Stylosanthes* spp.) have been reported and are grown across the region by small scale farmers who practice mixed crop/livestock systems (Rao and Muthuva, 2000).

CHAPTER THREE: EFFECTS OF TILLAGE METHOD AND FERTILIZER APPLICATION ON GROWTH AND YIELD OF MAIZE

3.1. Abstract

Maize is an important food crop produced under different agro-ecological zones in Kenya by both small and large-scale farmers. However, its production has remained low due to climatic and soil constraints. A trial to determine the effect of tillage method and fertilizer application on growth and yield of maize was set up in Busia, Embu and Kirinyaga Counties during 2014 long rains season. Tillage methods were no-till with crop residue retention (NT+CR) and conventional tillage without residue retention (CT-CR). Fertilizer combinations were NK, NP, PK, NPK and NPK+CaMgZnBS. The nutrients N, P, K, Ca, Mg, Zn, B and S were applied at 120, 40, 40, 10, 10, 5 and 26.3 kg/ha, respectively. The trials were laid in a randomized complete block design with a split plot arrangement and replicated three times. The tillage method was assigned to the main plots and fertilizer regimes to the subplots. The results showed that maize leaf area index, plant height, aboveground biomass, crop growth rate and grain yield were significantly higher under CT-CR than under NT+CR in most of the sites. The CT-CR system significantly out-yielded NT+CR system by 300 kg/ha and 600 kg/ha of maize grain in Alupe and Kirinyaga, respectively. However, NT+CR significantly out-yielded CT-CR by 400 kg/ha of maize grains at Embu. Across all the sites, application of PK and NPK+ZnBMgCaS fertilizer regimes resulted in significantly the lowest and highest, respectively, maize shoot biomass, leaf area index, crop growth rate, plant height and grain yield. The NPK fertilizer treatment regime yielded higher than NP fertilizer treatment which also out yielded NK treatment. In general, growth and yield performance of fertilizer varied in the order NPK+CaMgZnBS> NPK> NP> NK> PK The interaction between tillage method and fertilizer regime had no effect on all the parameters. Based on this study, application of wide range of nutrients should be encouraged to allow for better growth and yield of maize.

Key words: Conservation agriculture, conventional tillage, fertilizer, growth, maize, yield

3.2. Introduction

In Kenya, maize crop is grown and depended upon by over 80% of households as a staple food (Rockström *et al.,* 2007), income source and livestock feed and fuel (FAO, 2011). Despite the benefits, the average nationwide productivity of maize has remained low in the range of 1-2 t/ha over decades (Jagtap and Abamu, 2003) due to major constraints such as water stress (Hengsdijk and Langeveld, 2009), soil infertility (Okalebo *et al.,* 2007) and biotic stresses (weeds, diseases and insect pests) (Abate *et al.,* 2012).

High nutrient depletion levels have been reported in central, eastern and western parts of Kenya (Sanchez, 1997; Bekunda *et al.,* 2007) due to continuous cultivation without adequate external nutrient replenishment (Mwangi *et al.,* 1998). As reported by Drechsel *et al.* (2001), about 70, 90 and 100 % of all N, K and P nutrient losses, respectively, are due to erosion and plant extraction. Both erosion and leaching losses are high under conventional tillage due to low organic matter and inadequate management of soil moisture strategies. In contrast, retention of crop residue coupled with limited turning of soils, reduces N losses by volatilization, denitrification and leaching (Andraski *et al.*, 2000). Farmers have also been reported to use obsolete fertilizer recommendations (Mugwe *et al.,* 2009) which, in most instances, are used with high inefficiencies due to poor agronomic practices (Vanlauwe *et al.,* 2010) amounting further to low production under conventional tillage systems. As conventionally practiced, crop residue are exported from the fields for other functions (e.g. animal feed, thatching materials and fuel) leaving soils bare and therefore prone to high rates of erosion and runoff. This practice also reduces nutrient recycling potential of the soil through mineralization of immobilized organic compounds.

In addition, fertilizers applied in Kenya are majorly NPK-based sources with no attention given to other essential nutrients like Mg, Ca, Zn, B and S. This is despite several researches which have demonstrated contributions of Zn (Yerokun and Chirwa, 2014), sulphur and magnesium (Szulc *et al.* 2008), calcium (Fageria *et al.*, 2010) and boron (Ahmad *et al.*, 2009) to grain yields. On the other hand, limiting soil moisture is becoming common due to low and erratic rainfall during crop growth. Farmers also lack feasible and cost effective strategies of conserving the limited soil moisture, resulting in wilting and low maize yields (Abate *et al.*, 2012). However, augmentation of this low rainfall by irrigation method is not feasible and sustainable for most small-scale farmers (Neubert *et al.*, 2007).

Conservation agriculture, which entails crop rotation, crop residues management, minimum soil disturbance (Hobbs *et al.*, 2008; Erenstein, *et al.*, 2008) and inorganic fertilizer application (Vanlauwe *et al.*, 2014), offers an alternative option for addressing soil infertility and soil moisture production challenges. Conservation agriculture has shown several benefits in crop production and soil health improvement (Derpsch *et al.*, 2010; Marongwe *et al.*, 2011). Therefore, a study was set up to demonstrate the effect of tillage method and inorganic fertilizer application on growth and yield of maize.

3.3. Materials and methods

3.3.1. Description of study site

The trials were carried out at Kirinyaga Technical Institute (KTI) in Kirinyaga County, Kenya Agricultural and Livestock Research Organization (KALRO)-Embu in Embu County and KALRO- Alupe in Busia County during 2014 long rains season. Soils at Embu and Kirinyaga sites are characterized by humic nitisols while soils at Alupe are characterized by ferralsols (Jaetzold *et al.*, 2005 and 2006). All the sites are located on upper midland zone with bi-modal rainfall pattern, wet seasons from March to May (long rains season) and

October to December (short rains season). The characteristics of the study sites are shown in Table 3.1.

Table 3. 1: Climatic and soil characteristics of the study sites

Parameter	KALRO-Embu	KALRO-Alupe	KTI-Kirinyaga
Longitude	370 19’ 10.4’’ E	34^0 07’ 28.6’’ E	370 19’ 10.4’’ E
Latitude	000 33’ 29.4’’ S	00^0 30’ 10.1’’ N	000 33’ 29.4’’ S
Annual rainfall range (mm)	1200-1500[b]	1100 – 1450[a]	1200-1550[b]
Daily mean temperature (^{0}C)	18.7[b]	24[a]	23[a]
pH (water)	4.44	4.75	5.95
Total SOC (%)	2.00	1.29	2.56
Total nitrogen (%)	0.21	0.14	0.28
Extractable K (me %)	0.28	1.04	6.14
Phosphorus (ppm)	37.80	26.20	44.90
Calcium (me %)	1.60	0.32	1.70
Magnesium (me %)	5.20	3.28	7.46
Zinc (ppm)	18.80	4.30	10.30

Source: [a]Jaetzold *et al.* (2005); [b]Jaetzold *et al.* (2006). SOC= Soil Organic Carbon; KALRO= Kenya Agricultural and Livestock Research Organization; KTI= Kirinyaga Technical Institute.

3.3.2. Experimental design and treatments

The experiment was laid out in a randomized complete block design with a split-plot arrangement and replicated three times. Two tillage systems and five fertilizer regimes were evaluated. The tillage systems were no-till with crop residue retention (NT+CR) and conventional tillage practices with no crop residue (CT-CR). The percentage soil cover by the crop residue was above 75% on all no-till plots during planting in all the sites (This was estimated visually). The fertilizer regimes were NK, NP, PK, NPK and NPK+CaMgZnBS. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), boron (B) and sulphur (S) nutrients were applied at rates of 120, 40, 40, 10, 10, 5 and 26.3 kg/ha, respectively, using urea, triple superphosphate (TSP), muriate of potash (MOP), calcium sulphate, magnesium sulphate, zinc sulphate and borax nutrient, respectively (Table 3.2). The tillage systems were assigned to the main plots and fertilizer regimes assigned to the subplots. These rates were chosen to ensure adequate supply of nutrients without being limiting as required under omission trials. The experiment comprised 30 plots, each measuring 8 m x 10 m. A space of 1.5 m and 1 m was left between blocks and plots, respectively. Maize variety DK 8031 was used for the trials in all sites because of its popularity it the region.

Table 3. 2: Treatments combining tillage practices, crop residue and fertilizer inputs in all sites in Kenya

Tillage method	Crop residue management	Fertilizer regimes
No-tillage	+Crop residue (CR)	NK
,,	,,	NP
,,	,,	PK
,,	' '	NPK
,,	,,	NPK+CaMgZnBS
Conventional tillage (CT)	-Crop residue (CR)	NK
' '	' '	NP
,,	,,	PK
,,	,,	NPK
,,	' '	NPK+CaMgZnBS

+ = Addition of crop residue; - = Removal of crop residue

3.3.3. Agronomic practices

During 2013/2014 short rain season, DK 8031 maize variety was planted to deplete nutrients and to provide crop residue for 2014 long rains season. Land preparation on CT-CR plots was done a week before the onset of the rains, during which, tilling was done using locally available hoe tool. Planting of maize was done at the onset of the long rains at a row spacing of 75 cm and within row spacing of 25 cm using calibrated sisal strings to maintain at least 53,000 plants per hectare. The planting holes on all plots were made using hoe tool. At planting, correct quantities of fertilizers were placed in planting holes then mixed with soil before placing seeds to avoid direct contact that could otherwise cause germination failure.

Nitrogen was applied in three equal splits (at planting, V_4 and V_{10} stages of maize vegetative growth) while the rest of the nutrients were applied at planting. The V_4 and V_{10} are vegetative (V) growth phases of maize when the crop has 4 and 10 visible leaf collars, respectively (Ciganda *et al.*, 2009). Two maize seeds were planted per hill and later thinned to one plant per hill after emergence. At two days after planting, NT+CR plots were sprayed with a mixture of Dual Gold960EC® and Weedal 480 SL herbicides at a rate of 1.5 l/ha each to kill already existing perennial and emerging weeds. Dual Gold 960 EC® is a pre-emergent herbicide with S-metolachlor 960 g/ l as an active ingredient which is absorbed mainly by the emerging weeds during germination and seedling establishment in maize and beans fields. Therefore weeds are controlled prior to, during or shortly after emergence. Weedal 480SL (Roundup®) is a systemic non-selective herbicide for control of annual, biennial and perennial broad leaved weeds and grasses and has an active ingredient isopropylamine salt of glyphosate 480 g/l. The first and second weeding on conventional tillage plots and topdressing on all plots were done at V_4 and V_{10} stages of maize growth. Weed populations on no-till plots were monitored and contained below economic injury level using D-Amine 72% (2, 4-Dichlorophenylacetic acid 600 g/l). D-Amine herbicide is a selective post-emergence herbicide for the control of annual and perennial broad-leaved weeds in maize and wheat. The 2, 4-D salt is readily absorbed by the plant where it accumulates in the meristematic points causing growth inhibition. Pests were monitored regularly and remedial action taken as required. Bulldock® 0.05 GR at the rate of 6 kg ha^{-1} was applied to maize crop approximately 30 days after crop emergence by putting a pinch in the third leaf funnel of every crop to control stalk borers. Squirrels were also controlled through scaring from the time of planting to 10 days after emergence. At maturity (about four months after emergence), maize was harvested manually.

3.3.4. Data collection

Data collected were shoot biomass at 30, 60 and 90 DAE, leaf length and width, plant height, grain moisture at harvesting and total stover weight. Shoot biomass assessment was done at 30, 60, and 90 days after emergence (DAE) and at harvest. Fresh weights of plants sampled were taken and a subsample of 500 g oven dried to a constant weight at 65 ^{0}C. The dry and wet weights of subsamples were used to determine shoot biomass as indicated below;

$$\text{(1) Proportion of dry matter (PDM)} = \frac{\text{Subsample dry weight}}{\text{Subsample fresh weight}}$$

$$\text{(2) Shoot biomass (t/ha)} = \text{(PDM x fresh weight/net plot)} \times \frac{10{,}000\ \text{m}^2}{\text{Net-plot area (m}^2\text{)}}$$

Shoot biomass (per maize plant) was used to compute crop growth rates. Crop growth rate (CGR) is the rate of dry matter production per unit area. Crop growth rate was calculated based on two successive harvests using the following equation (Hunt, 2003):

$$\text{CGR (gm}^{-2}\text{d}^{-1}) = \frac{d\text{W} \div d\text{T}}{\text{GA}}$$

Where *d*W is change in shoot dry matter weight and *d*T is change in time over specific calendar days and GA is the ground area occupied by a maize plant.

At physiological maturity, plant heights were measured using a meter ruler and recorded in centimeters. During this activity, five plants were randomly picked within the same plot and their heights measured from the base of the plant to the tip of the plant and then averaged.

Leaf length (L) and width (W) were measured using a ruler from the tip to the base and at the widest part, respectively, at physiological maturity. These measurements were then used for calculation of leaf area (LA) using the formula, LA = 0.78 (L*W), as described in Blanco and Folegatti (2003) equation, where 0.78 is a constant. Leaf area index (LAI) was then computed as described below (Pierce and Running, 1988):

$$\mathrm{LAI} = \frac{N * \mathrm{LA}\ (\mathrm{cm}^2)}{\mathrm{GA}\ (\mathrm{cm}^2)}$$

Where N is the total number of leaves per plant and GA is the ground area occupied by a maize plant.

At 30, 60 and 90 DAE, soil moisture content (MC %) was assessed - the soils were sampled within 20 cm depth using soil auger across the plots. A constant 200 g of fresh soil was taken then dried at 105 0C to a constant weight. The MC % = [(W2 – W3)/ W3 – W2)] * 100, where W1, W2 and W3 respectively are weights of empty tin, moist soil + tin and dried soil + tin.

At crop maturity, the percentage soil cover by crop residues was estimated using line transect method as described by USDA (https://www.nrcs.usda.gov).

At harvest, net plot plant count and stover fresh weights were collected within a net plot measuring 3.75 m by 4 m (15 m^2). Harvesting was done at an average grain moisture content of 20%. Grain yield per ha was computed from the net plot and adjusted to 14% moisture content.

3.3.5. Statistical analysis

Collected data were subjected to analysis of variance (ANOVA) using Genstat statistics computer software, 15th version. Where F tests were significant, means were compared using Fisher's protected least significance difference (L.S.D.) procedure at $p \leq 0.05$ (Gomez and Gomez, 1984).

3.4. Results

3.4.1. General observations

Maize crop residue cover at physiological maturity varied from site to site with 75 % at Embu compared to 50% and 25% at Kirinyaga and Alupe sites, respectively.

There was generally low rainfall during the production period (week 1-15) (Figure 3.2). Planting and plant emergence occurred when soil moisture was low (week 1 and 2). Rainfall then increased sharply at Alupe during V_5 (week 5 and 6 after emergence) stage then decreased. The rainfall then remained low during the active vegetative phases (to week 8-9) for all sites. Stage V_T (week 8-9 after planting) of maize experienced reduction in rainfall throughout to R_1-R_3 (week 10 to 13 after planting) for Alupe but increased at Embu and Kirinyaga between this stages. Grain filling and maturation of maize crops occurred during low rainfall period (week 11 to 15) (Figure 3.2). The crops were harvested after the fourth month at grain moisture content of about 20%.

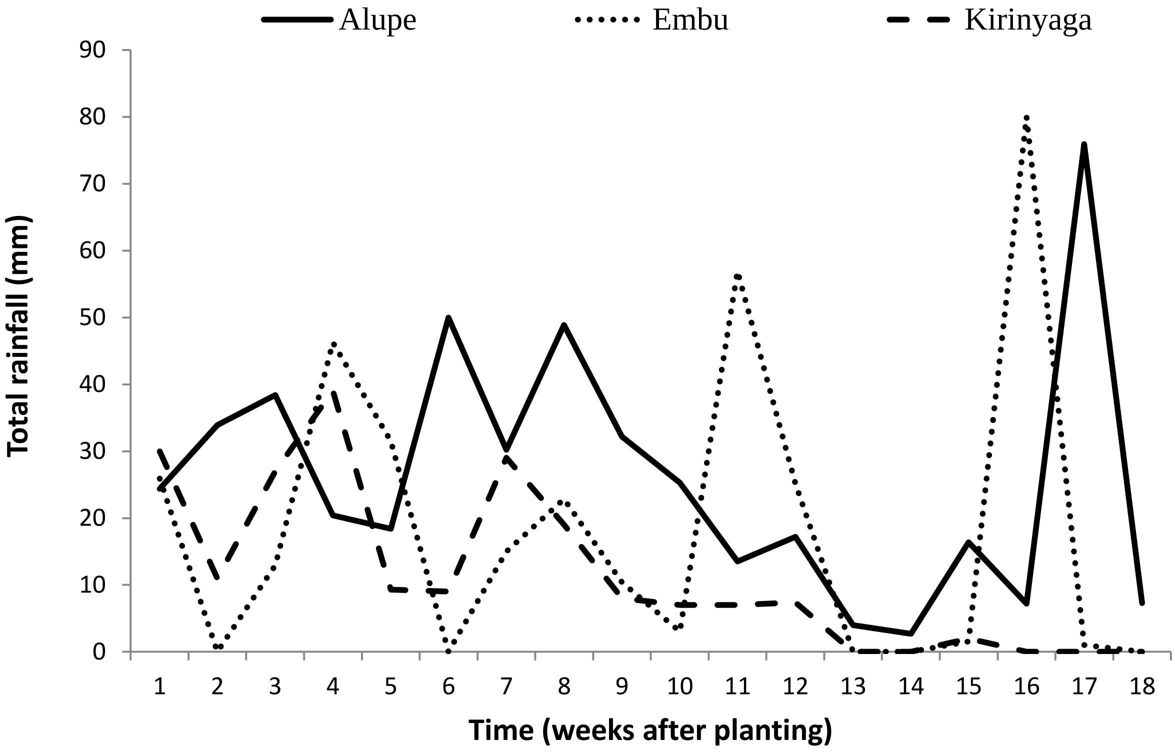

Figure 3. 1: Rainfall distribution and quantities in trial locations during 2014 long rain season

3.4.2. Effect of tillage method and fertilizer regimes on maize leaf area index

Tillage method had a significant effect on maize LAI at Kirinyaga and Embu (Table 3.3). Higher maize LAIs were recorded under conventional tillage with no crop residue retention (CT-CR) than under no-till with crop residue retention (NT+CR) at Embu and Kirinyaga. The NPK+ZnBMgCaS had higher LAI than NK, NP and PK treatments in both sites and NPK at Embu. No significant differences in LAIs were observed among NK, NP and PK treatments in all the sites. The NPK treatment had higher LAI than NK, NP and PK treatments at Kirinyaga and PK treatment at Alupe. At Alupe and Embu sites, NK, NP and NPK treatments were similar. There was no significant interaction effect of tillage method and fertilizer regime on LAI.

Table 3. 3: Effect of tillage method and fertilizer regimes on the maize leaf area index at Alupe, Embu and Kirinyaga trial sites during 2014 long rains season

	Alupe	Embu	Kirinyaga
Tillage method (TM)			
NT+CR	3.1	4.3	4.9
CT-CR	3.2	4.9	5.5
p-value	0.098	<0.001	<0.001
$LSD_{0.05}$	NS	0.2	0.2
CV %	10.7	6.1	8.4
Fertilizer regime (FR)			
NK	3.0	4.5	4.9
NP	3.0	4.5	4.9
PK	2.6	4.4	4.8
NPK	3.5	4.7	5.5
NPK+ZnBMgCaS	3.8	5.0	5.7
p-value	0.01	0.01	<0.001
$LSD_{0.05}$	0.6	0.3	0.4
CV %	12.2	11.8	5.3
Interaction (TM*FR)			
p-value	0.713	0.592	0.147
$LSD_{0.05}$	NS	NS	NS

CV % = coefficient of variation, NT+CR = no-till with crop residue retention, CT-CR = conventional tillage with no crop residue retention, LSD = least significant difference, NS = not significant.

