EFFECTS OF MANURE, LIME AND PHOSPHORUS FERTILIZER ON SOIL PROPERTIES AND SOYBEAN (*Glycine max*L.) YIELDS INEMBU COUNTY, KENYA

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DECLARATION

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

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

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To my late sister Nélia Serafim Carlos Verde

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LIST OF ACRONYMS AND ABBREVIATIONS

GDP : Growth Domestic Product

AEZ : Agro-Ecological Zone

ANOVA : Analysis of Variance

BNF : Biologic Nitrogen Fixation

CEC : Cation Exchange Capacity

DAP : Di-ammonium Phosphate

DM : Dry Matter

EA : Elemental Analysis

FAO : Food and Agriculture Organization

FYM : Farm Yard Manure

HI : Harvest Index

ISFM : Integrated Soil Fertility Management

LR : Long Rain

LSD : Least Significant Difference

MB : Microbial Biomass

RCBD : Randomized Complete Block Design

SMB : Soil Microbial Biomass

SOM : Soil Organic Matter

SR : Short Rain

TSP : Triple Super Phosphate

UM : Upper Midland

WAP : Weeks After Planting

ABSTRACT

Agricultural sector in Kenya, contributes with 25% on GDP, yet this sector is far to supply adequate food for an increasing population due to declining soil productivity. Soybean (*Glycine max* L. Merrill) is relatively new crop being introduced in smallholders farming system in the Central Highlands of Kenya as source of nutrition, income generation and soil fertility improvement. However, the crop yields are below the national average. Soil acidity and depletion of nutrients affect negatively performance and yields of soybean in the region. The study was carried out for two seasons in Embu County to determine the effects of manure, lime and phosphorus (P) fertilizer on: (i) soil chemical properties and soybean yields; (ii) nitrogen (N) and phosphorus (P) uptake, and biological nitrogen fixation (BNF) by soybean; (iii) soil microbial biomass. The treatments included goat manure (0, 5 and 10 ton ha^{-1}), lime (0 and 2 ton ha^{-1}), and P fertilizer (0, 30 and 60 kg P_2O_5 ha^{-1}). The experiment was laid out in a Randomized Complete Block Design (RCBD) with 4 replicates. Soils samples collected before and after the experiment were analyzed for soil chemical properties and microbial biomass (MB). Soybean N and P uptake, N fixation and yields were determined. Data generated was subjected to Analysis of Variance (ANOVA) and means were separated using Least Significant Difference (LSD) at 95% significance level ($p<0.05$). The results showed that lime alone (2 ton ha^{-1}) increased significantly soil pH (15.9%), extractable Ca (64.4%) and Mg (23.1%), and reduced exchangeable acidity by 3.5 times. Goat manure alone (10 ton ha^{-1}) increased significantly extractable K by 6.8 times, CEC (55.8%), available P (37.9%), N and P uptake (98.2% for N and 120.8% for P) and microbial biomass (73.5%). Integrated application of 5 ton ha^{-1} of goat manure with 2 ton ha^{-1} of lime plus 30 kg ha^{-1} P_2O_5 increased significantly soil pH (14.1%), Ca (87.7%), Mg (30.8%), K (3.7 times) CEC (73.7%) available P (38.0%) and 59.3% on microbial biomass. The integrated application of 5 ton ha^{-1} of goat manure with 30 kg ha^{-1} P_2O_5 increased significantly the uptake of N (99.2%) and P (153.2%). Soybean grain yields were significantly increased by 2.5 and 2.3 times under sole application of goat manure (10 ton ha^{-1}) and integrated application of 5 ton.ha^{-1} of goat manure with 2 ton.ha^{-1} of lime plus 30 kg P_2O_5 ha^{-1}, respectively. Goat manure proved to be an important soil amendment by providing nutrients, increasing soil pH, which in turn enhanced nutrient uptake, N fixation, microbial biomass, and increased soybean yields. Integrated application of manure with lime and P fertilizer contributed to improved soil chemical properties and soybean yields. Therefore, manure can substitute or supplement the inorganic fertilizers and could be recommended for the smallholder farmers of Embu County, Central Highlands of Kenya.

CHAPTER 1: INTRODUCTION

1.1. Background

The sector of agriculture is the major contributor to the economy of most developing countries, including Kenya where it contributes about 25% of the Gross Domestic Product (GDP) (World Bank, 2013). However, the achievement of adequate food supply for its ever increasing population is still far from reach due to the declining soil productivity (Ikombo, 1984). According to Sanchez and Jama (2002) the decline is a result of a combination of soil erosion, leaching, removal of crop residues, and continuous cultivation of the land without adequate fertilization or fallowing. This is aggravated by the inherent poor fertility and acidity in most tropical soils (Okalebo *et al.*, 2006).

In Kenya, production of soybean is relatively new and its production is expected to increase due to its importance in food nutrition, income generation and fodder (Mugendi *et al.*, 2010; Chianu *et al.*, 2009). Soybean is a multipurpose crop which is drought tolerant and grown for oil production, human food, livestock feed, industrial purposes, and recently for bio-energy (Mathu *et al.*, 2010). Additionally, the crop contributes to increased cereal crop yields and improved soil fertility through biological nitrogen fixation, due to the presence of *Rhizobium japonicum* in their roots (Sanginga, 2003). The rate of N_2 fixation varies considerably, depending on type of legume cultivar, method of measurement, the presence of appropriate rhizobia, and certain soil and environmental variables, including soil moisture (Danga *et al.*, 2009). According to Sanginga (2003), some varieties of soybean can fix 44 to 103 kg N ha^{-1} annually.

However, soybean yields are still below the Kenyan national potential of 3,000 - 3,600 kg ha^{-1} (Mahasi *et al.*, 2010). Inherent poor and declining soil fertility, soil acidity, poor management practices and low agricultural input use are the major causes of low soybean yields (Kanyanjua *et al.*, 2002; Kimani *et al.*, 2004; Okalebo *et al.*, 2006; Njeru, 2009). Effects of soil acidity are many; the most important being the retardation of plant growth through toxicity of Aluminum (Al) and Hydrogen (H) ions, unavailability of other plant nutrients, mainly Nitrogen and Phosphorus, and reduction of microbial activity in the soil (Ano & Ubochi, 2007). Reduced availability of Nitrogen (N) and Phosphorus (P) in predominantly acidic soils is responsible for reduced soybean performance through reduced photosynthesis and early root development, low microbial activity and poor nitrogen fixation, leading to low yields (Amba *et al.*, 2011; Kamara *et al.*, 2007).

