EFFECTS OF LIME, INORGANIC P AND INOCULATION ON SOIL CHEMICAL PROPERTIES AND GRAIN YIELDS OF MAIZE AND SOYBEAN IN WESTERN KENYA

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DECLARATION

Candidate's Declaration

This thesis is my original work and has not been presented for a degree or any other award in any other university. No part of this work should be reproduced without prior permission of the author and /or Kenyatta University

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DEDICATION

To God, my mom Irene, dad Silvins and son Ivan for their unwavering support and inspiration during the course of my studies.

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ABBREVIATIONS AND ACRONYMS

CBR	Cost-Benefit Ratio
BNF	Biological Nitrogen Fixation
FUE	Fertilizer Use Efficiency
ICRAF	World Agro-Forestry Centre
ISFM	Integrated Soil Fertility Management
KARI	Kenya Agricultural Research Institute
LM	Lower Midland Zone
LSD	Least Significance Difference
MOA	Ministry of Agriculture
MOARD	Ministry of Agriculture and Rural development
Ndfa	Nitrogen Derived from Atmosphere
RCBD	Randomised Complete Block Design
SSA	Sub-Saharan Africa

ABSTRACT

Low crop responses to fertilizer application among small holder farms are common phenomena in degraded acidic soils of western Kenya. Continuous growing of maize without commensurate soil nutrient replenishment coupled with application of soil acidifying fertilizers, especially Di-ammonium Phosphate (DAP) and Sulphate of ammonia (SA) have aggravated the soil acidity problem. An on-farm trial was sited in Shianda sub-location, East Wanga division in Mumias district, Western province, Kenya during the 2011 long rain (LR) and short rain (SR) seasons to determine the effect of lime, inorganic P, inoculation on soil chemical properties and yields of soybean (*Glycine max* L.) and maize (*Zea mays* L.). The treatments included, 2 lime rates (0, 2.5 t/ha), 2 inorganic P rates (0, 30 kg P/ha) with or without inoculation (*Rhizobium japonicum*) of soybean. The eight treatments were arranged as factorial in RCBD with four replicates. All data were analyzed with the ANOVA procedure of the GENSTAT statistical software and treatment means separated using least significance difference at ($P < 0.05$). Regression analysis was performed to examine relationships between plant and soil parameters. Benefit-cost analysis was performed on maize and soybean grain yields to determine the treatments with the most profitable returns. A combination of Lime + P + inoculation recorded the highest maize (4490 kg/ha, 3470 kg/ha) and soybean (970kg/ha, 830kg/ha) grain yields during the first and second seasons, respectively. Sole P treatment gave a higher average nodule number per plant and plant biomass (g), respectively (8 and 21.8) than sole inoculation (4 and 19.2) and sole lime treatments (2 and 16.8) during the first season. Lime application at 2.5 t/ha increased soil pH from 4.9 to 5.58. Increase in soil available P was in the order of lime > P > inoculation (9.35 > 6.50 > 5.10) mg/kg. Sole lime treatment proved to be a more profitable investment for the farmers as it gave a net benefit of Ksh 89,015.20 with a benefit-cost ratio (BCR) of 2.2. Therefore, integration of lime, inorganic P and inoculation needs to be disseminated among small-scale farmers in western Kenya for improved maize and legume production.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Maize is the staple food for most Kenyans. West-Kenya (Nyanza and Western provinces) is the second largest producer of maize (*Zea mays* L.) in Kenya accounting for 20% of Kenya's total production (MOA, 2008). However, maize production has been declining with time thus threatening food security. Soil fertility degradation in smallholder farms has been cited as the fundamental biophysical root cause of food insecurity and poverty in sub-Saharan Africa (SSA) (Sanchez *et al*., 1997). There is widespread evidence of nitrogen (N) and phosphorous (P) deficiencies in arable soils that are highly weathered and leached in the western Kenya region (Kanyanjua *et al*., 2002; Woomer *et al*., 2003 and Okalebo *et al*., 2007) which are further made unproductive through their soil acidity (H^+ + Al^+) constraint (Gudu *et al*., 2005).

Farm scale studies reveal negative nutrient balances in major soil elements such as nitrogen (> 46 kg /ha) and phosphorus (> 3 kg/ha) in most countries in sub Saharan Africa (Shepherd *et al*., 1996), with average nitrogen mining in some parts of western Kenya estimated at up to 112 kg N/ha (Bekunda *et al*., 2007). Phosphorus deficiency in many of the soils is largely due to low occurrence of P-containing minerals (Bunemann, 2003) and P-fixation (Okalebo *et al*., 2007) while mineral nitrogen (N), especially nitrate (NO_3^-), released during soil organic matter mineralization may be taken up by plants, immobilized by microbes, lost from the soil system through soil erosion, leaching and denitrification or retained in the soil profile (Shepherd *et al*., 2000).

Other factors that lead to low crop yields in western Kenya include: *Striga hermonthica* weed and stem borer damages, vagaries of weather (unreliability, hailstones) and low quality seed in the market. A number of insect pests and diseases attack maize from the seedling stage to storage. The most important pests include insects (stalk borers, termites, cutworms, and weevils) while diseases include leaf blight, head smut, maize streak virus, and ear rots (Odendo *et al*., 2001). However, this study focused on soil nutrient depletion and soil acidity, which are the key constraints to increased crop productivity in western Kenya (KARI, 2010). This is because smallholder farmers, who constitute about 95% of total farming community in western Kenya, either intercrop or rotate maize and beans season after season without commensurate soil nutrient replenishment (Gudu *et al*., 2005).

Most farmers lack the financial resources to purchase sufficient fertilizers to replace soil nutrients depleted through crop harvesting. As a result, crop yields continue to decline in the region to levels below 0.5 Mg/ha/season in maize and below 0.2 Mg/ha/season in beans within small holder farms (Gudu *et al*., 2005). Therefore, research should be directed to seek affordable and least risky, but profitable amendments necessary to keep soil nutrient balance neutral (Versteeg *et al*., 1998) and sustain high crop productivity. The use of mineral fertilizer to replenish soil nutrients is one of the major ways of counterbalancing low soil fertility in western Kenya. However, some researchers have reported low maize yield responses to applications of inorganic fertilizer because of high soil acidity and low soil organic matter content in western Kenya (Okalebo *et al*., 2007).

Application of organic inputs in the form of green manure or otherwise could increase the total amount of nutrients added, and also influence availability of nutrients (Palm *et al.*, 1997). However, more than 50% of the organic resource available in the region is maize stalk, of which 80% is used as fuel wood (Palm *et al.*, 1997). Moreover, low nutrient contents, <5g N kg^{-1} and <1g P kg^{-1} of organic inputs with such strong competition for crop residues between livestock feed, soil fertility and fuel wood in small holder systems (KARI, 2009), limit their use unless a suitable strategy that builds the organic resource capital is designed. The current recommendation of rock phosphate (PR) is effective as a cheap P and lime source. However, low availability and poor solubility make them unsuitable for direct application. This has led to low adoption among the small scale farmers (Okalebo *et al.*, 2007). Effective low cost technologies like liming can also be used to reduce soil acidity through its direct effect on increasing soil pH, Ca^{2+} and/or Mg^{2+} ions (The *et al.*, 2006).

In implementing Integrated Soil Fertility Management (ISFM) research and development strategies, legumes have been attracting substantial attention because of their potential to fix atmospheric N through symbiosis with N-fixing bacteria, harbored in their root nodules. In addition, legumes offer other benefits such as providing cover to reduce soil erosion, maintenance and improvement of soil physical properties, increasing soil organic matter, cation exchange capacity, microbial activity and weed suppression (Versteeg *et al.*, 1998).

It is also evident that intercropping maize with soybean is becoming a popular cropping system in western Kenya. Soybean crop ranks fourth among the oil crops grown in western Kenya, and has an average yield potential of 500 to 3000 kg/ha (KARI, 2010). In addition to use of inorganic fertilizers, there is need to enhance organic soil nutrient inputs through biological nitrogen fixation (BNF) and liming as low-cost soil fertility improvement options in western Kenya. Moreover, the above technologies have been studied for potential yields but comparative economic analysis has not been part of it. Yield output alone does not reflect much about the efficiency of production. There is need therefore to economically evaluate the profitability of the demonstrated soil replenishment options through Cost-benefit analysis.

1.2 Statement of the problem

Soil acidity and nutrient depletion are major causes of low soil fertility in western Kenya where about 57, 670 hectares is acidic with pH <5.5 (Sanchez *et al*., 1997; Kanyanjua *et al*., 2002), which has led to low crop responses even when inorganic fertilizers are applied. Continuous growing of maize without commensurate soil nutrient replenishment coupled with application of soil acidifying fertilizers, especially Di-ammonium Phosphate have aggravated the soil acidity problem. This has led to wide limitations of nitrogen (N) and phosphorous (P) through inhibited bacterial growth and P-fixation, largely contributing to the low and declining crop yields. Whereas it is sufficiently documented that use of legume inoculants can improve soil nitrogen through biological nitrogen fixation (BNF) leading to improved legume yields (Okereke *et al*., 2000; Ndakidemi *et al.*, 2006; Mugendi *et al*., 2010), farmers have not yet adopted the practice on their farms in order to tap these benefits because conditions where BNF works are not well understood by the small scale farmers.

The use of mineral fertilizer to replenish soil nutrients has for a long time been promoted as one of the major ways of counterbalancing low soil fertility in western Kenya. Although mineral fertilizer contains a large amount of nutrients by weight and release nutrients within a short time, the rates used in western Kenya are low due to high cost of fertilizers (Odendo *et al*., 2007). Majority of the small scale farmers have limited farm incomes due to low farm productivity, as a result they cannot afford to purchase sufficient amounts of inorganic fertilizers and therefore require combinations of soil improving inputs that reduce costs. However, combinations of soil improving inputs that have acceptable agronomic and economic performance are not known.

1.3 Objectives

The general objective of this study was to determine the effects of lime, inorganic P, inoculation and their combinations on soil chemical properties and grain yields of maize and soybean on smallholder farms in western Kenya.

The specific objectives were to:

1. Determine the effects of lime and inorganic P on soil chemical properties and grain yields of soybean and maize
2. Evaluate the effect of inoculation on nodulation, biomass production and grain yield of soybean
3. Assess financial returns to maize and soybean under the different treatments

1.4 Hypotheses

1. Lime and inorganic P application significantly improve soil chemical properties and grain yields of soybean and maize
2. Inoculation significantly improve nodulation, biomass production and grain yield of soybean
3. Different treatments result into different financial returns to maize and soybean production

1.5 Justification of the study

Kenya has become a net importer of maize due to increasing human population with the current low maize production due to the decline in soil fertility (MOA, 2008). However, the country has a potential of producing adequate food quantities through enhanced soil productivity, for example results from previous studies (Wasonga *et al*., 2008) have shown potential yields in maize between 4 to 5 Mg/ha on small scale farmers' fields in western Kenya. Whereas it is sufficiently documented that inoculation can improve BNF leading to improved legume yields (Mugendi *et al*., 2010), farmers have not yet adopted the practice on their farms.

The introduction of other soil nutrient replenishment technologies such as liming which reduces soil acidity thus enhancing P availability and legume inoculation for improved BNF and improved soil N status can supplement inorganic fertilizers and offer a more affordable option for resource limited small-scale farmers. Increased maize and soybean yields would lead to increased food security, income and reduced poverty among the small-scale farmers. Besides enriching knowledge in general on ISFM options for improved maize and soybean yields, this study assesses the costs and benefits of different treatments as an important indicator of return to resource use. The implementation of the findings of this study will contribute to breaking the vicious cycle of food insecurity and poverty among small-holder farmers emanating from land degradation.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Introduction

Recent studies have found that crop productivity is very low in western Kenya. The typical output from a ‘good’ rainy season is less than 1 Mega gram per hectare (Mg/ha) of maize (Jaetzold *et al*., 2005), although the potential lies between 4 to 5 Mg/ha on small scale farmers’ fields (Wasonga *et al*., 2008). Soil acidity is one of the factors limiting maize production in western Kenya (KARI, 2010). Having realized the importance of fertilizers application for higher crop yields, some large scale farmers use them indiscriminately. As a result, some nitrogenous fertilizers which are acid forming such as Di-ammonium phosphate (DAP) and Sulphate of ammonia (SA) lead to increased acidity of soils with weak buffering capacity (Sale and Mokwunye, 1993).

It is therefore imperative that other sustainable alternatives of soil fertility management are sought to ensure improved crop production and consequently improved food security. Unfortunately, most farmers in the region rarely use lime and P fertilizer combinations or inoculation to increase the growth and N_2 fixation of legumes. Relying on the biological nitrogen fixation (BNF) of grain legumes is a strategy to ease the burden that commercial fertilizers exert on poor farmers. The beneficial effects of intercropping soybean/maize have also not been fully exploited by farmers in the major soybean producing areas of western Kenya. There are a number of approaches open to smallholder farmers to address the problem of declining soil fertility within the study area. The following section sheds light on these approaches**.**

2.2 Cereal - Legume Multiple Cropping Systems in Western Kenya

Maize (*Zea mays* L.) is the most important food staple in Kenya providing about 40% of the populations' caloric requirements (MOA, 2008). Due to the ever growing human population, coupled with low yields and declining soil fertility, demand for maize continues to outstrip supply (Republic of Kenya, 2009). Kenya produces, in average, 30 million bags of maize per year most of which is from smallholder farms with an average of 1.5 – 2.5 acres per household (Jaetzold *et al*., 2005). At small holder farmer levels, yields are low; averaging 0.5 Mg/ha compared to research center yields of 4-6 Mg/ha (Obura *et al*., 2003). The growing of maize and soybean as intercrops is a major component of agriculture and source of livelihood especially in the western region of Kenya. Yield returns from the maize-beans intercrop system have been declining on most farms over the years due to continuous cultivation that has resulted into nutrient depletion and pest/disease accumulation (Tungani *et al*, 2002). Farmers commonly intercrop to secure food production by averting risk, and to maximize utilization of land, labour and available resources.

Intercropping is receiving attention because it offers potential advantages for resource utilization, decreased inputs and increased sustainability in crop production. The presence of a cereal, exploiting the soil mineral N, may even stimulate legumes to fix N (Marschner, 1995). The integration of legumes in maize-based systems can partially counter N losses through atmospheric N fixation, but basal N application remains indispensable (Giller, 2001). In addition, legumes offer other benefits such as; enhancing the supply of biologically fixed N to a cereal crop grown in subsequent rotation after the legume, weed suppression, soil erosion control and soil structure improvement. The beneficial effects come from plant residues and rhizo-deposition (Giller, 2001). However, contributions from the fallen leaves during legume senescence are likely to be more important than retaining the haulm residues at harvest (Ncube *et al*., 2007).

Intercropping legumes and cereals have been reported to contribute to increased nutrient uptake by the cereal crop. Li *et al*. (2003) reported increased P uptake by maize in a maize/faba bean intercropping, this is due to increased P mobilization by faba bean from otherwise unavailable sources. Similarly, mobilization of organic P by chickpea has been shown to increase P uptake by wheat in intercropping (Li *et al*., 2002). Intercropping systems has also been reported to contribute to conservation of soil organic carbon (Bationo *et al.*, 2005). Appreciable amounts of soybean leaves can be shed during the soybean crop cycle thus contributing to the N-balance in these systems. The organic input can also provide carbon sources for the microbial activity (unlike inorganic fertilizer) and assist in maintaining or increasing soil organic matter (SOM) content (Yadvinder-Singh *et al.*, 2004).

Mixed or row intercropping has been observed to influence BNF in legumes (Anders *et al.*, 1996). If a legume is intercropped with a cereal, its %Ndfa may increase partly by competition for soil N from the cereal (Giller, 2001). On the other hand, BNF can be negatively affected by intercropping. When nodulated legume plants are shaded, or kept under low light for several days, the rate of N_2 fixation is reduced as well as some proportion of nodules are discolored from the N_2 fixing red colour which indicate a functioning leghaemoglobin, to non-fixing types (Marschner, 1995). This leads to a reduction in biomass accumulation and BNF-N contribution to the system. The total amount of N_2 fixed by a plant is a function of photo-assimilation and total dry matter accumulation. Thus, the growth rate will influence the amount of N_2 fixed, both by provision of the necessary photosynthate to fuel BNF and by providing a sink to use the fixed N (Giller, 2001). The differences in the depth of rooting, lateral root spread and root densities are some of the factors of competition between the component crops in an intercropping system for water and nutrients, and hence input use efficiency.

The extent, to which biomass and the total amount of BNF-N accumulation by legumes are affected in an intercrop situation, depends on the complementarities between the legume and the companion crop (Giller, 2001). As a result the overall N contribution to the system can be less than that of a sole legume crop (Anders *et al*., 1996). Moreover, a more efficient use of soil nutrients in intercropping systems may accelerate soil nutrient depletion, particularly for P, because of higher removal through the produce (Anders *et al*., 1996). The cropping system can help reduce the level of, or sensitivity to, soil nitrate (Peoples *et al.*, 1995) that will affect the rate of BNF. Moreover, in situations where soil N content is very high, legumes thrive without fixing atmospheric N_2. But in the majority of soils in the tropics, levels of plant available N is usually insufficient to fully satisfy a legume’s N requirement (Gachengo *et al*., 1999).

2.3 Soil Fertility Constraints in Western Kenya

2.3.1 Soil Acidity

Soil degradation occurs due to nutrient depletion, soil structure deterioration, acidification and sub-optimal addition of organic and inorganic fertilizer to soil. Soil acidity is one of the main factors limiting maize production in some parts of Kenya notably in western Kenya. The pH ranges required for optimum growth of maize and soybean are (5.6-7.5) and (5.8-7.0) respectively. Having realized the importance of fertilizer applications for higher crop yields, some large scale farmers use some nitrogenous fertilizers, particularly DAP at planting, followed by Sulphate of ammonia as a topdress which increases the level of soil acidity. The reaction is shown below:

$NH_4^+ + 2O_2 \longrightarrow$ bacteria $\longrightarrow NO_3^- + \mathbf{2H^+} + H_2O$…………....equation (i)

Transformations of these sources of N into nitrate (NO_3^-) releases H^+ to create soil acidity. Therefore, fertilization with fertilizers containing ammonium or even adding large quantities of organic matter to a soil will ultimately increase the soil acidity and lower the pH. Some of the other sources of soil acidity include; alumino silicate clays, hydrous oxides of aluminium, exchangeable aluminium soluble salts and carbon dioxide. Acid soils with pH < 5.5, commonly found in western Kenya have high levels of Al^{3+} ions which are toxic to plants (Sale and Mokwunye, 1993).

Acidification of soil results in loss of exchangeable Ca^{2+} and Mg^{2+}, a decrease in effective cation exchange capacity, and an increase in exchangeable Al^{3+} (Graham *et al.*, 2002). This however, leads to a decline in soil quality and crop yields. As a consequence, soils are deficient in one or more nutrients, leading to very low yields. Crop production on acidic soils suffers from deficiencies of essential elements (N, P and Ca) and toxicity of Al, Fe and Mn (Sale and Mokwunye, 1993). Deleterious effects of acidic soils on crops include impairment of root development, which is later manifested in poor growth and delayed maturity (Yamoah *et al.*, 1996). Coupled to that, continuous cropping with little nutrient input depresses the fertility even more.

