NUTRIENT MANAGEMENT OPTIONS FOR ENHANCING MAIZE PRODUCTION UNDER CONSERVATION AGRICULTURE IN EMBU COUNTY, KENYA

NJUE D. MURIMI (B. ENV. S.)
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DECLARATION

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

Signed ____________________ Date 13/07/2018

Njue D. Murimi - N50/27706/2013
Department of Environmental Sciences

SUPERVISORS

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

Signed ____________________ Date 13/07/2018

Dr. Monicah Mucheru-Muna
Department of Environmental Sciences
Kenyatta University

Signed Zingore ____________________ Date 13/07/2018

Dr. Shamie Zingore
International Plant Nutrition Institute
ICIPE, Duduville-Kasarani

DEDICATION

This work is dedicated to my late dad Njue Gichoni and my mum Epharath Njue for their love, encouragement and sacrifices towards my education.

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LIST OF ACRYNOMS AND ABBREVIATIONS

ACT	African Conservation Tillage
ANOVA	Analysis of Variance
Ca	Calcium
CA	Conservation agriculture
CFU	Conservation Farming Unit
CT	Conventional Tillage
FAO	Food and Agricultural Organization
IFDC	International Fertilizer Development Centre
K	potassium
LR	Long rains
LSD	Least significant differences
Mg	Magnesium
N	Nitrogen
P	Phosphorous
SAS	Statistical Analysis Software
SR	Short rains
SSA	Sub Saharan Africa
UM	Upper Midland
Zn	Zinc

ABSTRACT

Smallholder farmers in Runyenjes are experiencing decline in agricultural productivity. The yield decline has been caused by degraded soils as a result soil erosion and inappropriate soil management, nutrients mining due to continuous cropping as well as leaching of minerals. To address these crop production challenges, there is need for balanced nutrient management options with appropriate tillage system. This study was therefore carried out under on-farm trials to: i) assess maize yield response to nutrient management options under conservation agriculture (CA) and conventional tillage (CT) methods, ii) assess the effects of NPK management options in contrasting tillage systems on soil macro-nutrient changes, iii) evaluate the economic feasibility of NPK management options in different tillage systems and iv) to assess effects of NPK, Ca, Zn and Mg nutrients on maize grain yields and the added benefits of Zn, Ca and Mg on maize grain and stover quality. The study was carried out in Runyenjes, Embu County. Two trials were established; i) Macro-nutrient omission trial which was laid out in a split plot design and arranged in a randomized complete block design and replicated 27 times, with tillage as the main factor while the sub-plots were the NPK inputs. ii) The micronutrient trial which was laid out in a randomized complete block design (RCBD) and replicated thrice. The treatments for micro-nutrients trials were NPKMgCa, NPKMg, NPKZn, NPKCa, NPK and the control. The key variables measured were soil macronutrients (nitrogen, phosphorus, and potassium), micronutrients (magnesium, zinc and calcium), grain and stover yields, maize and stover prices and labour costs. Soil samples were analysed using standard procedures. Data was subjected to analysis of variance (ANOVA) GLM procedure of SAS 9.3. Differences between treatments means were examined using fischer's LSD at 5% level of significance. Paired t-test was carried out to determine whether changes in soil chemical properties mean values were significant using fisher's LSD at ($p<0.05$). Post-analysis of variance was done using Proc GLM class orthogonal contrast to partition and compare the treatment means. The results showed that in SR2015 season, maize grain yields were significantly ($p\leq.0073$) higher under CT than CA. Application of NPK inputs led to significant ($p\leq.0001$) higher maize grain yields over control. Total soil N decreased by 15, 20, 15 and 10% in NPK, NP, NK and PK treatments, respectively. Soil P concentration increased by 18, 19, 36, and 13% under NPK, NP, NK and PK respectively. Extractable soil K increased by 5, 7, 11 and 12% under NPK, NK, NP and PK treatments, respectively. Total variable cost (TVC) was 4 and 2% higher under CT than CA while under NPK inputs, it was significantly ($p\leq.0001$) different and in the order NPK>NP>NK>PK>Control. Net benefit (NB) in both seasons was 2% higher under CA than CT. Benefit cost ratio (BCR) was increased by 8 and 13% under CA over CT in LR2015 and SR2015 seasons, respectively. Further, BCR was decreased by 37 and 36% with NP omission, 35 and 30% with NK omission and 22 and 24% with NPK omission in LR2015 and SR2015 seasons, respectively. Grain magnesium concentration was increased by 13, 6, 6 and 3% under NPKMg, NPKMgZnCa, NPKCa and NPKZn over NPK treatment, respectively. Maize Zn grain concentration was increased by 34, 27 and 25% under NPKZn, NPKMg and NPKMgZnCa over NPK treatment, respectively. Grain calcium concentration was increased by 19, 16 and 5% under NPKMg, NPKCa and NPKZn over NPK, respectively. Maize zinc stover concentration increased by 6 and 28% under NPKZn and NPKMgZnCa over NPK treatment. The NPKMgZnCa and NPKCa increased Ca stover concentration by 12% while NPKMg increased Ca stover concentration by 13% over NPK treatments. The findings of this study highlight the importance of NPK inputs with supplementation of other nutrients in enhancing crop yields, quality of maize grain and stover yields, soil nutrition and profitability. Use of the NPK, Ca, Mg and Zn should therefore be recommended to smallholder farmers in Runjenjes, Embu for sustained crop production.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Globally, agricultural food production is low in areas under rain-fed farming systems (Temesgen *et al.*, 2009). The production has remained low due to poor soil fertility and the associated nutrient limitations for crop growth which have been highlighted as pervasive constraints in smallholder farming systems (Buresh *et al.*, 1997; Sanchez, 2002; Sanchez and Swaminathan, 2005). Land degradation is also a major constraint causing low yield levels due to intensive soil preparation by hoe or plough combined with removal or burning of crop residues, leaving the soil exposed to climatic hazards such as rain, wind and sun (Benites, 1998; Derpsch, 1998).

Nutrient availability is also a yield-limiting factor in crop production. This is due to low use of inorganic fertilizer which has been found to be one of the main causes of environmental degradation (Bationo *et al.*, 2006). In Sub-Saharan Africa, little fertilizer is used by smallholder farmers due to inadequate supply, unstable commodity prices, scarce financial resources and lack of credit availability (Kayuki and Wortmann, 2001). Sanginga and Woomer (2009) stated that much of available fertilizer is not the correct type required by crops while most of the farmers are not familiar with its correct usage. Further, the negative nutrient balance indicates that farmers mine their soils nutrients and thus posing a major constraint to sustainable crop production (Bationo *et al.*, 2008). Nutrient requirement for maize varies from field to field due to high variability in soil fertility across farmer fields and single homogenous nutrient recommendations may not be very useful in improving maize yields (Vanlauwe *et al.,* 2014). Appropriate use of fertilizer results in substantial increases in crop productivity and in the availability of crop residues, across and within-farm soil fertility gradients, and more so on mid-distant and remote fields (Vanlauwe *et al.,* 2014). In the Central Highlands of Kenya, soil nutrient depletion is major challenge as a result of continuous cultivation of soils without adequate addition of external inputs and soil erosion (Mucheru-Muna *et al.,* 2007).

Conservation agriculture (CA) has increasingly been advocated as a potential alternative for redressing soil fertility decline and improving crop productivity and house food security (CFU, 2006). Conservation agriculture is based on permanent maintenance of soil surface cover by live or dead vegetative material and no burning or removal of residues is allowed and permanent no-tillage and direct seeding (Kaumbutho *et al*., 2007; ACT and FAO, 2012). According to Giller *et al*. (2009), conservation agriculture appears to offer great potential to address problems related to smallholder farming in the tropics, but region-specific conservation agriculture options need to be identified for implementation by resource poor farmers (Fowler and Rockstrom, 2000). Farmers' practices are quite different from the "ideal" conservation agriculture. According to Bolliger *et al.* (2006), conservation agriculture developed in on-station trials has lesser benefits compared to those realized by farmers under their conservation agriculture practices. Conventional tillage (CT) causes more physical disruption while producing less aggregate stabilizing materials (Bradford and Peterson, 2000). Tillage removes the protective cover of crop residues from the soil surface thus exposing the soil to various degradation processes. This intensifies the process of land degradation (Craswell and Lefroy, 2001). There is therefore need to examine maize yields performance on farmers’ fields under conservation agriculture practices (minimum tillage and mulching) and conventional tillage, assess their effects on soil macronutrients, evaluate economic implications of the tillage systems and the added benefits of soil macronutrients on maize grain and stover quality.

1.2 Problem statement and justification

In the central highlands of Kenya, soil fertility has declined over the years due to inappropriate soil management and nutrients depletion (Ngetich *et al.,* 2012). This has led to reduced maize yields. The decline in maize yield is attributed to degraded soils as a result of inappropriate tillage systems which results into soil erosion and nutrient losses through leaching besides crop removal. Smallholder farmers’ fields are spatially heterogeneous with respect to soil quality (Tittonell *et al.,* 2008) and application of soil nutrients results into various responses by crops to fertilizers within the farms. Crop growth is limited by a low supply of one or more of the major nutrients (Nitrogen N, Phosphorous P and potassium K). Nutrients applied as mineral fertilizers by the smallholder farmers are limited due to insufficient amounts used. In addition, application of different nutrients is unbalanced compared to the needs of the crops resulting to low yields. Continuous cropping characterized by inappropriate tillage practices results in low moisture retention, nutrients losses through crop harvest, leaching (N and K), volatilization of N and fixation of P and K hence low yields. In order to increase maize yields and ensure sustainable productivity in heterogeneous farms, crop management practices such as mulching and minimum tillage aimed at conserving soil moisture needs to be enhanced. Appropriate use and management of fertilizers combined with effective tillage methods are required to enhance maize yields. However, there is dismal use of these technologies in the study area. The study examined appropriate nutrient management options for sustainable maize production intensification under conservation agriculture.

1.3 Research questions

The study sought to answer the following questions:

i. How do macro-nutrients (NPK) management options affect maize yields response in farmer managed trials under conservation and conventional tillage systems?
ii. How do tillage system and macro nutrient inputs affect the soil macronutrients changes on farmers' fields?
iii. What are the economic implications of the macro nutrient inputs and tillage systems in farmers' fields?
iv. What are the added benefits of Zn, Ca and Mg to NPK on maize grain yield and, grain & stover quality?

1.4 Research objectives

The main objective of the study was to determine sustainable maize production intensification through appropriate nutrient management options in different tillage systems in the study area. The specific objectives were;

i. To assess maize grain yield response to macro-nutrients (NPK) management options under conservation agriculture and conventional tillage methods

ii. To assess the effects of macronutrient options and tillage systems on soil macro-nutrient under farmer managed trials

iii. To evaluate the economic feasibility of the nutrient management options in conservation and conventional tillage systems in farmer managed trials

iv. To assess the added benefits of Zn, Ca and Mg nutrients to NPK on maize grain yields and maize grain & stover quality

1.5 Research hypotheses

The study was guided by the following hypotheses:

1. Nutrient management options under contrasting tillage system have a positive significant effect on maize grain yield response in farmer managed trials

2. Macro-nutrient management options and tillage systems have significant effects on soil macro-nutrient changes under farmer managed trials

3. Nutrient management options under conservation agriculture have a significant impact in terms of profitability as compared to conventional tillage on farmers' fields.

4. Application of other nutrients (Zn, Ca and Mg) in addition to NPK have a significant effect on maize grain yields, grain and stover quality

1.6 Significance of the study

The results of the study provide information that will enrich the knowledge of extension service providers, small scale farmers and policy makers on nutrient management technologies for maize production intensification under conservation agricultural systems. The findings provide information on the tillage systems and

NPK inputs combinations as well as other nutrients supplementation that suit the study area in terms of yields, profitability and maintenance of soil fertility. The research findings on best combination of macro and micro nutrients as well the best tillage system in enhancing farmers' profitability, increasing maize grain yields, stover and grain quality as well as restoring soil fertility will be provided to policy makers, projects and programs aimed at recommending best fit tillage system and nutrients management options to enhance sustainable crop production in Runyenjes.

1.7 Conceptual Framework

Smallholder farmers in Embu County rely on rainfed conventional agriculture. Inherent soil fertility has been declining due to unsustainable tillage methods, lack or low use of external mineral fertilizers as well as continuous cropping (Figure 1.1). Implementing conservation agriculture practices such as minimum tillage and mulching offers a better option to reverse land degradation and enhance soil moisture retention, rain drops interception thus reduces run off and erosion thus reducing depletion of organic matter. On the other hand, balanced nutrient management options could enhance soil fertility and nutrients availability thus contributes in increasing nutrient uptake by crops. This would improve crop productivity. Economic analysis under conservation agriculture and conventional tillage systems provides farmers with cost-effective tillage system sustainable in the study area (Figure 1.1).

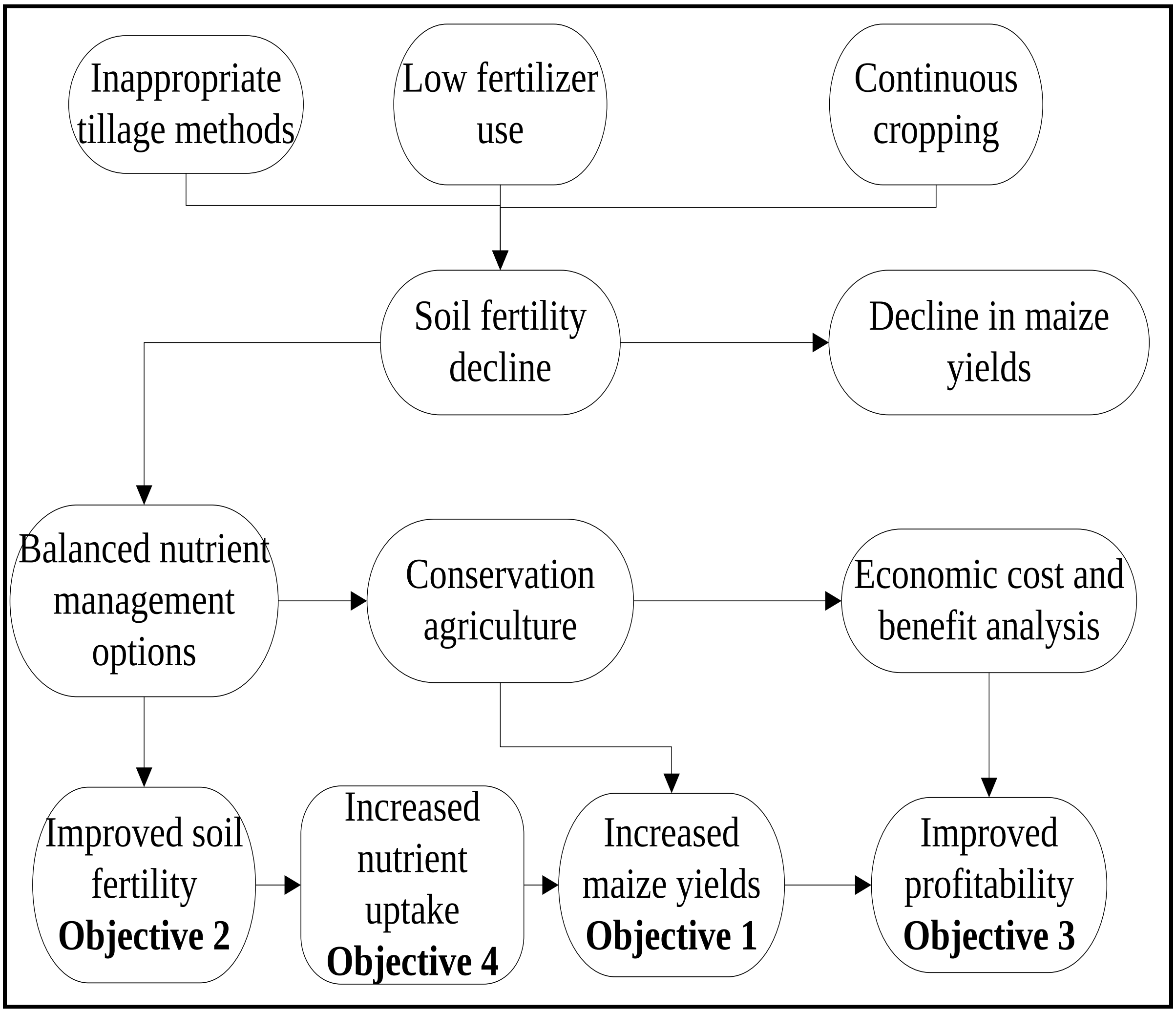

Figure 1: Conceptual framework showing interrelationship of variables

1.8 Definition of terms

Conservation agriculture	Farming practice aimed at minimal soil disturbance through minimum tillage and use of crop residues as mulch to conserve soil moisture
Conventional tillage	Farming practice involving intensive tillage of land during land preparation, planting and weeding. Hand hoe is used in tillage of the land.
Soil nutrients	The essential nutrients found in the soil for crop production. They determine the fertility of the soil. They are macro nutrients; nitrogen, phosphorous, potassium, Calcium, and Magnesium, and micronutrients; Zinc.
On-farm trials	Treatments set up on farmers' fields designed by the researcher but managed by the farmers. Type II.
V4 stage	Maize growth and development stage whereby the maize crop has 4 fully emerged leaves with collars visible.
V8 stage	Maize growth and development stage whereby the maize crop has 8 fully emerged leaves with visible collars.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview

Soil fertility depletion has been found to be the fundamental and biophysical cause of declining food production in Africa (Sanchez *et al.,* 1997). Soil fertility decline through nutrient mining (no inputs associated with large removal of nutrient), nutrient depletion (lower addition with larger removal of nutrients), acidification (decline in pH and/or an increase in exchangeable Al), the loss of organic matter, and an increase in toxic elements such as aluminum (Hartemink, 2003). This is attributed to low levels of nutrient inputs application in form of fertilizer due to inadequate supply, unstable commodity prices, scarce financial resources and lack of credit availability (Kayuki and Wortmann, 2001). The situation is similar in the central highlands of Kenya, where high costs of fertilizer, lack of credit, delays in delivery, poor transport and marketing infrastructure have individually or jointly constrained the optimal use of fertilizer (Mugwe e*t al.,* 2009). Within farms or communities, there is diversity and varied responses to technologies due to differential and preferential nutrient management under similar soil and climatic conditions (Zingore *et al.,* 2007).