Therefore, it is necessary to adopt improved technologies in order to increase per capita agricultural production. One of the approaches is the integrated soil fertility management (ISFM) that combines use of organic inputs with chemical fertilizers, improved germplasms, and better crop management. The beneficial effects of combined organic and inorganic fertilizers on soil fertility, maintenance of soil organic matter and crop yields have repeatedly been shown in field trials (Nandwa, 2003; Vanlauwe *et al.*, 2002). However, in acid soils these effects are more effective when lime is included due to its role in neutralizing soil acidity, raising the soil pH, providing Ca^{2+}, Mg^{2+} and decreasing aluminum (Al) and iron (Fe) toxicity. These positive effects on the soil stimulate microorganism's activity and crop growth (Kisinyo *et al.*, 2012; Kanyanjua *et al.*, 2002). In the acidic soils of central Kenya, the information is scarce regarding the use of lime, organic and inorganic fertilizers or their combination on soybean production, soil chemical properties and soil microbial biomass.

1.2. Problem Statement

Soybean is an important cash crop that has recently been introduced to smallholder farmers in central Kenya as source of food, income and for soil fertility improvement. However, its production levels are markedly low with yields not going beyond 800 kg ha^{-1} (Mahasi *et al.*, 2010; Vanlauwe *et al.*, 2003). Acidity and depletion of the major nutrients (N, P) attributed to continuous cultivation with removal of nutrients by crop, use of ammonium nitrogen fertilizers, leaching of exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}) and high concentration of Al, are the main factors that adversely affect the soybean production. In acid soils availability of phosphorus, biological nitrogen fixation, and microbial activity are reduced which in turn affects soybean development and yields. Acidic infertile soils maybe corrected through liming or the use of organic fertilizers (manures). Therefore, the increase of soybean yields starts by reducing soil acidity to a level at which crop can produce its potential, followed by increase and maintenance of soil fertility through application of fertilizers, mainly N and P. However, recommendation of the high rates of mineral N and P fertilizers application is not viable option for smallholder farmers because most of them lack financial resources. Thus to reduce the amount of mineral fertilizers required there is a need to adopt ISFM technologies which combine organic fertilizers with small amounts of mineral fertilizer and build up soil conditions to enhance biological N fixation. Studies on soil acidity amelioration in smallholder cropping system in the region are scanty. Therefore, the aim of the study was to determine the effect of applying manure, lime and inorganic phosphorus fertilizer on soil properties and soybean grain yields in an acidic soil of the central highlands of Kenya.

1.3. Justification of the study

Low availability and high cost of lime, largely due to transport cost, has kept lime and mineral fertilizers from reaching smallholder farmer's fields. Application of lime and organic materials alone or in combination with small amounts of inorganic fertilizers would alleviate soil acidity problems and improve soil fertility. The use of these inputs apart from supplying nutrients will also enhance soil microbial activity, biological nitrogen fixation, soil properties and soybean yields. Organic materials such as goat manure have been used to replenish soil fertility for long time by supplying nutrients, increasing soil organic matter, and improving soil physical properties. For instance Amba *et al.*, (2011) in Nigeria reported significant increase in soil chemical properties, nitrogen fixation and lastly soybean yields with application of P fertilizer. Farm yard manure (FYM) alone and combined with NP fertilizers increased significantly soil chemical properties (organic matter, extractable P, K, pH) (Antil & Singh, 2007; Adeniyan *et al.*, 2011), and soil microbial biomass (Onwonga *et al.*, 2010). In addition combination of lime and P fertilizer increased soil pH and extractable P in Western Kenya (Kisinyo *et al.*, 2012).

1.4. Research questions

i. What are the effects of goat manure, lime and P fertilizer on soil chemical properties and soybean yields?

ii. How are N, P uptake and N_2 fixation in soybean affected by goat manure, lime and P fertilizer in an acid soil?

iii. To what extent is soil microbial biomass affected by goat manure, lime and P fertilizer, in an acid soil?

1.5. Objectives

1.5.1. The overall objective

The overall objective was to determine the effects of goat manure, lime and phosphorus fertilizer on soil properties and soybean yields in an acid soil in Embu County, Kenya.

1.5.2. The specific objectives wrote to:

i. Determine the effect of goat manure, lime and P fertilizer on soil chemical properties and soybean yields;
ii. Determine the effect of goat manure, lime and P fertilizer on N, P uptake and N_2 fixation of soybean;
iii. Evaluate the effect of goat manure, lime and P fertilizer on soil microbial biomass;

1.6. Research hypotheses

i. Application of goat manure, P fertilizer and lime improves soil chemical properties and increases yields of soybean;
ii. Application of goat manure, lime and P fertilizer has a positive effect on N and P uptake and N_2 fixation by soybean;
iii. Application of goat manure, lime and P fertilizer significantly increases soil microbial biomass;

1.7. Significance of the study

Increasing soybean production through implementation of sustainable soil fertility practices in central highlands of Kenya for smallholder farmers is a concern among agriculture stakeholders. Therefore, this study will generate additional knowledge, to extension agents and policy makers on soybean production with emphasis on acidic soils. In addition, the smallholder farmers will use the results of this study to improve soil management practices for soybean production that is envisaged to increase soybean yields in the Central Highlands of Kenya. Moreover, the study will contribute generating income for farmers hence improving their livelihoods, food security and overall poverty.

1.8. Conceptual framework

Prevalence of unfavourable soil conditions that are associated with poor inputs use and agricultural practices management lead to low soybean and other crops yields. This results to low incomes, food insecurity and overall poverty on smallholder farmers' level. Adoption of soil fertility management practices (which include use of manure, lime in combination with mineral fertilizers) may enhance nutrient availability; improve soil conditions for microorganisms' development and nitrogen fixation; and consequently increase crop yields. The increased crop yields will influence the society by improving nutrition, income and reducing poverty (Figure 1.1).