2.3.2 Soil Nutrient Depletion

Nitrogen and phosphorus are the major nutrient limiting maize growth in Kenya (Kwabiah *et al.*, 2003). Several districts (Smaling *et al.*, 1997) and farm (Shephered *et al.*, 1996) scale studies further reveal negative nutrient balances in major soil elements such as nitrogen (> 46 kg /ha) and phosphorus (> 3 kg/ha) in most countries in sub Saharan Africa, with average nitrogen mining in some parts of western Kenya estimated at up to 112 kg N/ha (Bekunda *et al.,* 2007). Continuous cropping without commensurate nutrient replenishment is reported to contribute to low P content of many soils (Smaling *et al.,* 1997; Bunemann, 2003). Most soil N is derived from organic matter mineralization. Low organic carbon and low total N in western Kenya soils is due to high temperatures and soil moisture availability that favour rapid organic matter decomposition (Jaetzold *et al.,* 2005). Low mineral N levels, however, points to the dynamic nature of mineral N. Processes such as plant uptake, leaching, immobilization and denitrification determine the availability of mineral N to field crops.

The low P status of highly weathered acid soils is a particular problem because large amounts of P need to be applied in order to raise concentrations of available soil P to an adequate level for plant uptake (Sanchez *et al.,* 1997). This is because such soils contain large quantities of Al and Fe hydrous oxides which have the ability to adsorb P onto their surfaces. Thus, much of the added P is ‘fixed’ and is not readily available for crop use. Addition of rock phosphate to the soil has been shown to improve the yield of maize especially in phosphorous deficient soils and grain and biomass production of some legumes such as Lablab (*Dolichos lablab*) was increases when rock phosphate was applied to phosphorous deficient soils (Vanlauwe *et al*., 2000).

For many cropping systems in the tropics, application of N and P from organic and inorganic sources is essential to maximize and sustain high crop yield potential in continuous cultivation systems. The performance of soybean in the field depends to a great extent on the availability of soil nutrients such as N, P and micronutrients (Sanginga *et al*., 1995). Integrated soil fertility management is widely believed to improve nutrient supply to crops (Vanlauwe and Giller 2006). The use of legumes to supply N has been promoted to overcome soil fertility constraints, but without adequate P this strategy can have only limited success. Therefore, amending the soils with small amounts of inorganic N and P fertilizers can have an additive and synergistic effect in the intercropping system (Okalebo *et al.*, 2007).

2.4 Soil Fertility Management Strategies in Western Kenya

2.4.1 Liming

The practice of liming acid soils, i.e., applying $CaCO_3$ in order to raise soil pH has long been recognized as necessary for optimum crop production. In acid soils, there are problems of both plant nutrient deficiencies and toxicities from three elements Aluminium (Al) Manganese (Mn), and Hydrogen (H^+). Plant growth, and especially root growth, in acid soils is retarded by toxicities of Al^{3+}, Mn^{2+}, and H^+ ions. The degree of toxicity depends upon how high the concentration of exchangeable Al^{3+} is and how low the pH is (Havlin *et al*., 2005). The use of lime is maybe important for correction of soil acidity constraints so as to enhance the production of N-rich biomass in acid soils such as found in western Kenya.

Lime applied to acid soils raises the pH of soils, resulting in enhanced availability of nutrients, such as P, Ca, Mg, Mo and improved crop yields. Liming reactions begin with the neutralization of H^+ in the soil solution by either OH^- or HCO_3^- originating from the liming material (Havlin *et al.*, 2005). For example, $CaCO_3$ behaves as follows:

$CaCO_3 + H_2O \longrightarrow Ca^{2+} + HCO_3^- + OH^-$……………………….…equation (ii)

The rate of the reaction is directly related to the rate at which the OH^- ions are removed from the solution. As long as sufficient H^+ ions are in the soil solution, Ca^{2+} and HCO_3^- will continue to go into solution. When the H^+ ion concentration is lowered, however, formation of Ca^{2+} and HCO_3^- ions is reduced. The continued removal of H^+ from the soil solution will ultimately result in the precipitation of Al^{3+} and Fe^{3+} as $Al(OH)_3$ and $Fe(OH)_3$ and their replacement on the exchangeable sites by Ca^{2+} and/or Mg^{2+}. Liming has been shown to increase maize yields in various studies in western Kenya. Okalebo *et al.* (2007) reported increased maize yields up to 6.19 Mg/ha with a combination of lime and DAP fertilizer and 1.36 Mg/ha with sole DAP application in a maize and groundnut intercrop. In yet another experiment, lime (4 Mg/ha) and phosphorous (26 kg P/ha TSP), with a blanket 75 kg N/ha CAN applied to maize, raised the yields from 0.5 Mg/ha to 4-6 Mg/ha (Obura *et al.*, 2003).

Other studies reported that increased soil available P in acid soils due to lime application is because of decrease in P sorption due to the reduction of Fe^{3+} and Al^{3+} ions in the soil solution (Tisdale *et al.*, 1990). It is however highlighted that lime at different rates raised the soil pH and hence the available P in soils resulting in high maize yields reaching 4-6 Mg/ha (Gudu *et al*., 2007). Moreover, a decline in soil pH and available P was seen in consecutive cropping, suggesting the need to repeat lime application 2-3 years after initial application depending on soil lime requirement. Prolonged and better responses have been observed with higher doses of lime application at 4-6 Mg/ha (Gudu *et al*., 2007). Liming has also been reported to increase protein levels in soybean by improving the conditions for biological N-fixation as a result of reduced soil acidity and an increase in Mo availability (Marschner, 1995).

2.4.2 Mineral Fertilizer Use and Other Fertility Replenishments

With respect to agricultural productivity, Morris *et al.* (2007) found that low agricultural growth in Africa is positively correlated with and explained in large part by low fertilizer use. The primary aim of applying inorganic fertilizer is to increase the biological base of the plant system (Weight and Kelly, 1999). In doing so, inorganic fertilizer affords both plant productivity gains and long-term replenishment of nutrients back into the soil. Overall, the contribution of inorganic fertilizer to yields and, subsequently, increased agriculturally productivity is not disputed. The depletion of nutrients from the soil is also a major issue. Across all of SSA, Stoorvogel and Smaling (1990) estimate that an average of 660 kilograms of nitrogen per hectare, 75 kilograms of phosphorous per hectare, and 450 kg of potassium per hectare have been lost since the 1960s from about 200 million hectares of cultivated land. On the other hand, fertilizer use is estimated at 8 kg ha^{-1}, which is only 10% of the worlds' average (Smithson *et al.*, 1999). Similar trends are observed in Kenya.

Only about 20 percent of the land in Kenya is considered medium to high potential agricultural land (Bekunda *et al*. 2007). With high population growth, particularly in the agriculturally productive areas, farmers are forced not only to cultivate sub-optimal agricultural land (the other 80 percent of land), but also to use the same plots of land season after season without fallowing. Putting nutrients back into the soil, then, is the only realistic way to maintain the soil health necessary for sustained agricultural production. With evidence from western Kenya, Marenya and Barrett (2009) show that fertilizer profitability is contingent upon soil fertility levels, meaning farmers with poor soils are less likely to use fertilizer and get caught in the "trap" of low productivity due to the quality of their soil (i.e., soil structure, pore space, water-holding capacity, ability to release nutrients into the soil).

Fertilizer use is considered the obvious way to overcome soil fertility depletion given high N and P contents which are readily available to the crop. Improved soil P status has been reported with fertilizer application (Bunemann *et al.*, 2004). Traditional organic fertilizers (i.e., manure and compost) can be used to fix nutrients back into the soil (i.e., plants do not discriminate between organic and inorganic nutrient sources) but a much larger volume is required to do so. For example, most animal manure and plant material contain between 1 and 4 percent nitrogen content compared with 20 to 46 percent in inorganic fertilizers, and the phosphorous content of plant residuals and manure are generally not sufficient to meet crop growth requirements (Sanchez *et al*. 1997). Organic fertilizer use is generally recommended in addition to, but not as a replacement for, inorganic fertilizer (Weight and Kelly 1999).

Using a nationally representative panel, Ariga *et al.* (2008), found that the percentage of smallholder farmers using fertilizer on maize to have increased from 56 percent in 1996 to 70 percent in 2007 coupled with an increase in application amount from 34 kilograms per acre in 1996 to 45 kilograms per acre in 2007, with statistically significant variation across regions and districts, as expected. To the west in Vihiga and South Nandi Districts, Marenya and Barrett (2009) found that 88 percent of the 260 farmers sampled in their study used fertilizer in the 2004 main crop season. However, the rates applied were sub-optimal. Lack of access due to prohibitive costs limit optimal use of mineral N and P fertilizer in smallholder cropping systems (Odendo *et al.,* 2007). The unique socio-economic conditions and wide-spread rural poverty limit access to mineral fertilizers, inducing the search for cheap sources N such as BNF by grain legumes.

Makokha *et al.* (2001) observed that continuous cultivation using mineral fertilizers increased nutrient leaching, lowered the base saturation and aggravated soil acidification. Widespread use of N-fertilizers is limited by various socio-economic reasons: nitrogen can be applied in the form of organic inputs or nitrogenous chemical fertilizers. Usually only 30-50% of inorganic N fertilizer applied is used by the crop, the rest is lost through volatilization or leaching of nitrate down to the ground water (Makokha *et al.*, 2001). Therefore, there is need to improve the recovery of applied fertilizer N by crops, reduce losses of N and encourage the build-up of soil organic N, which would contribute to long-term soil fertility (Kibunja *et al.*, 2010). Inclusion of legumes such as soybean in maize intercrop and a moderate N application, targeted to the cereal crop, is therefore necessary to sustain yields in cereal–legume intercropping systems (Sanginga, 2003).

Research conducted in western Kenya has generated awareness of use of other soil fertility replenishment technologies which include: incorporation of crop residues such as, maize stover, wheat straw, bean trash and improved fallows (Palm *et al.* 1997; Gachengo *et al.* 1999), conservation tillage (Kihara *et al.*, 2011), farmyard manure (Jama *et al.*,1997), rock phosphates (Okalebo *et al*., 2007; Kifuko *et al.,* 2007) and tithonia green manure (Niang *et al.*, 1996). Niang *et al.* (1996) found greater maize yield following incorporation of tithonia biomass than biomass of other common shrubs and trees in western Kenya. He however cautioned that the transfer of tithonia biomass was not a universally appropriated intervention for soil fertility improvement in western Kenya. However, limited availability, high labour requirements for collection, carrying and cutting organic manures and low dissolution of phosphate rocks have led to their low adoption in western Kenya.

2.4.3 Biological Nitrogen Fixation

The unique socio-economic conditions and wide-spread rural poverty in sub-Saharan Africa limit access to mineral fertilizers, inducing the search for cheap sources of fertilization, such as nitrogen fixation by grain legumes. Nitrogen, in particular, is the most limiting element in crop production and is a key component of soil organic matter. Thus, emphasis should be given for establishment of efficient symbiotic N–fixing systems in legumes. Soybean is a multipurpose crop grown for industrial oil production, human food, while its’ by products can be used as livestock feed, and more recently, as a source of bio-energy. It grows to a height of 60–120 cm, maturing in 3 to 6 months depending on variety, climate, and location (Myaka *et* *al.,* 2006). Unlike most other legumes that contain about 20% protein, soybean contains 40% protein (Mugendi *et al.,* 2010).

Despite its possible potential of 3000 kg ha^{-1}, soybean grain yields have stagnated around 500 kg ha^{-1} among small scale farmers in western Kenya (KARI, 2010). Soybean has the ability to fix between 44 to 103 kg N ha^{-1} annually which can be used directly by the host plant (Sanginga *et al.,* 2003). However, several reports have highlighted low fixation capability of soybean especially if symbiotic association is constrained by various factors including inefficient strains capable of initiating the N-fixation process (Kihara *et al.,* 2011). This constraint could be alleviated through seed and/or soil inoculation with the proper Rhizobium bacteria before or at planting to facilitate N-fixation (Ndakidemi *et al.,* 2006).

Biological nitrogen fixation is a process in which atmospheric N_2 is reduced to ammonium (NH_4) by the nitrogenase enzyme complex. Only legumes of the sub-families *Caesalpinioideae, Mimosoideae* and *Papilionoideae* are involved in the process (Giller, 2001). It is carried out by prokaryotic micro organisms including bacteria, cyanobacteria and actinomycetes, in symbiotic or non-symbiotic associations with plants (Giller, 2001). Nodulation is used as an indicator of a legume's ability to fix N from the atmosphere. Nodulation of legumes is, however, affected by presence of native Rhizobia capable of nodulating the legumes. Legumes only grow vigorously if they have functioning nodules, and this depends upon their roots encountering the appropriate bacteria strains in the soil (Marschner, 1995).

Biological nitrogen fixation has various advantages including non repeated application of N fertilizers and higher pod yield (Sanginga *et al.,* 2003). Giller (2001) reported N fixation rates of 1 to 2 kg N ha^{-1} day^{-1} in a growing season by most tropical legumes. Peoples *et al.* (1995) noted that soybeans responded strongly to inoculation. He observed an increase in Ndfa by 56% (^{15}N) and 77% (Ureide), and a grain yield improvement of 7%. Ndakidemi *et al.* (2006) reported significant improvements in *P. vulgaris* and soybean growth with the application of inoculants in Tanzania. Cultivating legumes as intercrops or in rotation is key to exploiting BNF but it is crucial that soil nitrogen, including other nutrients, be limiting for BNF to proceed at its full potential (Giller 2001). Therefore, by exploring BNF, the systems optimize economic returns to farmers while minimizing the environmental concerns associated with high N use.

There are many environmental factors that limit BNF in field-grown soybean, including soil acidity, high soil N contents, nutrient deficiency, drought, pests and diseases (Giller, 2001). Low soil pH can induce deficiency in some essential plant nutrients, for example P and Mo, which leads to a reduction in the number of nodules and BNF (Marschner, 1995). High concentrations of protons (H^+) and aluminium (Al^{3+}) and low concentration of Ca and available P (Giller, 2001) in extremely acidic soils limit survival of rhizobia in the soil. Poor nodulation in legumes can also be caused by low survival and persistence of certain strains of rhizobia in acidic soils (Peoples *et al.,* 1995). The increase in soil pH by liming is therefore necessary in increasing nodule number and BNF in acid mineral soils (Peoples *et al.*, 1995).

Small quantities of available or fertilizer N have often been shown to have a stimulatory effect on legume nodulation and BNF the so-called “starter effect’’. This is mainly due to the stimulatory effect of N on growth and plant establishment during the period between root emergence and the onset of active BNF (Giller, 2001). In highly fertile soils, legumes thrive without fixing N_2. Under such conditions, they may derive all their N requirements from soil N. But in the majority of the soils in western Kenya, levels of plant available N are usually insufficient to satisfy a legume's N requirement (Gachengo *et al.,* 1999). Therefore, in presence of effective rhizobia, the unfulfilled N demand could be met by BNF (Peoples *et al.,* 1995). When levels of inorganic N increase, nitrogenase activity declines drastically, as well as the number of nodules. Shoot growth, however, continues to increase, indicating a shift from BNF to inorganic N nutrition (Fujita *et al.,* 1992). Most studies on the effect of fertilizer-N on soybean growth and N_2 fixation showed that N fertilization increased growth but reduced N_2 fixation through a reduction in the number, weight and activity of nodules (Walley *et al.*, 2005).

Several essential nutrients play a critical role in nodulation and biological nitrogen fixation. Phosphorous (P) is an essential plant nutrient and one of the most important nutrient elements in N_2-fixing legumes (Schulze *et al.,* 2006). Application of P has been widely reported to have a significant positive effect on biomass production, N accumulation and nodulation of legumes (Maschner, 1995). Symbiotic nitrogen fixation has a high P demand because the process consumes large amounts of energy (Schulze *et al.,* 2006) and energy generating metabolism strongly depends upon the availability of P (Plaxton, 2004). Several reports have documented that nodules are a strong P sink and nodule P concentration normally exceeds that of roots and shoots (Drevon and Hartwig, 1997). Somado *et al.* (2003) observed an increase in the amount of BNF-N to 36 mg N plant^{-1} in pots and to 84kg N ha^{-1} in the field after P application. Molybdenum (Mo) is a major component of the nitrogenase enzyme by forming the Mo-Fe protein complex. In acid soils of the tropics where Mo is mostly deficient, an induced N deficiency might be observed in legumes depending on N_2- fixation (Marschner, 1995). Calcium is important for nodule formation and appears to have a positive effect on the growth and survival of Rhizobium under acidic stress conditions (Giller, 2001).

Mineral nutrition in plants is linked to moisture availability (Fujita *et al.,* 1992). Legumes obtain nutrients from the soil in solution and require water for the translocation of the products of BNF to the shoot. Hence, drought stress or changes in plant water potential can cause a marked reduction in growth and nodulation in legumes due to reduction in nutrient uptake (Fujita *et al.,* 1992). This leads to a reduction in BNF and the translocation of fixed products. Soil moisture can also affect BNF indirectly by limiting plant growth, nodule formation and functioning (Sanginga *et al.,* 1995). Microorganisms that are responsible for BNF need soil moisture to carry out their activities. Drought stress will certainly have a negative effect on their activities in soil. Giller (2001) reported a reduction in the numbers of Rhizobia in the soil due to drought stress.

Pests and diseases affect vigour and depress growth potential, and as a result influence BNF negatively (Peoples *et al.,* 1995). High infestations of sap sucking, leaf eating, and stem or pod boring insects can drastically reduce legume biomass and yield. Corre-Hellou and Crozat (2005) observed a reduction in %Ndfa caused by pea weevil (*Sitona lineatus L.).* Kandji *et al.* (2003) reported heavy losses on field-grown common bean and maize in Kenya due to high incidence of root knot nematode (*Meloidogyne spp.)* and the spiral nematode (*Scutellonema spp*.). Supply of essential soil nutrients, adequate soil moisture and reduced soil acidity is therefore an important process and most likely a key regulatory component in the maintenance of nitrogen fixation in soybean that may influence plant growth. In addition calcium supplied through lime can perform multiple functions as it is an essential component in symbiotic N_2 fixation and nodule formation in legumes. In conclusion, the option of inoculation and lime application seems simple and low-cost technology which could be adopted by low income small scale farmers.

2.5 Economic analysis

Economic evaluation is a minimum extension to the various measures of total crop production frequently utilized to compare multiple cropping systems. Better understanding of how farmers' objectives change over time with higher returns and increased production appears to be a necessary input into more economic evaluation of a new technology (Kipsat, 2007). Those developing new technological systems have to anticipate changes in the agronomic and economic environments and evolving farmers' objectives since farmers will only be willing to adopt a system of farming if the returns on inputs are above alternative investments and are realized within a short time, one to three seasons. The fundamental point is that farmers would go for technologies that not only maximize yields but also accrue high profits. Therefore, it is important to move to economic analysis of the farm trials (Yadvinder-Singh, 2004).