3.4.3. Effect of tillage method and fertilizer regimes on maize plant height

Only the fertilizer regime recorded a significant effect on maize plant height in Alupe, Embu and Kirinyaga (Table 3.4). The PK fertilizer regime recorded shorter plants than NPK and NPK+ZnBMgCaS plots in all the sites. The PK and NK fertilizer regimes recorded similar plant heights at Alupe and Kirinyaga but NK had taller plants than PK at Embu. In all the sites, there were no significant differences between NP and NPK treatments and between NPK and NPK+ZnBMgCaS treatments in maize plant height. Generally, taller maize plants were recorded in NPK+ZnBMgCaS plots than NK, NP and PK plots across all trial sites. A non-significant interaction between tillage method and fertilizer regime was observed for maize plant height in all the sites (Table 3.4). Average plant heights varied from 221 cm at Alupe to 269 cm at Kirinyaga (Table 3.4).

Table 3. 4: Effect of tillage method and fertilizer regime on plant height at Alupe, Embu and Kirinyaga trial sites during 2014 long rains season

	Alupe	Embu	Kirinyaga
Tillage method (TM)			
NT+CR	219	228	265
CT-CR	222	225	273
p-value	0.131	0.072	0.083
$LSD_{0.05}$	NS	NS	NS
CV %	12	13	12
Fertilizer regime (FR)			
NK	206	224	263
NP	213	228	270
PK	200	218	262
NPK	235	230	274
NPK+ZnBMgCaS	248	233	276
p-value	<0.001	<0.001	<0.001
$LSD_{0.05}$	22	5	7
CV %	11	14	12
Interaction (TM*FR)			
p-value	0.412	0.093	0.096
$LSD_{0.05}$	NS	NS	NS

CV % = coefficient of variation, NT+CR = no-till with crop residue retention, CT-CR = conventional tillage with no crop residue retention, LSD = least significant difference, NS= not significant,

3.4.4. Effect of tillage method and fertilizer regime on maize crop growth rate

Across all sites, there was a general increase in crop growth rate (CGR) of maize (Table 3.5). Higher CGR was observed under CT-CR than under NT+CR. Low CGR was recorded at 30 DAE but CGR progressively increased to around 90 DAE. On average, CGR ranged from 0.81 g $m^{-2}d^{-1}$ (Embu) to 2.01 g $m^{-2}d^{-1}$ (Alupe) from planting to 30 DAE, 13.13 g $m^{-2}d^{-1}$ (Alupe) to 23.76 g $m^{-2}d^{-1}$ (Kirinyaga) from 30 to 60 DAE and 23.93 g $m^{-2}d^{-1}$ (Kirinyaga) to 32.97 g $m^{-2}d^{-1}$ (Embu) from 60 to 90 DAE (Table 3.5).

Significant effects of tillage methods on CGR were observed from planting to 30 DAE in KALRO-Embu and Kirinyaga and from 60 DAE to 90 DAE at Alupe (Table 3.5). The CT-CR system had significantly faster CGR (0.96 g $m^{-2}d^{-1}$) than NT+CR (0.67 g $m^{-2}d^{-1}$) from planting to 30 DAE, at Embu. Similarly, from 60 to 90 DAE, CT-CR system had significantly faster CGR (31.58 g $m^{-2}d^{-1}$) than NT+CR system (26.93 g $m^{-2}d^{-1}$) at Alupe (Table 3.5).

Effects of fertilizer regimes on CGR were significant across all the sites. The PK treatment recorded significantly lower rates of biomass production than NPK and NPK+ZnBMgCaS across all sites. The PK and NK treatments were similar except in Embu from 60 to 90 DAE where NK out performed PK. From 30 to 60 DAE and 60 to 90 DAE in Alupe and Kirinyaga sites, NK, NP and NPK treatments produced statistically similar CGRs. The NPK+ZnBMgCaS treatment had the highest CGR compared to all treatments except NPK. The NPK+ZnBMgCaS and NPK treatments were not significantly different in CGR from planting to 60 DAE at Embu and Kirinyaga and in all sites from 60 DAE to 90 DAE. The CGRs ranged from 0.49 g $m^{-2}d^{-1}$ (Embu site) to 40.56 g $m^{-2}d^{-1}$ (Alupe site) (Table 3.5). No significant interaction effect of tillage method and fertilizer application on CGR was observed.

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Table 3. 5: Maize crop growth rate (g $m^{-2}d^{-1}$) as affected by tillage method and fertilizer regimes at Alupe, Embu and Kirinyaga trial sites during 2014 long rains season

	Planting to 30 DAE			30 DAE to 60 DAE			60 DAE to 90 DAE		
	Alupe	Embu	Kirinyaga	Alupe	Embu	Kirinyaga	Alupe	Embu	Kirinyaga
Tillage Method (TM)									
NT+CR	1.86	0.67	1.05	13.13	21.15	23.61	26.93	31.96	23.93
CT-CR	2.15	0.95	1.83	13.34	19.94	23.76	31.58	32.97	25.38
p-value	0.067	0.01	0.01	0.093	0.088	0.105	0.01	0.099	0.068
$LSD_{0.05}$	NS	0.17	0.34	NS	NS	NS	2.93	NS	NS
CV %	14.10	12.10	10.20	15.30	14.40	11.00	13.30	13.90	13.70
Fertilizer regime (FR)									
NK	1.76	0.56	1.30	12.55	19.92	22.53	20.25	32.52	23.02
NP	2.05	0.90	1.49	12.88	21.04	23.63	26.57	32.54	24.63
PK	1.45	0.49	1.14	11.64	18.02	22.41	19.60	30.20	21.64
NPK	2.14	1.01	1.52	13.67	21.46	24.54	39.27	33.17	26.47
NPK+ZnBMgCaS	2.64	1.08	1.75	15.43	22.30	25.31	40.56	33.89	27.54
p-value	<0.001	<0.001	<0.001	<0.001	0.022	0.01	<0.001	<0.001	0.041
$LSD_{0.05}$	0.44	0.14	0.30	1.57	2.63	1.33	11.60	1.32	5.38
CV %	13.10	16.00	15.60	14.90	12.90	15.10	15.9	16.4	18.0
Interaction (TM*FR)									
p-value	0.071	0.091	0.101	0.240	0.174	0.332	0.099	0.491	0.187
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS

CV% = coefficient of variation, DAE= days after emergence, NT+CR = no-till with crop residue retention, CT-CR = conventional tillage with no crop residue retention, LSD = least significant difference, NS= not significant.

3.4.5. Effect of tillage method and fertilizer regimes on maize aboveground biomass production at Alupe, Embu and Kirinyaga

The effect of tillage method on aboveground biomass was significant in Embu and Kirinyaga sites at 30 DAE. The CT-CR had 90 kg/ha and 240 kg/ha significantly higher aboveground biomass than NT+CR at Embu and Kirinyaga, respectively (Table 3.6).

Significant effects of fertilizer regimes were observed at 30, 60, 90 and 120 DAE across all sites. Application of PK and NPK+ZnBMgCaS treatments resulted in the lowest and highest biomass, respectively, at 30, 60, 90 and 120 DAE across all the sites. The performance of fertilizer regimes was in the order of NPK+ZnBMgCaS> NPK> NP> NK> PK across all the sites. Significant differences of 0.11 t/ha and 1.16 t/ha in aboveground biomass were recorded between NPK and NPK+ZnBMgCaS treatments at 30 and 120 DAE, respectively, at Alupe site. However, these two treatments were not significantly different in aboveground biomass at 30 and 120 DAE in Embu and Kirinyaga and at 60 and 90 DAE in all the three sites.

At 30 DAE, PK and NK treatments were not significantly different in aboveground biomass in all the sites. Similarly, no differences in aboveground biomass were recorded for PK and NK at 90 DAE in Embu and 120 DAE in Alupe and Kirinyaga. At 60 DAE in Embu, no significant difference was recorded among NK, NP and PK treatments. At Alupe and Kirinyaga sites, NK, NP, PK and NPK treatments were not significantly different at 60 DAE. At 90 DAE, NK, NP and PK treatments were not significantly different in biomass at Alupe and Kirinyaga. Treatments NK, NP, NPK and NPK+ZnBMgCaS were not significantly different in biomass at Embu. At 120 DAE in Embu and Kirinyaga, NK, NP, NPK and NPK+ZnBMgCaS were not significantly different in aboveground biomass.

At 120 DAE in Embu and Kirinyaga, NK, NP, NPK and NPK+ZnBMgCaS treatments recorded similar effect. At all the three sites, the effect of interaction between tillage method and fertilizer regime was not significant.

Table 3. 6: Effect tillage method and fertilizer regime on aboveground biomass production (t/ha) at Alupe, Embu and Kirinyaga trial sites during 2014 long rains season

	30 DAE			60 DAE			90 DAE			120 DAE		
	Alupe	Embu	Kirinyaga	Alupe	Embu	Kirinyaga	Alupe	Embu	Kirinyaga	Alupe	Embu	Kirinyaga
Tillage Method (TM)												
NT+CR	0.52	0.20	0.31	4.50	6.55	7.75	12.78	16.00	14.56	3.53	5.81	7.54
CT-CR	0.64	0.29	0.55	4.51	6.27	8.00	13.84	16.33	15.41	3.43	5.30	7.40
p-value	0.191	0.01	0.01	0.067	0.291	0.070	0.085	0.810	0.729	0.891	0.581	0.648
LSD $_{0.05}$	NS	0.05	0.10	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV %	15.10	13.20	16.90	11.40	14.20	13.90	12.60	13.50	13.10	12.90	16.40	15.40
Fertilizer regime (FR)												
NK	0.51	0.17	0.39	4.02	6.14	7.31	11.13	16.04	14.21	2.42	5.45	7.35
NP	0.59	0.27	0.45	4.61	6.46	7.53	11.82	16.45	14.70	3.59	5.64	7.54
PK	0.45	0.15	0.34	4.00	5.68	7.31	10.07	15.27	14.02	2.40	4.77	6.78
NPK	0.61	0.30	0.46	4.70	6.74	7.81	16.11	16.50	15.98	3.68	5.82	7.63
NPK+ZnBMgCaS	0.72	0.33	0.53	5.20	7.01	8.07	17.41	16.61	16.02	4.84	6.07	8.05
p-value	<0.001	<0.001	0.01	0.01	0.031	0.041	<0.001	0.044	0.036	<0.001	0.01	0.05
LSD $_{0.05}$	0.11	0.04	0.09	0.71	0.79	0.52	2.66	1.02	1.80	0.60	1.24	0.69
CV %	17.00	10.10	13.50	15.20	13.90	16.40	14.30	12.70	18.00	17.50	17.90	16.10
Interaction (TM*FR)												
p-value	0.351	0.065	0.074	0.159	0.729	0.451	0.153	0.762	0.873	0.581	0.282	0.138
LSD $_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

CV % = coefficient of variation, DAE= days after emergence, NT+CR = no-till with crop residue retention, CT-CR = conventional tillage with no crop residue retention, LSD= least significant difference, NS= not significant, Biomass at 120 DAE had no cobs.

3.4.6. Effect of tillage method on soil moisture conservation

At 30, 60 and 90 DAE, tillage method had a significant effect on soil water retention ($p < 0.01$) in Embu and Kirinyaga (Table 3.7). No-till with crop residues retention had significantly higher soil moisture retention than conventional tillage with no crop residues retention at 30, 60 and 90 DAE at both Kirinyaga and Embu sites (Table 3.9). Numerically, higher moisture percentages were observed at Embu than at Kirinyaga site, irrespective of the tillage method, except at 30 DAE.

Table 3. 7: Effect of tillage method and crop residue management on soil moisture retention percentage during 2014 long rains season

	30 DAE		60 DAE		90 DAE	
	Kirinyaga	Embu	Kirinyaga	Embu	Kirinyaga	Embu
Tillage Method (TM)						
NT+CR	35.04	35.58	24.77	27.31	36.59	38.76
CT-CR	33.10	30.84	24.25	26.18	33.04	34.49
p-value	0.011	0.009	0.014	0.010	0.008	0.005
$LSD_{0.05}$	0.34	2.00	0.32	0.20	1.56	2.01
CV %	10.90	10.40	11.10	12.90	11.70	11.20

CV % = coefficient of variation, NT+CR = no-till with crop residue retention, CT-CR = conventional tillage with no crop residue retention, DAE= days after emergence, LSD= least significant difference.

Pooled means across sites showed a similar trend of high moisture percentages under NT+CR systems compared to CT-CR systems at 30, 60 and 90 DAE (Figure 3.3).

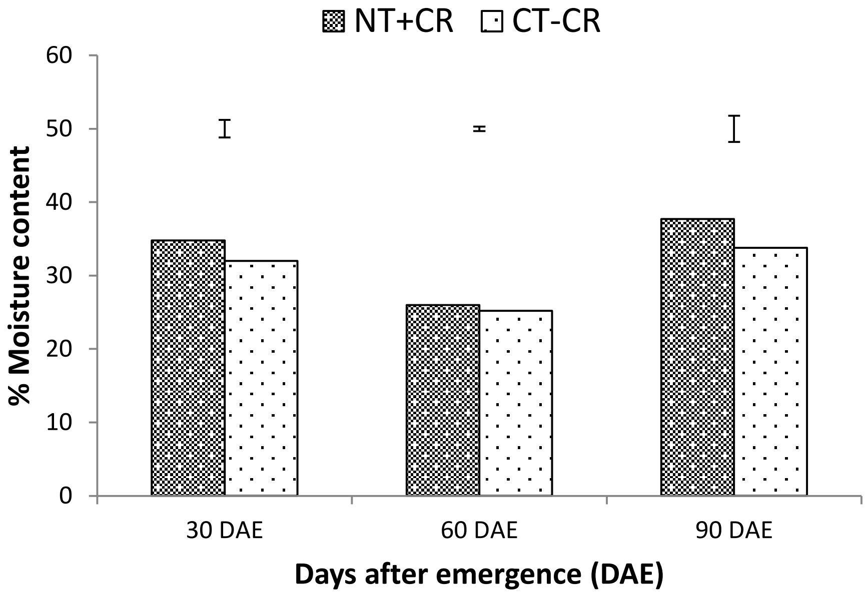

Figure 3. 2: Effect of tillage method and crop residue management on soil moisture retention levels. The bars represent LSD values

3.4.7. Effect of tillage method and fertilizer regime on maize grain yields

The tillage method had a significant effect on maize yield at all the sites (Table 3.8). The NT+CR tillage method significantly out-yielded CT-CR tillage system by 400 kg/ha at Embu (Table 3.8). In contrast, CT-CR system significantly out-yielded NT+CR by 300 and 600 kg/ha at Alupe and Kirinyaga, respectively. The fertilizer regime significantly affected grain yield at all sites. The NPK+ZnBMgCaS treatment generally had significantly higher grain yield than NK, NP and PK across all sites and NPK treatment at Embu. The PK treatment had significantly lower grain yield than NP treatment at Kirinyaga. At Alupe, no significant grain yield differences were recorded between NPK+ZnBMgCaS and NPK fertilizer regimes and among NK, NP and PK fertilizer treatment regimes. Fertilizer regimes NK, NP, PK and NPK were not significant in grain yield at Embu. At Kirinyaga site, no significant differences were recorded among NPK+ZnBMgCaS, NPK, NK and NP treatments. Generally, yield performance varied in the order NPK+ZnBMgCaS> NPK> NP> NK> PK, across all sites (Table 3.8). There was no significant interaction effect of tillage method and fertilizer regime on maize grain yield in all the sites. The average grain yield varied from 3.4 t/ha (Alupe) to 5.7 t/ha (Embu).

Table 3. 8: Effect of tillage method and fertilizer regime on grain yield of maize at Alupe, Embu and Kirinyaga trial sites

	Grain yield (t/ha)		
	Alupe	Embu	Kirinyaga
Tillage Method (TM)			
NT+CR	3.2	5.4	4.3
CT-CR	3.5	5.0	4.9
p-value	0.046	<0.001	<0.001
$LSD_{0.05}$	0.3	0.3	0.2
CV %	10.4	13.6	10.9
Fertilizer Regime (FR)			
NK	2.8	5.1	4.5
NP	3.0	5.1	4.7
PK	2.3	5.0	4.2
NPK	4.1	5.2	4.7
NPK+ZnBMgCaS	4.5	5.7	4.8
p-value	<0.001	0.038	0.010
$LSD_{0.05}$	0.9	0.4	0.3
CV %	13.0	11.4	10.9
Interaction (TM*FR)			
p-value	0.191	0.076	0.059
$LSD_{0.05}$	NS	NS	NS

CV % = coefficient of variation, LSD = least significant difference, NT+CR = no-till with crop residue retention, CT-CR = conventional tillage with no crop residue retention, NS= not significant.

3.5.Discussion

3.5.1. Effects of tillage method on growth and grain yield of maize

Maize under CT-CR recorded higher leaf area index (LAI), plant height, aboveground biomass, and crop growth rate (CGR) than under NT+CR at Alupe and Kirinyaga. However, at Embu, taller plants were recorded under NT+CR than under CT-CR system. Better growth performance of maize plants under CT-CR systems than under NT+CR has been reported by several researchers (Shrestha *et al.* 2013 and Memo *et al.* 2012). They reported that maize under tilled plots with no residue produced taller plants, higher dry matter and leaf area indices than maize under no-till plots.

The general increase in CGR across all sites from emergence to 90 DAE observed in this trial is in resonance with findings by Karimi and Siddique (1991) on maize where CGR was low at the beginning of the season and progressively increased to a maximum value at around 1250 growing degree day (GDD) from sowing. Higher maize CGR was recorded under CT-CR than under NT+CR systems. This observation confirms the findings of Simes *et al.* (1998) and Halvorson *et al.* (2006) that showed slower early growth rates under conservation agriculture than under conventional tillage. This may be attributed to the compacted soils especially under high clay content that reduces water infiltration and general root growth under no-till (Duiker, 2004). In addition, the use of herbicide has been showed to have some growth retarding effect- scorching of young plants and lower leaves- in the early stages of maize growth (Thomas, 1986).

Higher maize grain yields were recorded under CT-CR than under NT+CR at Alupe and Kirinyaga. This observation is similar to that of Hoffmann and Kismányoky (2001) who reported consistently higher maize yield under conventional tillage than under no-till and reduced till plots. Previous researchers have also shown reduction in maize grain yields with reduction in tillage (Uri, 2000; Filipović *et al.*, 2004 and Kihara *et al.*, 2012). However, NT+CR system out-yielded CT-CR system. This is similar to the findings by Sommer *et al.* (2007) who reported that conservation agriculture increased maize yields relative to conventional tillage system. The better performance of CT-CR sytem observed may be as a result of loose soils under conventional tillage practice which allowed faster maize root penetration and development, water infiltration and stronger anchorage (Kovar *et al.* 1992; Sharma *et al.*, 2010). Also, removal of crop residue under CT-CR system may have allowed easy penetration of soil by light showers of rainfall which would otherwise be blocked by crop residue cover under conservation agriculture (Li *et al.,* 2008; Wang *et al.,* 2012). Low yields under conservation agriculture at Alupe and Kirinyaga may be attributed also to early slower growth rate than under conventional tillage (Halvorson *et al.,* 2006). However, Beyaert *et al.* (2002) observed that early slow maize growth in zero tillage had a non-significant effect on ultimate grain yield.

On the other hand, higher maize yields recorded at Embu site under NT+CR than under CT-CR system may have been due to higher crop residue retention that lowered evaporation rates resulting to higher water rention than under CT-CR system. This is evidenced by the consistently higher soil water contents at Embu and Kirinyaga obtained in this trial despite the low and eratic rainfall recived. This obsevation confirms the findings by Shrestha *et al*., (2013) and Liu *et al.* (2013) on effect of zero and reduced tillage on soil water storage. The stored water may have been made available for uptake by maize during low rainfal periods at Embu but was never significatly influenced maize at Alupe and Kirinyaga. The stored water could have also increased the efficiency of nutrient utilization by maize crops hence better performance especially during low rainfal periods. High mulch cover is key in realizing immediate benefits of conservation agriculture in terms of soil moisture conservation. As realized at Embu, high crop residues cover of about 75% improved maize performance.