Conservation agriculture offers benefits to the farmers such as increased productivity, profits and food security while preserving and enhancing the environment (Corsi *et al.,* 2012; FAO, 2012). Conservation agriculture (CA) has steadily increased worldwide to cover about 8% of the world arable land (124.8 M ha) (FAO, 2012) in response to global sustainability of agriculture. In sub-Saharan Africa (SSA), conservation agriculture is being actively promoted to intensify smallholder farming system sustainably (Benites and Ashburner, 2003; FAO, 2011) as “Climate Smart” agricultural efforts (FAO, 2013). Compared to conventional tillage, conservation agriculture is a resource-conserving practice with the potential to increase plant available soil moisture, promote infiltration and reduce the costs of tillage operations (Thomas *et al.*, 2007; Hobbs *et al.*, 2008). Conservation agriculture is based on principles such as: permanent organic soil cover, minimum tillage with retention of cover crops or mulch as well as crop rotations (Thierfelder and Wall, 2009; FAO, 2010). Vanlauwe *et al.* (2014) advocated that appropriate use of fertilizers be considered as the fourth principle. Sommer *et al.* (2014) agreed that fertilizer inputs are essential to the successful implementation of conservation agriculture. However, variable responses to mineral fertilizers on already degraded soils, high fertilizer prices which limit purchasing power and opportunities for rural credit, have limited the use of fertilizer (Nandwa and Bekunda, 1998).

The benefits of conservation agriculture practices are linked to environmental and soil conditions of the area, management, crop type and duration of practice (Haggblade and Gelson, 2003; Thierfelder and Wall, 2010). African Conservation Tillage Network (2011) reported that conservation agriculture results in higher and more stable crop yields. However, success to adopting conservation agriculture on African farms has been reported to be limited (Kassam *et al.*, 2009). In practice farmers are limited by access to inputs such as (seeds, cover crops, herbicides), labour and resources constraints and therefore not able to adopt all the principles of conservation agriculture (Baudron *et al.*, 2007; Kaumbutho and Kienzle, 2007). In addition, decreases in crop productivity in initaial years of conservation agriculture crop production represents a major barrier for farmers considering conservation agriculture (Giller *et al.,* 2009; Brouder & Gomez-Macpherson, 2014).

Conventional agriculture involves intensive tillage of land which has been found to impedes soil water infiltration and root penetration (Twomlow *et al.*, 1999). It is believed that conventional tillage promotes salinization, increases soil organic matter mineralization, accelerates soil erosion and compaction, depletes soil nutrients as well as organic matter (FAO, 2001a; FAO, 2001b). Intensive tillage also affects soil structure through excessive break down of aggregates (Ben-hammouda, 2010) thus enhancing the potential of soil erosion. In addition, it contributes to emissions of greenhouse gases, loss of carbon and decline in crop productivity (Cox *et al.,* 1990; Ma *et al.,* 2009). Besides, extensive tillage associated with burning or removal of crop residue results into erosion of soil and consequently degradation of land (Verhulst *et al.,* 2010). This results into nutrient depletion and subsequent decline in productivity which affects food security in Africa (Giller *et al.,* 2009).

2.2 Maize response to macronutrients' management technologies

Fertilization plays a very important role in plant production because it is an essential part of production costs, influences the quantity and quality of the yield and modifies soil fertility (Pypers *et al.,* 2011). However, too large amounts of the used fertilizer components such as phosphorus and potassium lead to intensified processes of their immobilization which makes them unavailable for plants use (Tóth *et al.,* 2014). Appropriate balanced fertilization is therefore important to ensure sub-optimal and effective use of applied nutrients by crops.

2.2.1 Maize response to Nitrogen

Nitrogen is a major yield determining factor required for maize production (Adediran and Banjoko, 1995; Shanti *et al.,* 1997) and a limiting nutrient for crop production in SSA (Sanchez *et al*., 1997). In plant nutrition, it is a component of amino acids, proteins and enzymes. Nitrogen is also a constituent of the pyrimidic and puric bases as well as nucleic acids (Mills and Jones, 1996).

Plants take up nitrogen (N) not only in inorganic forms but also in organic forms (Näsholm *et al.,* 2009). The highest percentage of soil nitrogen is organic (Demari *et al.,* 2016). This organic form goes through a mineralization process and is transformed from organic to mineral nitrogen (Rangel and Silva, 2007). Nitrogen is taken up by plants as nitrates or ammonia. Ammonia (NH_4^+) is chemically altered by bacteria action which results in the production of nitrates (NO_3^-). Much of the nitrates (NO_3^-) is not adsorbed in the soil colloids due to the negative charge and thus stays in soil solution. Nitrates are easily washed by through leaching or lost through denitrification if they are not taken up by plants.

Since NO_3^- is soluble in water, it is susceptible to leaching (Simonne and Hochmuth, 2003; Alva *et al.,* 2006). Timing the right top-dressing periods is an effective way of ensuring maximum utilization of nutrients to meet crop demand (Giller *et al.,* 2006). Therefore, nitrogen application should be timely done at the right place and rate to enhance its contribution to maize production in sound tillage system.

2.2.2 Maize response to Phosphorous

Phosphorus (P) fertilizer is extracted from of rock phosphate. Phosphorus is a major soil fertility nutrient in crop production in SSA, but limited P reserves has made its supply short for agricultural crop production (Steen, 1998). This is because phosphorus reserves are globally limited and thus should be used sustainably in crop production (Cordell *et al.*, 2009; Zeng and Wang, 2015). According to Hue, (1995), P is less soluble in water while leaching is minimal when compared to nitrogen. Naturally, phosphorus is insoluble and only a small proportion exists in the soil solution (Holford, 1997). For instance, only 10-20% of P fertilizer applied is used by plants with much of the P applied being fixed or precipated into unavailabe forms in the year of application. in the year of application (Vu *et al*., 2008). The poor usage of phosphorus from mineral fertilizers can also be found in retardation of this element in soil and its losses as a result of soil washes and runoffs (Dodd *et al.*, 2014). Soils with high P fixation capacity have higher demand for phosphatic fertilizer (Hussain and Haq, 2000). Phosphorous must therefore be applied as an external input to attain sustainable crop production (IFDC, 1998). Phosphorous deficiencies in the soils impair crop production and jeopardize food security (Runge-Metzger, 1995) and this is common in soils with high calcium carbonate, which is responsible for reducing solubility of phosphorous (Ibrikci *et al.*, 2005). In eastern Africa, maize production is limited by P nutrient (Mamo and Wortmann, 2009), and its sufficient supply of the nutrient throughout the growing period is essential for maize growth to attain optimal yields (Kogbe and Adediran, 2003). However, year in year out application of P into the soil builds up soil P and thus becomes detrimental for crops growth (Potash and Phosphate Institute, 2003). Appropriate use of fertilizer is therefore essential to attain optimal yields.

2.2.2. Maize response to Potassium

Many crops need potassium in large quantities (Hue, 1995). Potassium is involved in water uptake and retention in the plant tissues, as well as transport of photosynthates in the phloem and water in the xylem (Marschner, 1995). Wiebold (2006) indicated that optimum potassium is essential in regulation of stomata opening and closure and as a result prevents water wastage and improves growth conditions in corns. In addition, potassium is an essential plant macronutrient that plays a key role in the synthesis of cells, enzymes, protein, starch, cellulose and vitamins in nutrient transport and uptake in conferring resistance to abiotic and biotic stresses and in enhancing crop quality (Epstein and Bloom, 2005; Pettigrew, 2008). Maize is relatively sensitive to K deficiency (Sharma *et al*., 2010; Niu *et al*., 2011; He *et al*., 2012). In maize the maturity is delayed, ears are smaller when K is deficient while the stalks are weak and lodging is common.

Potassium has been given less attention than nitrogen (N) and phosphorus (P) with respect to increasing cereal production because the effect of K on increasing cereal production is more gradual compared with N and P especially in K-enriched soils (Niu *et al.*, 2011; Tan *et al.*, 2012). Effective potassium fertilization is therefore important during plant production as it results into defined qualitative parameters (Niu *et al.,* 2013). Little attention has been given to nutrient management options under CA and CT tillage systems in the study area and hence the need of the study

2.2.4 Effects of other soil nutrients on crop production

There is growing evidence that micronutrients may be limiting crop productivity in many small-scale farming systems contributing to the current yield gaps (Lisuma *et al.,* 2006; Van der Zaag, 2010). Deficiency of micronutrients is a major constraint to crop production, yields stability and soils sustainability (Bell and Dell, 2008). Abdullahi *et al.* (2011) stressed the need for micro-nutrient inclusion in fertilizer package as supplements of macro-nutrients for higher yield especially in soils with micro-nutrients below critical levels. Addition of micronutrients can improve the yield response to macro-nutrients on deficient soils. For instance, zinc (Zn) is one of the most important micronutrients for growth and development of higher plants. It is involved in completing many vital physiological functions such as protein synthesis, energy production and maintenance of membrane integrity (Hansch and Mendel, 2009). Zinc deficiency is a worldwide nutritional constraint for crop production, especially cereals (Cakmak, 2008) and mainly occurs in sandy soils with low soil organic matter. Maize is known to be very sensitive to Zn deficiency (Lindsay and Norvell, 1977; Gupta *et al.,* 2008). However, Zn uptake is reduced by increase in soil pH and presence of high levels of phosphorous in the soil (Cakmak, 2008). An adequate Zn fertilization is known to enhance crop productivity (Cakmak, 2008).

Supplementation of S, Zn, B and K increased maize yields by 40% over the standard N-P recommendation alone (Wendt *et al.,* 1994). In an experiment to estimate the effect of nitrogen and sulphur Rasheed *et al.* (2004) reported that highest grain yield of 8.59 Mg ha^{-1} was recorded with fertilizer at the rate of 150 kg N and 30 kg S ha^{-1} as compared 100 kg N and 20 kg S ha^{-1}.

Magnesium is an important soil macro-nutrient in crop production. Crops grown in Mg deficient soils show obvious Mg deficiency symptoms such as chlorosis in older leaves due to the reasons of starch accumulation in the leaves, loss of plastic pigments from most plants and Mg translocated to actively growing sinks (Marschner, 2012). Magnesium is an ionic component of chlorophyll. Old leaves turn yellow in Mg deficiency and interior portions may express red or brown pigmentation leading to leaf drop. Magnesium deficiency in crops has become an urgent concern due to the overuse of chemical NPK fertilizers, introduction of high yield varieties and depletion of soil Mg pool after long-term crop harvest and no or bare application of Mg fertilizer (Cakmak, 2015; Guo *et al.,* 2015).

Calcium is involved in controlling basic functions such as photomorphogenesis, cell division, cell elongation, stress responses, and the maintenance of membrane structure and functions (Ahanger *et al.*, 2014; Ahmad *et al.*, 2015). In addition, calcium has the ability to mitigate the negative effect of abiotic stress by maintaining antioxidant potential and cellular water levels (Ahmad *et al.,* 2015). Calcium is essential for plant growth, cell division and enlargement and development of root shoot tips, storage organs and tissues (Ahmad *et al.,* 2015). On the other hand, calcium deficiency is caused by low soil pH, water shortage and excess magnesium (Sanginga and Woomer, 2009). In the study area, little has been done on Zn, Ca, Mg and S in balanced fertilization with NPK.

Addition of micronutrients in soils deficient of Zn and S dramatically increase fertilizer-use efficiency, yield response to available macronutrients, and overall farm profitability (Wendt *et al*., 1994). Manzeke *et al.* (2014) reported yields increment by 0.5 Mg ha^{-1} with Zn fertilization over the use of NPK fertilizer. Yield increments from the use of micronutrients have been reported by Zingore *et al. (*2007). Alley and Vanlauwe, (2009) reported that micronutrients may be included cheaply in fertilizer blends available in SSA. For instance, targeting P application to legumes doubled crop biomass and increased the agronomic efficiency of fertilizer to the following cereal crop (Giller *et al.*, 1998; Vanlauwe *et al.*, 2003).

2.2.5 Effects of soil macronutrients on maize grain yields

Research has shown that with NPK fertilizer additions differences in maize grain yield between fields types were smaller than for the control soils (Vanlauwe *et al.*, 2006). Variability of crop yield response to applied fertilizers in different fields is a clear indication that the response to applied inputs is likely to decrease with increasing soil fertility (Vanlauwe *et al*., 2006). According to Dai *et al*. (2013) when NPK fertilizer was omitted, the yield gap significantly increased with the continuous omission of nutrients. Vanlauwe *et al*. (2006) reported that with NPK fertilizer additions, differences in maize grain yield between fields types were smaller than for the control soils, indicating that low soil available N, P, and/or K are the most limiting factors to maize production. Dai *et al*. (2013) reported that P was more pivotal in long term maize growth and soil fertility conservation with N fertilizer input. According to Amanullah and Zakirullah (2010), application of P at 90 kg ha^{-1} was found to enhance maize grain yields far much higher than when applied at the rate of 60 and 30 kg ha^{-1} in different times before and after sowing.

Potassium also plays a critical role in crop production. According to Qiu *et al.* (2014) application of fertilizer K significantly ($P<0.05$) increased maize grain yields over control. Niu *et al*. (2011) also found that K fertilization increased grain yield under conventional practices and high yielding practices (use chemical N and P inputs with alternating planting techniques).

2.5 Conservation agriculture practices

2.5.1 Mulching

Mulching may be a suitable agronomic practice for conserving soil and water and controlling soil temperature regimes (Chakraborty *et al.*, 2008). The surface mulch favourably influences the soil moisture regime by controlling evaporation from the soil surface (Wang *et al.*, 2009). Mulch also helps in improving infiltration (Rockström *et al.*, 2009) and soil water retention (Thomas *et al.*, 2007; Adeniyan *et al.*, 2008; Tulema *et al.*, 2008). Achary *et al.* (2005) reported that mulching decreased bulk density and facilitated condensation of soil water at night due to temperature reversals. Mulching results to reduced risk of crop failure due to better water retention capacity of available rainfall (Scopel *et al.*, 2004), improves soil physical structure (Pagliai *et al*., 2004) as well as weed suppression (Essien *et al.*, 2009; Uwah and Iwo, 2011). Crop residues covers the soil surface thus reducing evaporation while maintaining the soil water (Lichter *et al.*, 2008). According to Erenstein (2002) the presence of crop residue mulch at the soil atmosphere interface has a direct influence on infiltration of rainwater into the soil and evaporation from the soil leading to improved soil water supply for crops.

According to Ngwira *et al.* (2012) there was maize yields increase of 7% under conservation agriculture and retained biomass by farmers as compared to when mulching materials were not used. According to Mupangwa *et al*. (2012) mulching increased maize yields with the regression analysis indicating a significant (P<0.001, r=0.59) in linear relationship between yields and mulch level applied regardless of the tillage system. A study in central highlands of Kenya, Okeyo *et al.* (2014) reported maize yield increase of 5 and 7% under mulching and minimum tillage respectively, compared with the control. However, little attention has been done on mulching combined with other conservation agriculture practices in the study area under balanced fertilization thus need for the study.

2.5.2 Minimum Tillage

Minimum tillage is a practice in which the soil is tilled to some extent but not fully inverted with the aim to maximize soil infiltration and soil productivity and minimize water losses while conserving energy and labour (Rockström *et al.,* 2002). Minimum tillage and mulching practices simultaneously conserve soil and water resources, reduce farm energy usage and increase or stabilize crop production (Mupangwa *et al.,* 2007). These practices lead to positive changes in the physical, chemical and biological properties of a soil (Bescansa *et al.,* 2006).

According to Moussa-Machraoui *et al.* (2010) no tillage had positive effects on nutrient N, P and K contents as compared to the control. According to Mupangwa *et al.* (2007), minimum tillage has positive influence on maize yields as well as the conventional way of ploughing.. Research results from the tropics suggest that no-tillage with mulch and herbicide application maintained and, in some instances, improved soil productivity and increased maize yields in comparison with conventional tillage (Owenya *et al.,* 2011; Thierfelder and Wall, 2012; Ngwira *et al.,* 2013). In addition, reduced tillage lowers required farm energy and cost of farming since less area is tilled (Monzon *et al.,* 2006). However, little has been done in the study area on balanced fertilization under minimum tillage.

Conservation agriculture is primarily used as a means to protect soils from erosion and compaction, to conserve soil moisture and to reduce production costs (Holland, 2004). However, proponents of conservation agriculture have sometimes argued that when several agronomic practices are practiced at the same time, conservation agriculture becomes profitable, sustainable and beneficial to the environment both in short and long term (Unger and Fulton, 1990; Derpsch, 1999; FAO, 2001b; Bollinger *et al.,* 2006; Gowing and Palmer, 2007).