Application of a unit input is economical, if the value of increase in the crop yield due to the quantity of input added is greater than the cost of input used. If a unit of input does not increase the yield enough to pay for its cost, its application will not be economical and will not return profit even after a constant increase in the yield (Yadvinder-Singh, 2004). Most studies which use nutrient replenishment inputs are invariably unaccompanied by economic (costs and returns) analysis. However, yield alone does not reflect much about the efficiency of production (Kipsat *et al.,* 2004). Kipsat (2007) reported that soil nutrient replenishment inputs that target smallholder farming communities must also contend with the resource constraints that affect the group. Therefore, there is need for agricultural production techniques that are capable of sustaining productivity and are affordable to the resource poor smallholder farmers.

The benefit-cost ratio (BCR) is one of the methods used on various studies to get the most economical treatments that are likely to be adopted by farmers (e.g. Mucheru-Muna *et al.,* 2010). Kipsat *et al.* (2004) defined BCR as a discounted measure of a project worth. It is given by the present worth of benefit stream divided by the present worth of the cost stream. The BCR shows the cost of production relative to the value of return of an enterprise. The benefit-cost (BCR) should be 2 or more for the technology to be feasible. Maize legume intercrop system which focuses on land use efficiency through row arrangement of crops and fertilizer use efficiency through strategic placement of inputs is one excellent way in which smallholder farmers can raise their returns on investments.

To be acceptable, a new technology needs to be:

- At a cost which the target group of farmers can handle
- Competitive with the present options that the farmers have for spending their cash
- Low risk of losing the cash investment

2.6 Gaps in literature

Despite all the above literature, the effectiveness of combined use of lime, inorganic P and inoculation has not been fully documented. Whereas it is sufficiently documented that inoculation can improve BNF leading to improved legume yields (Ndakidemi et al., 2006; Mugendi et al., 2010), farmers have not yet adopted the practice on their farms because conditions where BNF works are not well understood. Though previous research has been done on the effect of different P and lime sources such as inorganic fertilizers, rock phosphates, farmyard manure, tithonia green manure (Okalebo et al., 2007; Jama et al., 1999; Odendo et al., 2007) on soil chemical properties and maize-soybean grain yields, their use have been found to be limited, perhaps due to the low rate of dissolution of the rock phosphates, high costs of mineral fertilizers, high labour costs involved in manure use.

This study therefore aims at filling some of these gaps by investigating the effectiveness of lime application either as sole or combination with low rates of inorganic P and inoculation. This study will provide site specific best-fit solutions to the farmers and give valid advice on soil fertility management. It also comes clearly from research publications that the above technologies have been studied for potential yields but comparative economic analysis has not been part of it. Yield output alone does not reflect much about the efficiency of production. There is need therefore to economically evaluate the profitability of the demonstrated soil replenishment options.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area description

This study was carried out in Shianda sub-location, East Wanga division in Mumias district, western Kenya. The district lies between (34^o 29’ and 21^o E and 0^o 20’ and 11^o N) and receives bimodal type of rainfall with long rains (LR) expected in the months of March-June and short rains (SR) October-December (Jaetzold *et al.*, 2005). Annual rainfall ranges between 1650-2000mm with mean temperatures of 20.8-22 ^oC (MOA, 2007). Mumias district has a population density of 609 persons per square km on a total area of 590 km^2 with about 78, 685 households (Jaetzold *et al.* 2005). The households have good access to markets for both inputs and outputs with varying transaction costs. The district is predominantly in the lower midland agro-ecological zones (LM_{1-2}) with an average altitude of 1300 - 1500m above sea level (Jaetzold *et al.* 2005). The dominant soil types are humic acrisols characterized as well drained, moderately deep to deep, dark yellowish brown to dark reddish brown, friable, gravely sandy clay to clay, with an acid-humic topsoil (Jaetzold *et al.*, 2005).

Over 90% of the rural population depends on agriculture for its livelihood (MOA, 2004). Crop production and Livestock husbandry are practiced in the district whereby a range of crops are grown which include: maize, beans, sweet potato, sorghum, cassava, soybeans, ground nuts, vegetables and sugarcane among others. Sugarcane is the main cash crop in the area. Livestock comprises mainly local breeds of cattle (zebus), chicken, sheep and goats (MOA, 2004). Maize is an important food crop grown by almost all households in at least one cropping season per year. Soybean crop ranks fourth among the oil crops grown in western Province, and has average yield potential of 500 kg/ha (KARI, 2010). On-farm maize yields are low between 1.0 to 2 Mg/ha versus the potential of 6 Mg/ha (Okalebo *et al.,* 2007). Most farmers intercrop maize with beans.

The most important constraints perceived by farmers are low soil fertility, lack of financial resources to purchase inputs, especially fertilizers and seeds, and low technical know-how. Other constraints include; striga weed menace and stem borer damages, vagaries of weather (unreliability, hailstones) and low quality seed in the market. A number of insect pests and diseases attack maize from the seedling stage to storage. The most important pests include insects (stalk borers, termites, cutworms, and weevils) while diseases include smut, maize streak virus, and ear rots (Odendo *et al.,* 2001).

3.2 Experimental treatments and design

On-farm trials were set up on two farmers' fields during the 2011 Long rain and Short rain seasons, in Shianda sub-location. Eight (8) treatments were applied in each block. The treatments included:

1. Control (no lime, no inoculation and no inorganic P application).
2. Lime applied to both maize and soybean at a rate of 2.5 t/ha.
3. Inoculation of soybean.
4. Inorganic P applied to both maize and soybean at a rate of 30 kg P/ha.
5. Lime applied to both maize and soybean at a rate of 2.5 t/ha and soybean inoculation.

6. Lime applied to both maize and soybean at a rate of 2.5 t/ha and inorganic P applied to both maize and soybean at a rate of 30 kg P/ha.
7. Inorganic P applied to both maize and soybean at a rate of 30 kg P/ha and soybean inoculation.
8. Lime applied to both maize and soybean at a rate of 2.5 t/ha, inorganic P applied to both maize and soybean at a rate of 30 kg P/ha and soybean inoculation.

The experimental design was a (2 x 2 x 2) factorial arrangement laid out in a randomized complete block design (RCBD) with 4 replicates (Appendix 1). Each replicate acted as a block with 8 treatments per block. The plots measured 4.5 x 4.0 m with 1 m space between plots. The test crops were maize (*Zea mays* L, var. DK8031) intercropped with soybean (*Glycine max* L, var. Gazelle). Maize and soybean seeds were obtained from Kenya Agricultural Research Institute (Kakamega) since it is the most reliable supplier of certified seeds at standardized rates in the area. The agricultural lime ($CaCO_3$) was obtained from local agro-dealers in Kakamega town. The inoculum used was Biofix from MEA in Nairobi which contains the *Bradyrhizobium japonicum* bacterial strain. The inoculum solution was prepared 20 minutes before planting at the planting site. Single super phosphate was the source of inorganic P.

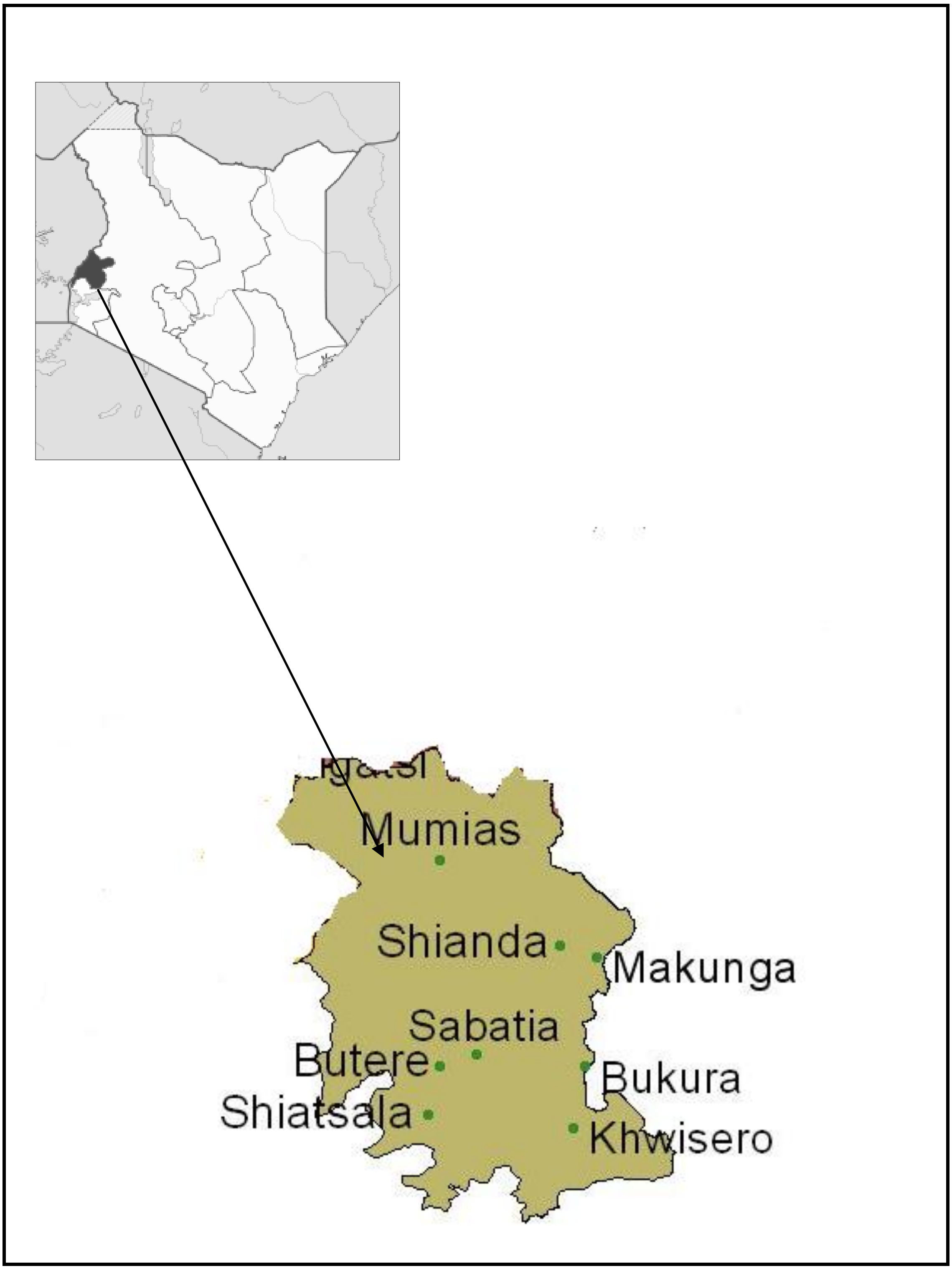

Figure 1: Map of western Kenya showing location of the study area.

3.3 Crop establishment and management

The field was cleared of grasses and other prevalent weeds then ploughed using a disc plough. Harrowing was done 2 weeks before planting using a hand hoe to a reasonable fine tilth followed by field layout. Agricultural lime at a rate of 2.5 t/ha was applied in the furrows 2 weeks before planting in season one. Single super-phosphate (SSP) fertilizer was applied to both maize and soybeans at planting to each hill at planting on soybeans and maize respectively. Maize crops were planted at a spacing of 75 cm between the rows and 30 cm within the rows, while soybean plants were sown in between maize rows at an inter-row spacing of 37.5 cm and 10 cm within the rows. Two seeds of maize were planted per hill and thinned to one 3 weeks after planting (WAP) to attain the recommended population of 44,444 plants/ha whereas soybean population was 133,333 plants/ha. The crops were kept weed free throughout the growing season through manual weed control. Bulldock pesticide was used to control stem borers in maize, while Ortiva fungicide and Diazinone pesticide were sprayed on soybean at early reproductive (R_1) stage to control leaf rust disease and aphids, respectively.

3.4 Soil and plant tissue sampling

Initial soil characterization was done at 0-20 cm depth before planting on each replicate at the beginning of the 1st season. Zigzag random sampling was carried out. Samples from each block were then mixed to form one composite sample per block giving a total of 4 composite samples (for baseline data). The second soil sampling was done at the end of the 2nd season, immediately after harvesting. 3 auger borings were made in each plot at three depths (0-20, 20-40 and 40-60) cm.

The soil from each depth was then mixed to form one composite sample giving a total of 96 soil samples from the 32 plots. The samples obtained from 0-20 cm depths were analyzed for soil particle sizes, available P, total N, total OC, soil pH(H_2O) and exchangeable bases (Ca, Mg and K). These were kept in polythene bags, dried in the sun and taken to the lab for analysis. The samples obtained from 0-20, 20-40 and 40-60 cm depths were used for available N analysis (NH_4^+-N and NO_3^--N) only. These were placed in a cool box and immediately transferred to the KARI soil lab freezer before analysis.

During the 1st season, 5 Soybean and maize seedling plants were cut above ground level with a knife from the two outer rows in every plot at four weeks after planting (4 WAP). For biomass and nodule data measurement, five soybean plants were uprooted carefully from the two outer rows in every plot at 8 WAP keeping the nodules intact. Roots were washed carefully; all nodules were separated and fresh weight determined. The nodules were cut open to determine the effective ones which were then counted. The plant tissues were sun-dried separately to a constant weight and dry biomass obtained. At R_1 (early bloom) stage, soybean leaves were sampled from 6 plants in the three middle rows from every plot for total N and P analysis. Soybean leaf tissue was obtained from the top fully developed trifoliate (three leaflets plus stem) at the time of first flowering since most of the plant nutrients are translocated to the top trifoliate in preparation for pod and seed formation. At 50% silking stage, 6 maize ear leaf tissues were sampled from the four inner plant rows in every plot for total N and P analysis. The plant tissues were all put inside brown sample bags, sun-dried in the brown bags then taken to the lab for analysis. In the lab, all plant tissue samples were chopped then ground to pass through a (<0.25 mm, 60 mesh) sieve and analyzed for total N and P following methods according to Okalebo *et al.* (2002). A composite sample made from each treatment was prepared for nutrient analysis; this is because of the high costs of analysis. Consequently, 16 maize and soybean seedling tissue samples, 8 soybean leaf tissue samples (R_1-stage) and 8 maize ear leaf tissue samples (50% silking stage) were prepared for lab analysis.

3.5 Crop yield determination

Maize plants within the harvest area were harvested by cutting the stalk at the root collar at maturity stage. The unshelled cobs were separated from the stover. The total fresh weight of the stover and unshelled cobs were measured using a field weighing balance in the farm and then sub-samples taken to KARI tissue reception lab where the sub-sample fresh weights were measured using an electronic balance. To obtain grain yields, maize grains were separated from the cob by hand shelling and then oven-dried to a constant weight. Similarly, after fresh weight measurement, empty cobs (without grain) and stover sub-samples were sun-dried to a constant weight. Grain yield was then determined.

Soybean crops within the harvest area were harvested at maturity stage by uprooting the whole plant. The total fresh weight of the whole plant biomass (haulms, pods and roots) was measured using a field weighing balance in the farm. Total numbers of pods per plant were counted and their fresh weight measured using a field weighing balance then pod and haulm sub-samples were taken to KARI tissue reception lab where the sub-sample fresh weights were measured using an electronic balance. To obtain grain yields, grains were separated from the husks by hand, grain sub-sample fresh weight obtained then oven-dried to a constant weight. Similarly, after fresh weight measurement, haulm and husk sub-samples were sun-dried to a constant weight. The proportion of dry matter for both maize and soybean was calculated by use of the formula:

$$\text{Yield (Mg/ha)} = (10 \times TFW \times SSDW) / (HA \times SSFW)$$

Where,

10 is a constant for conversion of yields in kg/m^2 to Mg/ha; TFW is total fresh weight (kg); SSDW is sub-sample dry weight (g); HA is harvest area (m^2) and SSFW is sub-sample fresh weight (g).

3.6 Soil and plant tissue analyses

3.6.1 Soil pH

A sample of 10g of soil was put in a 60 ml plastic bottle and 25ml of distilled water was added with a dispenser. The mixture was stirred for 10 minutes, allowed to stand for 30 minutes and stirred again for 2 minutes. The soil was allowed to settle for 30 seconds and then the electrode immersed into 60 ml bottle with soil and pH reading was recorded after the reading stabilized (about 30 seconds to 1 minute). The glass electrode was then removed from the bottle and rinsed with distilled water. Buffer solutions of pH 4 and 7 were used to calibrate the meter before measurements were taken (ICRAF, 1995).

3.6.2 Particle size analysis

The hydrometer method was used in this analysis (Gee and Bauder, 1986). An air-dry sample weighing 50 g was put in a 400 mL beaker and 125 mL of distilled water added. The organic matter was destroyed by use of 5 mL 30% hydrogen peroxide. Ten mL of 10% sodium hexametaphosphate solution was added to aid dispersion of soil particles. The sample was mixed with a high- speed mixer for 2 minutes and the suspension transferred quantitatively into 1000 mL measuring cylinder. The cylinder was then filled with water to the 1000 mL mark. The contents were then mixed thoroughly using a circular plunger attached to a wooden rod. Two to three drops of amyl alcohol were added to the cylinder to minimize foaming, and hydrometer readings taken at 40 seconds and 2 hours from the time mixing stopped. The 2 hours reading was used for calculating percentage clay while the 40 seconds reading was used in calculation of percentage sand. Percentage silt was obtained by subtracting the sum of percentage sand and clay from 100%.

3.6.3 Total soil organic carbon

Total soil organic carbon was determined by Walkley Black method (Black, 1965). About 1.0 g of soil sample, ground to pass through 0.2 mm mesh was weighed into labeled digestion tubes and 2 ml deionised water added. 10 ml of 5% $K_2Cr_2O_7$ solution was added into both standard and sample tubes. After this 5 ml concentrated H_2SO_4 was slowly added from an Eppendorf pipette. The acid was added 1 mL at a time while swirling on a vortex mixer. The suspensions were then digested at 150^0 C for 30 minutes and then allowed to cool. After cooling, 50ml 0.4% barium chloride solution was added and mixed thoroughly. The solution was allowed to stand overnight, so as to leave a clear supernatant solution. The following day, concentration of each standard sample was read at 600 nm on the spectrometer. This was done after determining the absorbance values for the standards so as to check on linearity of the standard curve and proper functioning of the spectrometer. The spectrometer was then calibrated in concentration mode, setting the calibration with the 15 mg C standard. Then blanks and samples were read in the concentration mode.

3.6.4 Determination of exchangeable calcium, magnesium and potassium

About 5 g of dry soil was extracted with 25ml of 1M NH_4 OAc (Ammonium acetate). The soil solution in the bottle was shaken for 30 for 10 minutes. The extract for analysis was then filtered through Whatman No.42 filter paper into a clean 60ml bottle. 1 ml of the extract or standard and 9 ml deionised water were dispensed into a clean 60ml bottle and 10 ml of 1% lanthanum solution added. Calcium and magnesium were measured using atomic absorption spectrophotometer while potassium was measured using a flame spectrophotometer (Anderson and Ingram, 1989).