3.5.2. Effect of fertilizer application on growth and grain yield of maize

Omission of nitrogen (PK treatment) resulted in shorter plants, reduced leaf area indices, biomass production, CGR and grain yields. From the nutrient responses, N was the most limiting nutrient followed by P then K. These findings are in line with those from a trial carried out in western Kenya by Ngome *et al.* (2013) who reported high maize yields due to N fertilizer application compared to P fertilizer application. The best performance in plant attributes was recorded under NPK+ZnBMgCaS followed by NPK, NP, and NK, in a descending order of performance. Previous studies have also shown that application of N fertilizer resulted in increased growth and yield of maize plants (Namakka *et al.*, 2012; Ibrahim *et al.*, 2008; Sharafi *et al.*, 2013). Such great influence of N is due to its pivotal roles in many physiological and biochemical processes such as protein formation and in chlorophyll synthesis (Fageria, 2014). This shows that N is very crucial and limiting in the study regions, hence, needs to addressed for improved maize production. Combined application of a wide range of nutrients (treatments NPK+ZnBMgCaS and NPK) resulted in better crop performance than a narrow range of nutrients (NP, NK and PK) in terms of biomass production, CGR, LAI, height and grain yield. These results are in agreement with previous findings by Adhikari *et al.* (2010) who reported that combined application of NPK with B, S, Zn and Mn resulted in higher maize biomass and grain yield than NPK treatment that in turn had higher maize biomass and grain yield than sole applied N, P and K fertilizers. Increased maize dry matter production and grain yield have been reported due to Cu, S and Mg applications (Khatri-Chhetri and Schulte, 2005) and due to Ca and B nutrients (Kanwal *et al.*, 2008). The current findings indicate that other than N, P and K, secondary nutrients (Mg, Ca and S) and micronutrients (Zn and B) maybe limiting in farmers field and need to be ameliorated. When nutrients are applied together, they work synergistically to ameliorate deficiencies and inefficiencies with which essential nutrients are used for improved growth and yield (Jakobsen, 2009). This may explain why maize under NPK+ZnBMgCaS out-yielded most other treatments while NPK out yielded NK, NP, PK treatments in most cases. Phosphorus plays an important role in energy storage and transfer in crop plants (Jones *et al.,* 2005). Together, P and K may have increased tolerance of maize to environmental stresses like drought and disease attacks through enhanced development of roots and stalks (Jin *et al.,* 2006; Fageria, 2009). Calcium and magnesium may have helped in enzyme activation, nutrient uptake and ion balance (Fageria and Gheyi, 1999), carbohydrate translocation, stiffness of maize straw and grain and seed formation (Fageria, 2009). Zinc may have also imparted maize crops with ability to resist biotic and abiotic stresses and improved photosynthesis and auxin production (Alloway, 2008). As a result, maize crops may have become taller and produced higher biomass and grain yield. These findings are similar to those observed by Galavi *et al.* (2011) when investigating the effects of bio-phosphate and chemical phosphorus fertilizer accompanied with foliar application of micronutrients on growth and yield of maize. Boron on the other hand may have helped in pollen germination and tube formation and seed formation resulting in increased number of seeds per cob and maize grain yield (Kaur and Nelson, 2015). Sherchan *et al.* (2004) at the National Maize Research Programme in Nepal also reported increased maize grain yield due to boron application.

3.6.Conclusion

Better maize performance was recorded under CT-CR than under NT+CR systems, in terms of leaf area index, plant height, aboveground biomass production at 30, 60 and 90 days after emergence, and crop growth rate at Alupe and Kirinyaga. However, at 60 after emergence at (Embu) and 120 days after emergence in all the sites, NT+CR recorded higher aboveground biomass than CT-CR in all sites in the same season. Higher moisture retention was also observed under no-till with crop residue retention than under conventional tillage with no crop residues retention. Fertilizer application also significantly influenced maize performance at all sites in all seasons. The NPK+ZnBMgCaS treatment had higher grain yield than most of the nutrient combinations across all sites while the PK treatment had the lowest maize growth and yield at all locations. The impact of tillage method was not dependent on the nutrient management. The yield performance of fertilizer treatments varied in the order NPK+ZnBMgCaS> NPK> NP> NK> PK.

CHAPTER FOUR: EFFECT OF TILLAGE METHOD AND RESIDUAL FERTILIZER NUTRIENTS ON GRAIN YIELD OF DRY BEAN GROWN AS A ROTATIONAL CROP WITH MAIZE

4.1. Abstract

Dry bean is the most important food legume crop in Kenya. However, its production is constrained by drought and soil infertility. Attempts to remove these limitations through irrigation and inorganic fertilizer applications have often failed due to resource constraints. A study was carried out at Kirinyaga Technical Institute in Kirinyaga County and the Kenya Agricultural and Livestock Research Organization, Embu, crop research centre in Embu County to evaluate the effects of tillage method and residual nutrients on yield performance of dry bean. Dry bean as a rotational crop was grown on plots previously occupied by maize that had been supplied with NK, NP, PK, NPK and NPK+CaMgZnBS fertilizer regimes. The trials were laid in a randomized complete block design with a split plot arrangement. The tillage methods (NT+CR and CT-CR) were assigned to the main plot and residual nutrients as subplots. The results showed that conservation agriculture (NT+CR) produced higher biomass, number of pods per plant, number of seeds per pod, 1000-seed weight and grain yield than conventional tillage (CT-CR) in all sites. Grain yields recorded strong and positive relationships with biomass at 60 days after emergence (DAE), number of pods, number of seeds, 1000-seed weight and harvest index. In all sites, plots previously supplied with NPK+ZnBMgCaS yielded significantly higher biomass at 60 DAE, number of seeds per pod, 1000-seed weight and grain yield than plots with other treatments. The NPK+ZnBMgCaS resulted in 3.67 and 5.17 higher pods per bean plant than NK in Embu and Kirinyaga, respectively. The NPK+ZnBMgCaS yielded 23 g and 33 g per 1000-seed weight more than residual PK at Embu and Kirinyaga, respectively. The

NPK+ZnBMgCaS and NPK treatments out yielded PK treatment by 600 kg/ha and 370 kg/ha, respectively, in Embu and by 710 kg/ha and 330 kg/ha, respectively, in Kirinyaga. Cultivation of dry bean on residual nutrients following fertilized maize crop grown under no-till with crop residue retention has the potential to improve the productivity of maize-bean rotation system.

Key Words: Bean nematode, conservation agriculture, conventional tillage, crop rotation, no-till, residual fertilizer

4.2. Introduction

Dry bean (*Phaseolus vulgaris*) is the most important food legume crop in Kenya. It is cultivated by over 85% of farming households in Kenya (Rockström *et al.,* 2009) mostly due to its cheap source of cholesterol-free proteins and fast maturity (Jones, 1999; Akibonde and Maredia, 2011; CIAT, 2013). The crop also offers the best alternative source of daily-recommended level of iron, rich source of complex carbohydrates and dietary fibre (CIAT, 2013). Dry bean also serves as a cash crop, in case of surplus, that enables farmers to meet some of their needs including acquisition of agricultural inputs such as fertilizer and herbicides (Kimani *et al.,* 2001). Integration of dry bean in to the existing cropping systems has the potential to improve soil fertility and provide nutrients for subsequent rotational cereal crops such as maize (Reeves, 1997; Bationo and Ntare, 2000; Bagayoko *et al.,* 2000).

A maize-dry bean rotation system has several potential agronomic benefits. It helps in soil water conservation, minimization of salinity problems in arid and semi-arid lands and weed management (Liebman *et al.* 1996; Turner, 2004). Crop rotation involving legumes influence soil nutrient cycling by changing the physical and biological nature of the soil environment (Ladd *et al.,* 1993) and freely fixing N from air (Ball *et al.*, 2005). According to Kihara *et al.* (2011), BNF by soybean increased under reduced tillage together with crop residue mulch. Under both conservation and conventional tillage systems, high quality bean residue release nutrients more quickly than more fibrous cereal residues upon putrefaction (Lu *et al.*, 2011). Economically, BNF through N-fixing legume crops like common bean helps farmers to supply soil N for cereal crop production thus easing the burden of buying commercial N fertilizer. For instance, Giller *et al*. (2001) reported that tropical leguminous plants could fix, on average, 1 to 2 kg N ha^{-1} growing season day^{-1}. Lunze and Ngongo (2011) reported that climbing beans have greater N fixing capacities than bush beans. They fix 16 to 42 kg N ha^{-1} season^{-1} compared to bush beans. This N fixed by legumes is affected by the population of compatible rhizobia bacteria in the soil (Mabood *et al.*, 2006) and the interaction of these rhizobia with the soil physical, chemical and biological characteristics (Goss and Varennes, 2002). These soil characteristics are influenced positively by conservation agriculture practices (Madari *et al.*, 2005). Soil moisture and temperature are both influenced by crop residue management, which also affects BNF (Salvagiotti *et al.*, 2008). Increased soil N and improved soil health through crop rotation increase crop yields. Kasasa *et al.* (1999) and Giller *et al*., (2001) reported doubling of yield of cereal crops that followed legumes in the same field. Copeland and Crookston (1992) also revealed that crops grown in rotation normally have higher accumulation of biomass than when grown in monoculture. On the other hand, a bean crop following maize benefits from increased soil surface mulch that reduces the rate of water loss and improves soil temperature for enhanced rhizobial growth. These together with residual nutrients left result to increased yields. Rotation increases microbial diversity thereby reducing the hazard of build up of pests and diseases through constant check on the population of the pathogenic microbes (Leake, 2003). For instance, crop pathogens with narrow or specific host range such as nematodes have their populations easily checked by inclusion of non-host crop in the program.

Although the maize-bean rotation system is practiced in Kenya, much of it is practised in small home fields by farming households (Zingore *et al*., 2007). Also during harvest, farmers normally uproot the whole legume plant leaving no residue in the field to build up soil N content upon decay. Despite dry bean's agronomic, economic and nutritive benefits, its production has been faced by numerous hindrances resulting in low production of less than 1 t/ha (Jagtap and Abamu, 2003; CIAT *et al.*, 2013). This low productivity of dry bean is due to low soil moisture in the production areas and depleted soil fertility (Recha *et al.*, 2012). Other than developed countries that apply adequate fertilizer to dry bean, underdeveloped countries in Sub-Sahara African countries have reported low consumption of such inputs (Katungi *et al.*, 2009). This is despite possible significant increase in dry bean production due to inorganic fertilizer application (Machado *et al.*, 2008). Utilization of residual fertilizer nutrients for dry bean production may help farmers to realise better yields and save on resources. This study was therefore, conducted to determine the effect of two tillage methods and residual fertilizer nutrients on yield and yield components of dry bean.

4.3.Materials and methods

4.3.1. Site description

The trials were carried out in 2014-2015 short rains at Kirinyaga Technical Institute (KTI) in Kirinyaga County and Kenya Agricultural and Livestock Research Organization's (KALRO) crop research centre in Embu County. The soils in these study sites are characterized by humic nitisols. The two sites located on upper midland zone with bi-modal rainfall pattern, experience wet seasons from March to May (long rains) and October to December (short rains). Rainfall ranges from 1100 mm to 1550 mm per annum. The characteristics of the sites are as shown in Table 4.1.

Table 4. 1: Rainfall, temperature and soil fertility characteristics of the experimental sites

Parameter	Embu	Kirinyaga
Longitude	370 19’ 10.4’’E	370 19’ 10.4’’E
Latitude	000 33’ 29.4’’S	000 30’ 18.3’’ S
Annual rainfall range (mm)	1200-1500[b]	1200-1550[b]
Daily mean temperature (^{o}C)	18.7[b]	23[a]
pH (water)	4.61	5.24
Total soil organic carbon (%)	2.01	1.73
Total nitrogen (%)	0.25	0.26
Extractable potassium (meq/100 g soil)	0.44	0.34
Phosphorus (ppm)	107.56	188.45
Extractable calcium (meq/100 g soil)	2.37	7.27
Extractable magnesium (meq/100 g soil)	1.10	3.70
Extractable zinc (ppm)	16.67	5.57
Sulphur (ppm)	66.61	39.79

Source: [a]Jaetzold *et al.* (2005); [b]Jaetzold *et al.* (2006)

4.3.2. Experimental design and treatments

The trials were laid out in a randomized complete block design with a split plot arrangement and replicated three times. The tillage method was assigned to the main plots and residual fertilizer nutrient combinations assigned to subplots. The tillage methods were conservation agriculture involving no tilling of land with retention of crop residue (NT+CR) and conventional tillage involving tilling of land with complete removal of crop residue (CT-CR). In the subplots were five residual fertilizer regimes (plots previously under maize crop) - NK, NP, PK, NPK and NPK+CaMgZnBS (Table 4.2). Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), boron (B) and sulphur (S) nutrients were applied at the rate of 120, 40, 40, 10, 10, 5 and 26.3 kg/ha, respectively, during maize production in 2014 long rains season. There were three blocks each comprising 10 experimental plots measuring 8 m by 10 m each. Path of 1.5 m and 1 m wide were left between blocks and plots, respectively.

Table 4. 2: Treatment combination of tillage practice, crop residue and residual fertilizer regime in all sites in Kenya

Tillage method	Crop residue (CR)	Residual Fertilizer regime
No-tillage (NT)	+CR	NK
,,	,,	NP
,,	,,	PK
,,	’’	NPK
,,	,,	NPK+CaMgZnBS
Conventional tillage (CT)	-CR	NK
’’	’’	NP
,,	,,	PK
,,	,,	NPK
,,	’’	NPK+CaMgZnBS

+ = Retention of crop residue; - = Removal of crop residue

4.3.3. Agronomic practices

Land preparation and planting were done in October, 2014 before the onset of the short rains. The CT-CR plots were prepared by tilling using hoe tool. The plots were planted at the beginning of the short rains at a seed rate of 50 kg/ha and spacing of 50 cm by 15 cm. On both systems, planting holes were made suing hoe tool. Two seeds were planted per hill. Two days after planting, NT+CR plots were sprayed with a mixture of Dual Gold960EC® and Weedal 480 SL herbicides at a rate of 1.5 l/ha, each to kill already existing perennial weed and germinating weeds.

Dual Gold 960 EC® is a pre-emergent herbicide with S-metolachlor 960 g/ l as an active ingredient which is absorbed mainly by the emergence of the weeds (hypocotyl/ coleoptile) during germination and seedling establishment in maize and beans fields. Therefore weeds are controlled prior to, during or shortly after emergence. Weedal 480SL (Roundup®) is a systemic non-selective herbicide for control of annual, biennial and perennial broad leaved weeds grasses. Round up® has isopropylamine salt of glyphosate (480 g/l) as an active ingredient. The herbicide is used for the control of weeds which are in the field at the time of planting.

Weeding was done twice by hand on conventional tillage system plots whereas Basagram herbicide at 1.5 l/ha was used to control weeds on no-till system plots so as to avoid soil disturbances. Basagram®, with Bentazon 480 g/L as active ingredient, is a selective post-emergence broadleaf weed control in many crops including dry bean. Weeds that were not controlled using this herbicide were mechanically controlled by hand uprooting. This experiment was carried out under rain fed conditions without supplement of irrigation.

4.3.4. Data collection

Data were collected at 60 days after emergence (DAE) and at harvest. Data collected were total aboveground biomass, plant count per plot, number of pods per plant, number of seeds per pod, 1000-seed weight, stover yield. Harvest index, grain to stover ratio and correlation between yield components were determined.

At 60 DAE, above ground biomass assessment was carried out from a 20 m^2 net plot for all plots in all sites. Plants were cut above the ground and their fresh weights recorded. A subsample of 500 g fresh weight (FW) was then oven dried at 65 ^{0}C to a constant weight. The fresh and dry weights of subsamples were used to determine biomass production as follows:

$$\text{(1) Dry matter} = \frac{\text{Subsample dry weight}}{\text{Sample fresh weight}}$$

$$\text{(2) Biomass Production (t/ha)} = \quad \text{(PDM * FW (t) in Netplot *} \frac{10{,}000\ m^2}{\text{Net-plot } (m^2)}$$

At physiological maturity, a net plot area of 20 m^2 was used to collect all other parameters. Plant count was taken in each net plot.

Number of pods per plant and number of seeds per pod were determined by randomly sampling 10 plants and 10 pods, respectively. The 1000-seed weight was computed from dried grains per plot by manually picking 1000 seeds at random and weighing using an electronic balance.

Stover yield (stems, stalks and pods of beans left after removing seeds) was calculated from a 500 g subsample dried to a constant weight at 65 ^{0}C. At pod setting, five bean plants per plot were pulled out to assess the percentage of nematode attack. The percentage infection was then scaled based on Nematology Laboratory chart at the Department of Plant Science and Crop Portection, University of Nairobi. Grain production per hectare was computed from yield components using Fegaria (2009) formula:

$$\text{Grain yield (t/ha)} = \quad \text{No. of pods ha}^{-1} * \text{No. of seeds pod}^{-1} * \text{1000-seeds weight (g)} * 10^{-6}$$

Harvest Index (HI) of dry bean was determined by the ratio of dried grain yield to the total aboveground dry matter. Grain to stover ratio was calculated by dividing the total grain per hectare by the total stover per hectare produced for every treatment.

4.3.5. Data analysis

All collected data was entered in Excel Computer Package. For each of the parameters considered, data was subjected to analysis of variance (ANOVA) using Genstat Software, 15th Edition statistical package. The means were separated using Fisher's protected least-significant difference (LSD) test at $P \leq 0.05$.

Regression analysis between means of grain yield and yield components was done using Microsoft Excel computer package. The key yield components considered were total biomass, number of pods per plant, number of seeds per pod, 1000-seed weight and harvest index.

4.4. Results

4.4.1. General observations

Rainfall was generally low with several days going dry (Figure 4.2). Planting and emergence of crops occurred under very low rainfall (week 1 and 2) (Figure 4.2). Small amounts of rainfall were received during mid-vegetative stage (week 3). Dry bean vegetative stage lasted for about 4-5 weeks after planting. Rainfall reduced immediately when crops were getting to initial reproductive stage (flower bud initiation) at the 6th week and continued to decline until 8th week. It then increased sharply into the 9th week and then declined throughout the rest of production period. Root gall nematode infestation was also visually observed during plant growth. The incidence level ranged between 3 and 4 (38 to 63 % roots galled) under conventional tillage (CT-CR) compared to 2 and 3 (23 to 38 % roots galled) under conservation agriculture (NT+CR).

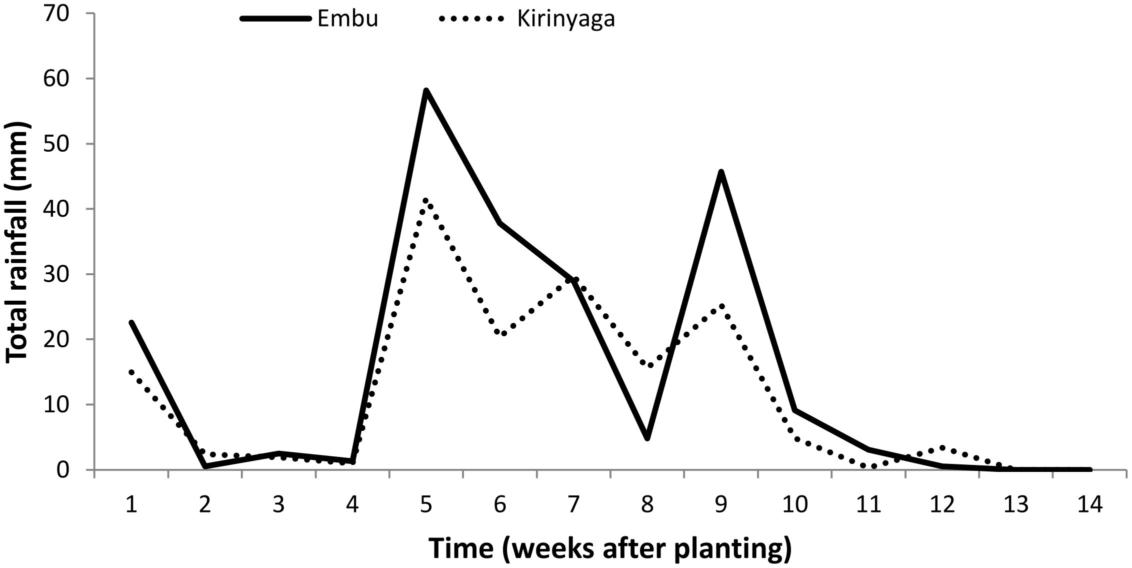

Figure 4. 1: Rainfall distribution and quantities during dry bean production as obtained from KALRO-Embu and Kirinyaga Coffee Estate station during 2014/2015 short rains season

4.4.2. Effect of tillage method and residual fertilizer on shoot biomass production at 60 days after emergence

Conservation agriculture (NT+CR) and residual fertilizer regime influenced shoot biomass at 60 DAE (Table 4.3). In both sites, PK residual treatments yielded significantly lower shoot biomass at 60 DAE than NPK and NPK+ZnBMgCaS (Table 4.3). No significant differences in shoot biomass were recorded among PK, NK, and NP treatments in all sites and between NPK+ZnBMgCaS and NPK treatments at Embu site. The latter two treatments out-performed PK treatment in shoot biomass by 1.43 t/ha and 0.78 t/ha respectively in Embu site. Treatment NPK+ZnBMgCaS recorded significantly higher shoot biomass (400 kg/ha) than NPK at

Kirinyaga. These two treatments had significantly higher biomass than other treatments. The interactive effect of tillage method and residual fertilizer on biomass was not significant.