2.6 Cost benefit analysis

Recent studies in SSA have showed better economic returns in conservation agriculture compared to traditional practices (Mazvimavi and Twomlow, 2009; Guto *et al.,* 2011). Low responses of crops to fertilizers is a major impediment to farmers considering the use of fertilizers due to low returns. According to Giller *et al*. (20116) economic efficiency of fertilizer use was achieved when fertilizer was applied at basal followed by split doses in relation to target yields (Giller *et al*., 2006). Smallholder farmers attribute costs and immediate benefits realized in short term than in the future due to the production constraints and food insecurity faced by the farmers (Giller *et al.,* 2011). However, a comparative analysis of the returns on investment in conventional tillage and conservation agriculture in Kenya showed the potential of doubling benefits when using conservation agriculture over conventional tillage (FAO, 2009). There is need to take into account all costs and benefits when evaluating the cost effectiveness of any conservation practices (Zhou *et al.,* 2009). However, the profitability of fertilizer use has been limited by the low response rate to applied nutrients, compounded by high fertilizer prices as well as crop price fluctuation which results to low demand for it by smallholder farmers (Dittoh *et al*., 2012). According to FAO (2011), conservation agriculture, when practiced comprehensively, results into improved crop yields and reduction of the production costs. Reduction in early labour requirement together with reduced turnover time, since less use of tractors is required as a result of no-till under conservation agriculture, saves on cost and increases time which can be used to carry out other activities in time for increased maize production (Hobbs *et al*., 2008). Little has been done on economic feasibility of nutrient management option under conservation agriculture and conventional tillage systems under on-farm conditions hence the need of the study.

2.7 Effects of fertilization on maize grain and stover quality

Nutrients concentration in maize seed has been found to greatly affect the ability of a maize seedling to tolerate biotic (such as diseases) and abiotic stresses (such as mineral nutrient deficiency) (Masclaux-Daubresse *et al.*, 2010). Nutrients in maize grain are usually derived from post-silking uptake and the remobilization of nutrients accumulated in vegetative organs during the pre-silking stage (Hirel *et al.*, 2007).

Grain K concentrations are well buffered against the deficiency or sufficiency of N or K supply (Zhang *et al.*, 2010; Niu *et al*., 2011). Kenyanya *et al.* (2014) reported an increase of K concentration in maize grains and stover following K fertilization in Nyamira, Kenya. Potassium fertilization significantly increased the grain K concentration at four of the seven site-years under conventional practices and at six of the seven site-years under high yielding practices (use of chemical N and P inputs with alternating planting techniques). Additionally, Priya, (2016) reported that balanced fertilization of NPK and NPK+ZnS fertilizers led to higher grain and stover protein content compared to the control. In an agronomy study done by Ferreira *et al.* (2001) on nitrogen utilization, they found that nitrogen fertilization improved grain quality by increasing protein and mineral nutrients content. Additionally, in a study carried out in Zimbabwe under integrated soil fertility management, Manzeke *et al.* (2014) reported that Zn application resulted in added maize grain and quality benefits. Research on balanced fertilization under conservation agriculture and conventional tillage systems and their contribution on quality of crop yields have received little attention and thus the need of the study.

2.8 Classification and regression tree (CART) analysis

Classification and regression tree (CART) is a non-parametric methodology that was first introduced by Breiman (1984). The CART (Salford Systems Inc., San Diego, CA, USA) is used to predict or explain the response of a categorical variable (classification trees) or a continuous variable (regression trees (Breiman *et al.,* 1984; Steinberg and Cola, 1997). The CART is inherently non-parametric, no assumptions are made regarding the underlying distribution of values of the predictor variables. Thus, CART can handle numerical data that are highly skewed or multi-modal as well as category predictors with either ordinal or non-ordinal structure. Splitting of left and right nodes is done by the CART which can either grow or prune the tree with minimum relative error (misclassification error). The terminal nodes represent groups with homogeneous characteristics. The variables explaining the model appear in the consecutive splitting nodes in a hierarchy of diminishing explanatory power (Steinberg and Cola, 1997).

The CART analyses were performed using the maize yield responses to applied fertilizers. Maize yield variables (responses to N, P and NP) were computed first in excel datasheet and used as the predictor variable while farms and tillage systems (conservation agriculture and conventional tillage) were used as categorical variables. Gini-classification method was used with minimum relative error. Pruning of the tree was done as part of exploratory analysis to reduce number of terminal and splitting nodes. CART tree was constructed independently for N, P and NP using CART default settings. Farms with high responses to N, P or NP were selected from the terminal nodes with high splitting values for both conservation agriculture and conventional tillage (Appendix 2). Purposive sampling was then used to select six farms to hold 6 treatments each, replicated thrice.

2.9 Literature gaps

The literature review showed that previous studies in the study area have mostly focused on integrated soil fertility management with more attention on organic and inorganic amendments. In addition, the use of mineral fertilizers was found to be minimal and below the required fertilizer recommendations for various nutrients such as nitrogen and phosphorous which are the most yield limiting nutrients in the study area. Use of mineral micronutrients as supplements to NPK fertilizers has received little attention in the study area. Further, the traditional conventional tillage system which involves tilling of land as well as removal of crop residues has been the norm by smallholder farmers with little attention to conservation agriculture practices. Furthermore, the use of inorganic mineral fertilizers as the fourth principle of conservation agriculture influences soil, maize grain as well as crop residue nutrient status due to their uptake and fixation. Implementing conservation agriculture independently with adequate fertilization presents the basis of evaluating its potential over conventional agriculture under on-farm conditions. In addition, integrating economic analysis presents a better basis of comparing the most cost-effective tillage system that can be encouraged to farmers for adoption. Further, determining the potential benefits of other nutrients presents the basis of evaluating the level of micronutrients depletion in the soils under study. This study was therefore set up with an objective to assess maize yield response to applied inorganic fertilizers, effects of fertilization on soil nutrient changes, evaluate the economic implications of the contrasting tillage systems and assess added benefits of fertility inputs on maize grain and stover quality.

CHAPTER THREE

METHODOLOGY

3.1 Study area

The study was done in Runyenjes sub-county in Embu County. Runyenjes sub-County lies in agro-ecological zones Upper Midland zone (UM2) to Lower Midland zone (LM3) on the central highlands of Kenya at an altitude ranging from 1200 to 1700 meters above sea level (Jaetzold *et al*., 2007). The experimental fields were located in Runyenjes which lies between 37°30′0″ to 37°40′0″ and 0°25′00″ to 0°30′00″ (Figure 3.1)

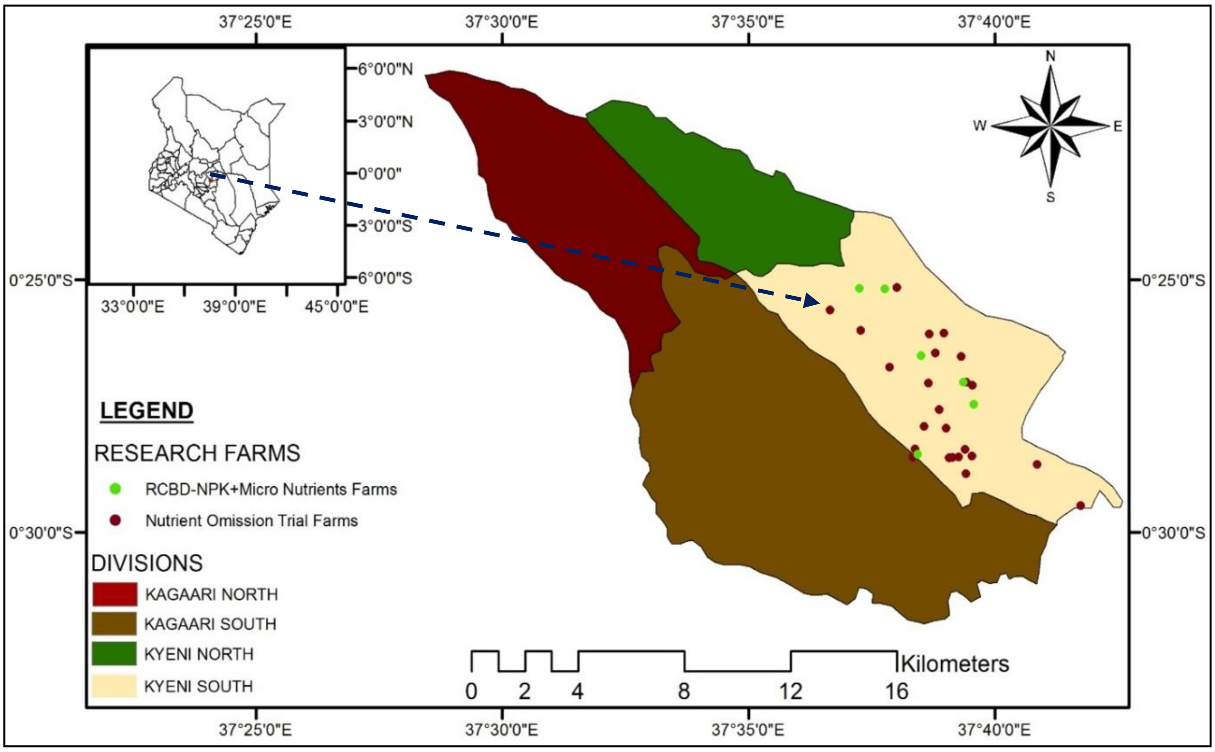

Figure 3.1: Map of the study area (The on-farm trial sites implemented within the brown (macronutrients omission trials) and yellow (micro-nutrient trials) in Kyeni South, Runyenjes

The average annual rainfall ranges from 930-1395 mm with mean temperatures of 20^{o}C per month. The area has a bimodal rainfall with long rains (LR) lasting from

March to May and short rains (SR) from October to December. The soils are humic-nitisols (red to red-brown in colour) which are deep weathered and with moderate to high inherent fertility (Jaetzold *et al.*, 2007). Complex farming systems involving integration of trees, crops and livestock is done on intensively managed farms (Mairura *et al.*, 2007). The main stable food crop is maize and is cultivated from season to season and mostly intercropped with beans. Coffee and tea are mainly grown as cash crops. Bananas, mangoes and sweet potatoes are either grown as food or cash crops while vegetables are mostly grown for subsistence consumption. Livestock production is done for the improved breeds of dairy cattle, goats, sheep and poultry.

3.2 Soil characteristics of the farms at the start of the experiments

Soils in the study area are humic nitisols with varying physical-chemical properties (Table 3.1). At the start of the experiments, pH value of the farms in the study area ranged from 4.84-6.6%, silt 5.13-17.75% and sand 8.26-13.8%. Soil total nitrogen ranged from 0.18-0.27%, total phosphorous 4.11-51.8 ppm, extractable potassium 166.5-696.5 ppm, extractable calcium 557-2,535 ppm, extractable zinc 2.95-37.7 ppm and extractable magnesium 147-433.5 ppm.

Table 3.1: Initial soil characteristics of 28 farms in Runyenjes, Embu County

Parameter	**Mean**	**Min**	**Max**
Sand %	10.99	8.26	13.80
Silt %	12.72	5.13	17.75
C %	2.82	2.360	3.28
CEC (meq/100g)	15.17	10.20	20.40
Ca(ppm)	354.00	258.00	577.00
EC(S)_uS/cm	44.59	27.50	68.00
K(ppm)	456.18	166.50	696.50
Mg (ppm)	277.25	147.00	433.50
N %	0.24	0.18	0.27
P(ppm)	21.81	4.11	51.80
pH	5.87	4.84	6.60
Zn (ppm)	16.59	2.95	37.70

Mean=Average of each parameters from all the farms; Min=Minimum values of each parameter; Max=Maximum value of each parameter

3.3 Rainfall measurement

Rainfall data was collected using a simple rain gauge calibrated in millimeters. Daily rainfall was measured and recorded. Monitoring visits were done to ensure accuracy of the rainfall data.

3.4 Experimental design and management

To address the objectives of the study, two experimental trials were established; i) Macro nutrient omission trial and ii) micro nutrient trial.

3.4.1 Nutrient Omission trials

The nutrient omission trials were laid-out in a split plot design arranged in a randomized complete block design with tillage systems (conservation agriculture and conventional tillage) as main treatments while fertilizer types, NPK, NP, NK and PK were the sub-plots. The trials were replicated in 28 farms. The treatments for conservation agriculture were mulching and minimum tillage system. Hoe tilling was done to 20 cm deep in conventional tillage treatments every season. Trials were implemented in plots measuring 5 by 5 m in every farm. The trials were researcher designed and farmer managed. Maize Duma 43 variety was planted at a spacing of 0.75 m between rows by 0.25 m within the rows. Two maize seeds per hill were planted. They were thinned out to one seedling per hill two weeks after emergence to maintain a plant population of 53,000 ha^{-1}. Maize stover was used for mulching and was applied immediately after crop emergence at the rate of 5 Mg ha^{-1}. NPK fertilizer was applied at the rates of 120-60-60 kg ha^{-1}. Urea was used as the source of (N), Triple Super Phosphate (TSP) as the source of (P) and Muriate of Potash (MOP) as the source of (K). Urea was applied in 3 splits, at basal, at V4 stage and the last at V8 stage. The trials were run for three consecutive cropping seasons, SR2014, LR2015 and SR2015.

3.4.1.1 Soil sampling

Soil sampling was done from each treatment before establishment and at the end of the experiments. Three soil samples were randomly collected per plot using an Edelman auger at a depth of 0-20 cm and composited to one.

3.4.1.2 Maize harvesting

The maize grain and stovers were harvested at maturity from a net plot measuring 3 by 2 meters after leaving out guard rows to minimize edge effect. The cobs in each plot were separated from the stover and fresh weight determined. Maize grains were then separated from the cobs through hand shelling and weighed to give the net grains weight. Maize stover was cut at ground level and a total above ground fresh weight determined. The grains were then air dried to 12.5% moisture content. Grain yield and stover was weighed in kg per net plot then converted to Mg ha^{-1}.

3.4.1.3 Economic analysis

Cost benefit analysis was done using partial budgets. Farm inputs costs was based on the retail prices as per agro-stockiest in the study area. The cost of maize seeds USD 2.06 kg^{-1}), TSP USD 1.62 kg^{-1}, urea USD 1.07 kg^{-1} and MOP USD 1.24 kg^{-1} fertilizers was valued at market prices during planting. The maize stover and grains were valued at USD 19.61 t^{-1} and USD 0.39 kg^{-1} during harvesting period, respectively (Table 3.2).

Table 3.2 Parameters used in economic analysis during LR2015 and SR2015 at Runyenjes Sub-County, Embu County

Parameter	Actual values
Price (Duma 43) maize seed	USD 2.06 kg^{-1}
Price (TSP) fertilizer	USD 1.62 kg^{-1}
Price (Urea) fertilizer	USD 1.07 kg^{-1}
Price (MOP) fertilizer	USD 1.24 kg^{-1}
Labour cost	USD 0.25 hr^{-1}
Price of 2, 4 D-Amine herbicides	USD 7.35 litre^{-1}
Price of Weedal 480 SL herbicide	USD 5.39 litre^{-1}
Price of Dual Gold960EC herbicide	USD 24.51 litre^{-1}
Price of Tremor® GR 0.05 insecticide	USD 2.45 kg^{-1}
Maize grains price	USD 0.39 kg^{-1}
Maize stover price	USD 19.61 t^{-1}

The official exchange rate was (1 USD=KES 102) in February 2016 at end the trial period.

Maize and stover market value was the average of the prevailing prices at harvest time in the area. Labour data necessary for cost and benefit analysis was collected every season during field operations (land digging/spraying, seed sowing, application of inputs, thinning and weeding as well as harvesting. The time taken for each activity was taken using stop watch and payments valued at work rate per hours. Total revenue (TR) was calculated based on grain yield and grain prices obtained from the local market. Total variable cost (TVC) was estimated from labor and input cost.

3.4.1.4 Soil analysis

All soil laboratory analyses (both physical and chemical parameters for soil characterization) were done following the standard methods of soil analysis described by Ryan *et al*. (2001). Where necessary, modifications were applied appropriately. They were analyzed as follows; total nitrogen and phosphorous by Kjeldahl method (Ryan *et al*., 2001) and potassium by flame photometer (Ryan *et al.*, 2001). Soil micro-nutrients (Ca, Mg and Zn) were analyzed using standard methods described by (Anderson and Ingram, 1993).

3.4.1.5 Data analysis

Maize yield data, soil nutrient concentration, net benefits and benefits cost ratio data was subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) SAS 9.3 software (SAS Institute, 2011) to test levels of significance due to treatments. Differences between the treatments means were examined using least significance difference (LSD) at 5% significance level. To determine changes in soil chemical properties over the study period for macro-nutrient trials, t-test was carried out to determine whether the mean values changes between the sampled periods were significant at $P<0.05$. Post-analysis of variance (polynomial contrasts) was done using Proc GLM class orthogonal contrast to partition and compare the treatment means of the macro-nutrients inputs with each other as well as with control. The matrix for each contrast was developed and tested to be orthogonal. Contrasts statements used were NPK, NP, NK and PK vs Control, NPK vs NP, NPK vs NK and NPK vs PK.