3.6.5 Determination of extractable soil phosphorous

Phosphorus was determined using the Mehlich I method (Mehlich, 1953). About 5 g of air dry soil pulverized to pass through 10 mesh sieve (< 2.0 mm) was put in a 50-mL glass or plastic Erlenmeyer flask. 25.0 mL of M1 extracting solution (0.05 N HCl and 0.025 N H_2SO_4) was added into the plastic flask and placed on reciprocating mechanical shaker for five (5) minutes. The suspension was immediately filtered into 20 mL plastic scintillation vials.
P content was determined spectrophotometrically at 882 nm. Phosphorus concentration was then calculated for blank and unknown samples after plotting a standard curve.

3.6.6 Determination of total soil nitrogen

Total N was determined by Kjeldahl digestion method (Anderson and Ingram, 1993). A dry soil sample (0.4g) ground to pass through 0.3 mm was weighed into a labelled digestion tube and 1.8 g of K_2SO_4 added. 7.5 ml of soil digestion mixture (Selenium powder, concentrated sulphuric acid and salicyclic acid) was the added and left to stand overnight. The contents were then heated at 100^0C for 2 hours after which 3 mL of hydrogen peroxide (H_2O_2) was put before heating for another 4 hours at 360^0C. The contents were stoppered and left to stand so that a clear solution could solution could be obtained for analysis. 5 mL of reagent N1 (68 g sodium salicyclate, 50 g sodium citrate, 50 g sodium tartrate, 0.24 g sodium nitroprusside mixed with deionised water to make 2 liters) was added to 0.2 mL of the digested solution, mixed well and then left for one hour for color development. The sample concentration was then read at 655 on the atomic adsorption spectrophotometer.

3.6.7 Extraction of soil for nitrate-N and ammonium-N determination

Soil was stored in a refrigerator (about 4^0C) between collection and extraction. Twenty grams of field moist soil was extracted using 5 mL of 2N KcL within one week after collection. This was followed by gravimetric filtration through a pre-washed Whatman No.5 filter paper. The filtered extract was kept in a refrigerator awaiting ammonium and nitrate determination. Ammonium was determined by colorimetric method (Anderson and Ingram, 1993). Nitrate concentration was determined by cadnium reduction (Dorich and Nelson, 1984).

3.6.7.1 Ammonium-N determination

This was done using the salicyclate-hypochlorite colorimetric method (Anderson and Ingram, 1993). This method makes use of two reagents, which are namely: Reagent N1 and reagent N2. Reagent N1 was prepared by dissolving 68 g sodium salicyclate, 50 g sodium citrate, and 50 g sodium tartrate in 1500 mL of deionised water and then adding 0.24 g sodium nitroprusside. After full dissolution the solution was made up to 2 liters by topping with deionised water. On the other hand, reagent N2 was prepared by dissolving 60 grams of sodium hydroxide in 1500 mL deionised water and left to cool. 12.5 mL of sodium hypochlorite solution was then added and the solution made up to 2 liters with deionised water followed by proper mixing. Five (5.0) mL of reagent N1 was added to 2.0 mL of each standard and sample. The solution was mixed thoroughly by use of vortex mixer and left for 15 minutes after which 5.0 mL of reagent N2 was added and mixed again and then left for one hour for full color development. The absorbance of samples, blanks and standards was then read at 655 nm using a spectrophotometer.

3.6.7.2 Nitrate-N determination

One (1) mL concentrated ammonium chloride was added into the Cd column and 3ml of sample pipette into column and the solution was then drained (into a test tube containing 5 mL sulphanilic acid reagent) almost to top of the granules, leaving 2 mm of solution on top. Forty-five (45) mL of dilute ammonium chloride solution was added to the reservoir and drained within 25-30 seconds leaving approximately 2 mm of solution on top of the column. The test-tube was then removed and stoppered, shaken well and let to stand for five minutes after which 5 mL of 5-amino-2-

naphthalene sulphanilic acid (5-2 ANSA) solution was added, stoppered well and shaken. The solution was left to stand for 30 minutes and then absorbance read using spectrophotometer at 525 nm. No effort was made to separate NO_3^- and NO_2^- because NO_2^- was assumed to be small relative to NO_3^-, the values were reported as NO_3^-.

3.7 Collection of economic data

The data used for cost-benefit analysis as shown in Table 2, was collected at specific time for each activity in the course of each season. The data were mainly from 10 farmers and three agro-input stockists randomly selected from the study area. The data collected were grain maize and soybean yields (kg/ha), quantities of inputs, and corresponding prices, quantities of labour and wage rates.

3.8 Data analysis

3.8.1 Statistical data analysis

For the first and second objectives, data on grain yields, soil chemical properties, plant tissue nutrient composition, nodule number and fresh weight, soybean plant biomass, pod number and soybean haulm yield was entered into a Microsoft Excel spread sheet and then subjected to analysis of variance (ANOVA), using GenStat software (GenStat Release 7.22, 2010). Treatment means were separated by Least Significant Differences (LSD) at $P < 0.05$. A simple regression analysis at 5% level of significance was performed to examine relationships between some plant and soil parameters. Microsoft excel was used to prepare graphs.

3.8.2 Economic analysis

Economic analysis was performed on the data obtained for the third objective. The information used for cost-benefit analysis in this study was collected at specific time for each activity in the course of each season. Labour was measured in terms of person-days using the mean prevailing market wage rates from the study area as opportunity cost for labour provided by household members. All costs and benefits were calculated on per hectare basis in Kenya shillings (KShs ha^{-1}) using the following concepts as defined in economic analysis (CIMMYT, 1988):

$NB = \mathbf{GF_b - TC}$

$BCR = \mathbf{NB / TC}$

where,

NB = net benefit

TC = total costs

BCR = Benefit-cost ratio

GF_b = gross field benefits which is the product of mean yield and farm gate price

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter the results of all the data analyzed are presented and discussed in four sub-sections. The first sub-section presents the changes in soil chemical properties during the two seasons. The second and third sub-sections present nutrient content, growth parameters and grain yields of maize and soybean. The fourth sub-section presents the findings of economic evaluation of the different soil fertility options.

4.2 Soil properties

Initial soil properties prior to establishment of the trial in the 1st season (Table 1); show that the soil was strongly acidic with a pH of 4.9. The soil had low available P and exchangeable base (Ca^{2+}, Mg^{2+} and K^{+}) concentrations. Soil organic C and total N levels were also very low. The results of the effects of various treatments on soil pH are presented in Table 3. The initial soil pH measured at the beginning of the 1st season was 4.9 (Table 1). At the end of the 2nd season, the highest pH (5.58) was recorded in plots treated with sole lime at 2.5 t ha^{-1} followed by lime + inoculation + P (5.52) then lime + P treatment (5.28) (Table 2). Sole inoculation treatment recorded the lowest soil pH (4.64). Sole lime, P + lime, lime + inoculation and lime + P + inoculation treatments showed a significant statistical difference from the control whereas inorganic P and inoculation treatments did not show any statistical difference from the control. Lime reduces soil acidity by changing some of the hydrogen ions into water and carbon dioxide (CO_2). A Ca^{2+} ion from the lime replaces two H^+ ions on the cation exchange complex. The carbonate (CO_3^-) reacts with water to form bicarbonate (HCO_3^-). These react with H^+ to form H_2O and CO_2. The pH increases because the H^+ concentration has been reduced. Kisinyo *et al.* (2012) reported a significant effect ($p< 0.001$) of lime on soil pH whereas the effects of inoculation and fertilizer P on soil pH were not significant.

Table 1: Soil properties at Shianda site (0-20 cm) at the beginning of the LR season

Soil property	**Mean**
pH (1:2.5 Soil:H_2O)	4.9
Total Organic Carbon (%)	1.3
Total Nitrogen (%)	0.16
Available P (mg kg^{-1})	8.1
Exchangeable Ca ($mgkg^{-1}$)	340.0
Exchangeable Mg ($mgkg^{-1}$)	34.0
Exchangeable K ($mgkg^{-1}$)	117.0
Sand (%)	80
Silt (%)	5
Clay (%)	15
Textural class	loamy sand
Nitrate-N ($mgkg^{-1}$)	3.4
Ammonium-N ($mgkg^{-1}$)	11.1

Table 2: Effect of different treatments on soil chemical properties at the end of the 2nd season

Treatment	Available P (mg kg^{-1})	Total N (%)	O C (%)	pH (H_2O)	K (mgkg^{-1})	Ca (mgkg^{-1})	Mg (mgkg^{-1})
Ctrl	5.23^{c}	0.135	0.81	4.85^{c}	83.50^{cb}	320.0^{cb}	21.6^{c}
Lime	9.35^{cba}	0.143	1.22	5.58^{a}	97.25^{ba}	531.9^{cba}	43.4^{ba}
Inoculation	5.10^{c}	0.148	0.83	4.64^{c}	92.03^{cba}	136.2^{c}	42.2^{ba}
P	6.50^{cba}	0.137	0.98	4.72^{c}	79.53^{c}	450.1^{cba}	39.0^{ba}
P + Lime	12.22^{a}	0.143	1.28	5.28^{ba}	78.27^{c}	875.8^{a}	35.0^{cb}
P + Inoc.	6.28^{cb}	0.145	0.91	4.68^{c}	83.00^{cb}	139.1^{c}	51.4^{a}
Lime + Inoc.	6.35^{cb}	0.144	0.95	5.37^{ba}	83.55^{cb}	399.8^{cb}	43.6^{ba}
Lime+P+Inoc	11.05^{ba}	0.151	1.20	5.52^{ba}	104.50^{a}	617.5^{ba}	39.0^{ba}
LSD	**5.78**	**NS**	**NS**	**1.15**	**17.21**	**432.8**	**15.2**

Values in the same column followed by the same letter are not significantly different at P=0.05.

Table 3: Percent (%) change in soil chemical properties from the initial soil chemical properties under different treatments at the end of the 2nd season

Treatment	OC	Available P	pH	Total N	Ca	Mg	K
Control	-37.7	-35	-1.0	-20.0	-5.9	-36.5	-28.6
Lime	-6.2	15	13.9	-12.0	56.5	27.6	-16.9
Inoculation	-36.2	-37	-5.3	-7.0	-59.9	24.1	-21.3
P	-24.6	-19	-3.7	-18.0	32.4	14.7	-32.0
P + Lime	-1.5	50	7.8	-12.0	157.5	2.9	-33.1
P + Inoculation	-30.0	-22	-4.5	-10.0	-59.1	51.2	-29.1
Lime + Inoculation	-26.9	-21	9.6	-11.0	17.6	28.2	-28.6
P + Lime + Inoculation	-7.7	36	12.7	-4.0	81.6	14.7	-10.7

Negative (-) values indicate % decrease while positive (+) values indicate % increase.

Generally, the soil pH in the control, sole inoculation, sole P application and P + inoculation treated plots decreased by 1.0, 5.3, 3.7 and 4.5 per cent, respectively from the initial soil pH (4.9) while P + lime, lime + inoculation, lime + P + inoculation and sole lime treatments increased soil pH by 7.8, 9.6, 12.7 and 13.9 per cent, respectively from the initial soil pH (Table 3). Most nutrients become less available at lower pH and consequently lead to low legume yields. Reduction in nutrient toxicities and corresponding increase in nutrient availabilities as a result of lime creating a conducive environment for soybean growth, rhizobial growth and activity has been observed from this study.

As shown from Table 2 above, the highest soil available P content was recorded in the lime + P (12.22 mg kg^{-1}) followed by lime + P + inoculation (11.05 mg kg^{-1}) then sole lime treatments (9.35 mg kg^{-1}) each giving an increase of 50, 36 and 15 per cent respectively from the initial soil P content (Table 3). This substantial increase could have been caused by quick action of lime in improving soil acidity and hence phosphorus availability (Kisinyo *et al.*, 2012) and the effect of P fertilizer in increasing P in the soil solution (Tisdale *et al.,* 1990).

Sole lime, inorganic P and inoculation treatments were not statistically different from the control. Sole inoculation treatment recorded the lowest soil available P content of (5.10 mg kg^{-1}) with a 37% decrease from the initial soil available P content (Table 3). This could be due to the fact that P is a key requirement for ATP production during the process of biological nitrogen fixation. Sole lime treatment recorded higher soil available P content (9.35 mg kg^{-1}) than sole P treatment (6.50 mg kg^{-1}). However, combined applications of lime + P and P + lime + inoculation led to an increase in soil available P which is significantly different from the control. In a study in western Kenya, Kisinyo *et al.* (2012) pointed out that both lime and P fertilizer applications are important to enhance soil available P in acid and P deficient soils. He reported mean soil available P increments of 92% and 209% following the application of lime and P fertilizer after 7 months of sesbania growth, respectively. The low levels of soil available P obtained at the end of the 2nd season could be attributed to crop uptake as maize and soybean have high P requirements and this also was observed in the increase in their shoot P content.

There was no significant difference in the effect of lime, inorganic P and inoculation on both total N and organic C contents of soil at the end of the 2nd season (Table 2). This was because there was no external N-input. This could be as a result of initial low levels of N in the soil coupled with high crop demands. However, treatments with inoculants, gave slightly higher levels of N. The positive effect of inoculation treatment on soil N content as observed in this study has also been reported by Patra *et al.* (2012).

A comparison between initial soil N at the beginning of the 1st season and at the end of the 2nd season, revealed that the soil N content decreased after maize and soybean cropping in all treatments as shown in Table34. The highest depletion (20%) was observed in the control plots, followed by sole P (18%) then inoculation (7%) treatments while the lowest depletion was observed in the lime + P + inoculation (4%) treatment. These results are in line with the observations of Patra *et al.* (2012), who reported a depletion of soil N status by 13.4-20.2% in the inoculation treatments and 29.6% in the un-inoculated treatments in a soybean cultivated field. Kamoni *et al.* (2000) also observed a decreasing trend in total soil N content during the growth period of maize with maximum uptake recorded at 10 days before tasselling to 25 to 30 days after tasselling. Losses of N could also be attributed to leaching, because of heavy rains in the area and microbial immobilization.

Lime + P treatment recorded the highest soil organic C content (1.28%) followed by sole lime treatment (1.22%) whereas the control gave the lowest organic carbon content (0.81 %) (Table 2). Plots with sole inoculation treatment registered lower soil organic C content (0.83%) than plots with sole P treatment (0.98%). A comparison between initial soil organic C content and at the end of the 2nd season revealed a general decline in organic C in all treatments. The highest depletion (37.7%) was observed in the control plots, followed by sole inoculation treatment (36.2%) then P + inoculation treatment (30.0%) while the lowest depletion was recorded in the lime + P treatment (1.5%) (Table 3). In a continental-scale research involving different sites in North and South America, diversity of soil bacteria communities increased as soil pH increased from acidic to near neutral (Fierer and Jackson 2006). Thus, farming practices such as liming that improve availability of soil nutrients also enhance soil microbial diversity. Positive relationship of bacterial diversity with soil nutrients such as organic carbon has been reported (Marschner *et al.*, 2003). The amount of soil organic C content as observed from this trial was decreased (Table 1). Organic C depletion in western Kenyan soils is enhanced by high temperatures and soil moisture availability that favor rapid organic matter decomposition (Jaetzold *et al.,* 2005).

Lime + P + inoculation and lime + P treatments gave significantly high concentrations of Ca^{2+} (617.5 mg kg^{-1} and 875.8 mg kg^{-1}), respectively (Table 4). Sole lime recorded higher increase in concentration of K^+ (97.25 mg kg^{-1}) than sole inoculation (92.03 mg kg^{-1}) and sole P treatments (79.53 mg kg^{-1}) from the control plots (83.50 mg kg^{-1}). However, sole inoculation recorded lower Ca^{2+} concentration (136.2 mg ka^{-1}) than the control (320.0 mg kg^{-1}) (Table 4). There was a general decline in soil exchangeable K^+ concentration in all treatments at the end of the 2nd season whereas both exchangeable Ca^{2+} and Mg^{2+} showed varied responses to the different treatments (Table 3). A comparison between initial soil exchangeable base concentrations at the beginning of the 1st season and at the end of the 2nd season revealed that, sole lime treatment increased soil mg^{2+} and Ca^{2+} concentrations by 27.6 and 56.5% respectively. Though the levels of K^+ did not show a significant increase from the initial soil status, a combination of lime + P + inoculation recorded the least decrease in K^+ (10.7%) followed by sole lime(16.9%) treatment (Table 4).On the other hand, sole P treatment increased soil exchangeable Ca^{2+} and Mg^{2+} concentrations by 32.4% and 14.7% with a 32% decrease in K^+ concentration (Table 4) while sole inoculation increased Mg^{2+} concentration by 24.1% with a 59.9% and 21.3% decrease in Ca^{2+} and K^+ concentrations respectively (Table 3).

These results are in line with the observations of Phengsouvana *et al.* (2009), who reported increased concentration of Ca^{2+} and Mg^{2+} from 154 to 314 mg kg^{-1} and from 66 to 93 mg kg^{-1} respectively due to liming. Caires *et al.* (2006) studied the effect of liming on Oxisols and found that liming resulted in a significant increase in pH and exchangeable Ca^{2+} and Mg^{2+}. Similar findings were observed by Ciful *et al*. (2004) who reported a significant increase in exchangeable Ca^{2+} and Mg^{2+} as a result of lime application. In another study, Guo *et al.* (2009) reported an increase in soil pH from 5.45 to 6.54, and exchangeable Ca^{2+} from12.42 ppm to 29.21 ppm soil due to liming.

There was an observed significant effect of lime, P and inoculation on ammonium-N (NH_4-N) at three different soil depths (Table 4). The highest concentration of NH_4-N was recorded in the sole inoculation treatment (12.6mg kg^{-1}) while the lowest concentration of NH_4-N was recorded in the lime + P + inoculation treatment (6.6mg kg^{-1}) at the top soil (0-20cm). The high level of NH_4-N in the inoculation treatment could be attributed to enhanced biological nitrogen fixation. The initial NH_4-N contents measured prior to sowing , at the beginning of the 1st season, in the 0-20cm, 20-40cm and 40-60cm depths were 11.1, 9.8 and 8.5 (mg kg^{-1}) respectively. Sole inoculation treatment gave the highest increase (13.5%) in NH_4-N level while lime + P + inoculation treatment gave the highest decrease (40.5 %) in NH_4-N level on the top soil from the initial soil NH_4-N content (Table 5). This could be due to nitrification process which increases under favorable environmental conditions such as increased soil pH and good aeration for the nitrifying bacteria.