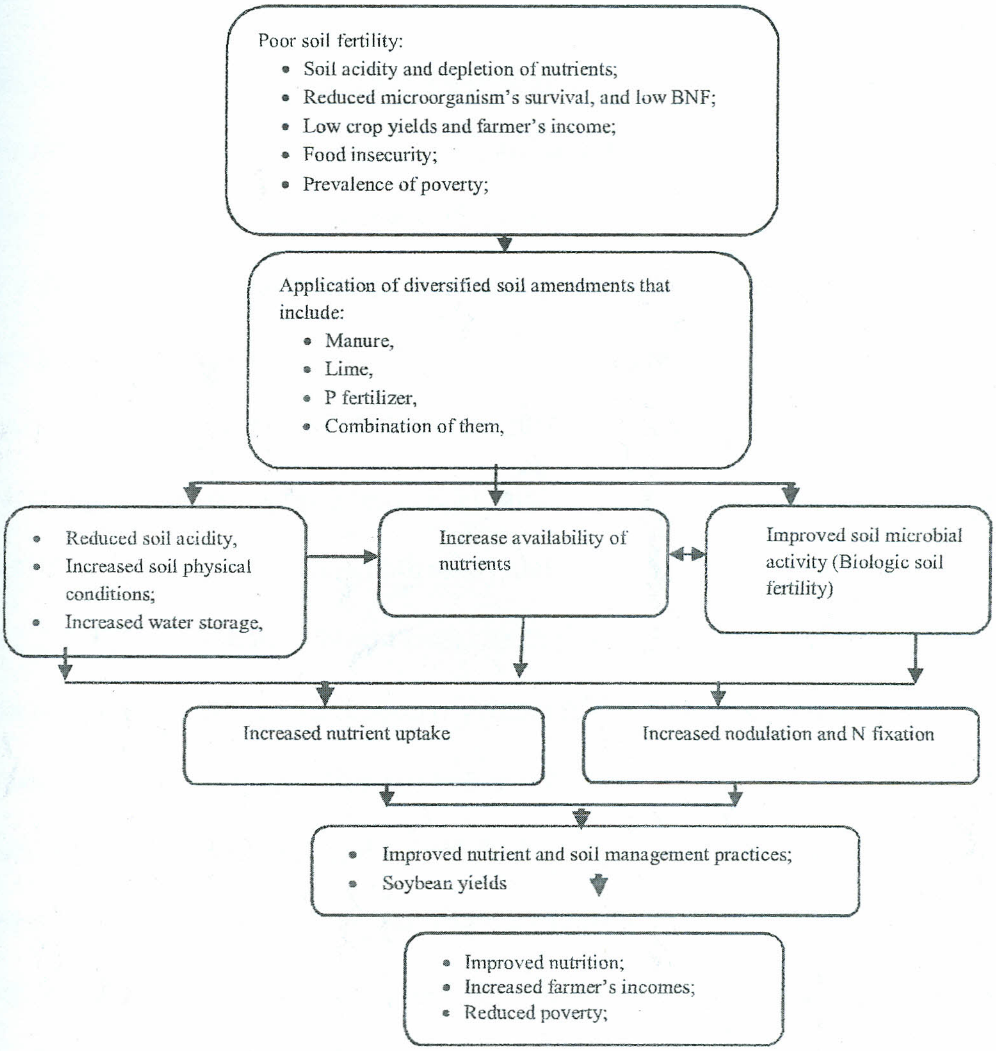

Figure 1.1: Conceptual framework of the study (Source: Author)

CHAPTER 2: LITERATURE REVIEW

2.1. Importance of soybean

Soybean, a native crop of China, is much widely spread as it is found in nearly every country in Sub-Saharan Africa where Nigeria is the largest producer. However, in Kenya it is grown in small scale and is second producer within Eastern Africa only after Uganda (Coulibaly *et al.*, 2009). The crop is a drought tolerant leguminous grain that grows in areas where maize and common beans are grown. It grows to a height of 60 – 120 cm, maturing in 3 to 6 months depending on the variety, climate, and location (Mathu *et al.*, 2010). Depending on the variety, the crop can be grown from 0 – 2,200 m altitude and under rainfall ranging from 300 to 1,200 mm (Mathu *et al.*, 2010). Soybean grows well in both sandy and heavy textured soils over a wide range of soil pH 5.5-8.5 (Nieuwenhuis & Nieuwelink, 2002; Kamara *et al.*, 2007). Soybean has a high commercial value and high concentration of protein (about 40%), calcium, phosphorus, fiber, and in addition it is cholesterol free (Greenberg & Hartung, 1998; Imas & Magen, 2007). Moreover, it provides food, cash and animal feed; and like other leguminous crops, soybean has impact on the soil improvement whereby the canopies cover the soil and protect it from recurrent erosion, and add nitrogen from the atmosphere through biological N fixation (Nieuwenhuis & Nieuwelink, 2002; Imas & Magen, 2007). In Kenya, the national average production is between 3.0 – 3.6 ton ha^{-1} (Mahasi *et al.*, 2010) and production is expected to increase due to its importance as human food, animal feed, income generation and soil fertility improvement (Mugendi *et al.*, 2010; Chianu *et al.*, 2009).

2.2. Soil acidity and its constraints for soybean production

Acidity refers to concentration of hydrogen cations in a solution (FAO, 2006). The pH values range from 0 to 14, in which below 7 indicates an acid solution, above 7 alkaline and 7 neutral solutions (Foth & Turk, 1972; Crawford, Singh & Breman, 2008). The natural pH of a soil depends on the nature of the material from which it was developed (TSO, 2010). In most soils pH ranges from 2.0 to 11 (Batjes, 1995) and is used for classifications of soils (Landon, 1991; Soil Survey Staff, 1993; Kanyanjua *et al.*, 2002). Table 2.1 shows classification of soils according to the level of pH.