3.4.2 Micro-nutrient trials

The trials were set up in 6 farms in a randomized complete block design replicated thrice. The treatments were NPK, NPK+Mg, NPK+Ca, NPK+Zn, NPK +MgCaZn and control. The trials were researcher designed and farmer managed. Maize (*Zea mays L.*), Duma 23 variety was used as the test crop. Trials were implemented in plots measuring 5 by 5 m in every farm. Maize was planted at a spacing of 0.75 m between rows by 0.25 m within the rows. Two maize seeds per hill were planted and then thinned out to one seedling per hill two weeks after emergence to maintain a plant population of 53,000 ha^{-1}. These farms were selected using classification tree analysis method from the 28 farms that had the macro-nutrient omission trials. These six farms were the ones that had high responses to N, P and NP; two farms per category (2N, 2P and 2 NP) were selected (Appendix 2)**.** Trials were run for two seasons (SR2015 and LR2016). Micro-nutrients Zn and macro-nutrient (Mg and Ca) were incorporated at basal at the rate of 2.5, 5 and 5 kg ha^{-1}, respectively. Magnesium sulphate was used as source of (Mg), Calcium sulphate as source of (Ca) and Zinc Sulphate as source of (Zn). NPK fertilizer was applied at the rates of 120-60-60 kg ha^{-1}. Urea was used the source of (N), Triple Super Phosphate (TSP) as the source of (P) and Muriate of Potash (MOP) as the source of (K). Urea was applied in 3 splits, at basal, at V4 stage and the last at V8 stage.

3.4.2.1 Maize leaf sampling

Maize leaves were randomly sampled at 50% silking stage in each plot that is 8 weeks after planting when pollen was falling. Fully extended healthy leaves opposite and below the ear were cut using a sharp clean knife at the base without including the sheath. A total of 15 leaves per plot were sampled and put in well labeled khaki bags. Samples were air-dried, grinded and then analyzed for nutrients in the laboratory.

3.4.2.2 Maize Harvesting

Maize grain and stovers were harvested at maturity from a net plot measuring 3 by 2 meters after leaving out guard rows to minimize edge effect. The cobs in each plot were separated from the stover manually and fresh weight determined. Maize grains were then separated from the cobs through hand shelling and weighed to give the net grains weight. Maize stover was cut at ground level and a total above ground fresh weight determined. The grains were then air dried to 12.5% moisture content. Grain yield and stover was weighed in kg per net plot then converted to Mg ha^{-1}.

3.4.2.3. Maize grain sampling

Five cobs per plot were selected randomly and hand threshed during harvesting. A total of 300 grams of grain sample was weighed for each plot and put in well labeled khaki bags. Grain samples were then taken to the laboratory and to a fine powder to pass through a 2 mm sieve and each sample was given a laboratory number. A complete nutrient analysis for macro and micro-nutrients was done using standard methods (Ryan *et al.*, 2001).

3.4.2.4. Data analysis

Maize yields, maize grain and stover data was subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) SAS 9.3 software (SAS Institute, 2011) to test levels of significance due to treatments. Differences between the treatments means were examined using least significance difference (LSD) at 5% significance level. Post-analysis of variance (polynomial contrasts) was done using Proc GLM class orthogonal contrast to partition and compare the treatment means of the nutrient inputs with each other as well as with control. The matrix for each contrast was developed and tested to be orthogonal. Contrasts statements used were NPKMgCaZn, NPKMg, NPKCa, NPKZn vs NPK/Control and finally NPK vs Control. Orthogonal estimates were then run to obtain estimates of grain yields in Mg ha^{-1} for each contrast and tested to be significant at P=0.05.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Rainfall distribution in Runyenjes during the study period

There was seasonal rainfall variability over the four seasons of the study period (Figure 4.1). Cumulatively, SR2015 season received highest amount of rainfall (1031 mm) as compared to LR2015 season (840.9 mm) with 19.3.mm being received during offseason (Figure 4.1).

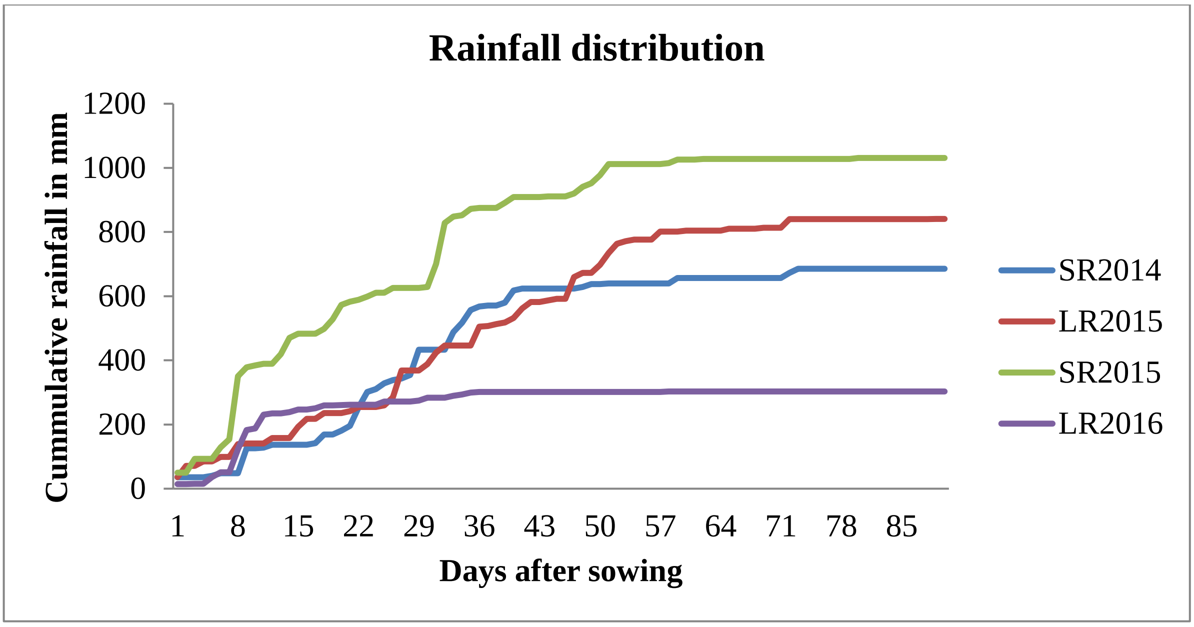

Figure 4.1: Rainfall distribution from 2014 to 2016 in Runyenjes for short rains 2014, long rains 2015, short rains 2015 and long rains 2016 seasons

In SR2014, 685.6 mm on-season was received. In SR2014 season, rainfall was uniformly distributed with 5 days dry spells experienced in each of the first two months. A 12 days drought towards the end of SR2014 season was experienced in December. In LR2015 season, drought of 16 days was also experienced before the onset of rains. Rains were however uniformly distributed till the end of SR2015 season (Figure 4.1). The least rainfall was received during long rains 2016 season compared to other seasons (Figure 4.1).

4.2 Effects of macro-nutrients (NPK) under conservation agriculture and conventional tillage methods on maize grain yield

There was seasonal variability of maize grain yields in the three seasons. Highest maize grain yield was recorded during the SR2015 season and was least in SR2014 season. In LR2015 and SR2015 season, high precipitations over the growth period was received compared to SR2014 season which could have boosted nutrient availability for maize uptake and development leading to production of high grain yields (Figure 4.1). During the SR2014 season, average yields were 7% higher under conservation agriculture than conventional tillage though the differences were not significant. Contrary to this, in LR2015 season, conventional tillage out-performed conservation agriculture by 4% though the differences were not significant. In the SR2015 season, average grain yields were significantly ($p \leq 0.0073$) higher under conventional tillage than conservation agriculture by 8%.

Use of macro-nutrients inputs significantly ($p \leq 0.0001$) affected the maize grain yields over control throughout the study period. Maize grain yields responses to NPK inputs was in the order NPK>NP>NK>PK>Control in SR2014, LR2015 and SR2015 seasons, respectively. On average, maize grain yields were significantly ($p \leq 0.0001$) higher in NPK, NP and NK than PK and control over the study period. In addition, Maize grain yields were significantly ($p \leq 0.0001$) higher under PK than control in the three seasons. Highest maize grain yields were attained under NPK treatments 5.62, 5.20 and 4.16 Mg ha^{-1} in SR2015, LR2015 and SR2014 seasons, respectively (Table 4.1). During SR2014 season, use of NPK inputs significantly ($p \leq 0.0001$) increased maize yields by 197, 180, 140 and 50% with NPK, NP, NK and PK over control treatments, respectively (Table 4.1). In LR2015 season, maize yields were significantly ($P \leq 0.0001$) increased by 238, 225, 199 and 82% with application of NPK, NP, NK and PK over control, respectively. Similar trend was observed in SR2015 season where NPK, NP, NK and PK treatments increased maize grain yields by 196, 191, 173 and 68% over control (Table 4.1). Highest maize yields under NPK were attained during the SR2015 season (Table 4.1). There was no significant difference between NPK and NP in the three seasons. Significant differences were observed between NPK and NK at ($p \leq .0001$) in all the seasons (Table 4.1). This showed the contribution of P fertilizer in influencing maize grain yields. Nitrogen and phosphorous were therefore a yield limiting nutrients in the study area. Maize grain yields were much lower with N and P omission than with K fertilizer omission. This could mean that the soils had relatively high levels of K and omission of K fertilizer was not effective as to when N or P were omitted. Nitrogen was the most yield-limiting macronutrient followed by P and finally K. This means that addition of N and P is essential in these soils in order to enhance maize grain yields.

However, there was variability in performance of various treatments under the two tillage systems. For instance, application of NPK, NP, NK and control under conservation agriculture was out-yielded by the same treatments under conventional tillage by 2, 13, 15 and 9% respectively, in SR2014 season though the differences were not significant. Application of PK under conservation agriculture was out-performed by PK under conventional tillage by 7, 12 and 1% in SR2014, LR2015 and SR2015 seasons, respectively though the results not significant. Compared to conventional tillage, maize grain yields under various treatments was higher than those under conservation agriculture by 2 and 5% with NPK, 2 and 3% with NP, 8 and 10% with NK, 12 and 3% with PK and 18 and 11% with control though the differences were not statistically significant in LR2015 and SR2015 seasons, respectively.

Table 4 1: Maize grain yields response to tillage and macro-nutrients options during SR2014, LR2015 and SR2015 seasons in Runyenjes, Embu County

Grain yields (Mg ha^{-1})			
Treatments	**Seasons**		
	SR2014	LR2015	SR2015
Tillage*Macro-nutrient inputs			
Conventional Tillage_NPK	4.11^{a}	5.25^{a}	5.78^{a}
Conservation Agriculture_NPK	4.21^{a}	5.13^{a}	5.48^{ab}
Conservation Agriculture_NP	4.16^{a}	4.89^{ab}	5.45^{ab}
Conventional Tillage_NP	3.69^{ab}	4.97^{a}	5.63^{a}
Conservation Agriculture_NK	3.59^{ab}	4.41^{b}	4.90^{b}
Conventional Tillage_NK	3.13^{b}	4.78^{ab}	5.40^{ab}
Conventional Tillage_PK	2.12^{c}	2.94^{c}	3.13^{c}
Conservation Agriculture_PK	1.98^{cd}	2.63^{c}	3.11^{c}
Conservation Agriculture_Control	1.46^{cd}	1.41^{d}	1.76^{d}
Conventional Tillage_Control	1.34^{d}	1.66^{d}	1.95^{d}
LSD	0.78	0.52	0.59
p	<.0001	<.0001	<.0001
Macro-nutrient inputs			
NPK	4.16^{a}	5.20^{a}	5.62^{a}
NP	3.92^{a}	5.00^{ab}	5.53^{ba}
NK	3.36^{b}	4.61^{b}	5.18^{b}
PK	2.1^{c}	2.80^{c}	3.20^{c}
Control	1.40^{d}	1.54^{d}	1.90^{d}
LSD	0.55	0.4	0.41
p	<.0001	<.0001	<.0001
Tillage			
Conventional Tillage	2.88^{a}	3.86^{a}	4.47^{a}
Conventional Tillage	2.88^{a}	3.86^{a}	4.47^{a}
LSD	0.35	0.23	0.26
p	0.45	0.15	0.0073

LSD=Least significant difference; Est=Estimate of grain yields (Mg ha^{-1}); Same superscript letters in the same column denote no significant differences between the treatments

In SR2014, class orthogonal contrast results showed that yields were significantly (p=0.0001) decreased by 2.76 Mg ha^{-1} with NPK omission (control), 2.06 Mg ha^{-1} (p=0.0001) with N omission (PK), and 0.80 Mg ha^{-1} (p=0.0048) with P omission (Table 4.2). Combined omission of N and P (NP), and N and K (NK) led to significant ($p \leq 0001$) decrease of maize grain yields by 2.40 and 1.96 Mg ha^{-1}, respectively (Table 4.2). Yield losses as a result of omitting the combined NPK was greater than that of combined NK or PK which shows that K was not limiting nutrient during SR2014 season. Similarly, maize grain yield losses were greater with combined NP (2.40 Mg ha^{-1}) than either single N (2.06 Mg ha^{-1}) or P (0.80 Mg ha^{-1}). Contrary to this is that maize grain yields losses were much higher with omission of either N or P alone than that of combined NK or PK, respectively. This could be due to antagonistic relationship occurred on applied nutrients where K had little yield increasing effect in SR2014 season and this could be as a result of omission of P in NK and N in PK that were pivotal in closing the yield gap for the single nutrient omitted. This means that there was synergetic relationship of N and P and their omission greatly decreased maize grain yields.

Table 4.2: Class Orthogonal Contrasts of NPK inputs on maize grain yields in Runyenjes for the SR2014, LR2015 and SR2015 seasons in Mg ha-^{1}

	SR2014	LR2015	SR2015
Contrast	EST	EST	EST
NPK vs NP	0.24 (<.329)	0.20 (<.27)	0.09 (<.67)
NPK vs NK	0.8 (<.0048)	0.59 (<.0084)	0.43 (<.0.045)
NPK vs PK	2.06 (<.0001)	2.40 (<.0001)	2.42 (<.0001)
NPK vs Control	2.76 (<.0001)	3.66 (<.0001)	3.7 (<.0001)
NP vs Control	2.4 (<.0001)	3.46 (<.0001)	3.61 (<.0001)
NK vs Control	1.96 (<.0001)	3.15 (<.0001)	3.26 (<.0001)
PK vs Control	0.74 (<.00087)	1.28 (<.0001)	1.28 (<.0001)

Values in the blacket denotes the P value

In LR2015 season, losses of grain yield as a result of omitting combined nutrient omission was in the order NPK (3.68 Mg ha^{-1}) >NP (3.46 Mg ha^{-1}) >, NK (3.15 Mg ha^{-1}) >PK (1.28 Mg ha^{-1}). Omission of N and P alone led to a significant ($p \leq 0001$, $p \leq 0.0084$)) maize grain yield losses of 2.39 and 0.52 Mg ha^{-1}, respectively (Table 4.2). The omission of combined NPK, NP and NK nutrients led to a much higher grain yield losses than that of either single N, P and K/ or N and P/ or N and K (Table 4.2). This shows the beneficial effect of balanced fertilization compared to application of one or two nutrients in order to attain optimal yields. In SR2015 season, the omission of combined NPK, NP and NK nutrients led to a much higher yield losses than that of either respective single N, P and K/ or N and P/ or N and K. This means that there was synergetic relationship of N and P inputs that was pivotal in enhancing maize grain yields. Contrast estimates showed similar trend in SR2015 season whereby, omission of macro-nutrient inputs led to a significant ($p \leq 0001$) maize grain yields losses of 3.70 Mg ha^{-1} with NPK omission (NPK vs Control, 3.61 Mg ha^{-1} with NP omission (NP vs Control) and 3.26 Mg ha^{-1} with NK omission (NK vs Control) (Table 4.2). Omission of PK (PK vs Control) led a 1.28 Mg ha^{-1} maize grains yields decline. Omission of N as a single inorganic fertilizer inputs led to 2.42 Mg ha^{-1} maize grain yield decline (NPK vs PK). Yield decline as a result of omitting P (NPK vs NK) was 0.43 Mg ha^{-1} and significant at ($p \leq 0.045$ (Table 4.2).

There was observed seasonal variation of yields from the first, second and third seasons. For instance, conservation agriculture recorded higher yields than conventional tillage in SR2014 season while in LR2015 and SR2015 seasons, conventional tillage outperformed conservation agriculture. The erratic and varying rainfall recorded during the study period could be the cause of variation of yields in the three seasons.