The NT+CR system had significantly higher shoot biomass at 60 DAE than CTR-CR at Kirinyaga site. However, the two tillage systems had similar total biomass in Embu (Table 4.3). The average shoot biomass varied from 2.58 t/ha at Kirinyaga to 3.05 t/ha at Embu.

Table 4.3: Effect of tillage method and residual fertilizer on shoot biomass at 60 days after emergence (DAE) at Embu and Kirinyaga during 2014/2015 short rains season

	Biomass at 60 DAE (t/ha)	
	Embu	Kirinyaga
Tillage method (TM)		
NT+CR	3.15	2.62
CT-CR	2.95	2.54
p-value	0.055	0.01
LSD $_{0.05}$	NS	0.07
CV %	17.5	18.1
Residual fertilizer (RF)		
NK	2.90	2.36
NP	2.98	2.37
PK	2.39	2.29
NPK	3.17	2.74
NPK+ZnBMgCaS	3.82	3.14
p-value	<0.001	<0.001
LSD $_{0.05}$	0.69	0.36
CV %	15.4	13.9
Interaction (TM*RF)		
p-value	0.064	0.059
LSD $_{0.05}$	NS	NS

CV% = coefficient of variation, TM*RF= interaction between tillage method and residual nutrients, LSD = least significant difference, NT+CR = no-till with crop residues retention, CT-CR = conventional tillage with no crop residues retention, NS= not significant.

4.4.3. Effect of tillage method and residual fertilizer on stover dry weight

The tillage method significantly influenced common bean stover in both sites (Table 4.4). At Embu, NPK+ZnBMgCaS had significantly higher stover dry weights than NK, NP, and PK. No differences in stover dry weights were noted among NK, NP and PK treatments and between NPK and NPK+ZnBMgCaS treatments. Treatment NPK+ZnBMgCaS had 0.41 t/ha higher stover dry weight than PK treatment. At Kirinyaga, NPK+ZnBMgCaS produced higher stover dry weights than all the other treatments. Treatment NPK had higher stover dry weights than NK, NP and PK. The interaction between tillage method and residual fertilizer regime had no significant effect on stover dry weights in both sites. The KALRO Embu site had 0.12 t/ha more stover dry weight than at Kirinyaga site. Average stover varied from 1.49 t/ha (Kirinyaga) to 1.55 t/ha (Embu).

Table 4. 4: Effect of tillage method and residual fertilizer on bean stover yield at Embu and Kirinyag during 2014/2015 short rains season

	Stover production (t/ha)	
	Embu	Kirinyaga
Tillage method (TM)		
NT+CR	1.70	1.57
CT-CR	1.39	1.40
p-value	<0.001	<0.001
LSD $_{0.05}$	0.03	0.08
CV %	16.10	12.00
Residual fertilizers (RF)		
NK	1.47	1.40
NP	1.55	1.42
PK	1.32	1.30
NPK	1.67	1.49
NPK+ZnBMgCaS	1.73	1.83
p-value	0.034	<0.001
LSD $_{0.05}$	0.26	0.13

CV %	12.90	11.30
Interaction (TM*RF)		
p-value	0.067	0.086
LSD $_{0.05}$	NS	NS

CV% = coefficient of variation, NT+CR = no-till with crop residues retention, CT-CR = conventional tillage with no crop residues retention, LSD = least significant difference, NS= not significant.

4.4.4. Effect of tillage method and residual fertilizer on the number of pods per plant and number of seeds per pod

The tillage method and residual fertilizer treatments significantly influenced the number of pod per plant in both sites (Table 4.5). No significant differences were observed among NP, PK and NPK treatments and between NK and NP treatment in the number of pods produced per plant in both sites. The NPK+ZnBMgCaS treatment resulted in 3.67 and 5.17 more pods per bean plant than NK treatment in Embu and Kirinyaga, respectively (Table 4.5). The effects of residual fertilizers across the sites on the number pods per plant were in the order of NPK+ZnBMgCaS> NPK> PK>NP> NK. There were no significant interactive effect of tillage method and residual fertilizers on the number of pods per plant in both sites. The pods per plant varied from 12.00 to 15.67 at Embu 10.83 to 16.00 at Kirinyaga.

The NT+CR system yielded significantly higher number of pods per bean plant than CT-CR system in both sites. The average number of pods was 12.74 and 14.30 per plant at Kirinyaga and Embu, respectively (Table 4.5).

The tillage method and residual fertilizer treatments significantly affected the number of seeds produced per pod at KALRO Embu (Table 4.5). The NT+CR tillage produced a higher number of seeds per pod than CT-CR system. A significantly lower number of seed per pod (3.84) was noted in PK plots at Embu. Treatments NPK+ZnBMgCaS had 0.99 and 0.50 higher number of seeds per pod than PK and NK treatments effect, respectively. No significant differences were noted among NK, NP and NPK treatment and among NPK+ZnBMgCaS, NPK and NP treatment. The average number of seeds per pod varied from 3.84 to 4.83 at Embu and 4.83 to 5.00 at Kirinyaga. The number of seeds per pod were in descending order of NPK+ZnBMgCaS> NPK> NP> NK> PK in both sites (Table 4.5). The interactive effect of tillage method and residual fertilizer was not significant in both sites.

Table 4. 5: Effect of tillage method and residual fertilizer on number of pods per plant and number of seeds per pod at Embu and Kirinyaga during 2014/2015 short rain season

	Pods per plant		Seeds per pod	
	Embu	Kirinyaga	Embu	Kirinyaga
Tillage method (TM)				
NT+CR	15.60	13.27	4.80	4.93
CT-CR	13.00	12.20	4.00	4.87
p-value	<0.001	0.045	<0.001	0.071
LSD $_{0.05}$	1.18	0.95	0.28	NS
CV %	12.5	10.9	13.2	10.7
Residual fertilizer (RF)				
NK	12.00	10.83	4.33	4.83
NP	13.67	11.50	4.50	5.00
PK	14.67	12.67	3.84	4.67
NPK	15.50	12.67	4.50	5.00
NPK+ZnBMgCaS	15.67	16.00	4.83	5.00
p-value	<0.001	<0.001	<0.001	0.092
LSD $_{0.05}$	1.87	1.51	0.45	NS
CV %	13.00	9.90	10.00	12.90
Interaction (TM*RF)				
p-value	0.061	0.114	0.057	0.099
LSD $_{0.05}$	NS	NS	NS	NS

CV% = coefficient of variation, NT+CR = no-till with crop residues retention, CT-CR = conventional tillage with no crop residues retention, LSD = least significant difference, NS= not significant.

4.4.5. Effect of tillage method and residual fertilizer on 1000-seed weight and grain yield

The tillage method significantly influenced 1000-seed weight in Embu but had no effect on this parameter at Kirinyaga (Table 4.6). At Embu, NT+CR system recorded higher 1000-seed weight than CT-CR system. Residual fertilizers had a significant effect on the 1000 seed weight in both sites. The lowest 1000-seed weight was recorded on PK residual plots in both sites. No differences were recorded among PK, NK, NP and NPK treatments at Embu and between PK and NK treatments at Kirinyaga. Residual NPK+ZnBMgCaS fertilizer treatment had higher 1000 seed weight than residual PK, NK and NP treatments at Embu and PK residual treatment at Kirinyaga. At Kirinyaga, NPK+ZnBMgCaS, NPK and NP residual fertilizer treatments were similar in 1000-seed weight. The average 1000-seed weight ranged from 299.5 g (Kirinyaga) to 346.5 g (Embu) (Table 4.6). No significant interaction was noted between tillage method and residual nutrients with respect to 1000-seed weight in both sites.

Dry bean plants grown under NT+CR plots significantly out-yielded those under CT-CR plots by 140 kg/ha and 200 kg/ha in Kirinyaga and Embu trial sites, respectively (Table 4.6). Residual fertilizer had significant effects on dry bean grain yield in both sites. The NPK+ZnBMgCaS treatment had significantly higher grain yield than all the other treatments. At Embu, NPK had significantly higher grain yield than NK and PK. The NPK+ZnBMgCaS and NPK treatments significantly out-yielded PK treatment by 600 kg/ha and 370 kg/ha, respectively, at Embu. The PK, NP and NK treatments were not significantly different in grain yield. At Kirinyaga, NPK significantly out-yielded NK, NP and PK treatments. There were no significant grain yield differences between NK and NP treatments and between NK and PK treatments. The NPK+ZnBMgCaS and NPK treatments out-yielded PK treatment by 710 kg/ha and 330 kg/ha, respectively (Table 4.6). The interaction between tillage method and residual fertilizer regime was not significant for grain yield in both sites. At both sites, grain yields varied from 1.14 t/ha (Kirinyaga) to 1.49 t/ha (Embu).

Table 4. 6: Effect of tillage method and residual fertilizer on 1000-seed weight average for each site and grain yield at Embu and Kirinyaga during 2014/2015 short rain season

	1000-seed weight (g)		Grain yield (t/ha)	
	Embu site	Kirinyaga site	Embu site	Kirinyaga site
Tillage method (TM)				
NT+CR	359	302	1.59	1.21
CT-CR	334	297	1.39	1.07
p-value	<0.001	0.192	<0.001	<0.001
LSD $_{0.05}$	10	NS	0.12	0.09
CV %	11.40	10.10	9.70	11.10
Residual fertilizers (RF)				
NK	344	293	1.39	1.01
NP	344	302	1.40	1.03
PK	337	282	1.23	0.87
NPK	346	304	1.60	1.20
NPK+ZnBMgCaS	360	315	1.83	1.58
p-value	0.021	0.045	<0.001	<0.001
LSD $_{0.05}$	16	19	0.20	0.14
CV %	11.10	12.30	9.20	10.70
Interaction (TM*RF)				
p-value	0.084	0.155	0.055	0.061
LSD $_{0.05}$	NS	NS	NS	NS

CV% = coefficient of variation, NT+CR = no-till with crop residues retention, CT-CR = conventional tillage with no crop residues retention, LSD= least significant difference, NS= not significant.

4.4.6. Effect of tillage method and residual fertilizer on grain to stover ratio and harvest index

In both sites, the tillage method had no significant effect on dry bean grain to stover ratio (Table 4.7). The tillage method had a significant effect on the dry bean harvest index at Embu site but had no effect on this parameter at Kirinyaga. The CT-CR tillage system produced a higher harvest index (0.499) than NT+CR tillage system (0.481) (Table 4.7).

The residual fertilizers had a significant effect on the harvest index in both sites. At Embu site, NPK+ZnBMgCaS had significantly higher harvest index than all the other treatments, whose harvest indices were similar. At KTI, NPK+ZnBMgCaS resulted in higher harvest indices than NK and NP. No significant differences were recorded between NK and NP, among NP, PK and NPK and among PK, NPK and NPK+ZnBMgCaS residual fertilizer. The interaction between tillage method and residual fertilizer nutrient had no significant effect on the harvest index.

Grain stover ratio varied from 0.758 (Kirinyaga) to 0.998 (Embu).

Table 4. 7: Effect of tillage method and residual fertilizer on grain to stover ratio and harvest index at Embu and Kirinyaga during 2014/2015 short rains season

	Grain to stover ratio		Harvest index	
	Embu	Kirinyaga	Embu	Kirinyaga
Tillage method (TM)				
NT+CR	0.927	0.762	0.481	0.431
CT-CR	0.998	0.758	0.499	0.429
p-value	0.149	0.136	<0.001	0.284
LSD $_{0.05}$	NS	NS	0.015	NS
CV %	15.100	13.800	10.000	9.900
Residual fertilizers (RF)				
NK	0.947	0.629	0.486	0.386
NP	0.907	0.710	0.475	0.414
PK	0.937	0.792	0.483	0.442
NPK	0.954	0.801	0.488	0.445
NPK+ZnBMgCaS	1.068	0.869	0.516	0.465
p-value	0.093	0.088	<0.001	0.031
LSD $_{0.05}$	NS	NS	0.025	0.040
CV %	10.400	9.600	11.000	10.900
Interaction (TM*RF)				
p-value	0.359	0.201	0.059	0.256
LSD $_{0.05}$	NS	NS	NS	NS

CV% = coefficient of variation, NT+CR = no-till with crop residues retention, CT-CR = conventional tillage with no crop residues retention, LSD = least significant difference, NS= not significant.

4.4.7. Linear regression relationship between dry bean grain and yield components

The significant linear regression relationship between dry bean grain yield and yield components were all strong and positive (Figure 4.2). Strongest and positive relationship was of 0.96 was observed between dry biomass and grain yield. This was followed by relation between grain yield and 1000-seed dry weight and number of seeds per pod at 0.93 and 0.91, respectively. Number of pods per plant and harvest index recorded 0.32 and 0.73, respectively, chances of predicting grain yield.

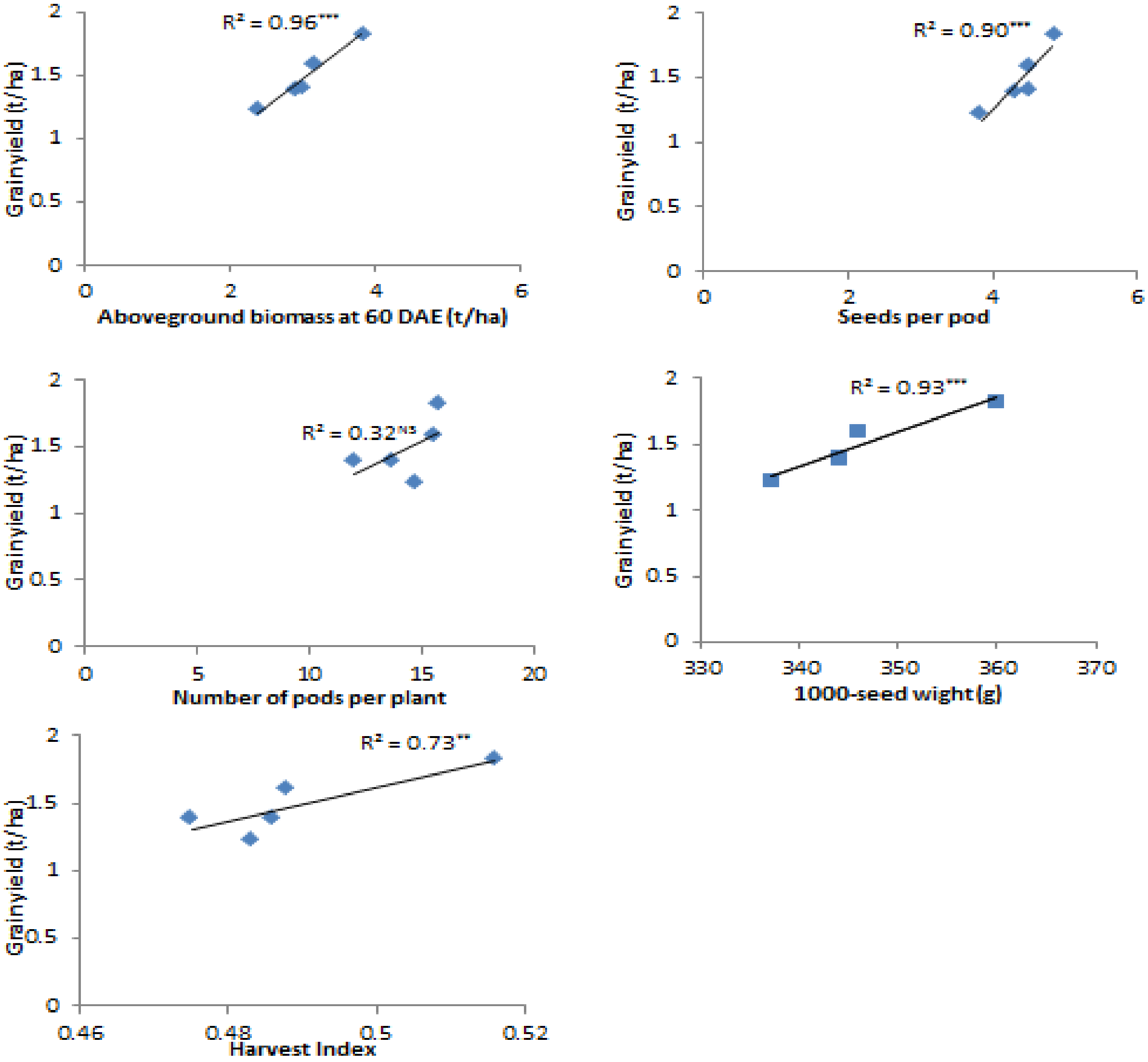

Figure 4. 2: Relationship between dry bean and yield component

= significant at $p< 0.01$; *= significant at $p< 0.001$; NS = not significant

4.5. Discussion

4.5.1. Effect of tillage method on biomass, yield components and grain yield of dry bean

The combination of no-till with residue retention (NT+CR) recorded higher dry bean shoot biomass (at 60 days after emergence), stover yield, number of pods per plant, number of seeds per pod, 1000-seed weight, grain yield and harvest indices than conventional tillage plot with no residue retention (CT-CR). These findings are in resonance with Abdul-Baki and Teasdale (1997) who observed higher snap bean yields under no-till with hairy vetch mulch than under conventional tillage. Micheni *et al.* (2014) reported higher grain yield of dry bean at Embu region under zero tillage than under conventional tillage. During a trial to determine the effects of tillage on yield of pea and chickpea, Ruisi *et al.* (2012) reported significantly higher yield under no-till plots than under conventional tillage. The better performance of dry bean under NT+CR system than under CT-CR system may be associated with the higher moisture retained and nutrients released as residue decompose in the former than in the latter cropping system. Since there was low rainfall during dry bean production (varied between 0 and 60 mm per week), the crop residue cover may have conserved soil moisture under no-till with crop residue retention that improved growth and yield relative to conventional tillage with no crop residue retention (Mupangwa *et al.,* 2012; Reddy *et al.,* 2013). This is supported further by findings under maize production (Chapter 3 in this thesis) that showed high moisture retention under no-till with crop residues compared to conventional tillage with no crop residue retention. Reduced soil disturbance (under no-tillage) of land may have resulted in improved soil physical, chemical and biological qualities for better crop production (Sommer *et al.,* 2014). Higher *Meloidogyne spp* incidence observed under CT-CR (range 3-4) than under NT+CR (range 2-3), may have affected crop anchorage and hindered water and nutrient absorption, hence leading to lower yield in the former tillage system than in the latter, as reported by Agu (2008). Crop residue retention and reduced tillage have been reported to diversify the rage of food sources and prove habitat for *Meloidogyne* spp. thereby diverting their attention from common bean attack (Mendoza *et al.*, 2008).

The yield performance of dry bean under no-till with crop residue retention (average 1.4 t/ha) was lower than the general varietal potential yield but much higher than yields obtained in farmers' fields in the study region. Farmers are reported to achieve average bean yields of less than 1 t/ha (Jagtap and Abamu, 2003; and CIAT *et al.*, 2013), however, the potential yield of Roscoco, EM-bean 14 variety is about 6 t/ha (KALRO-Embu website). The dry bean harvest indices varied between 0.43 and 0.50. These harvest indices are in the range of other previous studies; Vieira *et al.* (1973) found a range of 0.39 to 0.58 and Scully and Wallace (1990) found a range of 0.12 to 0.65 among accessions of dry bean studied.