Table 2.1: Classification of soil acidity according to the level of pH

Soil acidity class	**pH range**
Extremely acidic	< 4.5
Strongly acidic	4.5 – 5.0
Moderately acidic	5.0 – 6.0
Slightly acidic	6.0 – 6.5
Near neutral	6.5 – 7.0

Source: Kanyanjua *et al.* (2002)

In soils of low pH, containing high amounts of Al and Fe oxides, P is deficient in the soil solution because it is precipitated or surface adsorbed with Al and Fe as insoluble compounds (Kanyanjua *et al.*, 2002). Several other essential plant nutrients, which are present in the soil solution as cations, are deficient. In acid soils, soybean is affected directly and indirectly. These effects include injury on plant roots therefore reducing water and nutrient uptake, reduced availability of essential plant nutrients, toxicity of Al and Manganese (Mn); and survival of microorganisms in the soil (Crawford *et al.*, 2008; Onwonga *et al.*, 2008).

To enable crop production in acid soils, several means to correct nutrient deficiency can be adopted. These include liming, addition of organic matter, and fertilization with mineral fertilizers (Onwonga *et al.*, 2010; Masarirambi *et al.*, 2012). Liming reduces Al^{3+} and H^+ ions as it reacts with water leading to the production of OH^- ions, which react with Al^{3+} and H^+ in the acid soil to form $Al(OH)_3$ and H_2O. The precipitation of Al^{3+} and H^+ by lime causes the pH to increase, enhances microbial activity and nutrient availability (Onwonga *et al.*, 2008). Soybean as leguminous crop relies on microbial nitrogen fixation as source of N. However, under acid soils, the population of *rhizobia* bacteria is reduced and consequently nodulation and N fixation is impaired. This affects negatively on crop nutrition and yields. Therefore, liming acid soils for soybean production improves soils condition for microorganism development. Mineral fertilizers increase nutrient availability in the soil solution since they are readily available, and the addition of organic matter acts as supply of microorganism's food enhancing their population and therefore mineralization (Crawford *et al.*, 2008).

2.3. Effects of manure, lime and P fertilizer on soybean yields

2.3.1. Manure

Organic fertilizers are derived from plants and animal parts and have a wide role in agricultural production system. When added to the soil they increase its organic matter content and improve soil physical properties. Furthermore, improvement in soil organic matter (SOM) leads to slow release of crop nutrients (Nitrogen (N), Phosphorus (P) and Potassium (K)); improve buffering capacity of the soil and cation exchange capacity (Gachene & Kimaru, 2003).

The actual nutrient value of manure from a particular operation will differ considerably due to the type of animal, its food ration, manure collection, storage, application procedures and climate (Risse *et al.*, 2006). Manure effects on soil physical properties includes increased infiltration (Risse *et al.*, 2006), water holding capacity (Rasoulzadeh & Yaghoubi, 2010; Liang *et al.*, 2011) and reduced compaction and erosion (Salahin *et al.*, 2011).

According to Kihanda *et al.* (2007) manure application is one of the most effective ways of improving fertility in tropical soils. Despite its low availability, animal manure is the most widely used organic fertilizer by approximately 80% of households in Central highland of Kenya (Makokha *et al.*, 2001). These manures have been used as fertilizer on smallholder farmers in order to increase crop production, and have been shown to be an alternative for improvement of crop yields in central highlands of Kenya (Mugwe *et al.*, 2007). For instance Javaid and Mahmood (2010) in Pakistan, found significant effect of farm yard manure on soybean pod number. Elsewhere, the application of poultry manure also increased dry matter per hectare and grain yield (Maheshbabu *et al.*, 2008; Tagoe *et al.*, 2008; Chiezey & Odunze, 2009).

2.3.2. Lime

Lime are materials containing carbonates, oxides or hydroxides required to apply in acid soils to raise soil pH and in addition neutralize toxic elements in the soil. Soil pH is used to determine whether or not to lime a soil (TSO, 2010). Liming materials include $CaCO_3$, $Ca,Mg(CaCO_3)_2$, $Ca(OH)_2$, CaO and others, which vary according to their neutralizing value and degree of fineness (TSO, 2010). When lime is applied to the soil, Ca^{2+} and Mg^{2+} ions displaces H^+, Fe^{2+}, Al^{3+}, Mn^{4+} and Cu^{2+} ions from soil adsorption site resulting in increase in soil pH. Other than increasing soil pH, lime also supplies significant amounts of Ca and Mg, depending on the type. Indirect effects of lime include increased availability of P, Mo and B, and more favourable conditions for microbially mediated reactions such as nitrogen fixation and nitrification, and in some cases improved soil structure (Nekesa *et al.*, 2005). For instance application of lime significantly increased root and shoot yields in Nigeria (Anetor & Akinrinde, 2006), grain yields of soybean in Brazil (Kassel *et al.*, 2000; Caires *et al.*, 2006). Similarly in Croatia Andric *et al.*, (2012) reported increased soybean yield by 44% as a result of lime application. Moreover, Nekesa *et al.* (2011) in Western Kenya also found positive response of soybean grain yield to lime application either alone or combined with P fertilizer.

2.3.3. Phosphorus fertilizers

Phosphorus is a major plant nutrient essential for initial plant root development, energy transfer, photosynthesis, water use efficiency, nodulation, seed formation, size and number (Tisdale *et al.*, 1985; Gupta, 2011), thus affecting soybean yield. However, availability of P in soils is reduced by continuous cultivation through plant removal and fixation by Al^{3+} and Fe^{2+} ions in acid soils. To increase P availability, supply of P through application of P fertilizers and organic sources are used. While mineral fertilizers are readily available, the organic sources require microbial activity to decompose and nutrient release is slow. However, mineral P fertilizers accessibility and cost are major constraints for smallholder (Buresh & Smithson, 1997).

Mugendi *et al.* (2010), working in Chuka and Muthambi (Meru South District) found significant increase in fresh pod and 1000 seeds weights of soybean with application of 50 kg ha^{-1} P_2O_5. Also in Nigeria, application of P fertilizer at the rate of 30 kg P_2O_5 ha^{-1} significantly increased soybean grain yield in acid soil (Mahamood *et al.*, 2009). In South Africa Mabapa *et al.* (2010) reported an increase in above ground biomass and grain yields of soybean following application of 60 kg P_2O_5 ha^{-1}. Increased soybean grain yield and components have also been reported after application of P fertilizers in Nigeria (Kamara *et al.*, 2007; 2008; 2011).