Table 4: Effect of different treatments on mineral N at different soil depths at the end of the 2nd season

Soil Depth	**0-20cm**		**20-40cm**		**40-60cm**	
Treatment	**NH4+ ($mgkg^{-1}$)**	**$NO3^-$ ($mgkg^{-1}$)**	**NH4+ ($mgkg^{-1}$)**	**$NO3^-$ ($mgkg^{-1}$)**	**NH4+ ($mgkg^{-1}$)**	**$NO3^-$ ($mgkg^{-1}$)**
Ctrl	10.2^{edc}	3.00^{d}	$6.1d^{cb}$	1.625^{c}	6.9^{a}	1.53^{c}
Lime	10.6^{dcba}	3.72^{cd}	5.5^{d}	2.24^{a}	5.8^{ba}	2.2^{ba}
Inoculation	12.6^{a}	4.35^{ba}	6.9^{cba}	1.95^{cba}	6.5^{a}	2.15^{ba}
P	8.9^{ed}	3.23^{dc}	5.9^{dc}	2.03^{ba}	6.0^{ba}	1.73^{cb}
P + Lime	9.0^{edc}	4.68^{ba}	5.5^{d}	1.69^{cb}	3.5^{c}	2.1^{ba}
P + Inoculation	12.1^{ba}	4.34^{ba}	7.3a	1.92^{cba}	6.5^{a}	2.44^{a}
Lime + Inoculation	9.3^{edcb}	4.81^{ba}	4.1^{e}	2.14^{a}	4.8^{cb}	2.25^{a}
Lime + P + Inoculation	6.6^{e}	5.26^{a}	4.0^{e}	2.2^{a}	5.7^{ba}	2.38^{a}
LSD	**2.84**	**1.11**	**1.12**	**0.4**	**1.9**	**0.51**

Values in the same column followed by the same letter are not significantly different at P=0.05.

Table 5: Percent (%) change in soil mineral N under different treatments at the end of the 2nd season

	0-20cm		20-40cm		40-60cm	
Treatment	**NH_4^+**	**NO_3^-**	**NH_4^+**	**NO_3^-**	**NH_4^+**	**NO_3^-**
Control	-8.1	-11.8	-37.8	-47.6	-18.8	-43.3
Lime	-4.5	9.4	-43.9	-27.7	-31.8	-18.5
Inoculation	13.5	27.9	-29.6	-37.1	-23.5	-20.4
P	-19.8	-5	-39.8	-34.5	-29.4	-35.9
P + Lime	-18.9	37.6	-43.9	-45.5	-58.8	-22.2
P + Inoculation	9	27.6	-25.5	-38.1	-23.5	-9.6
Lime + Inoculation	-16.2	41.5	-58.2	-31	-43.5	-16.7
P + Lime + inoculation	-40.5	54.7	-59.2	-29	-32.9	-11.9

Negative (-) values indicate % decrease while positive (+) values indicate % increase.

There was an observed significant effect of the different treatments on NO_3-N at the three different depths (Table 4). The highest concentration of NO_3-N in was recorded in the lime + P + inoculation treatment (5.26mg kg^{-1}) while the lowest concentration was recorded in the control plots (3.00mg kg^{-1}) at the top soil. Initial NO_3-N content measured prior to sowing, at the beginning of the 1st season, in the 0-20 cm, 20-40 cm and 40-60 cm depths were 3.40, 3.10 and 2.70 (mg kg^{-1}) respectively. Lime + P + inoculation treatment recorded the highest increase (54.7%) in NO_3-N level while the control recorded the highest decrease (11.8%) in NO_3-N level on the top soil at the end of the 2nd season (Table 5).

The levels of both NH_4-N and NO_3-N showed a decreasing trend with soil depth increase (Table 5). The marked decrease in levels of soil mineral-N (ammonium-N + nitrate-N) at the end of the 2nd season could be as a result of crop uptake as observed from soybean shoot N concentration. Higher levels of mineral-N recorded in the inoculated plots could probably be due to increased soil N content as a result of biological nitrogen fixation. The decrease in mineral-N content with depth could be attributable to the rhizosphere effect, better substrate supply and higher microbial biomass in the upper soil depth than the sub-soil, and organic matter decrease with depth. This observation is in agreement with Kladivko (2001) who reported that soil microbial biomass (SMB) as well as mineralization of carbon and nitrogen tended to be greater in the upper layers of the soil and decrease with depth. He also indicated the existence of a relative high accumulation of nitrogen in the rhizosphere.

Mineralization of rhizo-deposition provides a possibility for `recycling´ organically bound nutrients such as N and P (Marschner *et al.*, 2003). Lelei *et al.* (2006) also observed the decline in organic matter in soil with depth increase. The relatively low available N observed at the end of the 2nd season could be due to increased crop uptake and competition between the legume and cereal components for soil available N. Cadisch *et al*. (2002) also observed a decrease in soil available N content at the end of a maize cropping season.

4.3 Soybean performance

4.3.1 Nutrient uptake in soybean at seedling and R_1 (early bloom) stages

Figure 2 shows the effect of different treatments on shoot N and shoot P contents of soybean at seedling and R_1 stages during the first season. Soybean shoot N content ranged between 2.0 to 4.2% at seedling stage and 2.5 to 5.2% at R_1 stage. Maximum shoot N content was recorded in the lime + P + inoculation treatment while lowest shoot N content was recorded in the control plots at both growth stages. At seedling stage, inoculation, sole lime and sole P treatments recorded shoot N contents of 4.0, 2.6 and 2.3% respectively while at R_1 stage, inoculation, sole lime and sole P treatments recorded shoot N contents of 4.8, 3.7 and 3.4% respectively. There was a general increasing trend of soybean shoot N content from the seedling to the R_1 stages.

The increase in N content in shoots of soybean from lime application is a function of both nitrogen-fixing ability of the legume and soil nitrogen availability, especially during the early growing stages (Edmeades *et al*., 1981). Inoculation and application of P increases nitrogenease activity, nodule mass that ultimately increases shoot N content. It is also possible that P enhanced more root development and root mass, which influenced more N uptake. These results corroborates to the findings of Hayat *et al*. (2008). However, they contradict the findings of Kisinyo *et al*. (2012) who observed increased shoot N contents by 73%, 182% and 36% with lime, inorganic P application and inoculation on sesbania seedlings after 8 weeks respectively. In addition, Shoot N concentration was significantly more at 3 levels of lime supply relative to the control.

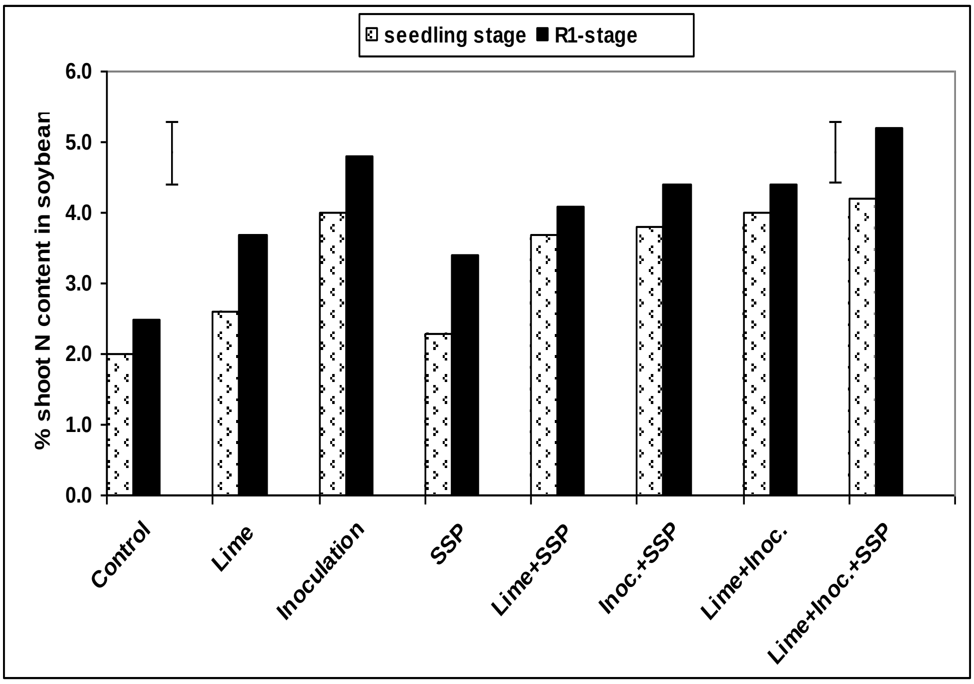

Figure 2: Effect of different treatments on soybean shoot N content at seedling and R_1 stages during the first season. Error bars represent standard deviation between treatment means at seedling and at R_1 stages respectively.

Soybean shoot P content ranged between 0.22 to 0.38% at seedling stage and 0.30 to 0.41% at R_1 stage (Figure 3). Highest shoot P content was recorded in the lime + P + inoculation treatment while lowest shoot P content was recorded in the control plots at both stages of growth. At seedling stage, sole P, sole lime and inoculation treatments recorded shoot P contents of 0.33, 0.32 and 0.31% respectively while at R_1 stage, sole P, inoculation and sole lime treatments recorded shoot P contents of 0.38, 0.38 and 0.36% respectively. There was a general increasing trend of soybean shoot P content from the seedling to the R_1 stages.

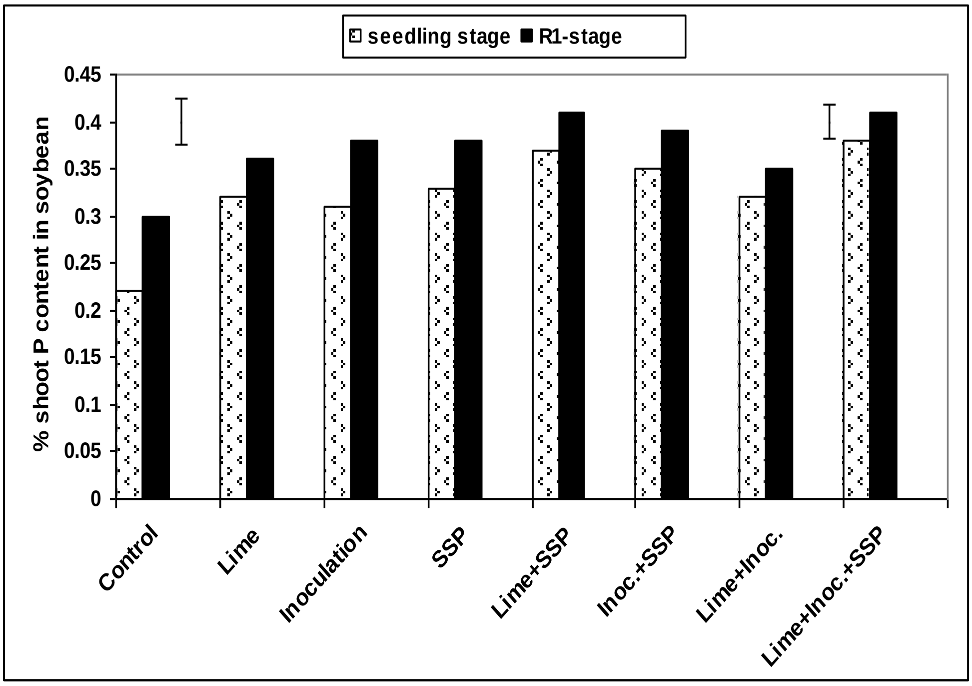

Figure 3: Effect of different treatments on soybean shoot P content at seedling and R_1 stages during the first season. Error bars represent standard deviation between treatment means at seedling and at R_1 stages respectively.

Higher P uptake due to inoculation could be attributed to the ability of applied rhizobia to solubilize precipitated P components thereby leading to increased P uptake in plants as reported by Fatima *et al.* (2007). The current results on increased shoot P content with lime and P applications agree with the findings of Hayat *et al.* (2008) and Kisinyo *et al.* (2012). In yet another study, Guo *et al*. (2009) reported increased shoot P concentration in lucern due to liming whereas Olivera *et al*. (2004) noted that phosphorous application to legumes increases plant biomass including nodule biomass and shoot P content due to the increased rate of nitrogen fixation. P is an essential element for energy transfer processes in plants. Phosphorus deficiency limits photosynthesis which leads to reduction in biomass accumulation (Neil, 1991).

4.3.2 Number of nodules per plant

The average number of nodules per plant in soybean at 8 Weeks after planting (WAP) was compared between different treatments during the first season (Table 6). Highest average number of nodules per plant was obtained from plots which received inorganic P + inoculation treatment (11), followed by both lime + inoculation and lime + inoculation + P (10). The lowest average number of nodules plant per plant was obtained from the control plots (1). Sole P application recorded (8) average number of nodules per plant. However, when combined with inoculation, significantly higher (11) average number of nodules per plant was obtained (Table 6). Inoculation recorded higher average number of nodules per plant (4) than sole lime (2).

Inorganic P plays a major role the process of symbiotic N_2 fixation because it facilitates signal transduction and membrane biosynthesis for generation of ATP for nitrogenase function. Several other processes involving P include; enzyme activation-inactivation, signal transduction, carbon partitioning, plastid function and membrane biosynthesis. Moreover, when N-fixing species are grown in low P conditions, P-fertilization leads to increased nitrogenase activity, nodule number, nodule mass and plant N accumulation (Giller, 2001).

Table 6: Effect of different treatments on average nodule number, nodule fresh weight, plant biomass and pod number per plant in soybean during the first season

Treatment	**Average nodule number per plant**	**Average nodule fresh weight per plant (g)**	**Average plant biomass (g)**	**Average pod number per plant**
Ctrl	1^{d}	0.085^{c}	14.4^{d}	10^{d}
Lime	2^{dc}	0.103^{c}	16.8^{dc}	13^{dc}
Inoculation	4^{dcb}	0.155^{cba}	19.2^{cba}	14^{dcb}
P	8^{cba}	0.157^{cba}	21.8^{ba}	14^{dcb}
P + Lime	4^{dc}	0.138^{cb}	18.8^{dcba}	14^{dcb}
P + Inoculation	11^{a}	0.205^{ba}	22.7^{a}	15^{cba}
Lime + Inoculation	10^{ba}	0.198^{ba}	17.3^{dcb}	18^{ba}
Lime+P+Inoculation	10^{ba}	0.228^{a}	19.7^{cba}	19^{a}
LSD	**5.7**	**0.08**	**4.7**	**4.2**

Values in the same column followed by the same letter are not significantly different at P=0.05.

The results from this study are in agreement with observation made by Hayat *et al.* (2008) who reported increased nodulation and N concentration of beans with P fertilization. Mugendi *et al.* (2010) also showed that number of nodules per plant of soybean was significantly influenced by addition of 25 kg P ha^{-1}; however he reported that nodule fresh weight per plant was not significantly influenced by application of fertilizer P at different levels. Noticeable numbers of nodules in the control treatments reflects the presence of indigenous rhizobia strains in this soil but were not effective in N-fixation (white in colour).

In an experiment in Nigeria, the percentage increase in nodule number and dry weight after inoculation of soybean cultivars with Bradyrhizobia strains ranged from 71-486% and from 0-200%, respectively (Okereke *et al.*, 2004). However, greater number of nodules due to inoculation suggested that there is better combining and symbiotic relationship between introduced rhizobia and soybean and high competitive ability of inoculant bradyrhizobia used (Okereke *et al.,* 2000). Lime application led to an increase in nodule number due to its effect on increasing soil pH leading to a reduction in Al toxicity (Giller, 2001) which in turn enhances the survival of Rhizobial population responsible for nitrogen fixation (Peoples *et al.,* 1995).

Increased nodulation, growth and N_2 fixation due to lime application have been reported in sesbania and other legumes in acid soils (Kodiango *et al.,* 2007). Studies by Giller (2001) have indicated that calcium deficiency in legumes depressed the calcium content of nodules, impairing nitrogen fixation due to inadequate calcium for nodule structure and metabolism. The importance of acidity correction for improving the symbiotic fixation of N_2 and the yield of soybeans grown under a conventional tillage system was demonstrated by Marschner (1995). Phosphorous fertilizer application led to an increase in nodulation of soybean which could be attributed to the fact that P is essential in energy transfer processes in living organisms; therefore, it controls the nodule growth and modulates the symbiotic processes of the legume and Rhizobium (Hellsten and Huss-Danell, 2000). In addition, phosphorous may increase the nodulation through stimulation of nitrogenase activity and improved plant growth (Gentilli and Huss-Danell, 2003). A comparison between inoculated and un-inoculated plots revealed higher values of average number of nodules per plant from inoculated plots with a range of 4 to 11 as compared to un-inoculated plots with a range of 1 to 8.

4.3.3 Nodule fresh weight per plant (g)

The Average nodule fresh weight per plant at 8 WAP was compared between different treatments during the 1st season (Table 6). The highest average nodule fresh weight per plant (0.23 g) was obtained in lime + P + inoculation treated plots followed by P + inoculation treatment (0.21g) whereas the lowest average nodule fresh weight per plant (0.09 g) was obtained from the control plots. Sole lime treatment recorded average nodule fresh weight per plant (0.10 g) which was not statistically different from the control (0.09 g). Sole P and inoculation treatments gave the same average nodule fresh weight per plant of 0.16 g.

A comparison between inoculated and un-inoculated plots revealed higher values of average nodule fresh weight per plant obtained from inoculated plots with a range from 0.16 to 0.23 g as compared to un-inoculated plots with a range from 0.09 to 0.16 g. The results from this trial agree with the findings of Mugendi *et al.* (2010) who found that nodule fresh weight of soybean across fields and varieties increased by 112.5% when fertilizer application was increased from 10 kg P ha^{-1} to 25 kg P ha^{-1}. Kihara *et al.* (2011) also observed higher nodule fresh weight of soybean with inorganic P application at 60 kg P ha^{-1} as compared to the control.

4.3.4 Soybean plant biomass (g)

Table 6 represents the average biomass per plant at 8 WAP as affected by different treatments during the 1st season. The average biomass per plant ranged from 14.4 g to 22.7 g. The highest average biomass per plant (22.7 g) was obtained in the plots which received the inoculation + P treatment followed by sole P treatment

(21.8g) while the lowest average biomass per plant was obtained in the control plots (14.4 g). Sole inoculation treatment recorded 21.8 g while sole lime treatment recorded 19.2 g average biomass per plant. The effect of inoculation on soybean biomass production could be due to enhanced BNF resulting to increased plant growth. Inorganic P on the other hand, enhances ATP production which is a key requirement for nodule development and functioning. The results in this study are in line with the observations of Mugendi *et al.* (2010), who concluded that application of 25 kg P ha^{-1} increased plant biomass by 10% in soybean crop. In another study, Guo *et al.* (2009) reported a significant ($p<0.05$) increase in plant biomass as a result of Sinorhizobium inoculation in lucern.

The increase in soybean biomass with P application and inoculation observed in this study could be attributed to the effect of P on enhanced crop growth and effect of inoculation on biological nitrogen fixation which also leads to increased plant growth. In their studies, Tsvetcova and Georgiev (2003) concluded that phosphorous deficiency in soybean led to a decrease in plant biomass, nodule weight, number and grain yield. A comparison between inoculated plots and un-inoculated plots revealed higher values of average plant biomass obtained from inoculated plots which ranged from 19.2 to 22.7 g as compared to un-inoculated plots which ranged from 14.4 to 21.8 g.