Generally higher average yields under conservation agriculture than under conventional tillage in SR2014 season could have been attributed to the combined beneficial effects of minimum tillage and mulching in conserving soil moisture. However, higher yields under conventional tillage than conservation agriculture in LR2015 and SR2015 seasons could be attributed to higher rainfall received and mixing of nutrients during weeding thus enhancing the availability of nutrients. Additionally, much of N applied under conservation agriculture could have been held by maize stover and lost through volatilization and thus not beneficial to crops while some could have been used by microbes in stover breakdown thus resulting to yield drag. Doran *et al.* (1998) explained the probable cause of the yield drag is as a result of crop nutrients being temporarily immobilized in the soil by increased number of microbes below the surface mulch (in conservation agriculture) which need nitrogen from the soil for their population increase, thus leaving little nitrogen for early plant development. Doran *et al.* (1998) argued that nutrients in the residue break down more slowly and are consumed by microbes and become unavailable to the plant. Additionally, plant residues with high C:N ratio (for example >42:1 for maize stover) have been found to stimulate immobilization of soil N by micro-organisms (Gentile *et al.,* 2009) and more N from external sources is therefore required to offset this negative effect of limited N supply to the growing crop. Further, Pittelkow *et al.* (2015) suggested that yield changes due to the implementation of conservation agriculture principles are usually negative and depend upon the duration and extent to which all three conservation agriculture principles are enacted as well as on the climate where conservation agriculture is practiced. Pittelkow *et al.* (2014) has reported that no-till reduces yields in the first few years regardless of whether the other two conservation agriculture principles are implemented with yield decline of -3% versus 11.4% reported, respectively when three pricnciples were compared with the application of one principle. This could also be an additional cause of yield variation in this study. On the other hand, Erenstein (2003) and Giller *et al*. (2009) have reported that the benefits of conservation agriculture are realized gradually over long-term. Temesgen *et al.* (2008) stated the beneficial effects of conventional tillage in reducing weed infestation, warming soil and increasing productivity. Similarly, Hittersay (2012) reported seasonal variation of yields with conservation agriculture outperforming conventional tillage and vice versa. This also corroborates the findings of Ngwira *et al.* (2012) who reported higher maize grains yields at one site under conservation agriculture than conventional tillage in the first season. Sime *et al.* (2015) reported that conventional tillage improved maize yields far more than conservation agriculture (minimum tillage and zero tillage). This contrasts the research findings that have identified conservation agriculture as an effective tool for sustainably increasing yields in many parts of the world (Hobbs *et al*., 2008; Pittelkow *et al*., 2015). For instance, Ghosh *et al.* (2015) reported an increase of about 27% maize grain yield with conservation agriculture (2000 kg ha^{-1}) as compared to conventional agriculture (1570 kg ha^{-1}). In an on-farm study carried out in Malawi by Ngwira *et al.* (2012), maize grain yields were significantly higher under conservation agriculture than conventional tillage in the second and third season at both trial sites. Further, Mcdonald (2015) found that average maize and system yields across conservation agriculture (fresh beds, reduced tillage and strip tillage) was 9.1% and 6.1%, respectively, greater than conventional tillage.

There was observed significant influence of NPK inputs over control under both tillage systems in the study period. However, there were no significant differences between NPK, NP, NK, PK and control under conventional tillage and conservation agriculture. Maize grain yields were higher in NK treatment than that of individual N and K in LR15 and SR2015 seasons unlike in SR2014 season. This means that in the latter seasons, there existed synergetic relationship between N and K unlike in SR2014 season. Fridgen and Varca (2004) reported that nitrogen and potassium influence plant growth in a synergetic way. This means that the N/K ratio was optimum in affecting grain yield in LR2015 and SR2015 seasons. Optimum N/K ratio has been reported to be promoting healthy plant growth while imbalanced N/K ratios lead to maladjusted plant growth (Niu *et al.,* 2011; Zhang *et al.,* 2011). Low rainfall recorded in SR2014 season compared to other seasons could be the cause of antagonistic relationship since K is essential in transportation of crop water and nutrients.

The response of maize grain yields to combined N and P fertilization (i.e. NP) was much greater than that of K fertilizer application combined with N or P (i.e. NK and PK treatments). Ogunlela *et al.* (2005) reported that the synergistic relationship between N and P may help in converting relatively unavailable native and residual P to chemical forms which are susceptible for uptake by plants after dissociation. On average, NPK out-yielded NP despite adequate levels of K in the soils which mean that in presence of N and P, uptake of K was higher inducing the yield differences in the two treatments. In addition, despite high (44-50 mg/kg) K levels in 0-20 cm depth of the soils in the study area (critical values 39-64 mg/kg), there was crop response to applied K which means that most of soil K was not readily available for crop uptake.

Application of NPK, NP and NK doubled maize grain yields over control in all the seasons. Rutunga *et al.* (2003), Vanlauwe *et al.* (2006) and Ngome *et al.* (2013) reported high maize yield decline due to lack of N followed by P nutrient applications and found that N and P were the major limiting nutrients for maize yields in western Kenya. 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). Kihara *et al. (*2016) reported more than double higher yields with application of NPK over control. Omission of N, P and K was found to induce maize grain decline. Dai *et al.* (2013) reported similar results with maize grain yields decrease of 77% with N omission, 78% with P omission, 26% with K omission, and 84% with no fertilizer, respectively. Tang *et al*. (2008) also reported similar results with a decrease of grain yields under maize wheat rotation with the yield decline in the order NPK>NP>NK>N>Control.

Omission of N alone as a single nutrient was found to have the highest maize yield decline. In a study to understand crop response to fertilizer amendments in SSA, Kihara *et al.* (2016) found maize grain yield reduction of at least 1 Mg ha^{-1} in some sites and highest reduction of more than 2 Mg ha^{-1} in other sites following N omission. Omission of K fertilizer was found to have the least decrease of maize grains yield throughout the study period. Losses of grain yields as a result of P or K omission were less than 1 t ha^{-1} far much below those under N omission. Contribution of K has been reported by Qiu *et al.* (2014) who found that K increased the average grain yields by 15.1% and 13.8% with 113 kg K ha^{-1} and 225 kg K ha^{-1} applications, respectively. According to Niu *et al*. (2011) a study carried out in the North China Plain found that on average, maize grain yields were increased by 9.9 and 14.9% under conventional practices and by 15.7 and 21.0% under high yielding practices (involving application of N and P) at two K site specific levels, respectively. He *et al*. (2012) found that K application increased maize grain yields by an average of 46% in a 19-year field experiment on the North China Plain. Vyn *et al.* (2002) also reported that K application significantly ($p \leq 0.05$) increased maize grain yields by 11.5% in a zero-tillage system and by 8.6% in a mulch tillage system in Canada. Balanced K application is therefore required to achieve optimal yields for various ecological zones (Qiu *et al*., 2014). According to Kogbe & Adediran (2003) application of K at the rate of 30 kg ha^{-1} was found to increase maize grain yields by 20% when compared to control. This could be attributed to K fertilization which significantly affects the concentration of P and N concentration in the tissues (Bahmanyar & Mashaee, 2010) thus resulting to increased yields. However, seasonal application of K was not significant in increasing maize grain yields over the study period. This could either be the fact that K application rate was exceeded or not synchronized to crop K demand, which makes the grain yield cease to increase thus K use efficiency decreases leaching of exchangeable K to occur (Qiu *et al*., 2014).

4.3 Effects of tillage systems and NPK inputs on soil N, P and K changes

Nutrient omission had a significant influence on nitrogen change. Total N significantly ($p \leq .0001$) decreased with an average negative change of (0.02) and (0.03) under conservation agriculture and conventional tillage from the start to the end of the study period, respectively (Table 4.3). However, there was no influence of tillage system on soil total N. A significant decrease in total soil N was observed under tillage and macro-nutrient input except under control. In N omission (PK) treatment, percentage total N significantly ($P \leq .0001$) decreased over the study period (Table 4.3).

Table 4.3 Effects of tillage system on soil percentage N, P and K change from SR2014 to SR2015 in Runyenjes Sub-County, Embu County

Treatment	% N SR14	% N SR15	Change	*P* Value	P SR14	P SR15	Change	*P* Value	K SR14	K SR15	Change	P value
Macro-nutrient												
NPK	0.23^a	0.20^b	-0.03	<.0001	16.93^a	20.24a	3.31	0.4	45.93^a	48.00^a	2.07	0.16
NP	0.24^a	0.20^b	-0.04	<.0001	18.12^a	21.67^a	3.55	0.21	44.33^a	49.03^a	4.7	0.07
NK	0.22^a	0.19^b	-0.03	<.0001	17.82^a	24.62^a	6.8	0.051	44.74^a	47.65^a	2.91	0.15
PK	0.22^a	0.20^b	-0.02	<.0001	18.28^a	20.76^a	2.48	0.34	43.70^a	49.11^a	5.41	0.05
Control	0.24^a	0.24^a	-0.002	0.6888	18.81^a	18.81^a	0.002	0.998	44.72^a	44.71^a	0.0005	0.998
P	0.9	0.044			0.96	0.53			0.9	0.8		
LSD	0.01	0.02			5.44	6.8			8.85	7.91		
Till*FI	0.98	0.9			0.78	0.62			0.96	0.54		
Conservation	0.23^a	0.21^a	-0.02	<.0001	14.31^b	19.01^b	4.19	<.0007	41.87^b	45.23^a	14.29	<.0001
Conventional	0.24^a	0.21^a	-0.03	<.0001	23.32^a	25.04^a	0.62	0.67	47.57^a	50.19^a	13.24	<.0001
P	0.53	0.053			<.0001	0.009			0.046	0.052		
LSD	0.006	0.011			3.44	4.43			5.6	5		

CA=Conservation agriculture; CT=Convectional agriculture; Till=Tillage system; FI=Fertility inputs; N, P & K SR14=N, P and K before the start of experiments; N, P and K SR15=N, P and K at the end of experiments; Till*FI=interaction between tillage and fertilizer inputs; *P*=*P* value. Same superscripts letters in the same column denote no significant differences between the treatments

The decrease of total N in PK treatments could be attributed to soil N pool being highly depleted through crop removal. Total nitrogen decreased by 15, 20, 15 and 10% in NPK, NP, NK and PK fertilizer inputs, respectively. As a result, there could have imbalanced nutrient supply or suboptimal nutrient ratios which are required for satisfactory growth and development of maize to attain optimal yields. This means that external augmentation of N is essential to enhance its availability in the soil for crop uptake.

Production of maize under different tillage systems and nutrient management options led to a positive increase of soil total P (Table 4.3). The highest increase of available P was observed under conservation agriculture (4.19 ppm) when compared to conventional tillage (0.62 ppm) though in the latter it was not significant (Table 4.3). On nutrient management options, there was no influence of macro-nutrients inputs on soil P change. The P concentration increased by 18% with no omission (NPK), 19% with K omission (NP), 36% with P omission (NK) and 13% with N omission.

Extractable K was significantly ($P \leq 0.046$) higher under conventional tillage than conservation agriculture at the start of the experiments but was not significant ($P \leq 0.052$) at the end of the experiment (Table 4.3). Potassium increase was higher under conservation agriculture (14.29 ppm) as compared to conventional tillage (13.24 ppm) (Table 4.3). Fertility inputs had no influence on soil extractable K over the study period. Compared to other fertility treatments, a significant positive change ($P \leq 0.05$) of extractable K was observed only under PK treatment while in other treatments, the change was not significant (Table 4.3). Compared to control, extractable K increase was least with no-omission (NPK), followed by P omission

(NK) then under K omission (NP). With no omission (NPK) and P omission (NK), K concentration increased by 5 and 7% while under K omission (NP) and N omission (PK), K concentration increased by 11 and 12%, respectively (Table 4.3). A surplus concentration of available K was significant ($P \leq 0.05$) when N was omitted (PK) treatment (Table 4.3).

The higher nutrient uptake with combined N and P than the sole P application could be attributed to the synergistic N enhancement of P uptake (Brady, 1984; Teng and Timmer, 1994). Similarly, Ogunlela *et al*. (2005) reported synergistic relationship between N and P which converts unavailable soil native P and its' residual to other chemical forms susceptible for uptake by plants after dissociation.

Under conservation agriculture tillage system, P concentration increase was highest compared to conventional tillage. This means that P uptake was least under conservation agriculture. Moldenhauer *et al.* (1994), reported that phosphorous (P) is more effectively available under crop residue management, and thus could be the probable reason of higher P concentration under conservation agriculture than conventional tillage. Urea was applied as source of N and its hydrolysis reaction utilizes H^+ ion which is responsible with pH elevation. In addition, the soils in the study area are acidic (Table 3.2) and thus responsible for rendering P unavailable through P fixation. A significant positive P concentration increase under conservation agriculture could have been attributed to lower P uptake compared to conventional tillage resulting to P immobilization. This means that on average, P was generally higher in farms where conventional tillage was implemented as compared to those farms where conservation agriculture was implemented.

There was no significant influence of applied P on NPK, NP and PK treatment to soil P changes. However, an increase of available P concentration meant that P uptake was lower than P applied. Bennet *et al.* (2001) and Childers *et al.* (2011) have reported that phosphorus not taken up by plants accumulates in soil and as a result of various processes undergoes retardation and is not available for plants uptake. On the other hand, a significant P increase under NK meant that P uptake from the soil was high in NK treatment. Following higher P uptake in NK treatment, P removal by maize could have been replenished by labile P adsorbed in the soil colloids, sparingly soluble or inorganic soil P to maintain the soil P equilibrium. External application of P is therefore necessary to augment soil supplies and help attain optimal crop yields while minimizing the depletion of soil P nutrient reserves.

Higher P levels under conservation agriculture than conventional tillage has been reported (Duiker and Beegle, 2006; Thomas *et al*., 2007; López-Fando and Pardo, 2009) due to limited mixing of soil with fertilizer P (Verhulst *et al.*, 2010). Total P increase has also been reported in other cereals such as rice and wheat. According to a study done on rice by Lin-lin *et al.* (2015), soil total P contents of balanced fertilization with mineral NPK was found to increase over a 33 years study period. Qiu *et al*. (2005) also discovered the significant positive increase of total P after 12-year fertilization (mineral P plus pig manure) in rice-rape system.

Phosphorous fixation might be another cause of increased P in the soil because of acidic soils in the study area. The soils were acidic and averaged 5.87 with the pH of the farms varying on the range 4.84-6.60 (Table 3.2). Phosphorous fixation is apparent on acidic soils leading to its addition on the soil. The P increase might also be due to residual effect of phosphorus fertilizer because of its low mobility and solubility in the soil. The low mobility of P in acid soils (Gupta, 2011) could be an additional cause of increased P fixation. Availability of P for crop uptake is relatively high in less acidic soils. Soil P availability is intensely affected by pH, below pH 6.0, P becomes tightly bound with aluminum and iron oxides, and above pH 7.0, P becomes tightly bound with calcium (Hinsinger 2001). In an experiment conducted over 15 years in china under wheat-maize cropping system, Tang *et al*. (2008) reported P accumulation on maize at an average 35 kg P ha^{-1} year^{-1} (26–42 kg P ha^{-1} year^{-1}) in the plough layer (0–20 cm) for NP treatments and 32 kg P ha^{-1} year^{-1} (23– 39 kg P ha^{-1} year^{-1}) under NPK treatments as result of phosphorous residue effect caused by P accumulation.

A significantly high K under conventional tillage as compared to conservation agriculture could be attributed to lower crop uptake under conventional tillage treatments as compared to conservation agriculture treatments. On the other hand, highest K change under conservation agriculture could either be as a result of lower uptake of K under conservation agriculture, K residual or additional input of K in soils through decomposition of crop residues applied as mulch. Further, increase of K under both conservation agriculture and conventional tillage could be as a result of K being regulated by its soil reserves in the colloids due to contact ion exchange mechanism. According to Sharma *et al*. (2010) aboveground K uptake from the soil solution is replenished by soil exchangeable K and non-exchangeable K reserves. Highest increase was observed under conservation agriculture tillage system and this could be as a result of additional K in stover returned as the mulching material. The majority of K is taken up in stover biomass (Mallarino and Higashi, 2008) and thus contributed to additional K after stover decomposition. In addition, high K under conservation agriculture could be attributed to minimum tillage which has been found to enhance K levels in the soil. For instance, Govaerts *et al.* (2007) reported 1.65 and 1.43 times higher K in 0–5 and 5– 20 cm layers of the soil in no-till when compared to conventional tillage system, respectively.

In PK treatment, a significant positive K increase could be attributed to seasonal application of K with lower K uptake of the applied fertilizer by crops. A surplus concentration of available K was significant ($p \leq 0.05$) when N was omitted which means that there exist a relatively lower synergetic relationship with N omission (PK) than P omission (NK). These results corroborates the findings by Dai *et al.* (2013) who reported that soil available P and K significantly improved in the treatments with P and K fertilizers (PK) when N fertilizer was omitted. Dai *et al.* (2013) also reported that soil available K was significantly accumulated in the plots with N and K fertilizer (NK) when P fertilizer was omitted and attributed that to deficiency of other nutrients that inhibited crop production since crops exhibited lower P or K uptake.

4.4 Cost Benefit Analysis

Production of maize resulted to a higher total variable cost (TVC) under conventional tillage than conservation agriculture in the in SR2015 and LR2015 seasons (Table 4.4). In LR2015, TVC was significantly ($P \leq .0065$) higher under conventional tillage than conservation agriculture (Table 4.4). Notably, macro-nutrient inputs under conservation agriculture in both seasons had a significantly ($P \leq .0001$) lower TVC than that of macronutrients inputs in conventional tillage (Table 4.4). Use of macro-nutrients inputs resulted to significantly ($P \leq .0001$) higher TVC than control in both seasons (Table 4.4). Additionally, TVC under macro-nutrients inputs was significantly ($P \leq .0001$) different and were in the order NPK>NP>NK>PK over the study period.