2.3.4. Combined effects of P fertilizers, lime and manure

The importance of applying fertilizers in organic or inorganic form has been proven in various researches. However, use of manures alone has a slow but positive effect in releasing nutrients since they require microbial activity to decompose it. On the other hand, mineral fertilizers are of rapid nutrient availability but expensive and are easily leached from the soil. However, application of combined organic and inorganic fertilizers is a viable solution to restore, maintain soil fertility and increase crop yields (Danga *et al.*, 2010; Sharief *et al.*, 2010). Maheshbabu *et al.* (2008) in India found that combination of FYM and mineral fertilizer had a significant effect not only on soybean grain yield but also on its growth parameters. Also, Anetor and Akinrinde (2006) in Nigeria found that combined lime and organic fertilizer had a significant effect on the number of pods, pod weight and seed number of soybean. Similarly in western Kenya, Nekesa *et al.* (2011) found that combined Diamonium Phosphate (DAP) or TSP and lime increased significantly soybean grain yields. Combined organic and inorganic fertilizers have also been reported to increase soybean yield 12.9% in India (Maheshbabu *et al.*, 2008), 19% in Indonesia relative to sole application of inorganic fertilizer (Yamika & Ikawati, 2012), and 50% against sole application of organic fertilizer (manure) (Zerihun *et al.*, 2013).

2.4. Effects of manure, lime and phosphorus fertilizer on soil chemical properties

Soil chemical properties include pH, exchangeable acidity (H, Al) and exchangeable bases (Ca, Mg, K and Na). These properties influence availability of nutrients to crop, and therefore have potential to reduce or increase crop yields. Application of soil amendments leads to improvement in soil chemical properties creating favourable conditions for crop nutrition, development and yield. For example Ndayegamiye and Cotê (1988) reported significant increase of 7.6% and 15.2% in CEC at the rates of 4.0 and 6.0 ton ha^{-1} of cattle manure, respectively. Similar reports on an Alfisol in Nigeria Ayuba *et al.* (2005) who found that available P increased significantly while total P was as high as 7.21 ppm following application of 15 ton ha^{-1} of FYM. In a comparative study of organic manures and NPK fertilizer in acid soil, Adeniyan *et al.* (2011) found that 5 ton.ha^{-1} of cattle manure significantly increased soil available P, pH, organic C and cation exchange capacity. Kheyrodin and Antoun (2012) found that manure increased significantly soil P, Ca and Mg contents in the 15 – 30 cm depth. Application of 2 ton ha^{-1} of lime decreased exchangeable Al, and increased pH, available Ca and Mg in Cameroon (The *et al.*, 2001). Lime and P fertilizers significantly improved soil pH and available P as reported by Anetor and Akinrinde (2006), who also attributed increased soil pH with lime which in turn reduced P fixation. Repsiene and Skuodiene (2010) found that lime and manure when applied sole or combined had a significant effect in reducing Al, increasing Ca, pH, and Mg. Ademba *et al.*, (2010) reported significant increase in soil total P, K, Ca, Mg with sole application of 10 ton ha^{-1} of manure, 60 kg P_2O_5 ha^{-1} and 250 kg ha^{-1} of lime. In addition, the same study revealed that lime and manure combined with DAP increased available P. In Nigeria, Ewulo (2005) found that application of 6 ton ha^{-1} of cattle manure increased total soil P, K, Ca, Mg and cations exchange capacity (CEC), and decreased exchangeable acidity. Improved physicochemical properties of acid soils have been reported through combination of manure with N, P fertilizers and lime (Onwonga *et al.*, 2010). The improvement was attributed to the integrated effect of the amendments by improving soil pH, microbial activity, nutrient release from organic matter decomposition and improved soil structure as well. In addition, Kisinyo *et al.* (2012) reported significant positive effects on soil pH and available P in acid soil of Western Kenya, with application of lime and P fertilizer in sole or in combination.

2.5. Effects of manure, lime and P fertilizer on N, P uptake and N_2 fixation of soybean

2.5.1. Nitrogen (N) and Phosphorus (P) uptake

Nitrogen is a macronutrient also known as vegetative nutrient and mostly used by the plants and therefore, an important nutrient for soybean grain yield (Kamara *et al.*, 2011). However, availability of N is highly affected by soil acidity and leaching. Acidity tend to reduce microbial mediate processed that results in poor organic matter decomposition, mineralization of nitrogen and consequently low N availability. Application of soil acidity amendments may improve soil conditions for mineralization take place and increase N availability in the soil, its uptake and finally positive influence on increasing crop yield. In Bangladesh, Jahangir *et al.* (2009) reported increased N uptake by soybean under P fertilizer application. Similarly in India, Sharma *et al.* (2011) found significant increase uptake of N in soybean under P fertilizer application. Additionally, Schmitt *et al.* (2001) found that application of manure increased significantly N uptake by soybean. Son *et al.* (2001) in a farmer's field experiment under moderate acidic soil also reported that application of organic resources alone and combined with inorganic resources recorded 5.81% and 5.83% N content, respectively, in the soybean grain. In addition, Tagoe *et al.* (2008) found increased 10.1% and 40.6% in seed and plant total N content as affected by application of manure respectively. Application of lime increased soil pH and favoured nitrogen fixation where N concentration in the plant was increased significantly by 3.1% as reported by Caires *et al.* (2006).

Phosphorus is an important plant macronutrient, making up to about 0.2% of a plant's dry weight (Schachtman *et al.*, 1998). Phosphorus is present in seed and fruit in large quantities and is essential for seed formation. Phosphorus has also been reported to be root growth stimulant and it is associated with early crop maturity (Abbas *et al.*, 2011). In acidic soils, most plant nutrients tend to be unavailable, but lack of P is said to be the one that largely affects crop growth, absorption of water and other nutrients hence low crop yields (Crawford *et al.*, 2008). Application of manure, lime and P fertilizers improve soil chemical, physical and biologic properties. They reduce P fixation by Al and iron (Fe) oxides in the soil, and increase availability of P, which increases its uptake by crop (Crawford *et al.*, 2008; Kisinyo *et al.* 2012). Anetor and Akinrinde (2006) reported 65.6% increase in P uptake by early growing soybean variety with application of lime (2 ton ha^{-1}). In India application of combined poultry manure (4.5 ton ha^{-1}) and P fertilizer (13, 26 and 39 kg P ha^{-1}) significantly increased soybean P uptake more than application of either sole poultry manure or sole P fertilizer (Toor, 2009). This was attributed to increased availability of P in the soil, enlarged proliferation of roots and to reduction of Fe and Al activity in the soil.