4.5.2. Effect of residual fertilizer on biomass, yield components and grain yield of dry bean

The PK residual treatment resulted in lower biomass (at 60 DAE), stover dry weight, number of seeds, 1000-seed weight and grain yields than the other treatments. This low bean performance due to N omission shows the importance of the nutrient in dry bean production. Otieno *et al.* (2009) observed significant increase in dry bean biomass due to N addition. This is because of the pivotal roles played by N in plants' biochemical and physiological processes like photosynthesis and protein formation (Fageria, 2014).

Application of fertilizers with a broad range of nutrients recorded higher range of growth and yield than fertilizers with one nutrient. Generally, combined application of N, P and K recorded higher biomass production, number of pods per plant, number of seeds per pod, 1000-seed dry weights and dry grain yields than when only NP, NK or PK were applied. These findings are in agreement with Mananu *et al.* (2012) who reported increased shoot dry weights due to combined application of N and P and N, P and K than when only N was applied in snap bean. Arjumand *et al.* (2013) also observed taller plants and higher number of branches per plant and number of leaves per plant due to combined application of N, P and K than when either of the nutrients was applied singly. They further observed that application of Zn, Ca, Mg, B and S nutrients together with NPK resulted in the best performance of dry bean in shoot biomass and grain yields. Abid *et al.* (2013) showed that the residual effect of zinc significantly increased wheat and cotton yield just as the plots that had continued application of these nutrient. Nitrogen, phosphorus and potassium nutrients are essential nutrients in photosynthesis, roots development, environmental stress resistance, energy transfer, enzyme function and general vegetative growth and general protein formation (Hüttemann, *et al.,* 2007; Pretorius, 2009). Therefore when these nutrients were applied together, they may have brought the synergy that resulted in increased biomass, stover production, yield components and grain yields. Similar observations were also made by Sieling *et al.* (2006) on residual N effect on growth and yield of oilseed rape, wheat and barley after three seasons. In contrast to this trial, a study showed that residual P from long-term P fertilization was not sufficient alone to provide all the P requirements of barley grown in a monoculture system when P fertilization was discontinued after 20 years of application (Karamanos *et al.,* 2007).

Secondary macronutrients and essential micronutrients play an important role in plant growth and production. From this trial Zn, Ca, Mg, B and S may have played important roles in dry bean growth and development resulting in significant increases in biomass at 60 DAE, stover, number of pods and grain yield. Combined application of B, Mo and Zn has been reported to increase dry bean plant height, number of branches and seeds per pod (Rahman *et al.*, 2014). This is because micronutrients play key roles in legume growth and grain yield production (Fegaria, 2014). For instance, boron is involved in pollen germination, pollen tube formation and seed formation (Fageria and Gheyi, 1999), thereby increasing the number of seeds per pod and grain yield (Kaur and Nelson, 2015). Also, Ca and Mg enhance ion uptake and balance, plant vigour and stiffness of straw (Fageria, 2009). These nutrients also may have boosted the photosynthetic process and translocation of photosynthates to the seeds (Zeidan *et al.,* 2006). This may explain higher 1000-seed weights and grain yields recorded due to NPK+ZnBMgCaS residual nutrients than all other treatments.

Dry bean production in Kenya often involves no fertilizer addition and this result in low bean production by small-scale farmers every season. With just the residual nutrients from previous season of maize production, farmers can increase their grain yields significantly from less than 1 t/ha as reported by most researchers to 2 t/ha as observed in this study. Adoption of the practice will improve farmers' economic stability, as yields are increased without addition of fertilizers. Production of dry bean as a rotational crop on residual fertilizers ensures maximum utilization of applied nutrients during maize production and improvement in soil fertility through BNF and organic matter- though was not tested, this has been reported by several researchers.

4.6. Conclusion

This study found out that no-till with crop residues retention has the potential to increase both biomass and yield of dry bean relative to conventional tillage with no crop residues retention.

Also the former tillage method has the potential to reduce the effect of nematode on dry bean yield compare to the latter.

The residual fertilizers significantly increased dry bean yield irrespective of the tillage method. Application of a broad range of nutrients increased plant growth and yield relative to application of single nutrients. From this trial, N was noted to be the most limiting nutrient followed by phosphorus and then potassium. Application of secondary and micro nutrients increased yields, but not by as high margin as the three primary macro-nutrients.

CHAPTER FIVE: ECONOMIC ANALYSIS OF A MAIZE-BEAN ROTATION SYSTEM UNDER DIFFERENT TILLAGE SYSTEMS AND FERTILIZER REGIMES

5.1. Abstract

Maize and dry bean are the most important food crops that feed over 85% of Kenyan households. However, the productivity of these crops is low due to high costs of land preparation and weed control under the current conventional tillage system of production. A study was carried to determine the economic returns of a maize-bean rotation system under different tillage systems and fertilizer regimes. The field experiments were carried out at Embu and Kirinyaga Counties.

Maize was produced during the long rains under two tillage systems -no-till with crop residue retention (NT+CR) and conventional tillage with no crop residue retention (CT-CR)- and different inorganic fertilizer regimes namely, NK, NP, PK, NPK and NPK+CaMgZnBS. During maize production N, P, K, Ca, Mg, Zn, B and S nutrients were applied at the rates of 120, 40, 40, 10, 10, 5 and 26.3 kg/ha, respectively. Dry bean were planted in the short rains in the plots where maize under the different nutrient management options and tillage systems had been grown and harvested. The trial was laid out in a split plot design with the tillage method assigned to the main plot and fertilizer regimes to subplot. Economic performance was assessed using partial budget analysis based on labour data and prices of all consumed inputs during the production period. Grain yields were reduced by 10% to reflect farmers' yield levels. Maize and dry bean grains were sold at unit prices of Ksh. 40 and KSh. 70 per kilogram respectively, while maize stover was sold at Ksh. 2000 per ton. Results showed that producing maize and bean in rotation was Ksh. 22,718 cheaper under NT+CR than under CT-CR. On average, NT+CR recorded Ksh 29,569 higher net benefit than CT-CR systems. The NT+CR recorded a benefit to cost ratio of 3.7 compared to 2.7 for CT-CR. Production of maize and bean is more profiting under NT+CR system with NK fertilizer regime application with a benefit to cost ratio of 4.92 for maize and 4.33 for maize-bean rotation system. Based on this study, is cheaper for farmers to produce maize and bean under conservation agriculture.

Key Words: Benefit to cost ratio, conservation agriculture, conventional tillage, dry bean, maize, residual nutrient

5.2. Introduction

Maize (*Zea mays* L.) and dry bean (*Phaseolus vulgaris* L.) are considered the most important food crops in Kenya. These crops are depended upon by over 85% of Kenyan households for food, income, soil improvement and maintenance, livestock feed and fuel (Muui *et al.*, 2007; Rockström *et al.,* 2009). Despite their importance in Kenya, the productivity of maize and bean has remained low (Kimaru *et al.*, 2012; CIAT *et al.*, 2013) and unable to meet rising population and food demands (Olwande, 2012). The low production among smallholder farmers is largely due to drought (Purcell *et al.*, 2007), low soil fertility (Okalebo *et al.*, 2007), biotic constraints (e.g. weeds, diseases and insects) and socio-economic constraints (Recha *et al.*, 2012).

Soil infertility has been cited as a key constraint to crop production in Kenya (Abate *et al.*, 2012). Farmers have been reported to use low quantities of organic and inorganic manure, with more attention on the homestead fields compared to other fields. Current maize and dry bean production practices involve removal of crop residues and tilling of land during field preparation and weed control. This system destabilizes the soil structure and encourages loss of water and nutrients through leaching and soil erosion thereby requiring farmers to replenish soil nutrients every season. Constant nutrient replenishment puts much pressure on farmers' financial resources and is therefore unsustainable.

Low and erratic rainfall also interferes with crop growth which consequently results in low yield (Abate *et al.,* 2012). Any attempt by farmers to augment this soil moisture limitation has failed because of weak financial capabilities to carry out irrigation (Neubert *et al.,* 2007). Moreover, the conventional method of crop production in Kenya, with its high level of farm operations, demands a lot of labour per season which translates to high cost of production beyond farmers' capability.

Alleviation of the financial constraints associated with the current system calls for efficient, cost effective and sustainable systems. This can be achieved by developing and adopting a cost effective, viable and sustainable method for maize and bean production that offers an adaptive mechanism to the current climate change. Conservation agriculture which entails crop rotation, crop residue management (Hobbs et al., 2008; Erenstein, *et al.*, 2008; Shaxson *et al.,* 2008), minimum soil disturbance (Banites, 2008) and inorganic fertilizer application (Vanlauwe *et al.*, 2014) is praised for its benefits in improving crop production and soil health (FAO, 2011; Giller *et al.,* 2011; and Kihara *et al.,* 2011). However, these potential benefits of conservation agriculture may not be appreciated by farmers unless translated into monetary terms. This is because adoption of any new technology or method of production depends on the farmers' perceptions of financial benefits assurance in terms of returns to investments (Kimani *et al.*, 2004). A study was carried to determine the economic returns of a maize-bean rotation system under different tillage systems and fertilizer regimes

5.3. Materials and methods

5.3.1. Study site description

The trials were carried out at the Kirinyaga Technical Institute (KTI) in Kirinyaga County and Kenya Agricultural and Livestock Research Organization (KALRO)'s, Crop Research Centre in Embu County during 2014 long rains and 2014/2015 short rains seasons. Kirinyaga site is located on longitude 370 19' 10.4''E and latitude 000 30' 18.3'' S while Embu site is located on longitude 370 19' 10.4''E and latitude 000 33' 29.4''S. The two regions are located within a similar recommendation domain characterized by a similar agro-ecological zone, soil type and cropping system. All sites were located in upper midland zones. The sites are characterized by humic nitisols, which originated from basic volcanic rocks. The soils are deep and highly weathered. The two sites have bi-modal rainfall pattern, wet seasons from March to May (long rains season) and October to December (short rains season) (Nicholson, 2000). Rainfall amounts range from 1100 mm to 1550 mm per year while mean daily temperature ranges from 12 ^{0}C to 23 ^{0}C.

5.3.2. Experimental design and treatments

The trial was a maize-bean rotation system where DK 8031 maize variety and EM-bean 14 Roscoco dry bean variety were used as main crop and rotational crop respectively. Maize was produced during the long rains with application of inorganic fertilizer whereas dry bean were produced in the short rain under the residual fertilizer nutrients. The trial was laid out in a split plot design. Tillage methods- no-till with crop residue retention (NT+CR) and conventional tillage with no crop residue retention (CT-CR) were assigned to main plots whereas fertilizer regime (NK, NP, PK, NPK and NPK+CaMgZnBS) were assigned to subplots. During maize production N, P, K, Ca, Mg, Zn, B and S nutrients were applied at the rates of 120, 40, 40, 10, 10, 5 and 26.3 kg/ha from urea, triple superphosphate (TSP), muriate of potash (MOP), calcium sulphate, magnesium sulphate, zinc sulphate, and borax nutrient sources respectively. There were three blocks each comprising 10 experimental plots each and measuring 8 m by 10 m. Paths of 1.5 m and 1 m wide were left between blocks and plots, respectively.

5.3.3. Agronomic practices

In the conventional tillage system, land preparation involved tilling of plots using a jembe before the onset of rains. On NT+CR plots, a mixture of Dual Gold 960EC® and Weedal 480 SL at a rate of 1.5 l/ha each was used, two days after planting, to ensure crops emerged on clean fields. Both maize and dry bean were planted at the onset of effective rain (after consecutive third rain day) during their respective seasons at a plant spacing of 75 cm x 25 cm and 50 cm x 15 cm, respectively. During 2014 long rains, one-third of N full doses of all other nutrients were applied to the maize crop at planting. The remaining two-thirds (80 kg N) was applied as first and second topdress at V_4 and V_{10} growth stages of maize, respectively. No fertilizer was applied during dry bean cultivation in the 2014/2015 short rains. Weed control was done using hoes on conventional tillage plots using jembe and panga in the production of maize and dry beans. Herbicides, 2, 4-D and Basagram® were used at rates of 1.5 l/ha each to control weeds on no-till plots during maize and dry bean production, respectively. A maximum of two hand weeding were done on conventional tillage plots. Pests were monitored regularly and remedial action taken as required. Bulldock® 0.05 GR at the rate of 6 kg ha^{-1} was applied to the maize crop approximately 30 days after the crop emergence to control the maize stalk borer *(Busseola fusca).* Manual harvesting of both crops was done at maturity.

5.3.4. Data collection and analysis

Data were collected right from seed acquisition to the sale of produce for both crops. All data collected were in monetary values- seed, fertilizer, labour, herbicides, pesticides costs, maize, bean and stover selling prices. The economic performance of a maize-bean rotation system under different tillage methods and fertilizer regimes was assessed through a partial budget analysis using labour data and prices of all applied inputs (seed, herbicides, fertilizers and pesticides) from each of the plots during the entire period of study (CIMMYT, 1988). These costs were referred to as total variable costs (TVC) and excluded costs incurred relating to harvest and sale of produce (CIMMYT, 1988). Harvested yields in each treatment were reduced by 10% to adjust to realistic farmers' yields, according to CIMMYT Economic Program (1988). This is because the management operations, in terms of planting, fertilizer application and weed control, are more precisely carried out on research plots than on farmer's plots, thus a reduction by 5% on yields is applied. In addition, research plots are smaller and tend to be more uniform than farmer plots leading to overestimation of yields from such research plots; thus, a reduction of 5% on yields is applied. The total variable cost (TVC) was calculated as follows:

TVC = Ksh. cost of (seeds + fertilizers + agrochemicals + labor + transport)

Field benefits were also calculated. Field benefit (FB) refers to the revenue accrued from the sale of crops after deducting all costs involved during harvesting, processing and sale of crop from gross field benefits (GFB). For maize, it was obtained from the sale of grains and stover whereas only grains were sold for bean since there were no leaves that could be used as livestock feed at the time of harvesting. Field benefits were calculated as follows:

FB = GFB - costs due to harvesting (labour + packaging materials)

The costs of fertilizers, pesticides, herbicides, and labour were obtained from local agro-dealers, scientists and farmers involved in maize and dry bean production in Embu and Kirinyaga. Labour cost was KShs. 200 man-day^{-1}. Man-day is a unit of production equivalent to the work one person can do in a day. One man-day is equivalent to 8 working hours in Kenya. Dry grains were sold at unit market prices of Ksh. 40 per kilogram for maize during August-October, 2014 and Ksh. 70 per kilogram for beans during February-April, 2015. Maize stover is a popular livestock feed in the study area and thus was sold at Ksh. 2000 per ton. The stover was collected from the field by the buyers using their own labor and transport. Maize and beans were harvested and sold immediately without the farmer incurring any storage costs. Net benefit (NB) and benefit to cost ratio (BCR) were calculated according to the CIMMYT Economic Program Manual (1988) as indicated below:

$$\text{Net benefit (NB)} = \text{Total variable costs (TVC)} - \text{field benefits (FB)}$$

$$\text{Benefit to cost ratio (BCR)} = \frac{\text{Field benefits (FB) ha}^{-1}}{\text{Total variable cost (TVC) ha}^{-1}}$$

Table 5. 1: Input and output unit prices

Item	Unit	Unit cost (Ksh)
Inputs		
Labour	Man-day	200.00
Maize DK 8031 seeds	Kg	200.00
Dry Bean EM-bean 14 seeds	Kg	300.00
Urea	Kg	50.00
Triple super phosphate	Kg	80.00
Muriate of potash	Kg	70.00
Calcium sulphate	Kg	300.00
Magnesium sulphate	Kg	600.00
Zinc sulphate	Kg	70.00
Borax	Kg	500.00
Dual Gold960EC^{â}	Litre	2,600.00
Weedal 480 SL	Litre	550.00
2,4 D-Amine	Litre	780.00
Basagram	Litre	2,400.00
Output		
Maize grain yield	Kg	40.00
Maize stover yield	ton	2,000.00
Dry bean grain yield	Kg	70.00

5.4. Results

Production of maize and dry bean resulted in higher total variable cost (TVC) under conventional tillage (CT-CR) than under conservation tillage (NT+CR) (Table 5.2 and 5.3), both as individual crops and under rotation system. Maize and bean production as individual crops resulted in TVC of KShs. 55,553 and KShs. 21,425, respectively, under NT+CR and TVCs of KShs. 68,096 and KShs. 31,600, respectively, under CT-CR. Total variable cost of producing maize due to fertilizer application ranged between KShs.35,297 (NK) and KShs.113,417 (NPK+ZnBMgCaS) under NT+CR and between KShs.47,600 (NK) and KShs.125,720 (NPK+ZnBMgCaS) under CT-CR systems.

Production of maize under NT+CR system resulted in Ksh. 14, 592 higher field benefit (FB) than under CT-CR system at Embu. However, a contrary observation was made in Kirinyaga where CT-CR recorded Ksh. 21 654 more than NT+CR system. During bean production, a consistently high FB was observed under NT+CR than under CT-CR in both sites. In both sites, treatment NPK+ZnBMgCaS resulted in highest FB for maize and beans under all tillage methods. At Embu, maize production recorded FB ranging from KShs. 170,259 (NK under CT-CR system) to KShs. 210,867 (NPK+ZnBMgCaS under NT+CR) while production of bean on residual fertilizer recorded FB ranging from KShs.67,760 (PK under CT-CR) to KShs.117,824 (NPK+ZnBMgCaS under NT+CR). At Kirinyaga, a range of KShs.134,768 to KShs.184,031 and KShs.48,182 to KShs.98,272 was recorded due to maize and bean production, respectively.

AT Embu, NT+CR system resulted in higher maize (Ksh. 135,740) and bean (Ksh. 71,695) net benefits (NB) than CT-CR system. This trend was also observed at Kirinyaga under bean production. However, during maize production at Kirinyaga, CT-CR system recorded KShs. 9,111 higher NB than NT+CR system.

Table 5. 2: Effect of tillage method and fertilizer regime on economic returns of a maize-bean rotation system at Kenya Agriculture and Livestock Research Organization, Embu trial site during 2014/2015 long and short rains season

	Yield (t/ha)										
	Mz	Bn	Mz TVC (Ksh/ha)	Bn TVC (Ksh/ha)	Mz FB (Ksh/ha)	Bn FB (Ksh/ha)	Mz NB (Ksh/ha)	Bn NB (Ksh/ha)	Mz-Bn NB (Ksh/ha)	Mz BCR	Mz-Bn BCR
Tillage method											
NT+CR (CA)	4.9	1.4	55,553	21,425	191,293	93,120	135,740	71,695	207,435	4.06	4.00
CT-CR (CT)	4.5	1.3	68,096	31,600	176,701	80,925	108,605	49,325	157,930	2.91	2.72
SEm ±	0.1	0.0	8	8	3381	2638	3381	2638	4665	0.07	0.06
Fertilizer regime											
NK	4.6	1.3	41449	26513	178968	81027	137519	54514	192033	4.45	3.96
NP	4.6	1.3	50169	26513	181147	81284	130979	54772	185749	3.69	3.52
NPK	4.7	1.4	55769	26513	185678	93645	129910	67133	197042	3.39	3.49
NPK+ZnBMgCaS	5.1	1.7	119569	26513	200145	108183	80576	81671	162247	1.69	2.14
PK	4.5	1.1	42169	26513	174049	70976	131880	44463	176343	4.24	3.69
SEm ±	0.1	0.1	13	13	5470.5	4268	5470.5	4268	7548	0.12	0.10
Interaction											
CA NK	4.8	1.3	35,297	21,425	187,676	83581	152379	62,156	214,534	5.32	4.78
CA NP	4.9	1.3	44,017	21,425	190,185	84,145	146,168	62,720	208,887	4.32	4.19
CA NPK	4.9	1.6	49,617	21,425	193,350	105,862	143,733	84,437	228,170	3.9	4.21
CA NPK+ZnBMgCaS	5.4	1.8	113,417	21,425	210,867	117,824	97,450	96,399	193,850	1.86	2.44
CA PK	4.5	1.2	35,417	21,425	174,387	74,191	138,970	52,766	191,736	4.92	4.37
CT NK	4.3	1.2	47,600	31,600	170,259	78,472	122,659	46,872	169,531	3.58	3.14
CT NP	4.4	1.2	56,320	31,600	172,109	78,423	115,789	46,823	162,611	3.06	2.85
CT NPK	4.5	1.3	61,920	31,600	178,006	81,428	116,086	49,828	165,914	2.88	2.77
CT NPK+ZnBMgCaS	4.8	1.5	125,720	31,600	189,422	98,542	63,702	66,942	130,644	1.51	1.83
CT PK	4.4	1.1	48,920	31,600	173,710	67,760	124,790	36,160	160,950	3.55	3
SEm ±	0.2	0.1	18	18	7560	5898	7560	5898	10431	0.17	0.13

SEM= Standard error of means, Mz= Maize, Bn= Bean, TVC= Total variable cost, FB= Field benefit, NB= Net benefit, BCR= Benefit to cost ratio.