4.3.5 Number of pods per plant

Table 6 shows the average number of pods plant per plant of soybean in response to different treatments during the first season. The highest average number of pods plant per plant (19) was recorded in plots treated with lime + P + inoculation while the lowest average number of pods per plant (10) was recorded in the control plots. There was no observed significance difference between sole inoculation (14) and sole P (14) treatments which gave a higher average number of pods per plant than sole lime treatment (13). The increase in number of pods per plant after P application might be due to enhanced pod and seed formation resulting from increased ribulose-1-5-diphosphate carboxylase activity caused by increased P supply from fertilizer P (Gentilli and Huss-Danell, 2003).

Tahir *et al.* (2009) also observed a 67% increase in number of effective pods per plant and 21% increase in seed yield of soybean with application of fertilizer P + inoculation. In other studies, Gentili and Huss-Danell (2003) concluded that combined application of P and inoculation increased growth, yield and nitrogenease activity as well as improved soil fertility for sustainable agriculture. Similar findings were reported by Zhang *et al.* (2002) who suggested that *B. japonicum* improved seed yield of soybean largely due to increase in pod and seed number.

4.3.6 Soybean grain yield (kg/ha)

The effect of different treatments on soybean grain yield was statistically significant in the two seasons (Table 7). Lime + P + inoculation treatment gave the highest grain yield of soybean (970 and 830 kg/ha), followed by inorganic P + inoculation (740 and 610 kg/ha) whereas the control plots gave the lowest grain yield of soybean (477 and 351 kg/ha) in the 1st and 2nd seasons, respectively. Sole lime treatment gave an average soybean grain yield of (610 kg/ha) followed by sole P (535 kg/ha) then sole inoculation treatments (505 kg/ha) in the two seasons. The increase in soybean grain yield under inoculation treatment could be attributed to improved N status in the soil due to enhanced biological nitrogen fixation (BNF). In a study carried out by Phengsouvana *et al.* (2009), lime increased soybean growth and yield due to enhanced pH. Enhanced nodulation and number of pods per plant in lime + P + inoculation treated plots contributed to observed higher soybean yields.

Table 7: Effect of different treatments on soybean grain yield during the first and second seasons

Treatment	**First season Kg/ha**	**Second season Kg/ha**
Ctrl	477^{c}	351^{d}
Lime	670^{cb}	550^{cb}
Inoculation	540^{cb}	470^{dcb}
P	560^{cb}	510^{dcb}
P + Lime	720^{b}	590^{cb}
P + Inoculation	740^{ba}	610^{cb}
Lime + Inoculation	710^{b}	580^{cb}
Lime + Inoculation + P	970^{a}	830^{a}
LSD	**240**	**170**

Values in the same column followed by the same letter are not significantly different at P=0.05.

Phosphorus is an important element in legume establishment and its deficiency limits legume production in most of agricultural soils (Fatima *et al.*, 2007). Similarly, combined application of fertilizer P and legume inoculation has also led to increased growth, yield and nitrogenase activity as well as improved soil fertility in various studies (Gentili and Huss-Danell, 2003; Fatima *et al.*, 2007). Soybean grain yields were lower in the 2nd season than in the 1st season probably due to inadequate soil moisture content during the crop growth period (Appendix 3 and 4). Other studies such as Okereke *et al.* (2004), have obtained soybean seed yield range between 1200 and 2180 kg/ha with inoculation against 1050 kg/ha in un-inoculated plants. The generally low soybean grain yields reported in this study could be attributed to low soil pH and infestation by the leaf rust disease at the early flowering stage of the crop.

Low nodulation status of the soybean crops observed in this study could have also contributed to the low grain yields obtained. Moreover, geared by modifications and utilization of light, water, nutrients and enzymes, intercropping systems between cereals and legumes may face a complex series of inter and intra-specific interaction. Generally, the cereal component is considered a suppressing crop in cereal-legume associations like maize-soybean (Muoneke *et al.*, 2007. There was a significant positive linear correlation between soybean grain yield, nodule fresh weight per plant (R^2 = 0.54) and pod number per plant of R^2 = 0.74 during the 1st season (Figures 4 and 5).

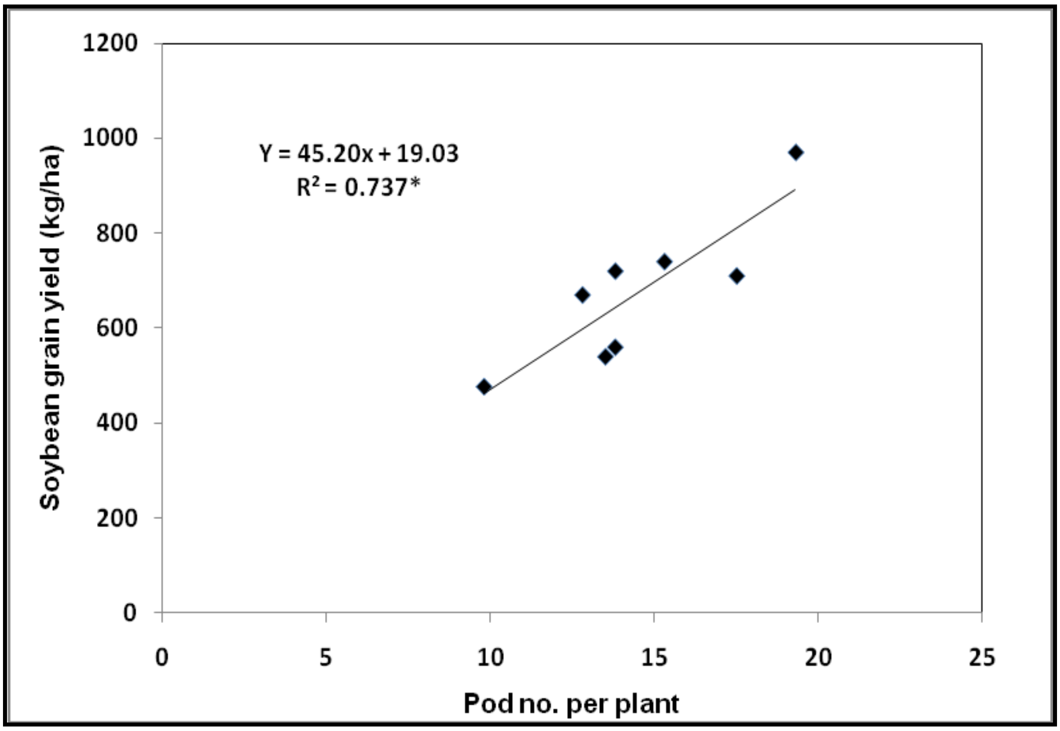

Figure 4: Correlation between soybean grain yield and average number of pods per plant during the 1st season. * = significant at 5% level of confidence.

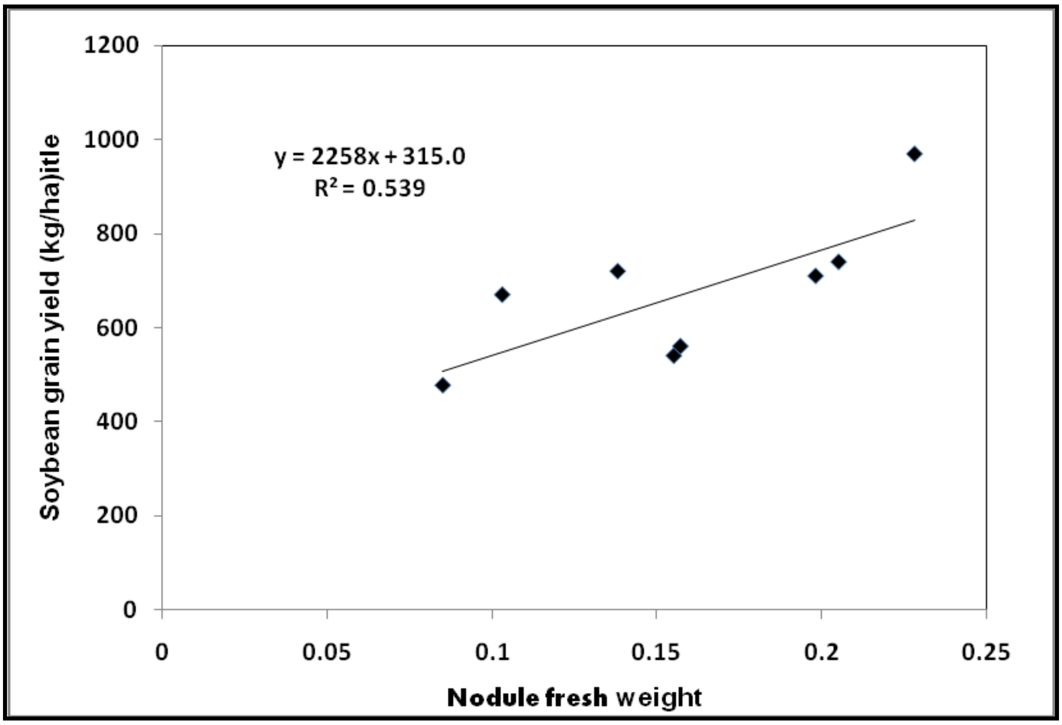

Figure 5: Correlation between soybean grain yield and nodule fresh weight per plant during the first season.

4.4 Maize performance

4.4.1 Nutrient uptake in maize at seedling and silking stages

Figure 6 shows the effect of different fertility treatments on shoot P content of maize at seedling and 50% silking stages during the 1st season. Maize shoot P content ranged from 0.25 to 0.37% at seedling stage and from 0.23 to 0.32% at silking stage. Maximum shoot P content was recorded in both sole P and lime + P treatments whereas lowest shoot P content was recorded in the control plots at seedling stage. At silking stage, maximum shoot P was recorded in both P + lime and lime + P + inoculation treatments whereas the lowest shoot P content was recorded in the control plots. At seedling stage, sole lime and sole P treatments recorded shoot P contents of 0.32 and 0.27% respectively while at silking stage, sole P and sole lime treatments recorded shoot P contents of 0.30, 0.25 respectively. There was a general decreasing trend of maize shoot P content from the seedling to the silking stages (Figure 6).

The results obtained from this experiment of increased shoot P content with lime and P applications in maize agree with the findings of Hayat et al. (2008) and Kisinyo et al. (2012). In another study by Mujeeb et al. (2008), It was reported that chemical and organic P sources alone as well as in combined form led to a significant increase in P concentration of maize plant over the control.

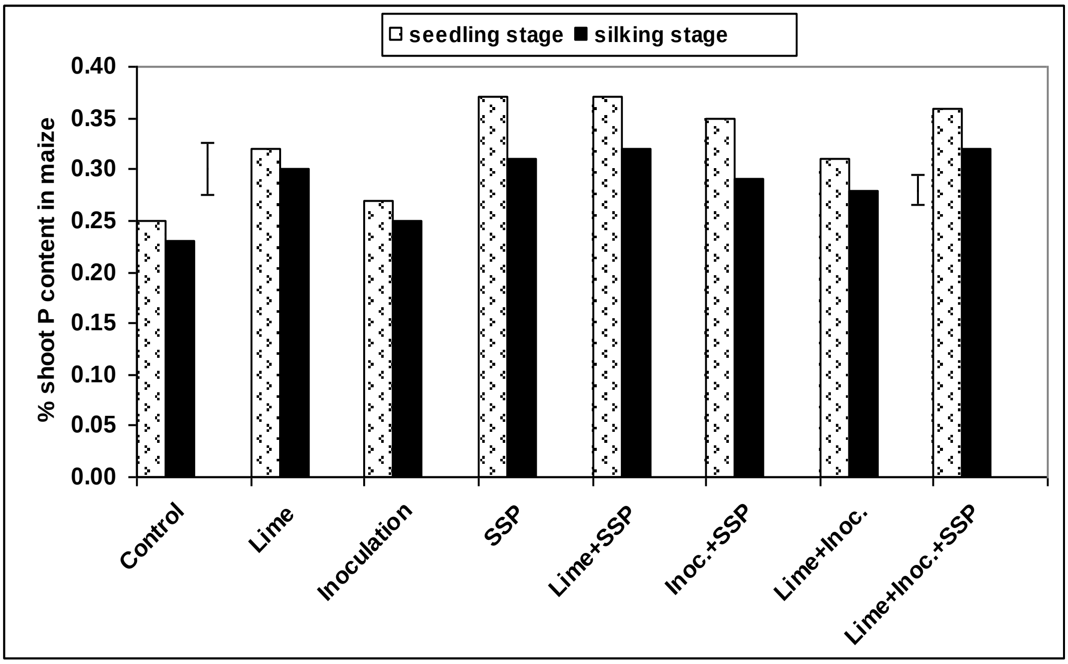

Figure 6: Effect of different treatments on maize shoot P content at seedling and 50% silking stages during the first season. 1st and 2nd error bars represent standard deviation between treatment means at seedling and 50% silking stages respectively.

4.4.2 Maize grain yield (kg /ha)

Maize grain yield varied significantly by application of different treatments (Table 8) in the two seasons. The average grain yield of maize for the various treatments ranged from 1860 to 4490 kg ha^{-1} and from 1650 to 3470 kg ha^{-1} in the 1st and 2nd season respectively. Lime + P + inoculation treated plots produced the highest grain yields (4490 kg/ha and 3470 kg/ha) followed by lime + P (4350 kg/ha and 3230 kg/ha) in the first and second seasons, respectively. Sole P, sole lime and sole inoculation treatments recorded average maize grain yields of 3380, 3385 and 1755 kg/ha respectively whereas the control gave average maize grain yield of 2295 kg/ha.

Table 8: Effect of different treatments on maize grain yield during the first and second seasons

Treatment	**1st season Kg/ha**	**2nd season Kg/ha**
Ctrl	2530^{cb}	2060^{dc}
Lime	3760^{ba}	3010^{cba}
Inoculation	1860^{c}	1650^{d}
P	3810^{ba}	2950^{cba}
P + Lime	4350^{a}	3230^{ba}
P + Inoculation	2650^{cb}	2320^{dcb}
Lime +Inoculation	3730^{ba}	2500^{dcba}
Lime+ Inoculation+ P	4490^{a}	3470^{a}
LSD	**1320**	**1150**

Values in the same column followed by the same letter are not significantly different at P=0.05.

During the first season, sole P treatment recorded higher maize grain yield (3810 kg/ha) than sole lime (3760 kg/ha) whereas in the second season sole lime application recorded higher maize grain yield (3010 kg/ha) than sole P treatment (2950 kg/ha). This could be due to the ability of lime to effectively neutralize soil acidity which raises pH, thus stimulating crop growth. The low maize grain yields obtained from the sole soybean inoculation plots could be as a result of the intercrop effect due to competition in soil moisture and by the legume-cereal component. Soybean performance might have negatively affected the performance of maize and hence low maize yields.

The results from this study agree with the results of Okalebo *et al.*, 2007 who obtained maize grain yield of 4620 kg/ha from TSP + lime treated plots and 580 kg/ha from the control plots in a maize- groundnut intercrop. In his study, Gudu *et al.* (2005) obtained maize grain yields of 550 and 3260 kg/ha from the control and combined lime + fertilizer P treatments, respectively in acidic soils of western Kenya. He noted that irrespective of the maize cultivar, external additions of nutrients including liming acid soils are needed to boost the production in the soil fertility depleted acid soils. The control plots had low maize yields probably because of reduced P availability due to fixation as well as other factors such as Al concentration in this acid soil, and competition among the intercropped species hence limited nutrient uptake by the maize crop and consequently poor performance.

According to Reddy *et al.* (2001), intercropping advantage depends on net effect in trade-off between interspecific competition and facilitation (positive facilitation) in which one plant species enhances the survival, growth, or fitness of another. In addition, Yamoah *et al.* (1996) attributed 44% reduction in maize yield to Al saturation in acid soils. There was an observed positive linear correlation between mean maize grain yield and soil available P content (R^2 = 0.65), soil exchangeable bases (Ca, Mg + k) of R^2 = 0.82 and soil organic C (SOC) content (R^2 = 0.63) at the end of the 2nd season (Figures 7, 8 and 9). This is in agreement with the results of Kifuko *et al.* (2007) who showed a significant positive relationship of r = 0.89 between maize yield and soil available P obtained from MPR at harvesting.

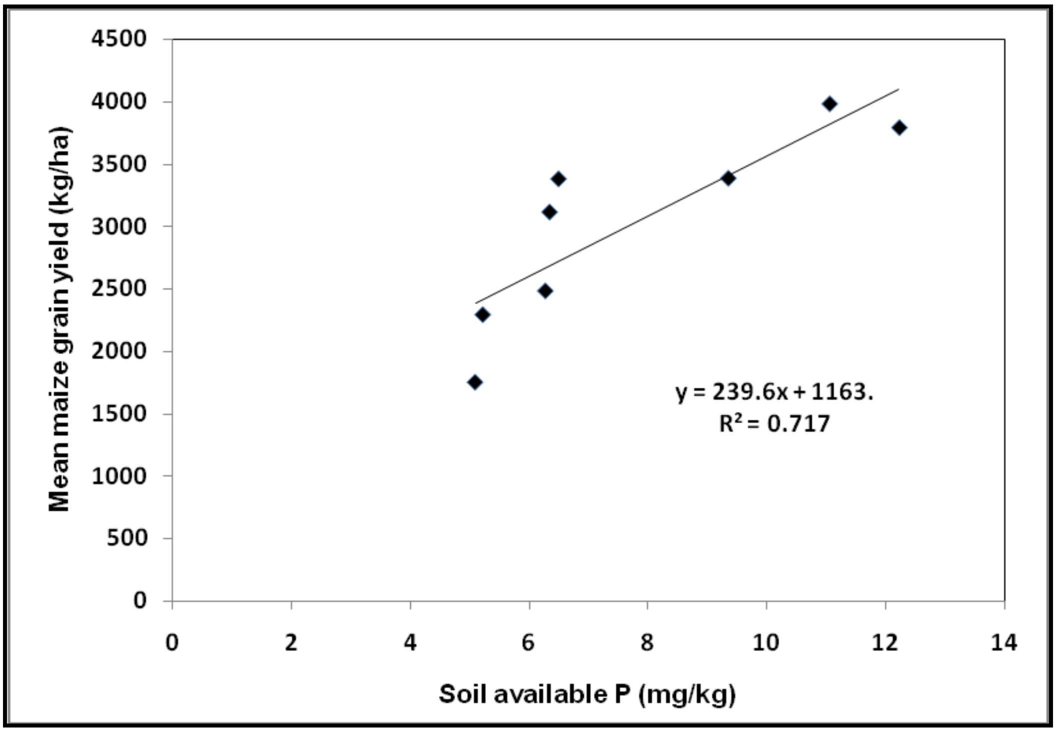

Figure 7: Correlation between mean maize grain yield and soil available P concentration at the end of the 2nd season.