2.5.2. Biological Nitrogen Fixation (BNF)

Biological N_2 fixation is the process through which a number of species of bacteria use the enzyme nitrogenase to convert atmospheric N_2 into ammonia (NH_3), a form of nitrogen (N) that is incorporated into organic components (Ukovich *et al.*, 2008). This process is common in leguminous plants such as soybean in which bacteria lives in nodules where N is fixed, converted and absorbed by the plant in a symbiotic process between the bacteria and the plant. The fixation starts with formation of nodules. This depends on crop root development and on the presence of rhizobium strains in the soil. Nodulation starts one week after infestation; and 2-3 weeks after planting. The nodules can be seen in the field and their effectiveness can be recognized by pink or reddish color of the nodules (Better Crops, 1999; Ukovich *et al.*, 2008). According to Bohlool *et al.* (1992), Peoples *et al.* (1989), Ukovich *et al.* (2008) Nitrogen fixation can contribute directly to agricultural production by providing the N of the leafy vegetative parts, pods, seeds and tubers of plants used as feed for livestock or harvested for human consumption.

Soybean is a legume crop known by its high capacity for N fixation which can supply crop requirement. Soybean N fixation is maximized at late flowering to early podfill and decreases during reproductive phases; and it is capable of fixing substantial (up to 97 %) amount of its required N from BNF (Keyser & Li, 1992). Some studies have reported that soybean has ability of fixing 44 to 103 kg N ha^{-1} annually (Sanginga, 2003). Therefore, BNF systems offer an economical and ecological means of reducing external inputs and improving internal resources.

The effectiveness of BNF depends on the management of other inputs such as nutrient availability, population of rhizobia and soil pH (Jones & Giddens, 1985; Keyser & Li, 1992; Peoples *et al.*, 1989; Ukovich *et al.*, 2008). The process of biological nitrogen fixation by legume nodules requires large amounts of P, and its availability is a primary constraint to N_2 fixation (Danso, 1992; Better Crops, 1999; Sanginga, 2003; Kamara *et al.*, 2007). Deficiencies of soil nutrients, especially P may restrict the development of a population of free-living rhizobia in the rhizosphere, limit the growth of the host plant, restrict nodulation itself, and cause an impaired nodule function (Better Crops, 1999; Danso, 1992). Moreover, limitation of N mineral in the soil tends to enhance fixation by legumes including soybean (Ukovich *et al.*, 2008). The population and activity of rhizobia is highly influenced in acid soils, affecting directly N fixation (Jones & Giddens, 1985).

Effects of P in enhancing N fixation have been demonstrated by various studies. For instance, Mugendi *et al.* (2010) in central highlands of Kenya obtained increased nodule fresh weight with increased levels of P fertilizer up to 25 kg P_2O_5 ha^{-1}. In Nigeria, application of P fertilizer at the rates of 30 kg P_2O_5 ha^{-1} and 60 kg P_2O_5 ha^{-1} significantly increased number of nodules (Ogoke *et al.*, 2004),whereas 26.4 kg P_2O_5 ha^{-1} recorded the highest amount of N fixed (Amba *et al.*, 2011). Similarly, Chiezey and Odunze (2009) found that P application significantly influenced N fixation in Nigeria. Meanwhile Lapinskas and Piaulokaitė-Motuzienė, (2006) working under acid soil in Lithuania found that lime applied to inoculated seed fixed 106 kg N ha^{-1}. Tagoe *et al.* (2008) recorded 39% of significant increase in number of nodules as a result of manure application. Meanwhile Bekere *et al.* (2013) reported that application of lime increased significantly the number of nodules in soybean grown in acid soil of South West Ethiopia.

2.6. Effects of manure, lime and P fertilizer on Soil Microbial Biomass

The Soil Microbial Biomass (SMB) is the active component of the soil organic pool, playing an important role in nutrient cycling, plant nutrition and functioning of different ecosystems. It is responsible for organic matter decomposition thus affecting soil nutrient content (Onwonga *et al.*, 2010). As such, the biomass is both a source and sink of the nutrients C, N, P and S contained in the organic matter (Lin *et al.*, 2010; Basu *et al.*, 2011). Soil microorganisms are significant determinants of organic matter decomposition, soil nutrient status, crop health, and overall crop productivity (Basu *et al.*, 2011). Soil MB is undoubtedly a valuable tool for understanding and predicting changes in soil fertility management and associated soil conditions such as nutrient dynamics and soil reactions (Sharma *et al.*, 2004). However, changes in soil conditions (plant or animal residues) will determine how fast the microbial biomass responds (Onwonga *et al.*, 2010). Therefore, understanding soil microbial biomass dynamics is particularly critical in the management of acid soils, to reverse declining soil organic matter content and to restore soil fertility. Soil amendments have been used and reported as improving SMB. In a study of different soil amendments, Onwonga *et al.* (2010) reported that manure significantly increased SMB throughout crop cycle. Similarly, Basu *et al.* (2011) found increased SMB with application of FYM combined with chemical fertilizers, although it was mostly increased when FYM and chemical fertilizers were combined with lime. Bhadoria *et al.* (2011) found that SMB increased with application of combined FYM and mineral fertilizer, both under lime and with no lime application. Fuentes *et al.* (2006) reported that application of lime at the rate of 4.4 ton ha^{-1} increased soil microbial biomass by 3.3 times which was attributed to increased soil pH.