Table 5. 3: Effect of tillage method and fertilizer regime on economic returns of a maize-bean rotational system at Kirinyaga Technical Institute trial site during 2014/2015 long and short rains seasons.

	Yield t/ha		Mz TVC (Ksh/ha)	Bn TVC (Ksh/ha)	Mz FB (Ksh/ha)	Bn FB (Ksh/ha)	Mz NB (Ksh/ha)	Bn NB (Ksh/ha)	Mz-Bn NB (Ksh/ha)	Mz BCR	Mz-Bn BCR
	Mz	Bn									
Tillage method											
NT+CR (CA)	3.8	1.1	55,553	21,425	156,808	69,554	101,255	48,129	149,384	3.34	3.34
CT-CR (CT)	4.4	1.0	68,096	31,600	178,462	60,986	110,366	29,386	139,752	2.95	2.67
SEm ±	0.1	0.0	8	8	2083	1848	2083	1848	2614	0.04	0.04
Fertilizer regime											
NK	4.1	0.8	41449	26513	164245	48953	122796	22440	145236	4.04	3.41
NP	4.2	0.9	50169	26513	170006	57357	119837	30845	150682	3.42	3.20
NPK	4.3	1.1	55769	26513	173697	68897	117929	42384	160312	3.14	3.17
NPK+ZnBMgCaS	4.3	1.4	119569	26513	175542	92603	55974	66091	122064	1.47	1.94
PK	3.8	0.9	42169	26513	154688	58541	112519	32029	144547	3.69	3.32
SEm ±	0.1	0.0	13	13	3371	2990	3371	2990	4229	0.07	0.07
Interaction											
CA NK	3.9	0.8	35,297	21,425	159,511	48,182	124,214	26,757	150,971	4.52	3.88
CA NP	3.9	1.0	44,017	21,425	159,183	66,578	115,166	45,153	160,319	3.62	3.64
CA NPK	4.0	1.2	49,617	21,425	163,526	76,091	113,909	54,666	168,575	3.3	3.55
CA NPK+ZnBMgCaS	4.1	1.5	113,417	21,425	167,053	98,272	53,636	76,847	130,483	1.47	2.06
CA PK	3.3	0.9	35,417	21,425	134,768	58,647	99,351	37,222	136,573	3.81	3.58
CT NK	4.2	0.8	47,600	31,600	168,978	49,723	121,378	18,123	139,501	3.55	2.93
CT NP	4.5	0.8	56,320	31,600	180,828	48,136	124,508	16,536	141,044	3.21	2.76
CT NPK	4.6	1.0	61,920	31,600	183,868	61,702	121,948	30,102	152,049	2.97	2.78
CT NPK+ZnBMgCaS	4.6	1.3	125,720	31,600	184,031	86,934	58,311	55,334	113,645	1.46	1.81
CT PK	4.4	0.9	48,920	31,600	174,607	58,435	125,687	26,835	152,521	3.57	3.06
SEm ±	0.1	0.1	18	18	4658	4131	4658	4131	5844	0.1	0.09

SEM= Standard error of means, Mz= Maize, Bn= Bean, TVC= Total variable cost, FB= Field benefit, NB= Net benefit, BCR= Benefit to cost ratio.

Under NT+CR, maize and bean production resulted in Ksh. 27,135 and KShs. 22,370, respectively, more net benefits (NB) than under CT-CR system at Embu site. Maize-bean rotation system under NT+CR system recorded KShs. 49,505 at Embu and KShs. 9,632 at Kirinyaga higher NB than under CT-CR system.

Under NT+CR and CT-CR, lower maize NB was recorded due to NPK+ZnBMgCaS treatment application on both sites. However, the highest NB of KShs. 152,379 due to NK under NT+CR and KShs. 125,687 due to PK under CT-CR were recorded at Embu and Kirinyaga sites, respectively.

Across both the sites, dry bean recorded the highest NB due to NPK+ZnBMgCaS treatment under NT+CR. The lowest dry bean NBs of KShs. 36,160 and KShs. 16,536 were due to PK and NP treatments at Embu and Kirinyaga sites, respectively, both under CT-CR system. Net benefits of the maize-bean rotation system ranged from KShs.228,178 to KShs.113,645, across both sites. Maize production under NT+CR recorded higher benefit to cost ratio (BCR) of 4.06 and 3.34 than under CT-CR at Embu and Kirinyaga, respectively. Across all sites, application of fertilizer regimes recorded maize BCR that varied between 1.46 and 5.32. Across both sites, treatments NPK+ZnBMgCaS and NK recorded the lowest and highest maize BCR, respectively.

At Embu and Kirinyaga, maize-bean rotation under NT+CR recorded higher BCR of 4.00 and 3.34 than CT-CR. The NK Fertilizer regime application recorded higher maize-bean BCR under NT+CR than under CT-CR in both sites (Table 5.2 and 5.3). Lower maize-bean BCR was recorded due to NPK+ZnBMgCaS in all sites.

5.5. Discussion

The no-till with crop residue retention (NT+CR) resulted in lower total variable cost (TVC) of maize-bean rotation system than under conventional tillage with no crop residue retention (CT-CR). Higher net benefit (NB) and benefit to cost ratio (BCR) were recorded under NT+CR than under CT-CR. These findings are in resonance with Micheni *et at*. (2014) who reported higher net benefits of maize and dry bean in no-till plots than on conventionally tilled plots. In a long term trial in Spain, Sanchez-Giron *et al.* (2004) reported higher gross margins under reduced tillage than under conventional tillage. These findings may be due to the reduced number of man-days required for management practices like cultivation and weed control in a NT+CR system compared to a CT-CR system (Pannell *et al.,* 2014) and time saving (Siemans and Doster, 1992). Omission of preplant activities such as cultivation may have reduced the cost of production under no-till plots (Uri, 1999). Similarly, Mloza-Banda *et al.* (2011) reported that constant tillling of land during land preparation and several weeding regimes as the key practices make conventional tillage system of production more expenssive than no-tillage.

No-till and crop residues retention under conservation agriculture may have helped in retention of soil moisture and release of nutrients upon decay of these residue. Noticeably higher water retention was recorded under no-tll with crop residue retention than under conventioanl tillage with no crop residue retention at Embu and Kirinyaga (Chapter three of this thesis). The effect of this is an increased yield of dry bean, which was high enough to help absorb the costs of production (Lampurlanes *et al*., 2001; Lal *et al*., 2003). However, Kihara *et at.* (2011) reported loss in revenue under reduced tillage than under convention tillage of maize and soybean in western Kenya. According to them, this loss in revenue was due to underperformance of maize crop under reduced tillage plots compared to conventional tillage plots.

Treatment NK under NT+CR resulted in higher NB and BCR than all other treatments in both sites. However, lower NB and BCR were recorded due to NPK+ZnBMgCaS treatment applications under both sites. These findings are in agreement with a report by Mucheru-muna *et al.* (2013) that showed higher benefit to cost ratio due to use of inorganic fertilizers in central highlands of Kenya under NT+CR than under CT-CR. Mazvimavi *et al.* (2012) also found higher net benefit and benefit to cost ratio of maize in rotation with legume crops under zero tillage with crop residue retention than under conventional tillage system.

The low net benefit and benefit to cost ratio due to NPK+ZnBMgCaS treatment may be due to the high cost of production that could not be adequately be offset by the field benefits accrued from the yield increments realized due to application of the treatment. Production of dry bean on residual fertilizers provided extra nutrient supply that increased total grain grain yield under the rotation system with minimal increase in total variable cost. This resulted in high net return and benefit to cost ratio realized in maize-bean roation system.

Maize-bean rotation system has the potential of generating enough revenue to offset money initially invested for production of maize, as evidenced by high benefit to cost ratio. Adoption of no-till with crop residues retention is therefore possible and may help farmers to generate income.

5.6.Conclusion

The no-till with crop residue retention recorded lower total variable cost and higher net benefit on maize and bean than conventional tillage with no crop residue retention at Embu and Kirinyaga sites. Application of NPK+ZnBMgCaS resulted in higher total variable cost and field benefit but lower net benefit and benefit to cost ratio under maize production. The highest net benefit and benefit to cost ratio was recorded on both sites due to the application of NK fertilizer under no-till with crop residue retention. Production of dry bean on residual fertilizer recorded lower total variable with increased net benefit under both tillage systems. The total variable and net benefit, respectively, were lower and higher under no-till with crop residue retention than under conventional tillage with no crop residue retention.

CHAPTER SIX: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1. Discussion

Maize grown under conventional tillage with no crop residue retention recorded higher crop growth rate (CGR), plant height, biomass at 30, 60 and 90 days after emergence and leaf area index than under no-till with crop residue retention in the all sites. These higher growth attributes under conventional tillage with no crop residue retention translated to higher grain yields under this cropping system than under no-till with crop residue retention at Alupe and Kirinyaga. This may be due to tilling of land that loosened soil particles thus encouraging infiltration, reducing surface crusting and enhancing penetration of plant roots thereby leading to increased soil moisture and nutrient uptake. However, a contrary observation made at Embu region, where no-till with crop residue retention produced higher maize yields than conventional tillage with no crop residue retention may have been due to the extra soil moisture preserved because of soil surface cover (as observed in chapter 3 of this thesis) that reduced evaporative loss of soil moisture.

Dry bean recorded significantly higher biomass at 60 DAE, stover, number of pods per plant, number of seeds per pod, 1000-seed weight, grain yield and harvest index under no-till with crop residue retention than under conventional tillage with no crop residue retention during 2014/2015 short rains. The previous maize residue may have covered the soil from direct sun heating leading to reduced evaporation loss of already stored moisture under no-till with crop residue retention, as evidenced by higher soil moisture in chapter 3 of this thesis. Having grown in the third season, dry bean may have benefited from nutrients released from decomposed crop residue. High *Meloidogyne* species infestation observed under conventional tillage with no crop residue retention plots may have also interfered with effective functioning of roots, hence impaired nutrients uptake that consequently led to poor growth and yield. The general yield performance of maize (CT-CR= 4.5 t/ha and NT+CR= 4.3 t/ha), irrespective of treatment, was much higher than the average yield (1-2 t/ha) obtained by farmers. Under the maize-bean rotation system, highest and lowest yields of maize were observed under NPK+ZnBMgCaS and PK treatments, respectively, in all sites. These two treatments, also recorded higher and lower performance, respectively, during dry bean production in terms of biomass, stover and grain yields in all sites. Combined application of nutrients resulted in better performance than when applied singly. This may be due to the synergistic effect of these nutrients leading to increased nutrient uptake and use efficiency. There were similar trends in the effects of individual N, P and K nutrients on yields under maize-bean rotation system where, on average, N resulted in the highest grain increment followed by P and then K.

Use of inorganic fertilizers under no-till with crop residue retention is cheaper and more profitable than under conventional tillage with no crop residue retention. Together with low total variable cost, the system resulted in higher benefit to cost ratio. Reduction in cost of production due to low labour requirements may have been the reason behind high net revenue accrued from the adoption of no-till with crop residues retention. Hence, farmers moving from conventional tillage with no crop residue retention system of crop production, characterized by high labour requirement in land preparation and weed control, to no-till with crop residue retention may be assured of greater financial gain since it is a cost saving technology.

6.2. Conclusions

Conservation tillage underperformed in maize crop growth and yield relative to conventional tillage system in Kirinyaga and Alupe sites that had low soil surface crop residue cover. In contrast, conservation tillage out-performed conventional tillage in growth and yield in Embu site that had high soil surface crop residue cover. Combined applications of a wide range of nutrients (NPK+ZnBMgCaS and NPK) performed better in maize growth and yield than a narrow range of nutrients (NP, NK and PK). Maize growth and yield performed in the order NPK+CaMgZnBS> NPK> NP> NK> PK. Higher soil moisture retention levels were observed consistently under no-till with crop residue retention than under conventional tillage with no crop residue retention across all the sites.

Tillage method resulted in higher bean biomass and yield under no-till with crop residue retention than under conventional tillage with no crop residue retention across all the sites. Growth and yield performance of beans grown in fields that had previously received a broad range of nutrients (NPK+CaMgZnBS and NPK) was higher than for bean that had received a narrow range of nutrients. This suggests that other than N, P and K, secondary nutrients (Mg, Ca and S) and micronutrients (Zn and B) may be limiting in farmers' fields and need to be ameliorated. The study also suggests that beans benefited from residual nutrients in previously fertilized crops.

Whereas combined applications of a wide range of nutrients (NPK+ZnBMgCaS and NPK) increased maize and bean yields relative to narrow range of nutrients (NP, NK and PK), they had lower net benefit and benefit to cost ratio due to higher total variable costs. The best treatment combination from this study based on net benefit and benefit to cost ratio is the application of NK fertilizer under no-till with crop residue retention.

6.3. Recommendations

6.3.1. Recommendations for further research

1. Conduct a study on soil nutrient dynamics during the growing season in order to effectively develop efficient nutrient management options for both conventional conservation tillage systems.
2. Carry out a similar trial in many seasons and agro-ecological zones, as the current study was conducted only for two seasons and three sites.
3. Set up a long-term trial to study changes in soil biology and physio-chemical characteristics due to different tillage systems and crop residue management.
4. Investigate for the impact of secondary and micro nutrients in a maize-bean rotation system to establish the nutrient responsible for growth and yield increase.

6.3.2. Recommendations for farmers

1. Farmers in Embu may be advised to shift to a no-till system with adequate crop residue retention to help in moisture conservation during low rainfall periods.
2. Farmers may be advised to ensure adequate application of NK-based fertilizers on their farms to realize high yield with minimal production cost.

6.3.3. Recommendations for policy makers

1. It is advisable for policy makers to support promotion of conservation agriculture across various agro-ecological zones of Kenya.

REFERENCES

Abate T, Alene AD, Bergvinson D, Shiferaw B, Silim S, Orr A and Asfaw S (2012) Tropical grain legumes in Africa and South Asia: knowledge and opportunities. Nairobi, Kenya: International Crops Research Institute for the Semi-Arid Tropics. 112 pp. Available online: www.icrisat.org/ tropicallegumesII.

Abdul-Baki AA and Teasdale JR (1997) Snap bean production in conventional tillage and in no-till hairy vetch mulch. Horticultural Science, 32(7): 1191-1193.

Adhikari BH, Shrestha JIBAN, and Baral BR (2010) Effects of Micronutrietns on Growth and Productivity of Maize in Acidic Soil. International Research Journal of Applied and Basic Sciences 1.1: pp 8.

African Conservation Tillage Network (2008) www.act-africa.org/

Agu CM (2008) Effect of organic manure types on root-gall nematode disease and African yam bean yield. Agriculture, 3(1): 14-16.

Ahmad W, Niaz A, Kanwal S and Rasheed MK (2009) Role of boron in plant growth: a review. Journal of Agricultural Research, 47(3): 329 – 338.

Akibode S and Maredia M (2011) Global and regional trends in production, trade and consumption of food legume crops. Report submitted to the CGIAR Standing Panel on Impact Assessment.

Alloway BJ (2008) Zinc in soils and crop nutrition. Second edition, published by International Zinc Association and International Fertilizer Industry Association, Brussels, Belgium and Paris, France. ISBN 978-90-8133-310-8.

Andraski T, Bundy L and Brye K (2000) Crop management and corn nitrogen rate effects on nitrate leaching. Journal Environment and Quality, 29:1095–1103.

Argwings-Kodhek G, Jayne TS, Awuor T, and Yamano T (1998) How can micro-level household information make a difference for agricultural Policy making? Selected examples from the KAMPAP survey of smallholder agriculture and non-farm activities for selected districts in Kenya. Tegemeo Institute of Agricultural Policy and Development. Nairobi: Tegemeo Institute, Egerton University.

Arjumand SS, Ananth NB and Puttaiah E (2013) Effectiveness of farm yard manure, poultry manure and fertilizer – NPK on the growth parameters of French bean (*Phaseolus vulgaris*) in Shimoga , Karnataka, 1(1): 31–35.

Åslund I (2012) Effects of applying biochar to soils from Embu, Kenya - Effects on crop residue decomposition and soil fertility under varying soil moisture levels. SLU, Swedish University of Agricultural Sciences Faculty of Natural Resources and Agricultural Sciences, Department of Soil and Environment.

Bagayoko M, Buerkart A, Lung G, Bationo A and Römheld V (2000) Cereal/legume rotation effects on cereal growth in Sudano-Sahelian West Africa: Soil mineral nitrogen, Mycorrhizae and Nematodes. Plant Soil, 218:103–116.

Ball BC, Bingham I, Rees RM, Watson CA, and Litterick A (2005) The role of crop rotations in determining soil structure and crop growth conditions. Canadian Journal of Soil Science, 85(5): 557-577.

Bationo A and Ntare BR (2000) Rotation and nitrogen fertilizer effects on pearl millet, cowpea and groundnut yield and soil chemical properties in a sandy soil in the semi-arid tropics. West Africa Journal of Agricultural Sciences, 134:277–284.

Baudron F, Mwanza HM, Tiomphe B, Bwalya M (2007) Conservation agriculture in Zambia: A case study of Southern province, Nairobi. African Conservation Tillage Network, Centre de Cooperation Internationale de Recherche Agronomique pour le Development, Food and Agriculture Organization of the United Nations. ISBN: 9966-7219-3-2

Benites J (2008) Effect of no-till on conservation of the soil and soil fertility. In: Goddard T, Zoebisch MA, Gan YT, Ellis W, Watson A, Sombatpanit S (eds) No-till farming systems. Special Publication No. 3, World Association of Soil and Water Conservation, Bangkok, ISBN: 978-974-8391-60-1, 544 pp.

Beyaert RP, JW Schott and PH White (2002) Tillage effects on corn production in a coarse-textured soil in Southern Ontario. Agronomy, 94: 767-774.

Blanco FF and Folegatti MV (2003) A new method for estimating the leaf area index of cucumber and tomato plants. Horticultura Brasileira, Brasília Journal, 21(4): 666–669.

Blanco-Canqui H and Lal R (2004) Mechanisms of carbon sequestration in soil aggregates. Critical Review. Plant Sciences, 23: 481–504.

Blank D (2008) A fresh look at life below the surface. In: Goddard T, Zoebisch MA, Gan YT, Ellis W, Watson A, Sombatpanit S (eds) No-till farming systems. Special Publication No. 3, World Association of Soil and Water Conservation, Bangkok, ISBN: 978-974-8391-60-1, 544 pp.

Bolliger A (2007) Is zero-till an appropriate agricultural alternative for disadvantaged smallholders of South Africa? A study of surrogate systems and strategies, smallholder sensitivities and soil glycoproteins. PhD Thesis. University of Copenhagen, Copenhagen, p. 67.

Buhler DD (2002) Challenges and opportunities for integrated weed management. Weed Science, 50: 273-280.

Buresh RJ, Smithson PC and Hellums DT (1998) Building soil phosphorus capital in Africa. In: Buresh, Roland J., Paul C. Smithson, and Deborah T. Hellums. "Building soil phosphorus capital in Africa." Replenishing soil fertility in Africa replenishingsoi (1997): 111-149.

Busscher WJ, Frederick JR, and Bauer PI (2000) Timing effects of deep tillage on penetration resistance and wheat and soybean yield. Soil Science Society of America Journal, 64: 999–1003.

CIAT (2013) The impacts of CIAT's collaborative research. Cali, Colombia: International Center for Tropical Agriculture (CIAT). Available: http://hdl.handle.net/10568/51592

CIAT, ICRISAT, and IITA (2013) A bulletin of the tropical legumes ii project, pp. 1–12.