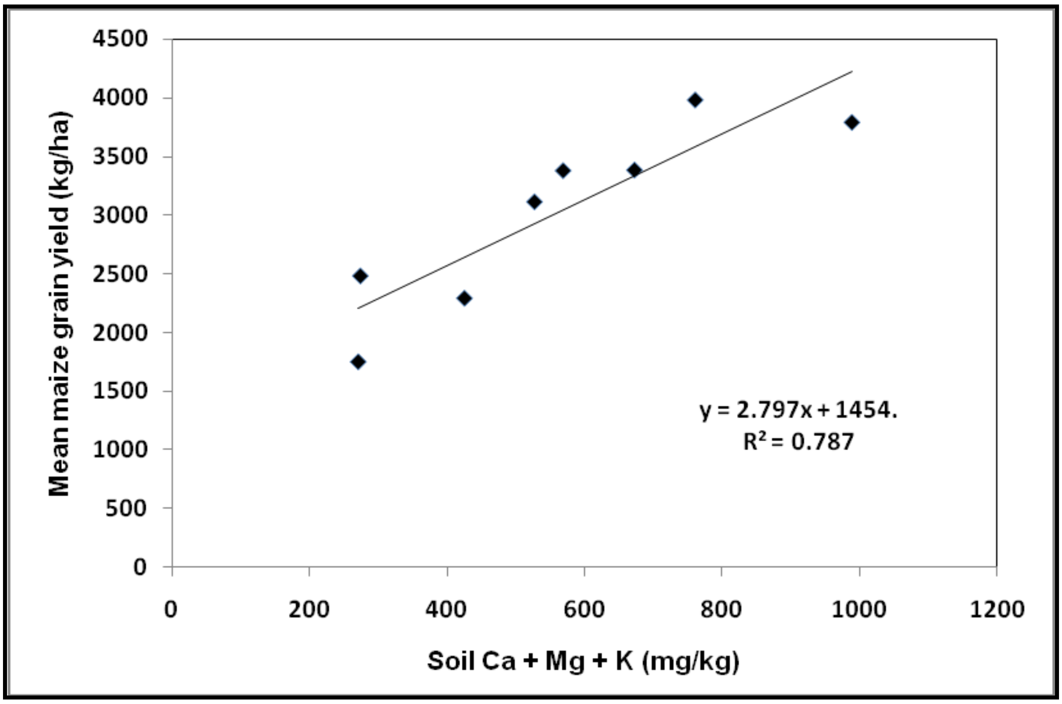

Figure 8: Correlation between mean maize grain yield and exchangeable bases (Ca, Mg + k) at the end of the 2nd season.

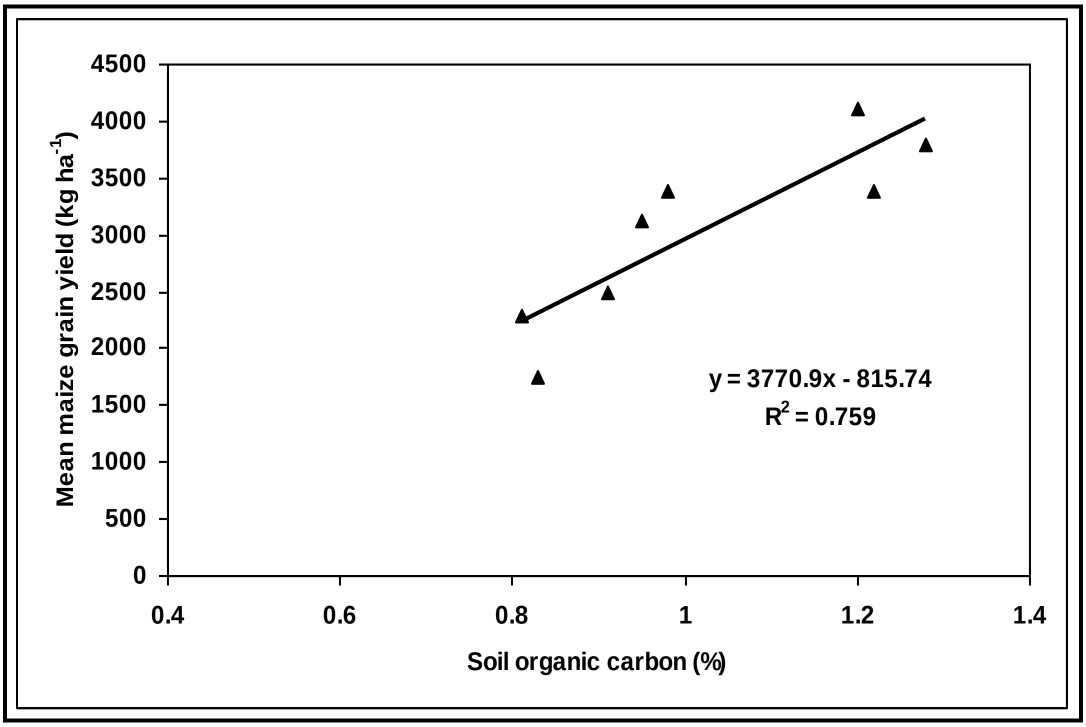

Figure 9: Correlation between mean maize grain yield and percent soil organic carbon at the end of the 2nd season.

4.5 Benefit-cost analysis

Economic analysis was done using average yields (kg/ha) from the 1st and 2nd seasons (Table 9 and 10) (Appendix 2). On average, across the treatments during the two seasons benefit-cost analysis indicated that the lime + P + inoculation treatment gave the highest net benefit (Ksh 107,518.60) followed closely by sole lime application with Ksh.89,015.20 (Table 10). The lowest net benefit was recorded in the sole inoculation treatment (Ksh 61,575.20) followed by control plots (Ksh 67,795.90).

Table 9: Labor and input costs for economic analysis during the year 2011

Parameter	**Actual value (Kshs)**
1 kg of maize grain field price	25.30
1 kg of soya bean grain field price	34.40
1 kg of grain threshing cost	1.80
1 kg of grain transport cost	1.00
1 kg soybean grain harvest cost	1.80
1 kg of maize grain harvest cost	0.90
1 kg of grain bagging cost	1.00
1 kg of SSP fertilizer	53.00
1 kg of lime	5.40
Cost of biofix	350.00 @ 200 g
Transport of 1 kg fertilizer or lime	2.00
Wage rate for 1 man-day	200.00

Yield adjusted downward by 10% Exchange rate: 1 dollar = Kshs. 85.00

Table 10: Benefit-cost ratios of average maize-soybean yields under different treatments during the first and second seasons

Treatment	Gross benefit (Kshs.ha^{-1})	Total cost (Kshs.ha^{-1})	Net benefit (Kshs.ha^{-1})	Benefit-cost ratio
Control	87765.93	19970.00	67795.93	3.4
Lime	129396.15	40381.00	89015.15	2.2
Inoculation	83275.20	21700.00	61575.20	2.8
SSP	122849.55	41212.00	81637.55	2.0
SSP + Lime	142477.65	61623.00	80854.65	1.3
SSP + Inoculation	114478.20	42962.00	71516.20	1.7
Lime + Inoculation	126250.20	42131.00	84119.20	2.0
Lime + Inoc. + SSP	170891.55	63373.00	107518.55	1.7

Benefit-cost analysis (BCA) during the 1st and 2nd seasons indicated that the control plots yielded the highest benefit-cost ratio (BCR) of 3.4 followed by sole inoculation treatment (2.8) and sole lime treatment (2.2) (Table 10). Sole lime treatment had higher BCR as compared to sole P treatment (2.0). Although some treatments had higher net benefit (NB), they respectively had a lower benefit-cost ratio (BCR) as exemplified by results in Table 10. For example lime + P + inoculation had a net benefit of Ksh 107, 518.60 and a benefit-cost ratio of 1.7 compared to sole lime treatment with a net benefit of Ksh 89,015.20 and a benefit-cost ratio of 2.2 thus, considering net benefit alone could be misleading as far as cost effectiveness of the different soil fertility amendment inputs is concerned, therefore, BCR seems to be the most appropriate economic tool for determining the most economical soil fertility amendment technologies as it shows the return per shilling invested.

In a study in western Kenya, Nekesa *et al.* (2005) accrued a gross margin of Ksh. 110, 284 with a value-cost ratio of 1.69:1 from application of DAP and lime whereas sole P application accrued a gross margin of Ksh. 81, 070 with a value-cost ratio of 1.65:1. On average, sole lime application gave higher net benefits than integration of lime with fertilizer P. This could be attributed to the high costs of inorganic fertilizer. Considering that farmers may not be able to afford the high cost of purchasing mineral fertilizers, the use of lime may form a major supplement or complement to correcting nutrient deficiencies and ensuring high crop yields in western Kenya. With time the farmers can target higher earnings at higher rates of lime and P application.

The integration of mineral fertilizers with lime inputs or sole lime application has been regarded as a more profitable alternative in low input systems, countering the large cost of fertilizers (Okalebo *et al.*, 2007). The findings of this study also indicate that sole application of lime and or their integration with mineral fertilizers can be an alternative to the limited use of fertilizers.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Major conclusions emanating from the findings of this study have been presented as follows:

- Application of lime at 2.5 t ha^{-1} significantly increased soil pH from 4.9 to 5.58. However, combined application of lime + P + inoculation increased soil pH from 4.9 to 5.52. This confirms the superiority of liming as an effective method of controlling soil acidity in western Kenya.
- Results indicate that the increase in soil available P was in the order of lime > inorganic P > inoculation (9.35>6.50>5.10 mg kg^{-1}). Maximum soil available P (12.22 mg kg^{-1}) was obtained with lime + P treatment. A similar trend was observed on increased levels of exchangeable Ca^{2+} as affected by lime > inorganic P > inoculation (531.9>450.1>136.2 mg kg^{-1}) with lime + P treatment recording the highest level of exchangeable Ca^{2+} (875.8 mg kg^{-1}). This shows that application of both lime and inorganic P is a more effective remedy to the low levels of P and exchangeable bases in the soils of western Kenya.
- Sole P gave the highest increase in average nodule number per plant and plant biomass (490% and 51.4%) followed by inoculation (230% and 33.3%) then lime treatment (76% and 16.75%) in soybean, respectively. The highest increase in nodule number (723%) and plant biomass (57%) was obtained from P + inoculation treatment. Therefore inorganic P and inoculation are

highly effective in enhancing soybean nodulation and biomass production which leads to improved yields.

- Sole P, lime and inoculation treatments gave average grain yields of 3380, 3385 and 1755 kg/ha in maize and 535, 610 and 505 kg/ha in soybean, respectively during the two seasons. Sole lime and P application proved to be more effective in increasing soybean and maize yields than inoculation. The highest average maize grain yields of 4115 kg/ha and soybean yields of 900 kg/ha were obtained with lime + P + inoculation treatment. These results indicate that a combination of lime + P + inoculation offers a better option for increasing maize and soybean grain yields in the degraded soils of western Kenya.
- Sole lime treatment proved to be cost effective as it gave a benefit-cost ratio of 2.2 with net benefit of Ksh: 89,015.20 while a combination of lime + P + inoculation gave a benefit-cost ratio of 1.7 with a net benefit of Ksh: 107,518.60.

5.2 Recommendations

The following recommendations can be drawn based on the findings from this research:

- Integration of lime, inorganic P and inoculation needs to be disseminated among resource limited small-scale farmers in western Kenya because it leads to improved soil chemical properties such as soil pH, available P, exchangeable bases, increased maize-soybean yields and high returns as well as an acceptable benefit-cost ratio.

- Since the nodulation and soybean grain yield results were not satisfactory, more research is required to venture into other strategies of improving soil physical and chemical properties as well as reducing soil acidity such as the use of green manure e.g. *Tithonia diversifolia* or organic manure for enhanced maize and soybean production in western Kenya.
- More research needs to be carried out on other lime sources since integration of lime with inorganic fertilizer and inoculation has proved to be highly effective in improving soil properties and grain yields of maize and soybean in western Kenya.
- The Government should come up with a policy on lime blending with all commonly used fertilizers by manufacturers as a way of reducing unnecessary costs by farmers and as a way of continuously decreasing acidity in soils.

References

Anders, M.M., Potdar, M.V and Francis, C.A (1996). Significance of intercropping in cropping systems. In: Ito, O., Johansen, C., Adu-Gyamfi, J.J., Katayama, K., Kumar- Rao, J.V.D.K and Rego, T.J (Eds), Dynamics of Roots and Nitrogen in Cropping Systems of the Semi-arid Tropics. Japan International Research Centre for Agricultural Sciences, Tokyo, pp. 1–18.

Anderson, J.M and Ingram J.S.L (1993). Tropical Soil Biology and Fertility: A handbook of Methods. CAB International, Wallingford, UK.

Ariga, J., Jayne, T. S., Kibaara, B and Nyoro, J. K (2008). Trends and Patterns in Fertilizer Use by Smallholder Farmers in Kenya, 1997-2007. Working Paper Series No. 28. Nairobi, Kenya: Tegemeo Institute.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B and Kimetu, J (2005). Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems* (2006), doi:10.101.

Bationo, A., Lompo, F and Koala, S (1998). Research on nutrient flows and balances in West Africa: State-of-the-art. In: Smaling, E.M.A. (ed), Nutrient Balances as Indicators of Production and Sustainability in Sub-Saharan African Agriculture. *Agriculture, Ecosystem and Environment* vol. 71, pp. 19–36.

Bekunda, M., Gallooway, J., Syers, K and Scholes, M (2007). Background, Current status and context the African Context of the International Nitrogen Initiative: In; Batiano (eds). Advances in integrated soil fertility Management in sub-Sahara Africa: Challenges and opportunities, Pp. 115-119.

Black, C.A (1965). Methods of Soil analysis. Agronomy no.9, American Society of Agronomy, Inc. Bowden J.W., Nagarajah S., Barrow N.J., Posner A.M. and Quirk J.P. (2001). Describing the adsorption of phosphate, citrate and selenite on a variable charge mineral surface. *Australian Journal of Soil Science Research* 18: 49 - 60.

Bunemann, E.K., Smithson, P.C., Jama, B.Frossard, E and Oberson, A (2004). Maize productivity and nutrient dynamics in maize-fallow rotations in Western Kenya. *Plant and Soil* 264:195-208.

Bunemann, E.K (2003). Phosphorus dynamics in a Ferralsol under maize-fallow rotations: The role of the soil microbial biomass. PhD Thesis, Swiss Federal Institute of Technology Zurich, pp. 162.

Cadisch, G., Gathumbi, S.M., Ndufa, J.K and Giller, K.E (2002). Resource acquisition of mixed species fallows—competition or complementarity?. In B. Vanlauwe *et al*. (ed) Integrated nutrient management in sub-Saharan Africa. CAB Int. Wallingford, UK, pp. 143–154.

Caires, E. F., S. Churka, F. J. Garbuio, R. A. Ferrari and M. A. Morgano (2006). Soybean yield and quality as a function of lime and gypsum applications. *Agricultural Science* 63 (4): 370-379.

CIMMYT (1988). From Agronomic Data to Farmer Recommendations. An Economic Training Manual Copmpletely Revised Edition, Mexico D.F.

Ciful, M., L. Xiaonan, C. Zhihong, H. Zhengyi and M. Wanzhu (2004). Long – term effects of lime application on soil acidity and crop yield on a red soil in Central Zhejiang. *Plant and Soil* 256: 101-109.

Corre-Hellou, G and Crozat, Y (2005). N_2-fixation and N supply in organic pea (Pisum sativa L.) cropping systems as affected by weeds and pea weevil (Sitona lineatus L.).*European Journal of Agronomy* 22:449-458.

Dorich, R.A and Nelson, D.W (1984). Evaluation of manual cadmium reduction methods for determination of nitrate in potassium chloride extracts of soil. Soil Science Society. *America Journal* 48:72-75.

Drevon, J.J and Hartwig, U.A (1997). Phosphorus deficiency increases the argon-induced decline of nodule nitrogenase activity in soybean and alfalfa. *Plant and soil* 200: 463-469.

Edmeades, D.C., Judd, M and Sarathmchandra, S.U (1981). The effect of lime on nitrogen mineralization as measured by grass growth. *Plant and Soil* 60:177–186.

Fatima, Z., Zia, M and Chaudhary, M.F (2007). Interactive effect of Rhizobium strains and P on soybean yield, nitrogen fixation and soil fertility. *Journal of Botany* 39(1): 255-264.

Fierer, N and Jackson, R.B (2006). The diversity and biogeography of soil bacterial communities. National Academy of Sciences of the USA (PNAS) 103(3):626-631.

Fujita, K., Ofosu-Budu, K.G and Ogata, S (1992). Biological nitrogen fixation in mixed legume-cereal cropping systems. *Plant and Soil* 141: 155-175.

Gachengo, C.N., Palm, C.A., Jama, B and Othieno, (1999). Tithonia and senna green manures and inorganic fertilizers as phosphorous sources for maize in western Kenya. *Agro forestry Systems* 44:21-36.

Gee, G. W and Bauder J.W (1986). Particle size analysis. In: Klute A (ed) Methods of soil analysis. Part 1. 2nd edition Agron. Monog. 9 ASA SSSA, Madison, W1, pp. 383-411.

GenStat (2010). The GenStat Teaching Edition. GenStat Release 7.22 TE. Copyright 2008, VSN International Ltd.

Gentili, F and Huss-danell, K (2003). Local and systematic effects of phosphorous and nitrogen on nodulation and nodule function in Alnus incana. *Journal of Experimental Botany* 54:2 757-2.

Giller, K.E (2001). Nitrogen fixation in tropical cropping systems. 2nd ed. Wallingford, CABI International, Wallingford, UK.

Graham, M.H., Haynes, R.J and Meyer, J.M (2002). Changes in soil chemistry and aggregates stability induced by fertilizer application, burning and trash relation on a long-term sugarcane experiment in South Africa. *European Journal of Soil Science* 53: 589–598.

Gudu, S.O., Okalebo, J.R., Othieno ,C.O., Kisinyo, P.O., Obura, P.A and Ligeyo, D.O (2007). New Approach for improving phosphorous acquisition and aluminium tolerance of plants in marginal soils; Soil Research Component (2003-2007). Presented at a Workshop in France, October, 2007.

Gudu, S.O., Okalebo, J.R., Othieno, C.O., Obura, P.A., Ligeyo, D.O., Schulze, D and Johnson, C (2005). Response of five maize genotypes to nitrogen, phosphorous and lime on acid soils of western Kenya. African Crop Science Conference Proceedings 7, 1109-1115.

Guo, Y., Yu, N., Yuan, L and Huang, J (2009). Effects of liming and Sinorhizobium inoculation on growth, nodulation and nutrient concentrations of lucerne in acid soil. *Tropical Grasslands* Vol. 43:112-117.

Havlin, J.L., Beaton, J.D., Tisdale, S.L and Nelson, W.L (2005). Soil Fertility and Fertilizers: An Introduction to Nutrient Management. Pearson Education, Inc., Upper Saddle River, NJ.

Hayat, R., Ali, S., Siddique, M.T and Chatha, T.H (2008). Biological nitrogen fixation of summer legumes and their residual effects on subsequent rainfed wheat yield in Pakistan. *Journal of Botany* 40(2): 711-722.

Hellsten, A and Huss-Danell, K (2000). Interaction effects of nitrogen and phosphorus on nodulation in red clover. Acta. Agric. Scand. Section B. *Plant and Soil* 50: 135-142.