CHAPTER 3: MATERIALS AND METHODS

3.1. Study area

The study was carried out for two seasons, 2012 Short Rains (SR) and 2013 Long Rain (LR), in Embu West district. The district is located in Embu County, in the Kenyan Central Highlands and occupies 708 Km^2. It borders to the North with Meru South, to the South East and East with Mbeere district and Kirinyaga to the West. The experimental site was located at Embu Agricultural Staff Training College, Embu County (Figure 3.1) which lies between 0^0 35' 25.58"S and 37^0 25' 31.84"E at an elevation of 1494 m above sea level with an annual mean temperature of 20°C and average annual rainfall of 909-1230 mm. The rainfall is received in two seasons; the long rains (LR) lasting from March to June, and short rains (SR) from October to December (Jaetzold *et al*., 2006).

The major agro-ecological zone (AEZ) of the area is Upper Midland 2 (UM 2), and the soils are mainly classified as humic Nitisols (Jaetzold *et al.,* 2006) which are deep, well weathered with moderate to high inherent fertility. Soil fertility has declined over time due to continuous mining of nutrients without adequate replenishment. Recent studies have reported that they have generally low levels of nitrogen (<0.2 %), phosphorus (< 10 ppm) and are moderately to strongly acidic (pH ranges from 4.8 – 5.4), conditions that result in low crop production (Mugwe *et al*., 2007). The district is a predominantly maize growing zone with small land holdings ranging from 0.1 to 1.5 ha with an average of 1.2 ha per household. The area is characterized by rapid population growth, low soil fertility and agricultural productivity, and increasing demands on agricultural resources. The farming systems are complex consisting of an integration of crops trees, livestock, and smallholder farms that are intensively managed

(Mairura *et al.*, 2007). The main cash crops are coffee (*Coffea arabica* L.) and tea (*Camelina sinensis* (L.) O. Kuntze) while the main staple food crop is maize (*Zea mays* L.), which is cultivated from season to season mostly intercropped with beans (*Phaseolus vulgaris* L.). Other food crops include sweet potatoes (*Ipomea batatas* (L.) Lam), bananas (*Musa* spp. L.) and vegetables that are mainly grown for subsistence consumption. Livestock production is a major enterprise especially improved breeds of dairy cattle, sheep, goats and poultry. Figure 3.2 shows the amount of rainfall observed during the growing periods of the 2012SR and 2013LR (data obtained from KARI-EMBU).

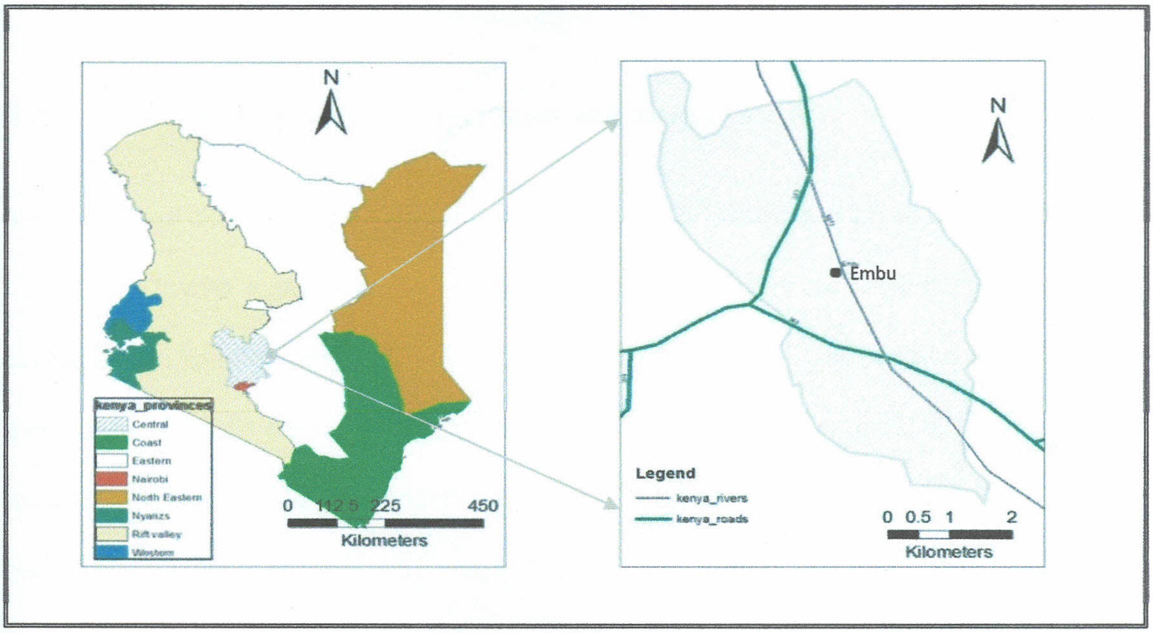

Figure 3.1: Study area: Left - Major regions; Right - Embu County.

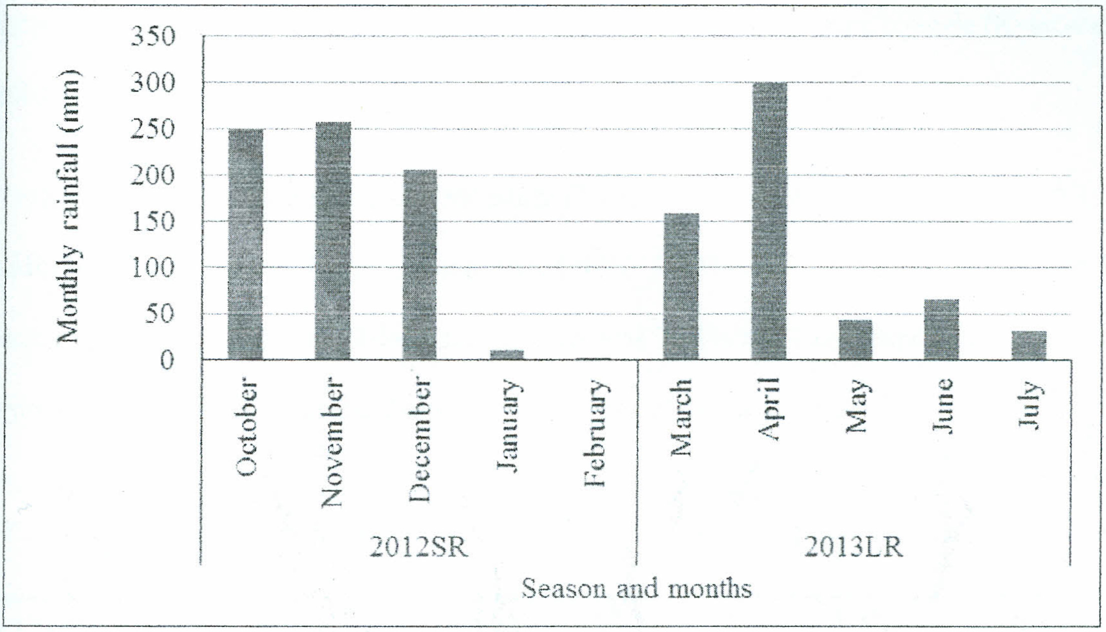

Figure 3.2: Rainfall amount during 2012SR and 2013LR at Embu, Kenya.