Table 4.4: Economic analysis of nutrient management options under conservation and conventional tillage systems during LR2015 and SR2015 seasons at Runyenjes, Embu County

Economic Analysis (ha^{-1}) in US$						
	LR2015			SR2015		
Treatments	TVC	NB	BCR	TVC	NB	BCR
Tillage*Macro-nutrient Input						
Conservation_NPK	555^{b}	1823^{a}	3.28^{abcd}	552^{b}	1655^{ab}	3.02^{ab}
Conventional_NPK	576^{a}	1892^{a}	3.27^{abcd}	574^{a}	1831^{a}	3.19^{ab}
Conservation_NP	480^{d}	1794^{a}	3.73^{a}	477^{d}	1697^{ab}	3.53^{a}
Conventional_NP	498^{c}	1802^{a}	3.62^{ab}	492^{c}	1651^{ab}	3.35^{a}
Conservation_NK	454^{f}	1729^{a}	3.80^{a}	446^{e}	1439^{b}	3.20^{ab}
Conventional_NK	467^{e}	1588^{a}	3.39^{abc}	468^{d}	1614^{ab}	3.44^{a}
Conservation_PK	381^{h}	1120^{b}	2.93^{bcd}	378^{g}	987^{c}	2.60^{bc}
Conventional_PK	396^{g}	1027^{b}	2.58^{d}	395^{f}	980^{c}	2.48^{bc}
Conservation_Control	175^{j}	488^{c}	2.77^{cd}	177^{i}	535^{d}	2.98^{ab}
Conventional_Control	192^{i}	496^{c}	2.57^{d}	190^{h}	407^{d}	2.15^{c}
P	0.0001	0.0001	0.003	0.0001	0.0001	0.0033
LSD	9.21	324	0.71	10.4	366	0.75
Macro-nutrient input						
NPK	565^{a}	1758^{a}	3.28^{a}	566^{a}	1855^{a}	3.10^{ab}
NP	488^{b}	1647^{a}	3.68^{a}	479^{b}	1797^{a}	3.42^{a}
NK	460^{c}	1508^{a}	3.61^{a}	460^{c}	1665^{a}	3.27^{a}
PK	388^{d}	1038^{b}	2.77^{b}	394^{d}	1078^{b}	2.61^{bc}
Control	183^{e}	460^{c}	2.68^{b}	184e	491^{c}	2.51^{c}
P	<.0001	<.0001	<.0001	<.0001	<.0001	0.0034
LSD	10	266	0.49	17	219	0.52
Tillage						
Conservation	409^{b}	1391^{a}	3.30^{a}	412^{a}	1357^{a}	3.19^{a}
Conventional	426^{a}	1361^{a}	3.09^{a}	419^{a}	1230^{a}	2.83^{a}
P	0.045	0.85	0.26	0.83	0.41	0.062
LSD	16	319	0.37	69	303	0.38

TVC=Total variable cost; NB=Net benefit; BCR=Benefit Cost Ratio; LSD=Least significant difference; *P*=P value of the model. Same superscripts letters in the same column denote no significant differences between the treatments

Under NPK inputs, TVC was statistically significantly at ($P \leq .0001$) and followed the order NPK>NP>NK>PK>Control in LR2015 and SR2015 seasons (Table 4.4). Under both tillage systems, TVC ranged from US$576 and US$574 in NPK to US$175 and US$177 in control in LR2015 and SR2015 seasons, respectively. During the LR2015 season, TVC significantly ($P \leq .0001$) declined by 209% with NPK omission, 167% with NP omission, 151% with NK omission and 112% with PK omission (Table 4.4). In SR2015 season, TVC decline was 208% with NPK omission, 160% with NP omission, 150% with NK omission and 114% with PK omission and significant at ($P \leq .0001$) (Table 4.4).

There was no influence of tillage system on net benefits (NB) over the study period. Net benefit (NB) in LR2015 and SR2015 seasons was 2% higher under conservation agriculture than conventional tillage. Net benefits were significantly ($P \leq .0001$) higher under N treated macronutrient inputs (NPK, NP and NK) than N omitted (PK and control) treatments in the two cropping seasons. In LR2015 season, omission of NPK, NP, NK and PK led to a significant ($P \leq .0001$) deficit of 282, 258, 228 and 126% US$, respectively. Similarly, NPK, NP, NK and PK led to a respective deficit of 278, 266, 239 and 120% US$ at ($P \leq .0001$) in SR2015. Net benefits ranged from US$1758 to US$460 in LR2015 and US$1595 to US$455 in SR2015. Higher net benefits in LR2015 compared to SR2015 could be attributed to the high farm gate prices of maize grains US$ 0.33 kg^{-1} in LR2015 season compared to US$ 0.30 kg^{-1} in SR2015 season.

There was no influence of tillage system on benefit to cost ratio (BCR). Conservation agriculture increased benefit cost ratio by 8% and 13% over conventional tillage in LR2015 and SR2015 seasons, respectively (Table 4.4). Highest benefit cost ratio was attained under K omission (NP treatment) (US$ 3.73 and 3.53) under conservation agriculture in both LR2015 and SR2015 seasons, respectively (Table 4.4). Benefit cost ratio followed the order NP>NK>NPK in both seasons with variability observed under Control and PK treatments (Table 4.4). Least BCR was attained under N omission (PK treatment) in LR2015 (US$ 2.58) and in control (US$ 2.15) in SR2015 season both under conventional tillage (Table 4.4). Omission of N (PK) and NPK (control) significantly decreased benefit cost ratio in LR2015 at ($P \leq .003$) (Table 4.4). This could be as a result of high total variable cost incurred under N omission (PK) treatments with relatively low net benefits. Benefit cost ratio was decreased by 37 and 36% with NP omission, 35 and 30% with NK omission and 22 and 24% with NPK omission in LR2015 and SR2015 seasons, respectively. Results showed that for every US$ invested on NP and NK treatments gives 3 times US$ profit. Whereas NPK treatments had highest net benefits, the total cost of production was also relatively higher compared to that of NP and NK thus rendering it profitable to invest on. On control treatments, the result showed that for every US$ invested without the fertility inputs, there is possibility of getting US$2 in returns (Table 4.4).

Generally, TVC was 4 and 2% higher under conventional tillage than conservation agriculture in LR2015 and SR2015 seasons, respectively. In addition, significantly ($P \leq .0001$) higher TVC under NPK inputs in conventional tillage than conservation agriculture could be attributed to high cost incurred during land preparation and weeding. In conservation agriculture, use of herbicides could be the cause of reduced total variable costs. Use of herbicides substantially decreases the hand-weeding labor costs (Tulema *et al.*, 2008) and excluding herbicides from conservation tillage increases the labor requirements for weeding (Giller *et al.*, 2009; Ngwira *et al.*, 2012). According to Govaerts *et al.* (2009) a reduction in cost of production under conservation tillage practices than conventional tillage happens when herbicides are used. In addition, mulching could be another added advantage for reduced cost of production under conservation agriculture as compared to conventional tillage. Mulching has been found to reduce weed density and labor costs for weeding by (Thomas *et al*., 2007; Tulema *et al*., 2008; Sime *et al.*, 2015). In a study done in South Asia under rice maize cropping system, Gathala *et al.* (2015) reported higher maize production costs of US$1,027 ha^{-1} under conventional tillage compared to US$922 ha^{-1} with conservation agriculture based fresh bends. These findings are contrasted by the results done in Malawi over three cropping seasons by Ngwira *et al*. (2012) who reported higher total variable costs under conservation agriculture systems US$416 compared to conventional practice US$344.

Higher net benefits of 2 and 10% under conservation agriculture than conventional tillage were observed in LR2015 and SR2015 seasons, respectively. This could be attributed to lower cost of production under conservation agriculture than conventional tillage with the yield differences not able to offset net returns. Similar results have been reported by Micheni *et al* (2014) who found higher net benefits under no-till compared to conventional tillage. Ngwira *et al*. (2012) also reported more than double gross margin under conservation agriculture compared to conventional tillage (US$705 versus US$344 ha^{-1}). In addition, Gathala *et al.* (2015) reported lower maize net returns of $945 ha^{-1} under conventional tillage compared to $1350 ha^{-1} under conservation agriculture-based crop establishment permanent beds. Further, Mcdonald (2015) reported higher maize net returns of US$1350 ha^{-1} under conservation agriculture (permanent beds) compared to US$945 ha^{-1} under conventional tillage. According to Fowler and Rockström (2001), lower cost for seedbed preparation is the immediate benefits of conservation tillage.

Benefit to cost ratio under conservation agriculture was increased by 7 and 13% over conventional tillage in LR2015 and SR2015 seasons, respectively. This could be attributed to lower total variable costs (as a result of using herbicides) under conservation agriculture thus reducing the number of man-days compared to high variable costs incurred in digging and weeding, that was not offset by yield differences in the two tillage systems. Various studies have reported similar results. For instance, Mcdonald (2015) reported a higher benefit cost ratio (BCR) under conservation agriculture (permanent beds) of 2.4 compared to 1.9 under conventional tillage. Gathala *et al.* (2015) also reported maize BCR of 2.4 under conservation agriculture-based crop establishment permanent beds compared to 1.9 under conventional tillage. Benefit to cost ratio was higher in N treatments than in N omitted treatments and was in the order N>P>K with the differences varying by tillage system. This is as a result of higher maize grain yields recorded under N treatments compared to N omitted treatments that was able to offset the production cost. These results are in resonance with those reported by Priya, (2016) who reported a higher benefit to cost ratio of 1.08, 0.83, and 0.73 with NPK, NP, and N, respectively compared to 0.17 under control. Similarly, He *et al.* (2012) reported a benefit to cost ratio of 2.8, 7.8 and 4.6 with N, P and K fertilizer application, respectively (with higher BCR under P due to low application rate and prices of P compared to N and K.

4.5 Effects of macro and micro nutrients on quality of maize components during SR2015 at Runyenjes, Embu County

4.5.1 Effects of macro and micro nutrients combination on maize grain yields during SR2015 and LR2016 seasons in Runyenjes, Embu County

Application of NPK in combination with micro-nutrients led to a significant (*P*<0.001) increase of maize grain yields when compared to the control (Table 4.5). In SR2015 season, highest yields were attained under NPKCaMgZn treatment (Table 4.5). The maize grain yields decreased in the order NPKCaMgZn > NPKZn > NPKCa > NPKCaMg > NPK > Control (Table 4.5). There were no significant differences between NPKCaMgZn, NPKZn, NPKCa, NPKCaMg and NPK (Table 4.5). Maize grain yields were increased by 210, 204, 202, 201 and 178% with NPKCaMgZn, NPKZn, NPKCa, NPKCaMg and NPK treatments over control, respectively (Table 4.5). There was no significant individual Ca, Mg or Zn yield increase over NPK treatment (Table 4.5). Higher yields were obtained with application of NPK together with Ca, Mg and Zn nutrients over NPK though the differences were not significant (Table 4.5). Maize grains yields were increased by 0.43 Mg ha^{-1} with Mg and Ca application and by 0.48 Mg ha^{-1} with Zn application over NPK treatment.

Table 4.5: Maize grain yields as affected by soil macro and micro nutrients during SR2015 and LR2016 in Runyenjes Sub-County, Embu County

	Grain yields (Mg ha^{-1})	
	Seasons	
Treatment	**SR2015**	**LR2016**
NPKCaMgZn	5.81^{a}	2.96^{a}
NPKZn	5.69^{a}	2.88^{a}
NPKCa	5.65^{a}	2.97^{a}
NPKMg	5.64^{a}	2.97^{a}
NPK	5.21^{a}	2.80^{a}
Control	1.87^{b}	1.36^{b}
P	<.0001	<0.001
LSD	0.822	0.63

Ylds_Est=Yields estimate in Mg ha^{-}1; LSD=Least significant difference; *P*=P-value. Same superscripts letters in the same column denote no significant differences between the treatments

In LR2016, application of NPK with other nutrients inputs significantly ($P \leq 0.001$) increased maize grain yields over control (Table 4.5). Highest grain yields were attained under NPKMg treatment with the least attained under control (Table 4.5). There were no influence of Ca, Mg or Zn over the NPK fertilizers. Maize yields under various treatments followed the order NPKMg > NPKCa > NPKMgCaZn > NPKZn > NPK > Control. Lower yields were attained in LR2016 season compared in SR2015 and this could be attributed to the higher rainfall that was received in SR2015 season than in LR2016 season (Figure 4.1). As a result, this could have led to low moisture in the soil and subsequently unavailability of soil nutrients in soil solution over the growing period. In addition, the N applied in second and third split could have not been utilized by crops in LR2016 season resulting to low yields.

Compared to Ca and Mg nutrients, Zn had lesser grain yields increment in LR2016. The least yield increment of 0.12 Mg ha^{-1} was recorded when NPKCaMgZn vs NPKZn were contrasted, as compared to other polynomial contrast estimates (Table 4.6). The NPKCaMgZn vs NPK contrast showed an enhanced maize grain yields increase compared to the one attained by Ca and Mg alone. This means that Zn was pivotal in enhancing uptake of Ca and Mg which led to higher yields of 0.60 compared to 0.12 Mg ha^{-1}. Maize grain yields increase as a result of combined CaMg, ZnMg and ZnCa were lower than that of combined ZnMgCa which means that applying all the three nutrients is beneficial than applying either one or two of them combined (Table 4.6).

Table 4.6: Class Orthogonal Contrasts of macro and micro-nutrients inputs on maize grain yields in Runyenjes for the SR2015 and LR2016 seasons

	SR2015	**LR2016**
Contrast_Statements	**Yld_Est (p value)**	**Yld_Est (p value)**
NPKCaMgZn vs NPK	0.6 (<0.13) 12%	0.16 (<0.69)
NPKCaMgZn vs NPKCa	0.17 (<0.67)	0.01 (<0.99)
NPKCaMgZn vs NPKMg	0.17 (<0.66)	0.01(<0.99)
NPKCaMgZn vs NPKZn	0.12 (<0.75)	0.08 (<0.87)
NPKCaMgZn vs Control	3.94 (<.0001)	1.6 (<0.0001)
NPK vs Control	3.34 (<.0001)	1.24 (<0.0001)
NPKMg vs NPK	0.43 (<0.28)	0.17 (<0.71)
NPKCa vs NPK	0.43 (<0.28)	0.17 (<0.72)
NPKZn vs NPK	0.48 (<0.23) 9%	0.08 (<0.87)

Contrast statements=Class orthogonal statements; Ylds_Est=Estimate of grain yields in Mg ha^{-1}

Zinc increased yields by 0.48 Mg ha^{-1} over NPK treatment when NPKZn was contrasted with NPK (Table 4.6) which means that adequate levels of nutrients is important to maintain high soil N, P and Zn fluxes for improved crop yields (Mtambanengwe, 2006). These findings corroborate the research findings by Biljon *et al.* (2010) who reported that zinc foliar fertilization led to grain yield increase of 18% compared with NPK fertilizer treatments only. Biljon *et al.* (2010) reported a significant increase in total N uptake as well as grain yields on plants fertilized with 1.0 kg Zn/ha. The increase was attributed to zinc vital physiological functions such as energy production, protein synthesis and maintenance of membrane integrity (Hansch and Mendel, 2009). Eteng *et al.* (2014) reported a significant maize grain yield increase over control by the application of 8 kg·Zn·ha^{-1}, though there was no significant increase of yields with further addition of Zn exceeding 12 kg·Zn·ha^{-1}. In addition, maize has been found to be sensitive to zinc supply as indicated by its high content in grain as compared to other micronutrients (Lošák *et al*., 2011; Maňásek *et al.*, 2013). Zinc is important for performance of yield components in maize from the early stages of growth to maturity (Grzebisz *et al*., 2008). Potarzycki *et al.* (2016) reported grain yield gain of 11-19% due to zinc application with yield increase at the stage of 4th leaf by 19% (+1.65 Mg ha^{-1}) while before sowing by 7% (+0.58 Mg ha^{-1}) higher as compared to the NPK. Zinc has also been found to increase yields by (Fecenko & Ložek, 1998; Potarzycki & Grzebisz, 2009 and Asif *et al*., 2013). However, in LR2016 season, yield grains increase due to applied Zn was lower compared to SR2015 season. This could be as a result of low rainfall recorded over the growth period in LR2016 with no rains received after second N split application thus hindering uptake of applied nutrients by crops.

During the SR2015 season, Mg increased maize grain yields by 0.43 Mg ha^{-1} over NPK (Table 4.6). Research studies showing immense contribution of magnesium have been reported, for instance, Aitken *et al*. (1999) showed that magnesium fertilizer application significantly increased grain yield in magnesium-deficient Australian acid soils. In a study done in China, Wang *et al*. (2016) reported an average yield increment of 16.6% ± 3.19% at $P \leq 0.05$ as a result of Mg fertilization with an increase of 6.5% reported for cereals. A pH less than 7.0 (Table 3.1) could be an additional cause of increased mazie grain yields. Maize grain yield increment is more pronounced in soils with pH <7.0 than that with pH > 7.0 (Wang *et al*., 2016). Abunyewa and Mercer-Quarshie (2004) reported a maize grain yield increment of 16.5% when magnesium was applied as magnesium-sulphate. Rasheed *et al.* (2004) also reported a maize grain yield increment of 13%, (1.1 Mg ha^{-1}) when magnesium was applied as a supplement to NPK fertilizers. These yield increments could be attributed to Mg critical roles in improving root growth, photosynthesis and translocation of photosynthates and enzyme activities (Shaul, 2002; Marschner, 2012; Dechen *et al.,* 2015). However, using a mixture of nutrients would affect uptake of some of the nutrients. For instance, the rate at which Mg is taken up by plants can be depressed by other soil cations like K^+, NH_4^+, H^+, Ca^{2+}, Al^{3+}, and Mn^{2+} leading to plant Mg deficiency (Rengel and Robinson, 1990; Marschner, 1995).