ICRAF (1995). International Centre for Research in Agroforestry: Laboratory methods of soil and plant analysis. Nairobi, Kenya.

Jaetzold R., Schimdt H., Hornetz B and Shisanya C (2005). Farm management handbook of Kenya Volume I. Natural conditions and farm management information. 2nd Edition, part A West Kenya, subpart A1 Western Province. Ministry of Agriculture, Nairobi, Kenya.

Jama, B., Palm, C.A and Buresh, R.J (1999). Using tithonia and fertilizers on maize in western Kenya. Maseno Agroforestry Research Centre Newsletter, ICRAF, Nairobi, Kenya. Miti ni Maendeleo 6:3-4.

Jama, B., Swinkles, R.A and Buresh, J.R (1997). Agronomic and economic evaluation of organic and inorganic sources of phosphorous in Western Kenya. *Agronomy Journal* 89: 597-604.

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

Kandji, S.T., Ogol, C.K.P.O and Abrecht, A (2003). Crop damage by nematodes in the improved fallow fields in Western Kenya. *Agroforestry Systems* 57: 51- 57.

Kanyanjua, S. M., Ireri, L., Wambua, S and Nandwa, S.M (2002). Acidic soils in Kenya: Constraints and remedial options. KARI Technical Note No.11, pp. 28.

Kenya Agricultural Research Institute (KARI) (2010). Annual Report. KARI, Kakamega.

Kibunja, C.N., Mwaura, F.B and Mugendi, D.N (2010). Long-term land management effects on soil properties and microbial populations in a maize-bean rotation at Kabete, Kenya. *African Journal of Agricultural Research* Vol. 5 (2), pp. 108-113.

Kifuko, M.N., Othieno, C.O., Okalebo, J.R., Kimenye, L.N., Ndung'u, K.W and Kipkoech, A.K (2007). Effect of combining organic residues with Minjingu Phosphate Rock on phosphorous sorption, availability and maize production in Busia, western Kenya. *Experimental Agriculture* 43:51-66.

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

Kinraide, T.B (2003). Toxicity factors in acidic forest soils: attempts to evaluate separately the toxic effects of excessive Al^{3+} and H^+ and in sufficient Ca^{2+} and Mg^{2+} upon root elongation. *European Journal of Soil Science* 549: 323–333.

Kipsat, M.J., Maritim, H.K. and Okalebo, J.R. (2004). Economic analysis of non-conventional fertilizers in Vihiga District, Western Kenya. In: Batiano, A. (ed) (2004). Managing nutrient cycles to sustain soil fertility in sub-saharan Africa. Academy of science publishers, Nairobi Kenya.

Kipsat, M.J (2007). Social-Economics of soil Conservation in Kericho District, Kenya. In: Bationo, A.; Waswa, B. S.; Kihara, J.; Kimentu, J.; (eds). Advances in integrated soil fertility management in sub-saharan Africa: Challenges and Opportunities. Springer, Dordrecht, NL, pp. 679-689.

Kisinyo, P.O., Gudu, S.O., Othieno, C.O., Okalebo, J.R., Opala, P.A., Maghanga, J.K., Agalo, J.J., Ng'etich, W.K., Kisinyo, J.A., Osiyo, R.J., Nekesa, A.O., Makatiani, E.T., Odee D.W and Ogola, B.O (2012). Effects of lime, phosphorous and rhizobia on Sesbania sesban performance in a western Kenyan acid soil. *African Journal of Agricultural Research* Vol. 7(18) pp. 2800-2809.

Kladivko, E. J (2001). Tillage Systems and Soil Ecology. *Soil and Tillage Research* 61:61-76.

Kodiango, R.O., Onkware, A.O and Gudu, S.O (2007). Effect of lime on growth and development of Leucaena leucocephala in acid soils of Kenya. Discov. Innov., 18: 359–368.

Kwabiah, A.B., Stoskopf, N.C., Palm, C.A., Voroney, R.P., Rao, M.R and Gacheru, E (2003). Phosphorus availability and maize response to organic and inorganic fertilizer inputs in a short term study in Western Kenya. *Agricultural Ecosystems and Environment* 95: 49-59.

Lelei, J.J., Onwonga, R.N and Mochoge, B.O (2006). Interactive effects of lime, manure, N and P fertilizers on maize (Zea mays L.) yield and N and P uptake in an acid mollic Andosol of Molo Kenya. Egerton Journal: *Science and Technology* series, 6. No. 2.

Li, L., Tang, C., Rengel, Z and Zhang, F (2003). Interspecific facilitation of nutrient uptakes by intercropped maize and faba bean. *Nutrient Cycles in Agro-ecosystems* 65:61–67.

Li, L., Tang, C., Rengel, Z and Zhang, F (2002). Chickpea facilitates phosphorus uptake by intercropped wheat from an organic phosphorus source. *Plant and Soil* 248:297–303.

Makokha, S., Kimani, S., Mwangi, W., Verkuijl, H and Musembi, F (2001). Determinants of fertilizer and manure use in maize production in Kiambu District, Kenya. CIMMYT/KARI Report.

Marenya, P. P and Barrett, C. B (2009). Soil quality and fertilizer use rates among smallholder farmers in western Kenya. *Journal of Agricultural Economics* 40(5), 561-572.

Marschner, P., Kandeler, E and Marschner, B (2003), Structure and function of the soil microbial community in a long-term fertilizer experiment. *Soil Biology and Biochemistry* 35:453-461.

Marschner, H (1995). Mineral nutrition of higher plants. Academic Press, San Diego, pp. 889.

Mehlich, A (1953). Determination of P, Ca, Mg, K, Na, and NH4. North Carolina Soil Test Division (Mimeo 1953).

Ministry of Agriculture (MOA) (2008). Economic Survey, MOA and Tegemeo Computation reports. Western Province, Kenya.

Ministry of Agriculture (MOA) (2007). Annual Report. Ministry of Agriculture, Kakamega, Kenya.

Ministry of Agriculture and Rural Development (MOARD) (2004). Annual Reports for Mumias and Kakamega districts: Surveys on Population and Agricultural Production.

Morris, M., Kelly, V., Kopicki, R. J and Byerlee, D (2007). Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines. Washington DC: World Bank.

Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckx, R and Vanlauwe, B (2010). A staggered maize-legume intercrop arrangement robustly increases yields and economic returns in the highlands of Central Kenya. *Field Crops Research* 115:132-139.

Mugendi, E. Gitonga, N. Cheruiyot, R and Maingi, J (2010). Biological nitrogen fixation by promiscuous soybean (Glycine max L. Merril) in the central highlands of Kenya: Response to inorganic fertilizer soil amendments. *World Journal of Agricultural Sciences* 6 (4): 381-387, 2010.

Muoneke, C.O., Ogwuche, M.A.O and Kalu, B.A (2007). Effect of maize planting density on the performance of maize/soybean intercropping system in a guinea savanna agroecosystem. *African Journal of Agricultural Resources* 2: 667-677.

Mwangi, T.J., Ngeny, J.M., Wekesa, F and Mulati, J (2001). Acidic soil amendment for maize production in Uasin Gishu district. National Agricultural Research Centre. Kitale, Kenya.

Myaka, F.M., Sakala, W.D., Adu-Gyamfi, J.J., Kamalongo, D., Ngwira, A., Odgaard, R., Nielsen, N.E and Hogh-Jensen, H (2006). Yields and accumulations of N and P in farmer-managed intercrops of maize-pigeonpea in semi-arid Africa. *Plant and Soil* 285, 207–220.

Ncube, B., Twomlow, S.J., van Wijk, M.T., Dimes, J.P and Giller, K.E., (2007). Productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in southwestern Zimbabwe. *Plant and Soil* 299, 1–15.

Ndakidemi, P.A., Dakora, F.D., Nkonya, E.M., Ringo, D and Mansoor, H (2006). Yield and economic benefits of common bean (Phaseolus vulgaris L.) and soybean Glycine max L. Merr.) noculation in northern Tanzania. *Australian Journal Experimental Agriculture* 46(4): 571-577.

Neil, C (1991). Ground works 1: Managing soil acidity. In: In: Claude N (ed.). Proceedings of Tropical Soils Workshop on soil acidity and liming. Raleigh, NC, pp. 1-23.

Nekesa, A.O., Okalebo, C.O., Othieno, M.N., Thuita, M., Kipsat, A., Bationo, A., Sanginga, N., Kimettu, J and Vanlauwe, B (2005). The potential of Minjingu phosphate rock from Tanzania as a liming material: Effect on maize and bean intercrop on acid soils of Western Kenya. African Crop Science Conference proceedings, Vol. 7. pp.1121-1128.

Niang, A., Amadalo, B., Gathumbi, S and Obonyo (1996). Yield response to green manure application from selected shrubs and tree species in Western Kenya: A preliminary assessment.

Obura, P.A. Okalebo J.R., Othieno C.O., Gudu S.O., Ligeyo D.O and Schulze D (2003). Effects of lime and phosphorous on the performance of five maize genotypes in acid soils of western Kenya. Presented at KARI Headquaters Seminar, Dec. 2003, pp. 22.

Odendo, M., Ojiem, J., Batiano, A and Mudeheri, M (2007). On-farm evaluation and scaling-up of soil fertility management in Western Kenya. In Batiano, A. (eds.) Advances in integrated soil fertility Management in sub-Sahara Africa: Challenges and opportunities, 969- 978.

Odendo, M., De Groote, H and Odongo, O.M (2001). Assessment of farmers preferences and constraints to maize production in Moist Midaltitude zone of Western Kenya. Paper presented at the 5th International Conference of the African Crop Science Society, Lagos, Nigeria October 21-26, 2001.

Okalebo, J.R., Woomer, P.L., Othieno, C.O., Karanja, N.K. Ikerra, S., Esilaba, A.O., Nekesa, A.O., Ruto, E.C., Thuita, M.N., Ndung'u, K.W., Kifuko, M.N and Bationo, A (2007). The potential of underutilized phosphate rocks for soil fertility replenishment in Africa: case studies in western Kenya. African Crop Science Conference Proceedings Vol. 8, pp. 1589-1598.

Okalebo, J.R., Gathua, K.W and Woomer, P.l (2002). Laboratory methods of soil and plant analysis: A Working manual, 2nd edition, TSBF-CIAT, SSSEA, KARI, Sacred Africa, Moi University, pp. 128.

Okereke, G.U., Onochie, C.C., Onukwo, A.U., Onyeagba, E and Ekejindu, G.O (2000). Response of introduced Bradyrhizobium strains infecting a promiscuous soybean Cultivar. *World Journal of Microbiology and Biotechnology* 16: 43–8.

Okereke, G.U., Onochie, C.C., Onukwo, A.U., Onyeagba, E (2004). Effectiveness of foreign bradyrhizobia strains in enhancing nodulation, dry matter and seed yield soybean (Glycine max L.) cultivars in Nigeria. *Biology and Fertility of Soils* 33:3-9.

Olivera, M., Tejera, N., Iribarne, C., Ocana, A and Lluch, C (2004). Growth, nitrogen fixation and ammonium assimilation in common bean (Phaseolus vulgaris): Effect of phosphorus. *Plant Physiology Journal* 121: 498-505.

Palm, C.A., Myers, R.J.K and Nandwa, S.M (1997). Organic-inorganic nutrient interactions in soil fertility replenishment. In: Buresg, R.J., Sanchez, P.A and Calhoun, F (eds) replenishing soil fertility in Africa. Soil Science Society of America Special Publication 51, pp. 193-218. Soil Science Society of America , Madison WI, USA.

Patra , R.K., Pant, L.M and Pradhan, K (2012). Response of soybean to inoculation with Rhizobial strains: effect on growth, yield, N uptake and soil N status. *World Journal of Agricultural Sciences* 8 (1): 51-54.

Peoples, M.B., Herridge, D.F and Ladha, J.K (1995). Biological nitrogen fixation: An efficient source of nitrogen for sustainable Agriculture production. *Plant and Soil* 174: 3-28.

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

Plaxton, W.C (2004). Plant response to stress: biochemical adaptations to phosphate deficiency. In: Goodman R (eds.) Encyclopedia of Plant and Crop Science. Marcel Dekker, New York, pp. 976-980.

Quainoo, A.K., Lawson, I.Y.D and Yawson, A (2000). Intercrop performance of maize, sorghum and soybean in response to planting pattern. Ghana Science Association 2: 31-35.

Reddy, G.S., Maruthi, V and Vanaja, M (2001). Effect of soil depth on productivity of sorghum (Sorghum bicolor) and pigeonpea (Cajanus cajan) in sole and intercropping systems. *Indian Journal of Agricultural Science* 71: 510–515.

Republic of Kenya (2010). The 2009 population and housing census, volume 1: Population distribution by administrative areas and urban centres. Central Bureau of Statistics (CBS), Ministry of Finance and Planning, Nairobi, Kenya.

Rhoades, J.D (1982). Cation exchange capacity. In: Page, A.L., Miller, R.H and Keeney, D.R (eds) Methods of soil analysis. Part 2. Agron. Monog. 9, American Society Agronomy Journal, Madison, WI, pp.149-157.

Sale, P.G and Mokwunye, A.U (1993). Use of rock phosphates in the tropics. *Fertility Resources* 35: 33-45.

Sanchez, P.A., Shepherd, K., Soule, M.J., Place, F.M., Buresh, R and Izac, A.M (1997). Soil fertility replenishment in Africa: an investment in natural resource capital. In: Buresh, R.J., Sanchez, P.A and Cahoun, F (eds.).

Replenishing soil fertility in Africa. SSA Special Publication No 51, SSA, Madison, Wisconsin, pp. 1–46.

Sanginga, N (2003). Role of biological nitrogen fixation in legume based cropping systems; a case study of West Africa farming systems. *Plant and Soil* 252, 25–39.

Sanginga, N., Abaidoo, R., Dashiell, K., Carsky, R.J and Okogun, A (1995). Persistence and effectiveness of rhizobia nodulating promiscuous soybeans in moist savanna zones of Nigeria. *Applied Soil Ecology Journal* 3: 216– 24.

Schulze, J., Temple, G., Temple, S.J., Beschow, H and Vance, C.P (2006). Nitrogen fixation by white lupin under phosphorus deficiency. *Annual Botany Journal* 98: 731-740.

Shepherd, G., Buresh, R.J and Gregory, P.J (2000). Land use affects the distribution of soil inorganic nitrogen in smallholder production systems in Kenya. *Biological Fertility Soils Journal* 31:348-355.

Shepherd, K.D., Ohllson, E., Okalebo, J. R and Udifu, J. K (1996). Potential impact of Agroforestry on soil nutrient balances at farm scale in the East Africa highlands. *Fertility Resources* 44: 87-89.

Smaling, E.A., Nandwa, S.M and Janssen, B.H (1997). Soil fertility in Africa is at stake. In: Buresh, R.J., Sanchez, P.A and Cahoun, F. (eds). Replenishing soil fertility in Africa. SSA Special Publication No 51, SSA, Madison, Wisconsin, pp. 47–61.

Smithson, P. In: Buresh, R and Sinclair, F.L (eds) (1999). Special issue on phosphorous availability, uptake and cycling in tropical agroforestry. Agroforestry Forum ,Vol. 9. No. 4, pp. 37-40.

Somado, E.A. Becker, M., Kuehne, R.F., Sahrawat, K.L and Vlek, P.L.G (2003). Combined effects of legumes with rock phosphorous on rice in West Africa. *Agronomy Journal* 95:1172-1178.

Stoorvogel, J. J and Smaling, E (1990). Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. Wageningen, the Netherlands: Win and Staring Ctr.

Tahir, M.M., Abbasi, M.K., Rahim, N., Khaliq, A and Kazmi M.H (2009). Effect of Rhizobium inoculation and NP fertilization on growth, yield and nodulation of soybean (Glycine max L.) in the sub-humid hilly region of Rawalakot Azad Jammu and Kashmir, Pakistan. *African Journal of Biotechnology* Vol.8(22), pp. 6191-6200.

The, C., Calba, H., Zonkeng, C., Ngonkeu, E.L.M and Adetimirin, V.O (2006). Response of maize grain yield to changes in acid soil characteristics after soil amendment. *Plant and Soil* 284: 45-57.

Tisdale, S.L., Nelson, W.L and Beaton, J.D (1990). Soil fertility and fertilizers. 5th ed. Macmillan, New York, USA.

Tsvetkova, G.E and Georgiev, G.L (2003). Effect of phosphorous nutrition on the nodulation, nitrogen fixation and nutrient use efficiency of Bradyrhizobium japonicum soybean (Glycine max L. Merr.) symbiosis. Bulg. *Journal of Plant Physiology* 3:331-335.

Tungani, J.O., Mukhwana, E.J and Woomer, P.L (2002). MBILI is number 1; A handbook for innovative maize-legume intercropping. SACRED, Bungoma, pp. 20.

Vanlauwe, B and Giller, K.E (2006). Popular myths around soil fertility management in sub-Saharan Africa. *Agricultural Ecosystems and Environment* 116:34–46.

Vanlauwe, B., Aihou, K., Aman, S., Tossah, B. K., Diels, J., Lyasse, O and Hauser, S (2000). Nitrogen and phosphorus uptake by maize as affected by particulate organic matter quality, soil characteristics, and land-use history for soils from the West African moist savanna zone. *Biology and Fertility of Soils* 30(5-6), 440-449.

Versteeg, M.N., Amadji, F., Eteka, A., Gogan, A and Koudokpon, V (1998). Farmers' adoptability of Mucuna fallowing and agroforestry technologies in the coastal savanna of Benin. *Agricultural Systems* 56:269-287.

Walley, F.L, Kyei-Boahen, S., Hnatowich, G and Sterenson, C (2005). Nitrogen and Phosphorous fertility management for desi and kabuli chick pea. Canadian *Journal of Plant Science* 85:73-79.

Wasonga, C.J., Sigunga, D.O and Musandu, A.O (2008). Phosphorous requirements by maize varieties in different soil types of western Kenya. *African Crop Science Journal* Vol. 16, No. 2, pp.161-173.

Weight, D and Kelly, V (1999). Fertilizer Impacts on Soil and Crops of Sub-Saharan Africa. Agricultural Economics. MSU International Development Paper No. 21. East Lansing, Michigan.

Woomer, P.L., Musyoka, M.W and Mukhwana, E.J (2003). Best-Bet maize-legume intercropping technologies and summary of 2002 Network Findings. Best-Bets Bulletin No.1, SACRED-Africa, NGO, Bungoma, Kenya, pp.18.

Yadvinder-Singh, B.S., Ladha, J.K., Khind, C.S., Gupta, R.K., Meelu, O.P and Pasuquin, E (2004). Long-term effects of organic inputs on yield and soil fertility in the rice-wheat rotation. *Soil Science Society of American Journal* 68:845-853.

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

Zhang, H., Aoust, F.D., Charles, T.C., Driscoll, B.T., Prithiviraj, B and Smith, D.L (2002). Bradyrhyzobium japonicum mutants allowing improved soybean yield in short season areas with cool spring soil temperature. *Soil Science Society American Journal* 42:1186-1