Ciganda V, Gitelson AA and Schepers JS (2009) Non-Destructive Determination of Maize Leaf and Canopy Chlorophyll Content. Journal of plant physiology, 166(2), 157-167.

CIMMYT (1988) Economics Program. (1988). From agronomic data to farmer recommendations: an economics training manual (No. 27). CIMMYT.

Conservation Farming Unit (CFU) (2006) "Reversing Food Insecurity and Environmental Degradation in Zambia through Conservation Agriculture." *ZNFU, CFU, Lusaka*.

Cook RJ (2001) Management of wheat and barley root diseases in modern farming systems. Australian Plant Pathology, 30: 119–126.

Copeland PJ and Crookston RK (1992) Crop sequence affects nutrient composition of corn and soybean grown under high fertility. Agronomy, 84(3): 503–509.

Davis AS, Hill JD, Chase CA, Johanns AM, Liebman M (2012) Increasing cropping system diversity balances productivity, profitability and environmental health. PloS one, 7(10), 47149.

Derpsch R (2005) The extent of conservation agriculture adoption worldwide: implications and impact. In Proceedings of the Third World Congress on Conservation Agriculture: Linking Production, Livelihoods and Conservation, Nairobi, Kenya, 3–7 October 2005.

Derpsch R (2008) No-tillage and conservation agriculture: a progress report. No-till farming systems. Special publication, (3): 7-39.

Derpsch R and Friedrich T (2009) Global overview of conservation agriculture no-till adoption. In 4th World Congress on Conservation Agriculture New Delhi, India (Vol. 4).

Derpsch R, Friedrich T, Kassam A and Hongwen L (2010) Current status of adoption of no-till farming in the world and some of its main benefits. International Journal of Agricultural and Biological Engineering, 3(1): 1-25.

Drechsel P, Kunze D, and Vries FP De (2001) Soil nutrient depletion and population growth in Sub-Saharan Africa : A Malthusian Nexus ? Population & Environment, 22(4): 411–423.

Duiker SW (2004) Effects of soil compaction. Produced by Information and Communication Technologies in the College of Agricultural Sciences. Available at http://extension.psu.edu/plants/crops/soil-management/soil-compaction/effects-of-soil-compaction/extension_publication_file

Erenstein O, Sayre K, Wall PC, Dixon J, Hellin J (2008) Adapting No-tillage agriculture to the conditions of smallholder maize and wheat farmers in the tropics and sub-tropics, World Association of Soil and Water Conservation (WASWC), 253–278.

Fageria NK (2014) The use of nutrients in crop plants. CRC Press Taylor & Francis Group.

Fageria NK and HR Gheyi (1999) Efficient crop production. Campina Grande, Brazil: Federal University of Paraiba.

Fageria NK and VC Baligar (2009) Response of common bean, upland rice, corn, wheat, and soybean to soil fertility of an Oxisol. Journal of Plant Nutrition, 20:1279–1289.

Fageria NK, Baligar VC, Moreira A and Portes TA (2010) Dry bean genotypes evaluation for growth, yield components and phosphorus use efficiency. Journal of Plant Nutrition, 33:2167-2181.

FAO (2002a) Agriculture: Towards 2015/2030; FAO, Rome, p 420.

FAO (2002b) Conservation agriculture in development: The Case of Africa. Accessed from FAO Website: http://www.fao.org/ag/ca/ca-publications/act%20jinja%202002.pdf on 20th May, 2014.

FAO (2006) State of food insecurity. Rome: FAO.

FAO (2010) Food and Agriculture Organization website: http://www.fao.org/ag/ca. Accessed in June 16th, 2014.

FAO (2011a) Situation analysis : Improving food safety in the maize value chain in Kenya. Report prepared for FAO by Prof. Erastus Kang'ethe, College of Agriculture and Veterinary Science, University of Nairobi. September 2011.

FAO (2011b) Socio-economic analysis of conservation agriculture in Southern Africa, Network No. 2. Rome: FAO.

FAO (Food and Agriculture Organization of the United Nation) (2012a) Agricultural Production Domain. Global Maize Productivity: faostat.fao.org/site/339/default.aspx. Accessed on 16th June, 2014.

FAO (Food and Agriculture Organization of the united nation) (2012b) Average maize crop production data in Kenya: As accessed from FAOSTAT Gateway Website: http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E. on 17th May, 2014.

FAO (Food and Agriculture Organization of the United Nations) (1990) Integrated plant nutrient systems: State of the Art; Commission on Fertilizers, 11th Session, 4–6 April 1990; FAO: Rome, 1990.

FAO: Conservation Agriculture Website: http://www.fao.org/ag/ca/index.html. Accessed on 10th June, 2014.

Filipović D, Košutić S and Gospodarić Z (2004) Influence of different soil tillage systems on fuel consumption, labour requirement and yield in maize and winter wheat production. POLJOPRIVREDA, 10(2), 17-23.

Fowler R and Rockstrom J (2001) Conservation tillage for sustainable agriculture: An agrarian revolution gathers momentum in Africa. Soil and Tillage Research Journal, 61: 93-107.

Friedrich T, Derpsch R and Kassam A (2011) Global overview of the spread of conservation agriculture. Paper presented at the 5th World Congress on Conservation Agriculture, Brisbane, 26-29 September.

FURP (1987) Description of the first priority sites. Fertilizer use research project. Phase 1, Final report Annex III. Minitry of Agriculture, Kenya in Co-operation with the German Agency for International Co-operation. Nairobi, Kenya.

Galavi M, Yosefi K, Ramrodi M, Mousavi SR (2011) Effect of bio-phosphate and chemical phosphorus fertilizer accompanied with foliar application of micronutrients on yield, quality and phosphorus and zinc concentration of maize. Journal of Agricultural Science, 3(4): 22-29.

Giller KE, Amijee F, Brodrick SJ and Edje OT (2001) Environmental constraints to nodulation and nitrogen fixation of *Phaseolus vulgaris* L. in Tanzania. II. Response to N and P fertilizers and inoculation with Rhizobium. African Crop Science Journal 6(2):171-178.

Giller KE, Corbeels M, Nyamangara J, Triomphe B, Affholder F, Scopel E and Tittonell P (2011) A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field Crops Research, 124(3): 468-472.

Giller KE, Witter E, Corbeels M Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: The heretics view. Field Crops Research, 114: 23–34.

Gomez KA and Gomez AA (1984) Statistical Procedures for Agricultural research with Emphasis on Rice. The International Rice Research Institute, Los Banos, Philippines, 1976, 294 pp.

González YRS (2012) Assessment of Conservation Agriculture (CA) Practices in Bungoma, Western Kenya: Towards an Insight in CA Adoption and It's Constraints.

Goss MJ and Varennes A (2002) Soil disturbance reduces the efficacy of myccorrhizal associations for early soybean growth and N_2 fixation. Soil Biology and Biochemistry, 34: 1167-1173.

Gowing JW and Palmer M (2008) Sustainable agricultural development in sub-Saharan Africa: The case for a paradigm shift in land husbandry. Soil Use and Management, 24(1): 92-99.

Gressel J, Hanafib A, Head GN, Marasasd W, Obilanae NAB, Ochandaf J, Souissig T and Tzotzosh G (2004) Major heretofore intractable biotic constraints to African food security that may be amenable to novel biotechnological solutions. Crop Protection, 23(8): 661–689.

Habte M (2006) The role of abuscular mycorrhizas in plant and soil health. In: Uphoff N, Ball AS, Fernandes E, Herren H, Husson O, Laing M, Palm C, Pretty L, Sunchez P, Sanginga N, and Thies J(Eds) Biological Approaches to Sustainable Soil System. (Uphoff, N. et al. Eds.). CRC Press, Taylor and Francis Group, 131-147.

Haggblade S and Tembo G (2003) Conservation farming in Zambia, EPTD discussion paper number 108: International Food Policy Research Institute.

Halvorson AD, AR Mosier, CA Reule and WC Bousch (2006) Nitrogen and tillage effects on irrigated continuous corns. Agronomy, 98: 63-71.

Hansen J W and Indeje M (2004), Linking dynamic seasonal climate forecasts with crop simulation for maize yield prediction in semi-arid Kenya, Agricultural and Forest Meteorology, 125, 1-2: 143-157.

Henao J and Baanante C (2006) Agricultural production and soil nutrient mining in Africa. Excerpted from: International Center for Soil Fertility and Agricultural Development (IFDC) Technical Bulletin: Agricultural Production and Soil Nutrient Mining in Africa Policy Development, (March, 2006).

Hengsdijk H and Langeveld JWA (2009) Yield trends and yield gap analysis of major crops in the world (No. 170). Wettelijke Onderzoekstaken Natuur & Milieu.

Hobbs PR, Sayre K, and Gupta R (2008) The role of conservation agriculture in sustainable agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences, 363 (1491): 543-555.

Hoffmann S and Kismányoky T (2001) Soil fertility in a long term fertilizer trial with different tillage systems. Archives of Agronomy and Soil Science Journal, 46(3-4), 239–250.

Huho JM and Edward M (2010) The effects of droughts on food security in Kenya. International Journal of Climate Change: Impacts and Responses, 2(2), 61-72.

Hunt R (2003) Growth analysis, individual Plants. In: Thomas B, Murphy DJ and Murray D (Eds) Encyclopaedia of applied plant science, 588-596.

Hüttemann M, Lee I, Samavati L, Yu H and Doan JW (2007) Regulation of mitochondrial oxidative phospho- rylation through cell signaling. Biochimica et Biophysica Acta (BBA)- Molecular Cell Research Journal, 1773: 1701-1720.

Ibrahim S, Atala A, and Kandil A (2008) Growth, yield and chemical composition of corn (*Zea mays* L.) as affected by nitrogen and phosphorus fertilization under different irrigation intervals. Journal of Applied Sciences Research, 3(10), 1112-1120

Ito M, Matsumoto T and Quinones MA (2007) Conservation tillage practice in sub-Saharan Africa: The Experience of Sasakawa Global 2000. Crop Protection Journal. 26: 417–423.

Jaetzold R, Schmidt H, Hornetz B, Shisanya CA (2006) Farm Management Handbook of Kenya. Natural Conditions and Farm Information, 2nd edition, vol. 11/C. Ministry of Agriculture/GTZ, Nairobi, Kenya (Eastern Province).

Jaetzold R. (2006) Farm Management Handbook of Kenya Vol. II 2nd edition. Part C, East Kenya, Sub part C1, Eastern Province. Ministry of Agriculture, Nairobi Kenya

Jaetzold R. et al. (2005) Farm management handbook of Kenya, Vol. II – Natural Conditions and Farm Management Information – 2nd edition. Part A, West Kenya, Subpart A1, Western Province. Ministry of Agriculture, Nairobi Kenya.

Jagtap SS and F Abamu (2003) Matching improved maize production technologies to the resource base of farmers in a moist savanna. Agricultural Systems, 76:1067–1084.

Jakobsen ST (2009) Interaction between plant nutrients: Theory and analytical procedures. Acta Agriculturae Scandinavica Section B, Plant and Soil Sciences Journal, 42(4): 208-212.

Jin J, Wang G, Liu X, Pan X, Herbert JS and Tang C (2006) Interaction between phosphorus nutrition and drought on grain yield, and assimilation of phosphorus and nitrogen in two

Soybean cultivars differing in protein concentration in grains. Journal of Plant Nutrition, 29: 1433-1449.

Jones AL (1999) Phaseolus bean: post-harvest operations. Rome, FA

Jones CA, Jacobsen JS, and Wraith JM (2005) Response of malt barley to phosphorus fertilization under drought conditions. Journal of Plant Nutrition, 28(9): 1605-1617.

Jung WS, Kim KH, Ahn JK, Hahn SJ, Chung IM (2004) Allelopathic potential of rice (*Oryza sativa* L.) residues against *Echinochloa crusgalli*. Crop Protection Journal, 23: 211–218.

Kamanu JK, Chemining'wa GN, Nderitu JH, and Ambuko J (2012) Growth, yield and quality response of snap bean (*Phaseolus vulgaris L.*) plants to different inorganic fertilizers applications in central Kenya. Journal of Applied Biosciences, 55, 3944 - 3952.

Kanwal S, Rahmatullah, Aziz T, Maqsood MA and Abbas N (2008) Critical ratio of calcium and boron in maize shoot for optimum growth. Journal of Plant Nutrition, 31: 1535 – 1542.

Karamanos RE, Harapiak JT and Kruger GA (2007) Long-term phosphorus fertilization effects on crop yields and soil phosphorus. Better Crops, 91 (2), 25 - 27.

KARI (1998) Soil fertility research priorities in Kenya. Nairobi: Soil Fertility and Plant Nutrition Research Program of the Kenya Agricultural Research Institute.

Karimi MM and Siddique KHM (1991) Crop growth and relative growth rate of old and modern wheat cultivars. Australian Journal of Agricultural Resources, 42:13 - 20.

Karlen DL, Berry EC and Colvin TS (1991) Twelve-year tillage and crop rotation effects on yields and soil chemical properties in Northeast Iowa. Communications in Soil Science and Plant Analysis Journal, 22: 1985–2003.

Kasasa P, Mpepereki S, Musiyiwa K, Makonese F and Giller K, (1999) Residual nitrogen benefits of promiscuous soybeans to maize under field conditions. Africa Crop Science Journal, 7: 375–382.

Kassam A and Friendrich T (2009) Perspectives on nutrient management in conservation agriculture. In: IVth World Congress on Conservation Agriculture, New Delhi, February 2009. New Delhi, FAO, 1–16.

Kassam A, Friedrich T, Shaxson F, and Pretty J (2009) The spread of conservation agriculture: justification, sustainability and uptake. International Journal of Agricultural Sustainability, 7(4): 292-320.

Katungi, E, Farrow A, Chianu J, Sperling L and Beebe S (2009). Common bean in Eastern and Southern Africa: a situation and outlook analysis. International Centre for Tropical Agriculture, 61.

Kaumbutho P and Kienzle J (2007) Conservation agriculture as practiced in Kenya: Two case studies. Africain Conservation Tillage Network, Centre de Coope´ ration Internationale de Recherche Agronomique pour le De´veloppement, Food and Agriculture Organisation of the United Nations, Nairobi, Kenya.

Kaur G and Nelson KA (2015) Effect of foliar boron fertilization on fine textured soils on corn yields. Agronomy, 5(1): 1–18.

Kennedy AC (1999) Soil microorganisms for weed management. Journal of Crop Production, 2: 123–138.

Kihara J, Martius C, Bationo A, and Vlek PLG (2011) Effects of tillage and crop residue application on soybean nitrogen fixation in a tropical ferralsol. Journal of Agriculture, 1(1): 22–37.

Kihara J, Mukalama J, Ayuke FO, Njoroge S, B Waswa , J Okeyo , S Koala and A Bationo (2012) Crop and soil response to tillage and crop residue application in a tropical ferralsol in sub-humid Western Kenya. In A. Bationo et al. (eds.), Lessons learned from Long-term soil fertility management experiments in Africa, © Springer Science+Business Media Dordrecht 2012.

Kimani **PM**, Buruchara R, Ampofo K, Pyndji M, Chirwa RM, and Kirkby R (2001) Breeding beans for smallholder farmers in Eastern, Central, and Southern Africa: Constraints, achievements, and potential. PABRA Millennium Workshop, Arusha, Tanzania, 28 May – 1 June 2001.

Kimani SK, Macharia JM, Gachengo C, Palm CA and Delve RJ (2004) Maize production on the central highlands of Kenya using cattle manures combines with modest amounts of mineral fertilizer. Uganda Journal of Agricultural Sciences, 9: 480-490.

Kimaru SM, Mugwe J, Mucheru-Muna MW and Mugendi DN (2012) Influence of education levels on dissemination of soil fertility management information in central highlands of Kenya. Journal of Agriculture and Rural Development in Tropics and Subtropics (JARTS), 113: 89–99.

Knowler D and Bradshaw B (2007) Farmers’ adoption of conservation agriculture: A review and synthesis of recent research. Food policy, 32(1), 25-48.

Kovar JL, Barber SA, Kladivko EJ and Griffith DR (1992) Characterization of soil temperature, water content, and maize root distribution in two tillage systems. Soil Tillage Research, 24: 11–27.

KOwino IO (2010) Conservation agriculture in Kenya: Analysis of past performance and emerging trends, (March).

Kumar K and Goh KM (1999) Crop residues and management practices: effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. Advances in Agronomy, 68: 197–319.

Kumwenda JDT, Waddington SR, Snapp SS, Jones RB and Blackie MJ (1996) Soil fertility management research for the maize cropping systems of smallholders in southern Africa: A review. Natural Resources Group Paper 96-02. Mexico City: International Maize and Wheat Improvement Centre (CIMMYT).

Ladd JN, Foster RC and Skjemstad JO (1993) Soil structure: Carbon and nitrogen metabolism. Geoderma, 56: 401–434.

Lal R (1998) Soil quality changes under continuous cropping for seventeen seasons of an alfisol in Western Nigeria. Land Degradation and Development Journal, 9: 259–274.

Lal R, Follett RF, and Kimble JM (2003) Achieving soil carbon sequestration in the United States: a challenge to the policy makers. Soil Science, 168: 827-845.

Lampurlanes J, Angas P, and Cantero-Martinez C (2001) Root growth, soil water content and yield of barley under different tillage systems on two soils in semiarid conditions. Field Crops Research, 69: 27-40.

Leake AR (2003) Integrated pest management for conservation agriculture. In Garcia-Torres L, Benites J, Martinez-Vilela A, and Holgado-Cabrera A (Eds) Conservation agriculture: environment, farmers experiences, innovations, socio-economy, policy 2003pp. 271–279. Dordrecht, The Netherlands; Boston, Germany; London, UK:Kluwer Academia Publishers.

Li QQ, Chen YH, Liu MY, Zhou XB, Yu SL and Dong BD (2008) Effects of irrigation and straw mulching on microclimate characteristics and water use efficiency of winter wheat in North China. Plant Production Science, 11: 161–170.

Liebman M, Drummond FA, Corson S and Zhang J (1996) Tillage and crop rotation effects on weed dynamics in potato production systems. Agronomy Journal, 88: 18-26.

Lu M, Yang Y, Luo Y, Fang C, Zhou X, Chen J, Yang X and Li B (2011) Responses of ecosystem nitrogen cycle to nitrogen addition: a meta-analysis. New Phytologist, 189: 1040–1050.

Lunze L and Ngongo M (2011) Potential nitrogen contribution of climbing bean to subsequent maize crop in rotation in South Kivu Province of Democratic Republic of Congo. In: Innovations as Key to the Green Revolution in Africa, A. Bationo et al. (eds.), 677 – 681, Springer Science, Dordrecht, The Netherlands .

Mabood F, Zhou X, Sand mith D (2006) *Bradyrhizobium japonicum* preincubated with Methyl Jasmonate increases soybean nodulation and nitrogen fixation. Agronomy Journal, 98(2), 289-294.

Machado RMA, Bryla DR, Verissimo ML, Sena AM, and Oliveira MRG (2008) Nitrogen requirements for growth and early fruit development of drip-irrigated processing tomato (*Lycopersicon esculentum* Mill.) in Portugal. Journal of Food, Agriculture and Environment, 6(3 and 4): 215-218.

Madari B, Machado PLOA, Torres E, de Andrade AG, Valencia LIO (2005) No tillage and crop rotations effects on soil aggregation and organic carbon in a Rhodic Ferrasol from southern Brazil. Soil and Tillage Research, 80(1): 185-200.

Maina I, Newsham A, and Okoti M (2013). Agriculture and climate change in Kenya : Climate Chaos , Policy Dilemmas. Brighton BN1 9RE UK.

Makokha S, Kimani S, Mwangi W, Verkuijl H and Musembi F (2001) Determinants of fertiliser and manure use for maize production in Kiambu District, Kenya. CIMMYT. ISBN: 970-648-070-6.

Marongwe LS, Kwazira K, Jenrich M, Theifelder C, Kassam and Frierich T (2011) An African success: the case study of conservation agriculture in Zimbabwe. International Journal of Agricultural Sustainability, 9(1): 1-9.

Mashingaidze N, Madakadze C, Twomlow S, Nyamangara J and Hove L (2012) Crop yield and weed growth under conservation agriculture in semi-arid Zimbabwe. Soil and Tillage Research, 124: 102–110.