Yield increment because of combined Mg and Ca was the least at 0.12 Mg ha^{-1}. This could be because of antagonistic relationship between Ca and Mg which has been reported by Pozna *et al.* (2016). However, application of Zn with Mg or Ca alone or in combination increased maize grain yields. This could be because of Zn roles in kick-starting growth through improved seedling vigour, enhancing root growth and chlorophyll concentration which enhances nutrient uptake and crop yields (Cakmak *et al*., 1999; Alloway, 2008).

4.5.2 Effects of Mg, Ca and Zn supplementation on maize grain and stover quality

Application of soil Mg, Ca and Zn nutrients had no significant influence of maize grain quality (Table 4.7). However, application of magnesium increased maize Mg concentration over control (Table 4.7). Highest increment of Mg concentration in maize grain was observed under NPKMg treatment 13% over control (Table 4.7). In NPKMgZnCa and NPKCa fertilizer inputs an increase of 9% Mg grain concentration was observed over control. The least increment was under NPKZn 3% over control (Table 4.7). Compared to NPK, NPKMg increased Mg grain concentration by 13%. NPKMgZnCa and NPKCa increased maize Mg concentration by 6% while NPKZn increased grain Mg concentration by 3% compared to NPK (Table 4.7).

Table 4.7: Maize grain and stover nutrient concentration as affected by Mg, Ca and Zn nutrients inputs during SR2015 at Runyenjes, Embu County

	Grain (mg kg^{-1})			Stover (mg kg^{-1})		
Fertility Input	**Mg**	**Zn**	**Ca**	**Mg**	**Zn**	**Ca**
NPKMg	3600^{a}	41.54^{a}	680^{a}	700^{a}	28.67^{ab}	680^{a}
NPKMgZnCa	3400^{a}	40.82^{a}	580^{a}	630^{a}	37.13^{a}	670^{a}
NPKCa	3400^{a}	35.64^{a}	660^{a}	600^{a}	22.9^{b}	670^{a}
NPKZn	3300^{a}	43.83^{a}	600^{a}	630^{a}	30.68^{ab}	530^{a}
NPK	3200^{a}	32.62^{a}	570^{a}	680^{a}	28.9^{ab}	600^{a}
Control	3200^{a}	34.43^{a}	580^{a}	570^{a}	28.83^{ab}	570^{a}
LSD	630	11.76	490	210	11.48	200
P	0.68	0.3	0.996	0.807	0.028	0.59

Mg=Magnesium, Zn=Zinc and Ca= calcium (grain and stover concentration in mg kg^{-1}).

Application of Zn increased maize grain quality by increasing Zn grain concentration over control though the increment was not statistically significant. The increase of maize Zn grain concentration was 19% and 27% under NPKMgZnCa and NPKZn over control, respectively. An increase of 21% maize Zn grain concentration was observed under NPKMg fertilizer input over control. Contrary to this, a decrease of 5% maize Zn concentration was observed under NPK fertilizer input. Maize Zn grain concentration was increased by 34, 27 and 25% under NPKZn, NPKMg and NPKMgZnCa over NPK fertilizer inputs, respectively. The least increment of 3% was observed under NPKCa treatment over NPK.

Maize Ca grain concentration was not influenced by other nutrients inputs. However, an increase of 17, 14 and 3% maize grain Ca concentration was observed under NPKMg, NPKCa and NPKZn, respectively over control. This means that uptake of Ca was observed even in treatments where Ca was not applied due to inherent soil Ca available for crop uptake. A decrease of 2% maize grain Ca concentration was observed in NPK treatment over control. Compared to NPK, highest maize grain Ca concentration was increased under NPKMg (19%) followed by NPKCa (16%) and then NPKZn (5%). The NPKMgZnCa treatment had the least Ca grain concentration increase of 2% over NPK. High Ca concentration reported in this study could be attributed to its inputs and it role in vegetative growth and grain filling. In addition, the least increase under NPKMgZnCa treatment could be as a result of reduced Ca uptake due to high level of exchangeable cations by magnesium and potassium which are responsible for reduced Ca.

Several studies have reported an increased in Zn maize grain concentration with addition of Zn. For instance, Manzeke *et al.* (2014) reported that application of Zn increased maize grain Zn concentrations by 18% in sole mineral fertilizer treatments with sole mineral NPK leading to a significant increase in grain Zn concentration 20.7 mg kg^{-1}, amounting to a 34% increase over the absolute control treatment. This means that Zn is crucial in improving the quality of crop yields. However, application of NPKMg and NPKCa resulted to an increase of maize grain Zn concentration. This could mean that the treatments enhanced the uptake of the inherent Zn soil reserves. There was no increase of maize grain Zn concentration under NPK over control. This means that combination of mineral NPK with micronutrients enhanced uptake of Zn and its filling on grains. The importance of Zn in improving grain quality has also been reported by Cakmak (2008). Pozna *et al.* (2016) observed that maize grown on the medium K soil had 40% magnesium accumulation in the grains with higher Mg content in grain observed where plants were grown on K fertile soils. According to Ning *et al.* (2013) vegetative P and K contributes 1–75% and 45–447% to the grain, respectively. These could be responsible for synergetic remobilization of micronutrients.

Application of NPKMgZnCa significantly ($P<0.028$) increased stover Zn concentration by 29% at silking stage over control (Table 4.7). An increase of stover Zn concentration was also observed under NPKMg, NPKCa and NPKZn by 1, 21 and 6% over control, respectively (Table 4.7). Use of mineral NPK alone led the least stover Zn concentration of less than 1%. Maize zinc stover concentration increased by 6 and 28% under NPKZn and NPKMgZnCa over NPK treatments, respectively. There was no increase of Zn stover concentration under treatments without Zn fertilization when compared to NPK (Table 4.7).

Similarly, an increase of 18% maize stover calcium concentration was observed with its incorporation in NPKMgZnCa and NPKCa over control. An increase of 19 and 5% was also observed under NPKMg and NPK over control, respectively (Table 4.7). However, a decrease of 7% Zn stover grain concentration was observed under NPKZn when compared to control (Table 4.7).

The NPKMgZnCa and NPKCa increased Ca stover concentration by 12% while NPKMg increased Ca stover concentration by 13% over NPK treatments. This could mean that much of the applied Ca was translocated to the growing leaves. This could mean that Ca uptake from the soil and its mobilization was adversely affected by other macro and micro nutrients inputs in the treatments. Pozna *et al.* (2016) found that nitrogen doses of 150 kg N ha^{-1} had positive effect on calcium accumulation in maize leaves but there was no Ca content response to N fertilizer on maize grains. This means that there exists both synergetic and antagonistic relationship between primary and secondary nutrients in the soil that influence uptake and the remobilization of these nutrients during the growth of maize. Additionally, the slightly acidic soils could have affected the uptake of applied nutrients. Application of K in NPK treatments could have negatively affected Mg remobilization on leaves in some treatments. For instance, in NPKMgZnCa, NPKCa and NPKZn treatments had no influence of Mg concentration on maize stover at silking. According to Çelik *et al.* (2010) high doses of K exert negative impacts on Mg accumulation in leaves. Chen *et al.* (2016) found that Ca, Mg, B and Cu showed nutrient accumulationduring grain filling stage on the vegetative organs. Chen *et al.* (2016) reported Zn remobilization of 25 % with more remobilization reported from the leaves at 43%. Grzebisz *et al.* (2008) and Bender *et al.* (2013) have found Mn, Fe and Zn are only remobilized from stalks while Ca and Mg are remobilized from old leaves with high supply of N. Chen *et al.* (2016) reported that Ca and Mg and were mostly remobilized from the stalks with the recovery efficiency of 9 and 23%, respectively on husk and cob in grain filling stage.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONLUSIONS AND RECOMMENDATIONS

5.1 Summary and conclusions

Nitrogen and Phosphorous were found to be the most yield limiting macro-nutrients under both conservation agriculture and conventional tillage. The NPK, NP and NK were found to be the best combination of nutrients under conservation agriculture and conventional tillage for improved maize grain yields. Application of PK was least in enhancing maize grain yields over control. On average, use of NPK inputs led to above 1 Mg ha^{-1} maize grain yields increase over control in the three seasons. Implementing balanced fertilization should therefore be enhanced to increase crop productivity under both conservation agriculture and conventional tillage.

Total nitrogen decreased by 15, 20, 15 and 10% in NPK, NP, NK and PK fertilizer inputs, respectively. Available P concentration increased by 18% with no omission (NPK), 19% with K omission (NP), 36% with P omission (NK) and 13% with N omission. With no omission (NPK) and P omission (NK), K concentration increased by 5 and 7% while under K omission (NP) and N omission (PK), K concentration increased by 11 and 12%, respectively. Balanced fertilization with NPK fertilizer is therefore the best fit technologies to enhance crop productivity while maintaining the soil nutrient levels.

Conservation agriculture increased benefit cost ratio by 8% and 13% over conventional tillage in LR2015 and SR2015 seasons, respectively. Benefit to cost ratio was increased by 37 and 36% with NP input, 35 and 30% with NK input and 22 and 24% with NPK input in LR2015 and SR2015 seasons, respectively. TVC increased by 209 and 208% with NPK input, 167 and 160% with NP input, 151 and 150%with NK omission and 112 and 114% in LR2015 and SR2015 seasons, respectively. The combination of NPK, NP and NK mineral fertilizers gave the highest benefit cost ratio compared to other fertilizer inputs. Implementing NPK, NP and NK fertilizer inputs under both tillage systems offers the best technologies of enhancing profitability under on-farm conditions in smallholder farms at Runyenjes.

The combined mixture of CaMgZn nutrients increased maize grain yields by 12 and 6% in SR2015 and LR2016 seasons, respectively over NPK treatment. In addition, individual Zn increased grain yields by 9 and 3%, Ca increased maize grain yields by 8 and 6% while Mg increased maize yields by 8 and 6% in SR2015 and LR2016 seasons, respectively. Supplementation of soil Mg, Ca and Zn nutrients over NPK inputs resulted to improved yields and would thus be essential to enhance productivity of small holder farms in Runyenjes. Incorporating other mineral nutrients on NPK enhanced maize grain and stover quality. Compared to NPK, NPKMg was found to increase Mg grain concentration by 13%. NPKMgZnCa and NPKCa increased maize Mg concentration by 6% while NPKZn increased Mg grain concentration by 3% compared to NPK. Maize Zn grain concentration was increased by 34, 27 and 25% under NPKZn, NPKMg and NPKMgZnCa over NPK fertilizer inputs, respectively. Maize zinc stover concentration was increased by 6 and 28% under NPKZn and NPKMgZnCa over NPK treatments. The NPKMgZnCa and NPKCa increased Ca stover concentration by 12% while NPKMg increased Ca stover concentration by 13% over NPK treatment. Supplementation of other soil nutrients on NPK inputs should therefore be enhanced in order to produce quality grains and residues by smallholder farms in Runyenjes.

Conventional tillage was the best technology under balanced fertilization to enhance maize grain yields. In contrast, conservation agriculture was found to be best fit technology for enhanced returns. However, for the success of both conservation agriculture and conventional tillage, use of macro and micro-nutrients in balanced fertilization is essential. To improve productivity, mineral NPK fertilizers should be applied on time and in adequate amounts to realize returns and ensure maximum utilization of nutrients by crops.

5.2 Recommendations

Based on the findings from this study, the following recommendations were made;

- Conventional way of farming has been shown to be costly for small scale farmers due to high cost incurred in digging and weeding. Additionally, use of herbicides in weeding has been found to lower the production cost and thus offer a profitable option to normal way of land tilling. As such, balanced fertilization of nitrogen and phosphorous fertilizer under conservation agriculture should be recommended to farmers in Runyenjes in order to enhance the profitability of their farming.

- Supplementation of soil Mg, Ca and Zn on NPK fertilizers is essential and should be recommended to small holder farmers in Runyenjes in order to enhance maize grain yields and the quality of the residues.

5.3 Areas of further research

The following areas for further research that were identified by this study;

- Explore the potential of conservation agriculture when implemented over a longer period of time under on-farm conditions in the study area.
- Explore the potential of soil micro-organisms in influencing soil fertility under conservation agriculture system.

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APPENDICES

Appendix 1: Soil nutrient laboratory analysis

Total Nitrogen

Nitrogen was analyzed following the kjeldahl method (Ryan *et al.,* 2001). This involved digestion of soil samples to reduce nitrogen to nitrates and distillation of the nitrate formed. Soil sample was ground into a fine sample (15mm) and sub-samples of 3 grams made and put on a plain paper. Sub-samples were then put in 250 ml digestion tubes. About 10 ml distilled water was added to form a solution and then swirled to fully mix the soil and water.

A standard digest was prepared by adding 0.1 g of EDTA digest and 10ml potassium permanganate solution. About 20 ml of Sulfuric acid was slowly added to wash down the digest material on the upper tube and then swirled. Pumice granules were then added and swirled while distilled water was added drop by drop to avoid excessive fronting. The digest solution was then allowed to stand overnight

The solution was pre-digested by cooling followed by heating at about 100^{o}c for 45-60 minutes. A mixture of 5g catalyst and about 25 ml sulphuric acid was added on each standard sample and swirled to mix. The standard samples were put again on block-digester and heated to about 100^{o}c for 10 minutes then temperature was increased to 240^{o}c for 1 hour. The funnels were removed on tubes and placed besides each standard sample during boiling. Water was then removed, and the funnels replaced back, and the block-digester heated up to around 380^{o}c. Distilled water was put and allowed to cool. The solid precipitate formed was broken down before being allowed to cool.

Distillation of acid digests was done by adding NaOH. About 1 ml of boric acid was then added followed by distilled water in an evaporating dish which was placed underneath a condenser with a tube tip touching the surface of the solution. This enabled dispensation of NaOH down the flask and the distillation unit was held at an angle 50^{o}. Distillation was done for 5 minutes and the distillate was allowed to drain.

About 50 ml of distillate collected was titrated using an auto-titrator to a pH of 5.0 with a 0.01 N H_2SO_4 acid. This was followed by washing the burette tip, stirring bar using teflon-coated magnetic in a dish with distilled water. Disconnection of digest sample and distillation flasks was then done, and distillation had at least 2 standards and 2 blanks from which N percentage was calculate using below equations.

Total Nitrogen

$$\% \text{ Recovery } = \frac{\text{N}* \text{R}*(\text{V} - \text{B})*186.1* 100}{\text{Wt3}* 1000} \quad \text{Equation 1}$$

$$\% \text{ N } = \frac{\text{N}*(\text{V} - \text{B})*\text{R}* 14.01* 100}{\text{Wt4}*1000} \quad \text{Equation 2}$$

B=Volume of blank titration of the digest (ml)

R=Ratio of total volume of the digest to volume of digest used for distillation.

Wt4=Weight of dry soil (g)

186.1=Equivalent weight of EDTA

V=Volume of concentrated sulphuric acid sample in ml

N= Sulphuric acid solution normality.

Wt3= EDTA weight (g)

14.01=Atomic weight of N.

Total Phosphorous

Total phosphorous was analyzed following the Kjeldahl method described by (Ryan *et al.*, 2001). Soil samples were digested with a strong acid and it involved the following; 2 grams of well ground soil sample was put in the digestion tube and 30 ml of 60% perchloric acid and pimice granules added and mixed. In the bloc-digester, tube racks were placed and heated to 100^{o}C. The temperature of the block-digester was then increased to 180^{o}C for 15 minutes until white fumes appeared. Perchloric acid (15ml) was put in the digester to wash down materials on upper of tubes until whitish looking insoluble sediments were formed.

After cooling, distilled water was added to form 250 ml solution. This was followed by filtering the solution using whatman filter paper. The sample digest was pipette into a volumetric flask. About 10 ml of ammonium vanadomolydate was added followed by distilled water to dilute the solution. About 5 ml of the standard sample was pipette and a standard curve prepared, and this was repeated for the blanks (prepared using 10 ml of ammonium-vanadomolybdate reagent). The reading of the curves was done after 10 minutes and plotted on absorbance against phosphorous concentrations. The concentration of P was then read on calibration curves and then calculated using the equations.

Total P (ppm)

$$Total\ P = P\ (\ calibration\ curve) * \frac{A}{Wt} * \frac{50}{V} \qquad \text{Equation 3}$$

Where:

Wt=Dry soil weight(g)

A=Total extract volume (ml)

V=Measured extract volume (ml)

Extractable Potassium

Potassium was analyzed following the flame photometer method described by (Ryan *et al.*, 2001). About 5 grams of dry air was put in centrifuge tube and a solution of ammonium acetate was added. This was followed by shaking and centrifuging the extract into a volumetric flask and filtering using a filter paper. The process was repeated to get standard samples. The extract was then diluted with 1 N ammonium acetate to 100 ml and used to prepare a series of standards. Calibration curves were drawn and readings done on the flame photometer at a wavelength of 767 nm using the equations.