Mazvimavi K and Twomlow S (2009) Socioeconomic and institutional factors influencing the adoption of conservation farming by vulnerable households in Zimbabwe. Agricultural Systems, 101: 20–29.

Mazvimavi K, Ndlovu PV, An H and Murendo C (2012) Productivity and efficiency analysis of maize under Conservation Agriculture in Zimbabwe. In selected paper for presentation at the International Conference for Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.

Mazvimavi K, Ndlovu PV, Nyathi P and Minde IJ (2010) Conservation agriculture practices and adoption by smallholder farmers in Zimbabwe By. In Poster presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 2010: 19-23.

Mbithi L and Huylenbroeck GV (2000) A comparison of maize production in Kenya before and during liberation period. Tropicultura, 18(4): 181–186.

McCalla TM (1958) Microbial and related studies of stubble mulching. Journal of Soil Water Conservation, 13: 255–258

McGechan MB, Henshall JK and Vinten AJA (2005) Cultivation and soil organic matter management in low input cereal production following the ploughing out of grass leys. Biosystems Engineering, 90: 85–101.

McGonigle TP and Miller MH (1996) Mycorrhizae, phosphorus adsorption and yield of maize in response to tillage. Soil Science Society of America Journal, 60: 1856–1861.

McNeely JA and Scherr SJ (2001) (draft): Common ground; Common future: Ecoagriculture strategies to help feed the world and save wild biodiversity. IUCN, Future Harvest.

Memon SQ, Mirjat MS, Mughal AQ, and Amjad N (2012) Effects of different tillage and fertilizer treatments on growth and yield components of maize. Pakistan Journal of Agriculture, Agricultural Engineering, Veterinary Sciences, 28(2): 160-176.

Mendoza RB, Franti TG, Doran JW, Powers TO and Zanner CW (2008) Tillage effects on soil quality indicators and nematode abundance in loessial soil under long-term no-till production. Communications in Soil Science and Plant Analysis, 39(13-14): 2169–2190.

Met Office (2005) Climate change, rivers and rainfall; recent research on climate change science from the Hadley Centre, Exeter/UK.

Micheni A, Mburu D, Kanampiu F, Mugai N, and Kihanda F (2014) Glyphosate-based herbicides on weeds management and maize performance under conservation agriculture practices in eastern Kenya. International Journal of Agricultural Resources, Governance and Ecology 27, 10(3), 257-268.

Micheni A, Ouma J, Kanampiu F, Mburu D and Mugai N (2014) Maize-bean farming system under conservation agriculture : Assessing productivity and sustainability in Eastern Kenya, 2012–2014. Available at: http://www.ctic.org

Ministry of Agriculture (MOA) (2014) Soil suitability of evaluation for maize production in Kenya. A Report by National Accelerated Agricultural Inputs Access Programme (NAAIAP) in collaboration with Kenya Agricultural Research Institute (KARI) Department of Kenya Soil Survey, February 2014.

Mlamba JL (2010) Factors Affecting Adoption of Conservation Agriculture in Malawi (A Case Study of Salima District). In 5 th World Congress on Conservation Agriculture.

Mloza-Banda HR and Nanthambwe SJ (2011) Conservation agriculture program and projects in Malawi: Impacts and lessons. National Conservation Agriculture Task Force Secretariat Land Resources Conservation Department, Lilongwe. Available at: http://hdl.handle.net/10919/69913

MOA (2012) Crop, livestock and fisheries high rainfall areas assessment 2012. Prepared by the agriculture livestock sector working group of the kenya food security steering group (KFSSG): Joint work between Food Agriculture Organization of the United Nations (FAO), WFP, FEWS NET and Ministries of Agriculture, Livestock Development and Fisheries Development Kenya. Nairobi Kenya, December 2012.

Mucheru-muna BM, Mugendi D, Pypers P, Mugwe J, U, J. K, Vanlauwe B and Merckx R (2013) Enhancing maize productivity and profitability using organic inputs and inorganic mineral fertilizers in central Kenya under small holder farms. Experimental Agriculture, 50(2), 250-269.

Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N and Foley JA (2012) Closing yield gaps through nutrient and water management. Nature, 490(7419): 254-257.

Mugwe J, Mugendi D, Kungu J and Muna MM (2009) Maize yields response to application of organic and inorganic input under on-station and on-farm experiments in central Kenya. Experimental Agriculture, 45: 47-59.

Muliokela SW, Hoogmed WB, Steven P and Dibbits H (2001) Constraints and possibilities of conservation farming in Zambia. In: Garcia-Torres, L, Berutes, J, Martinez-Vilela, A. (Eds.), Conservation Agriculture, A World Challenge, Volume II: Offered Contributions, Environment, Farmers' Experiences, Innovations, Socioeconomic Policy. XULAvda, Medina, Spain, 61–65.

Mupangwa W, Twomlow S and Walker S (2012) Reduced tillage, mulching and rotational effects on maize (Zea mays L) cowpea (*Vigna unguiculata* L. (Walp)) and sorghum (*Sorghum bicolor* L. (Moench)) yields under semi-arid conditions. Field Crops Research, 132: 139–148.

Musandu AAO and Njul NA (1999) Response of maize to phosphorus fertilization at selected sites in western Kenya. African Crop Science Journal, 7(4): 397-406.

Muui CW, Muasya, RM, Rao N and Anjichi VE (2007) Pollen longevity in ecologically different zones of western Kenya. African Crop Science Journal, 15: 43–49.

Mwangi JN, Mugendi DN and O'Neill KM (1998) Crop yield response to incorporation of leaf pruning in sole and alley cropping systems. East Africa Agricultural Journal, 62:209–218.

Mzezewa J and Van Rensburg LD (2011) Effects of tillage on runoff from bare clayey soil on a semi-arid ecotope in the Limpopo Province of South Africa. Water South Africa, 37(2): 165-172.

Namakka A, Abubakar IU, Dadari SA, Ado SG, Hamid AH, Kura HN and Halliru I (2012) Effect of tillage system and nitrogen level on growth of maize (*Zea Mays* L.) in Northern Guinea zone of Nigeria. Greener Journal of Agricultural Sciences, 2(5): 172-179.

Neubert S, Valeska H, Simone I, Japheth OO, Wilfred O, Valérie P, Antti S and Daniel T (2007) Poverty oriented irrigation policy in Kenya. Empirical results and suggestions for reform. discussion paper / Deutsches Institut für Entwicklungspolitik, 12.

Ngome AF, Becker M, Mtei MK, and Mussgnug F (2013) Maize productivity and nutrient use efficiency in Western Kenya as affected by soil type and crop management. International Journal of Plant Production, 7(3): 517- 536.

Nicholson S.E (2000) The nature of rainfall variability over Africa on time scales of decades to millennia Global and Planet. Change, 26: 137–158.

Nyanga HP (2012) Factors influencing adoption and area under conservation agriculture: a mixed methods approach. Sustainable Agriculture Research, 1(2): 27-40.

Oerke EC (2006) Crop losses to pests. Journal of Agricultural Science, 144: 31-43.

Okalebo JR, Othieno CO, Woomer PL, Karanja NKM, Semoko JRM, Bekunda, MA, Mugendi DN, Muasya RM and Batiano A (2007) In Batiano A (Eds.) Advances in integrated soil fertility management in Sub-Sahara Africa: Challenges and Opportunities, 45-62.

Olwande J. (2012) Small holder maize production efficiency in Kenya. Regional workshop on an integrated policy approach to commercializing smallholder maize production on 6th – 7th June, 2012 at The Norfolk Hotel, Nairobi Kenya.

Otieno PE, Muthomi JW, Chemining'wa GN and Nderitu JH (2009) Effect of rhizobia inoculation, farm yard manure and nitrogen fertilizer on nodulation and yield of food grain legumes. Journal of Biological Sciences, 9(4): 326-332.

Pannell DJ, Llewellyn RS, and Corbeels M (2014) The farm-level economics of conservation agriculture for resource-poor farmers. Agriculture, Ecosystems and Environment, 187: 52–64.

Peigne J, Ball BC, Roger-Estrade J and David C (2007) Is conservation tillage suitable for organic farming? A review. Soil Use and Management, 23: 129–144

Pierce LL and Running SW (1988) Rapid estimation of coniferous forest leaf area using a porta integrating radiometer. Ecology, 69:1762-1767

Porter JR, Xie L, Challinor AJ, Cochrane K, Howden M, Iqbal MM, Lobell DB and Travasso MI (2014) Food security and food production systems. Climate Change: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment report. Geneva, Switzerland.

Pretorius H (2009) The ability of a novel compound to enhance the effect of urea on nitrogen deficient tomatoes. University of the Free State, Bloemfontein.

Purcell LC, Edwards JT and Brye KR (2007) Soybean yield and biomass responses to cumulative transpiration: Questioning widely held beliefs. Field Crops Research, 101: 10–18.

Ragab R and Prudhomme Ch (2002) Climate change and water resources management in arid and semi arid regions: Prospective and challenges for the 21st Century; Biosystems Engineering, 81(1): 3-34.

Rahman IU, Afzal A, Iqbal Z, Ijaz F, Manan S, Ali A and Qadir G (2014) Growth and yield of *Phaseolus vulgaris* as influenced by different nutrients treatment in Mansehra, 4(3), 20–26.

Ramirez-Villegas and **Thornton PK** (2015) Climate change impacts on African crop production. CCAFS Working Paper no. 119. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org.

Rao MR and Mathuva MN (2000) Legumes for improving maize yields and income in semi-arid Kenya. Agriculture, Ecosystems and Environment, 78(2): 123–137.

Ravi S, Channal HT and Shailendra Kumar G (2010) Response of sulphur and micronutrients (Zn and Fe) on yield and available nutrients of safflower (*Carthamus tinctorius* L.). An Asian Journal of Soil Science, 5(2): 402-405.

Recha CW, GL Makokha, PS Traore, C Shisanya, T Lodoun and A Sako (2012) Determination of seasonal rainfall variability, onset and cessation in semi-arid Tharaka district, Kenya. Theoretical and Applied Climatology, 108: 479-494.

Reddy KN, Zablotowicz RM and Krutz LJ (2013) Corn and Soybean rotation under reduced tillage management: Impacts on soil properties, yield and net return. American Journal of Plant Sciences, 4, 10-17.

Reeves DW (1997) The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Tillage Research, 43: 131–167.

Rockstrom J, Hatibu N, Oweis TY, Wani S, Barron J, Brugge- man A, Farahani J, Karlberg L and Qiang Z (2007) Managing water in rain-fed agriculture. In: CAWMA (2007) Water for food, water for life: a comprehensive assessment of water management in agriculture (Chapter 8). Earthscan, London.

Rockström J, Kaumbutho P, Mwalley J, Nzabi AW, Temesgen M and Mawenya L (2009) Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. Soil and Tillage Research, 103:23-32

Ruisi P, Giambalvo D, Miceli GD, Frenda AS, Saia S and Amato G (2012) Tillage effects on yield and nitrogen fixation of legumes in Mediterranean conditions. Agronomy Journal, 104(5): 1459-1466.

Ruto JK (1992) Co-ordination and management of the National Maize Research Program. In: Proceedings of a workshop held at Golf Hotel, Kakamega, Kenya. November 19-23, 1992.

Salvagiotti F, Cassman KG, Specht JE, Walters DT, Weiss A and Dobermann A (2008) Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. Field Crops Research, 108: 1-13.

Sanchez PA, Shepherd KD, Soule MJ, Place FM, Buresh RJ. Izac AMN, Uzo MA, Kwesiga FR, Ndiritu CG and Woomer PL (1997). Soil fertility replenishment in Africa: an investment in natural resource capital. In: Replenishing soil fertility in Africa; RJ Buresh, PA Sanchez and F Calhoun (Ed.). WI. Soil Sci. Soc. Am. Madison. Special Publication, 51:1-46.

Saturnino HM and Landers JN (2002) The environment and zero tillage; APDC-FAO, Brasilia, Brazil UDC 504:631/635, CDD 631.521, 144 p.

Scully BT and Wallace DH (1990) Variation in and relationship of biomass, growth rate, harvest index, and phenology to yield of common bean. Journal of American Society of Horticulture Sciences, 115: 218–225.

Sharafi M, Mehranzadeh M and Mirakzadeh AA (2013) Effect of no tillage method and nitrogen fertilizer levels on maize (*Zea mays* L.) yield under conditions of southern part of Lorestan province in Iran. Annals of Biological Research, 2013, 4 (5): 233-240.

Sharma AR, Singh R, Dhyani SK and Dube RK (2010) Moisture conservation and nitrogen recycling through legume mulching in rain-fed maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system, Nutrient Cycling in Agroecosystems, 87: 187–197.

Shaxson T F, Kassam A H, Friedrich T, Boddey R and Adekunle A (2008) Underpinning Conservation Agriculture's Benefits: The Roots of Soil Health and Function. Integrated Crop Management Vol.6-2008, Appendix 1, FAO, Rome.

Sherchan DP, Upreti R and Maskey SL (2004) Effect of micronutrients on production of maize in the acid soils of Chitwan Valley. pp. 169 - 180. In: Proceedings of an International Workshop. Micronutrient in South and South East Asia (September 8- 11, 2004). Kathmandu, Nepal.

Shetto R and Owenya M (2007) Conservation agriculture as practised in Tanzania: Three case studies. African Conservation Tillage Network, Centre de Coope´ ration Internationale de Recherche Agronomique pour le De´veloppement, Food and Agriculture Organization of the United Nations, Nairobi, Kenya.

Shrestha J, Bk SB, Srivastav SB, Gurung SB, and Ferrara GO (2013) Effect of conservation agriculture on growth and productivity of maize in Terai Region of Nepal. Merit Research Journal of Agricultural Science and Soil Sciences, 1(5), 66-77.

Sieling K, Brase T and Svib V (2006) Residual effects of different N fertilizer treatments on growth N uptake and yield of oilseed rape, wheat and barley. European Journal of Agronomy, 25: 40–48.

Simes Al Schepers JS, Olson RA and Power JF (1998) Irrigated corn yield and nitrogen accumulation response in a comparison of no-till and conventional till: Tillage and surface-residue variables. Agronomy Journal, 90: 630-637.

Six J, Conant RT, Paul EA and Paustian K (2002) Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. Plant and Soil, 241: 155–176.

Smaling EMA, SM Nandwa and BH Janssen (1997) “Soil fertility in Africa is at stake.” In: Buresh RJ, PA Sanchez and F Calhoun (eds.). Replenishing soil fertility in Africa. Soil Science Society of America, Special Publication 51. SSSA and America Society of Agronomy, Madison, Wisconsin, p. 47-61I, SBN: 978-0-89118-946-6.

Snapp SS, and SN Silim (2002) Farmer preferences and legume intensification for low nutrient environments. Plant and Soil, 245: 181–192.

Sommer R, Piggin C, Feindel D, Ansar M, Delden L Van, Shimonaka K, Ryan J (2014) Effects of zero tillage and residue retention on soil quality in the mediterranean region of Northern Syria. Open Journal of Soil Science, 4, 109-125.

Szulc P, Waligóra H and Skrzypczak W (2008) Better effectiveness of maize fertilization with nitrogen through additional application of magnesium and sulphur. Nauka Przyroda Technologie, 2(3), 19.

Thierfelder C, Amezquita E and Stahr K (2005) Effects of intensifying organic manuring and tillage practices on penetration resistance and infiltration rate. Soil Tillage Research, 82: 211–226.

Thomas PEL (1986) Evaluation of the effects of scorching caused by the directed application of a paraquat-containing herbicide mixture to the base of maize plants at various ages, South African Journal of Plant and Soil, 3(1) 18-20.

Torbert HA, Prior SA and Runion GB (2004) Impact of the return to cultivation on carbon (C) sequestration. Journal of Soil Water Conservation, 59: 1–8.

Tubiello F (2012) Climate change adaptation and mitigation: challenges and opportunities in the food sector. Natural Resources Management and Environment Department, FAO, Rome.

Prepared for the high-level conference on world food security: the challenges of climate change and bioenergy, Rome, 3-5 June 2008.

Turner NC (2004) Sustainable production of crops and pastures under drought in a Mediterranean environment. Annals of Applied Biology, 144(2), 139-147.

UNESCO [United Nations Educational, Scientific and Cultural Organization] (2001) Securing the food supply. Paris: UNESCO. Available online: http://unesdoc.unesco.org

United States Department of Agriculture (USDA) Estimating crop residue cover using line transect method. Agronomy Tech Note #MN-19. https://www.nrcs.usda.gov

Uri ND (2000) The economic benefits and costs of conservation tillage. Journal of Sustainable Agriculture, 15(1): 5-27.

USDA [United States Depertment of Agriculture] (2015) World Agricultural Production. Circular Series, WAP 7-15, July 2015.

Valbuena D, Erenstein O, Tui SHK, Abdoulaye T, Claessens L, Duncan AJ,Gérard B, Rufino MC, Teufel N, van Rooyen A and van Wijk MT (2012) Con-servation Agriculture in mixed crop–livestock systems: Scoping crop residuetrade-offs in Sub-Saharan Africa and South Asia. Field Crops Research, 132: 175–184.

Vanlauwe B, Bationo A, Chianu J, Giller KE, Merckx R, Mokwunye U, Ohiokpehai O, Pypers, P, Tabo R, Shepherd K, Smaling EMA, Woomer PL, (2010) Integrated soil fertility management: operational definition and consequences for implementation and dissemination. Outlook Agriculture. 39: 17–24.

Vanlauwe B, Wendt J, Giller KE, Corbeels M, Gerard B, and Nolte C (2014) A fourth principle is required to define conservation agriculture in sub-Saharan Africa : The appropriate use of fertilizer to enhance crop productivity. Field Crops Research, 155, 10-13.

Vieira C, Santa Cecília FC and Sediyama CS (1973) Índice de colheita de alguns cultivares de feijão (*Phaseolus vulgaris* L.). Review Ceres, 20: 120–128.

Wambugu P.W. and Muthamia Z.K (2009). The state of plant genetic resources for food and agriculture in Kenya: KARI, National Gene bank of Kenya. Available on: www.kalro.org

Wang XB, Wu HJ, Dai K, Zhang KDC, Feng ZH, Zhao Wu XP, Jin K, Cai DX, Oenema O and Hoogmoed WB (2012) Tillage and crop residue effects on rain-fed wheat and maize production in northern China, Field Crops Research, 132: 106–116.

Watson CA, Bengtsson H, Ebbesvik M, Loes AK, Myrybeck A, Salomon E, Schroder J and Stockdale EA (2002) A review of farm-scale nutrient budgets for organic farms as a tool for management of soil fertility. Soil Use and Management. 18: 264–273.

Wopereis MCS, Becker M, DE. Johnson and Sow A (2006) Rice yield gaps in irrigated systems along an agroecological gradient in West Africa. Zeitschrift für Pflanzenernahrung und Bodenkunde. Journal of Plant Nutrition and Soil Science, 166(1), 61-67.

World Bank (2014) Fertilizer consumption (kilograms per hectare of arable land). Available online at http://data.worldbank.org/indicator/AG.CON.FERT.ZS.

Yamoah C, Ngueguim M, Ngong C and Dias DKW (1996) Reduction of P fertilizer requirements using lime and Mucuna on high P sorption soils of North West Cameroon. African Crop Science Journal, 4: 441-451.

Yerokun OA and Chirwa M (2014) Soil and foliar application of Zinc to maize and wheat grown on a Zambian Alfisol. African Journal of Agricultural Research, 9(11), 963-970.

Zeidan MS, M Hozayn and MEE Abd El-Salam, (2006) Yield and quality of lentil as affected by micronutrient deficiencies in sandy soils. Journal of Applied Sciences Research, 2: 1342-1345.

Zingore S (2011) Maize productivity and response to fertilizer use as affected by soil fertility variability, manure application, and cropping system. Better Crops, 95(1), 4-6.

Zingore S and Johnston A, (2013) The 4R nutrient stewardship in the context of smallholder agriculture in Africa. In: Vanlauwe B, Blomme G, van Asten P (Eds.) Agro-ecological intensification of farming systems in the East and Central African highlands. Earthscan, UK.

Zingore S, Murwira HK, Delve RJ and Giller KE, (2007) Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. Agriculture, Ecosystem and Environment, 119: 112–126.