Extractable K (ppm)

$$Extractable\ K = K(calibration\ curve) * \frac{A}{Wt} \qquad \text{Equation 4}$$

Wt=Dry weight of soil in grams

A=Extract volume (ml)

Extractable Ca/Mg

About 5 g of dry soil was weighed and put in a 60 ml tube in a 1;5 ratio of mixture of 0.1N HCl and 0.025N H_2SO_4 was added and mixed. Stir bar was removed and distilled water added to full volume then inverted several times to allow mixing. The solution was then extracted into a solution 0.1N HCl and 0.025N H_2SO_4. All extraction was put in bottles and placed on a rack of mechanical shaker and shaken at 250 cycles per minute for 5 minutes. The extract solution was poured in each bottle through a funnel lined with filter paper to capture the filtrate. A calibrated Eppendorf with, 30mls and

3 mls for Ca and Mg, respectively was put in 10ml pipette as 1000ppm reference solutions in a volumetric flask. The extract was collected after repeating the process for Ca and Mg. Ammonium acetate extracts was then diluted and series of Mg and Ca standards were run from which calibration curves were drawn. The soil extracts were measured on a flame photometer with emission readings taken at 767 nm wavelength as per equation

Extractable Ca/Mg

$Extractable\ \mathrm{Ca/Mg}\ (ppm) = ppm\ \mathrm{Ca/Mg}(\ calibration\ curve) * \frac{A}{Wgt}$ Equation 4

A=Extract volume in ml

Wgt=Dry soil weight (g)

Appendix 2: Plant samples laboratory analysis

Procedures for the analysis of both maize stover and grain samples was done following the ones described by (Walinga *et al.,* 1989). Digestion of the samples was done as follows; about 3 g of plant sample was dried at 70^0 C and then transferred to a 50 ml volumetric flask. A 3.ml of hydrogen peroxide (H_2O_2) was added with 4 beads and swirled after which blank digest solutions was prepared. The flask was heated at 100 ^oC for about 1 hour and allowed to cool down as hydrogen peroxide was added in drops. The flask was then heated to 280 ^oC and heated for 5-10 minutes to evaporate water (appearance of white vapour). The flask was then removed again, more drops of hydrogen peroxide then added and then heated for 5-10 minutes. The process was repeated until the solution turned colourless to light-yellow. The flask was then removed and cooled at room temperature. This was followed by adding 10ml of water and swirled to mix the digest and to ensure that most of the digest had dissolved.

About 10ml concentrated sulphuric acid was added to complete the digestion at a temperature of around (330^0 C) with SiO_2 catalyst. The digest was then filtered using a coarse filter paper to remove any SiO_2 that might have dissolved and that would interfere in the determination.

Phosphorous

The digest was put in pipettes for standard series (0 – 10 – 20 – 30 – 40 – 50 mg/l) of the stock solution. About 4.5 ml of H_2SO_4 was then added to the standard banks and digests and allowed to cool. Distilled water (2 ml) was then added drop by drop, allowed to mix and to cool. Phosphorous absorbance was determined from the graph at a wavelength of 880 nm.

Phosphorous calculation

(A-B) *(0.01053)*(V/w)

Whereby:

A = P concentration digest sample mg l^{-1}.

B = P concentration of blank digest in mg l^{-1}

W = Weight of plant material sample (g)

V =The volume of digest in ml.

Potassium

Potassium was calculated in mmol/kg as:

0.02558 *V /W *(A-B)

A = Concentration of K in digest sample in mg/l.

B = Concentration of K in blank digest (mg/l).

W = Weight of plant material sample (g)

V = volume of digest solution.

Calcium

About 3 g of dried $CaCO_3$ was added in a 1-litre volumetric flask. Hydrochloric acid was then added and boiled to expel CO_2. The sample was cooled and 30 ml of concentrated hydrochloric acid was added to make 1 litre solution. A series of standards of blank and digest were made and diluted with lanthanum nitrate solution. The standard series were used to determine both Ca, K and Mg concentration with flame automatic absorption spectrophotometer at a wavelength of 2.85, 766.5 and 422.7 nm for Mg, Ca and K.

Calcium calculation

0.02495*(A-B)*V / w

whereby:

A=Concentration of Ca in digest sample (mg/l).

B =Concentration of Ca blank digest sample (in mg/l)

W = Weight of plant material sample (g)

V =Volume of digest solution in ml

Magnesium

0.04114*V / w*(A-B)

Whereby:

A = Concentrated Mg digest sample in mg/l.

B = Concentration of Mg blank digest in mg/l.

W = Weight of plant material sample (g)

V =Volume of digest solution

Zinc

On the digests, about 4.5 ml of HCL was added for the standard series and allowed to cool. Zinc is then determined using air-acetylene flame on automatic absorption spectrophotometer at a wavelength of 213.9 nm.

Zinc calculation (mg/kg)

(A-B) *(V/W)

Whereby:
A = Zn concentration (diluted digest sample) in mg/l.

B = Zn concentration (diluted blank digest sample) in mg/l

W = Weight of plant material sample (g)

V =Volume of digest solution in ml

Appendix 3: Classification tree analysis

The highest response of maize grain yields per farm was under NP treatment 5.11 Mg ha^{-1} followed by N treatment 3.97 Mg ha^{-1} and the least were under P treatment (3.83 Mg ha^{-1}). On average, NP had the highest response of 2.58 Mg ha^{-1} followed by N response 2.44 Mg ha^{-1} while P response had the least with 0.78 Mg ha^{-1}.

Summary of maize grain yields responses to inorganic fertilizer that was used in classifying farms during SR2014 and LR2015 seasons at Runyenjes Sub-County, Embu County**.**

	N	**Mean (Mg ha^{-1})**	**Min (Mg ha^{-1})**	**Max (Mg ha^{-1})**
Farms	28			
Tillage	2			
P_Responses	28	0.78	-1.48	3.83
NP _Responses	28	2.58	0.67	5.11
N_responses	28	2.44	0.59	3.97

N=total number of farms; Mean=Average for each nutrient responses in (Mg ha^{-1}); Max=Maximum values in (Mg ha^{-1}); Min=Minimum values in (Mg ha^{-1})

The farms were selected from terminal node 4 which had 4 conservation agriculture and 3 conventional tillage farms with high NP responses of greater than 3.31 Mg ha^{-1} (Figure 1). Farms with an average of lower than 3.31 Mg ha-1were not selected. A total of 8 farms were selected.

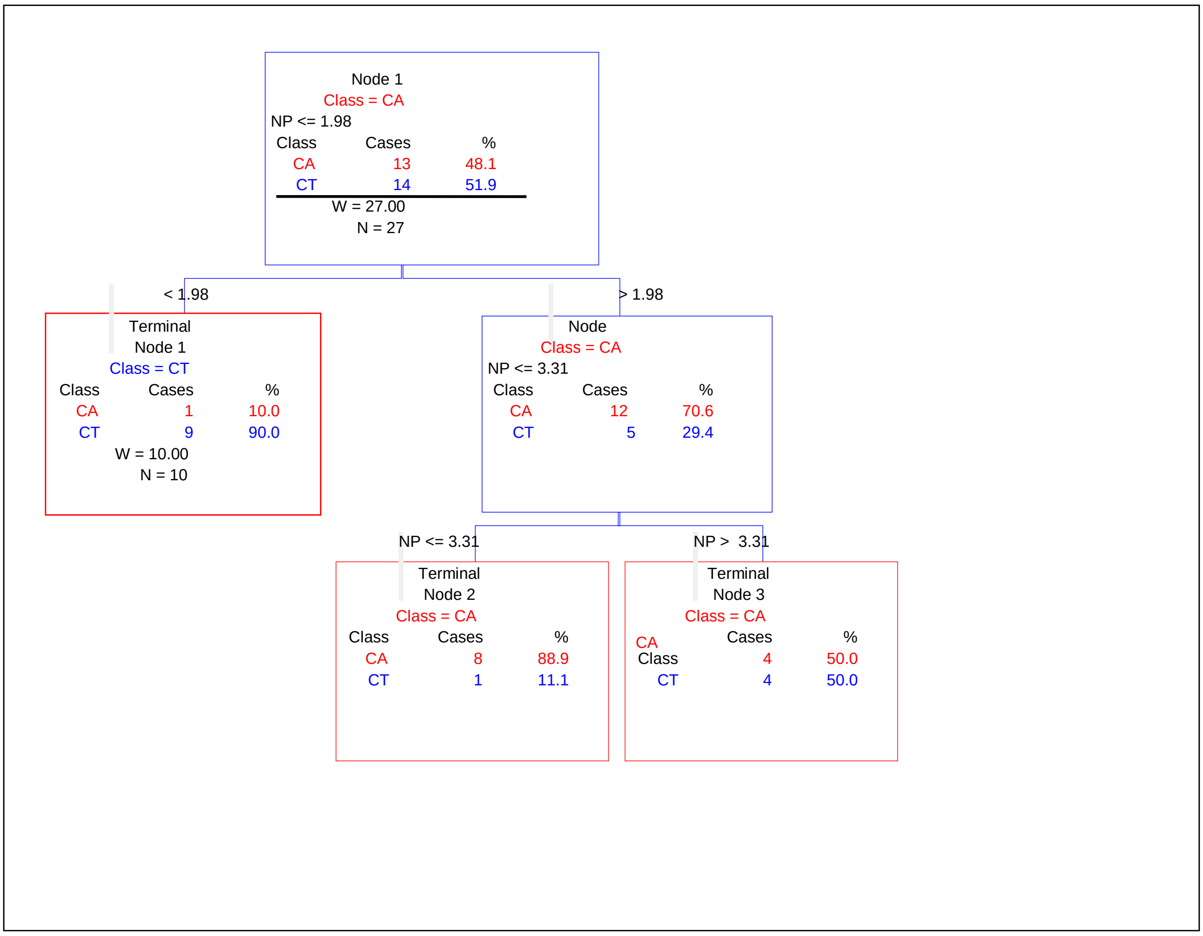

Figure 7.1: Net classification of farms with respect to NP responses for SR2014 and LR2015 in Runyenjes, Embu County

Farms were selected from terminal node 3 and 4 which had the farms showing high responses to N. Highest number of N responses with greater than 2.61 tons ha^{-1} was under conservation agriculture with 9 farms while conventional tillage had the least with 4 farms. In terminal node 3, additional 3 conventional tillage farms showing high response to N (>2.43 Mg ha^{-1}) were also included for selection. A total of 16 farms were selected.

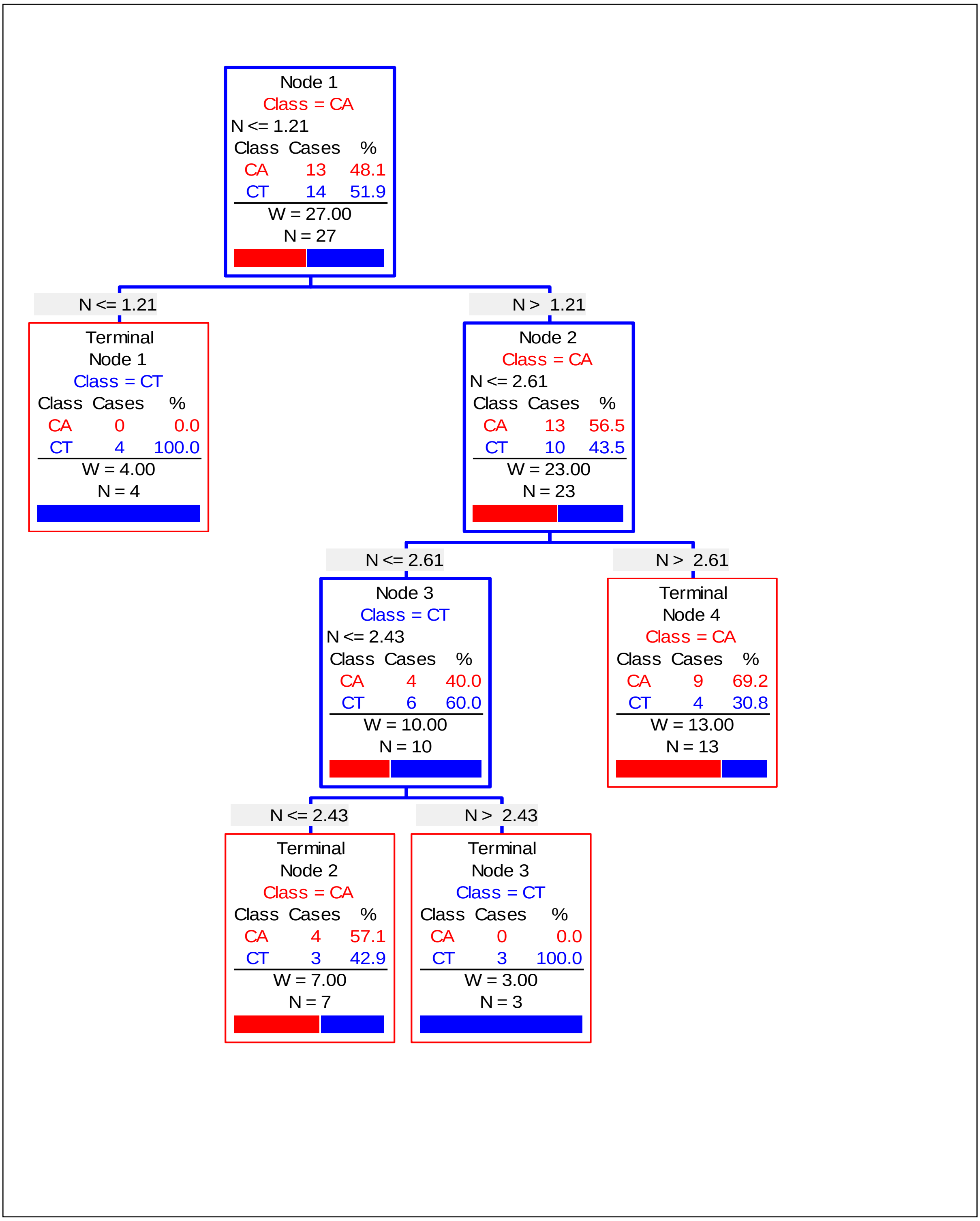

Figure 7.2: Tree net classification of farms with respect to N responses for SR2014 and LR2015 seasons in Runyenjes, Embu County

Five farms were selected from terminal node 3 under conventional tillage only since there were no farms showing high responses greater than 1.77 Mg ha^{-1} under conservation agriculture. The selected farms hosted the experimental trials where micro-nutrients were supplemented into macro-nutrients, to assess their contribution on yields and grain quality as well as sover quality.

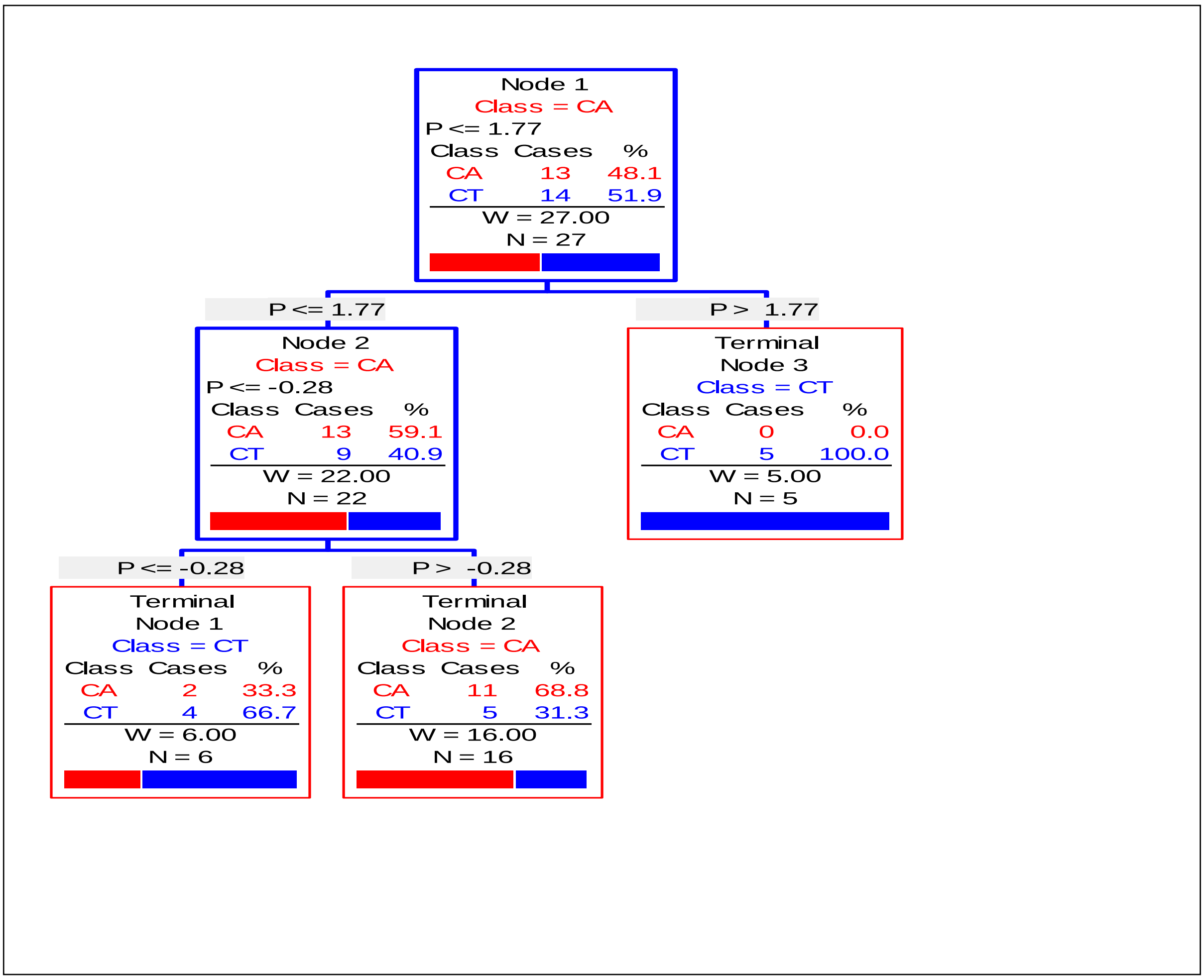

Figure 7.3: Tree net classification of farms with respect to P responses