3.2. Soil fertility status prior to experiment and manure quality

The initial soil characterization of the study site (Table 3.1) indicated pH in water ranged from 4.75 to 5.31 with a mean of 5.07 indicating that the soils were moderately acidic. Soil exchangeable acidity ($Al^{3+} + H^{+}$) was of 3.72 cmol(+) kg^{-1} soil and is rated moderate. Soil available P was 7.54 mg kg^{-1}, which is classified as low (Okalebo *et al.*, 2002), and therefore, indicates the need for supplemental P in this soils. The mean soil exchangeable Ca, Mg, K and Na were 0.63 cmol(+) kg^{-1}, 0.51 cmol(+) kg^{-1}, 0.12 cmol(+) kg^{-1} and 0.14 cmol(+) kg^{-1}, respectively. The cation exchange capacity (CEC) of the soil was 1.40 cmol(+).kg^{-1} soil. The soils at the experimental site had moderate organic C (2.12%) and total N (0.21%) (Okalebo *et al.*, 2002). This gives a C:N ratio of 10.1 which is known to enhance N mineralization. According to the soil particle size analysis, the soil had 45% clay, 20% sand and 35% silt therefore classified as sandy clay loam in structure, based on soil textural triangle (Ryan *et al.*, 2001).

Analysis of manure used in the current study (Table 3.1) showed that pH water was 9.3. In addition, it had 0.46% of total P, and also 0.91%, 0.44% and 1.69% of Ca, Mg and K, respectively. The total C and N content of manure was 21.3% and 1.6% respectively, therefore with a C:N ratio of 13.3, a ratio that favours net mineralization.

Table 3.1: Initial soil properties (characterization prior to experiment) and quality of manure used.

Parameters	**Value**	
	Soil	Manure
Physical properties		
Clay (%)	45	-
Sand (%)	20	-
Silt (%)	35	-
Texture	Clay loam	-
Bulk density (g cm^{-3})	0.95	-
Chemical properties		
pH water (1:2.5)	5.06	9.33
pH KCl (1:2.5)	4.21	-
Exchangeable acidity (cmol(+) kg^{-1} soil)	3.72	-
Exchangeable cations (cmol(+) kg^{-1} soil)		Total (%)
Ca^{2+}	0.63	0.92
Mg^{2+}	0.51	0.44
K^+	0.12	1.69
Na^+	0.31	0.43
CEC	1.40	-
Available P (mg kg^{-1} soil)	7.54	-
Total P (%)	-	0.46
Total Nitrogen (%)	0.21	1.60
Total Carbon (%)	2.12	21.34
Biological properties		
Microbial Biomass (mg kg^{-1} soil)	27.2	-

3.3. Experimental design and treatments

The experiment consisting of 9 treatments (Table 3.2) was conducted during the Short Rain season (October to December) in 2012 and Long Rain season (March to June) in 2013. The treatments comprised manure at three levels (0, 5 and 10 ton ha^{-1}) as goat manure, P fertilizer at three levels (0, 30 and 60 kg P_2O_5 ha^{-1}) as Triple Superphosphate (TSP), and lime at two levels (0 and 2.0 ton ha^{-1}) as CaO. The experiment was laid as Randomized Complete Block Design (RCBD) and replicated four times in 4.5 m x 4.0 m (18.0 m^2) plot size. Prior to planting in each season, the land was ploughed to a depth of 15 cm using a hand hoe. Manure and lime were uniformly surface broadcasted and then incorporated within 15 cm soil depth two (2) weeks before planting. The P fertilizer was applied per row and mixed with soil at planting. The test crop was soybean, variety Gazelle, recommended for Embu district agro ecological (Upper Midland 2) zone (Krause & Wasike, 1998). Soybean was planted at 50 cm x 10 cm spacing, on 13th October 2012 (2012SR – Short Rain season) and on 23rd March 2013 (2013LR – Long Rain season). Two weeks after emergence, the seedlings were thinned to two (2) plants per hill to adjust plant density to 400,000 plants per hectare. The crop was weeded using hand hoe, three times (vegetative, flowering and podding stages) each season. Insecticide Thunder was sprayed for insect and termites control twice during 2012 SR and thrice during 2013LR.

Table 3.2: The experiment treatments and their descriptions

Treatments	Abbreviation	Treatment description
Manure	M	10 ton ha^{-1} goat manure at recommended rate (Micheni *et al.*, 2004)
Lime	L	2 ton CaO ha^{-1} at recommended rate (Okalebo *et al.*, 2002)
P fertilizer	P	60 kg P_2O_5 ha^{-1} at recommended rate (Micheni *et al.*, 2002)
½ Manure+Lime	ML	5 ton ha^{-1} M + 2 ton CaO ha^{-1}
½ Manure+ ½ P	MP	5 ton ha^{-1} M + 30 kg P_2O_5 ha^{-1}
½ Manure+Lime+ ½ P	MLP	5 ton ha^{-1} M+2 ton CaO ha^{-1}+30 kg P_2O_5 ha^{-1}
Lime+ ½ P	LP	2 ton CaO ha^{-1}+ 30 kg P_2O_5 ha^{-1}
Reference crop	RC	Non nodulating variety of soybean
Control	CL	No inputs

3.4. Soil and plant sampling, preparation and analysis

3.4.1. Soil sampling

Soil sampling was conducted prior to planting and soil ameliorant application. Composite soil samples of nine topsoil samples were collected at 0-15 cm depth, in each plot using an auger. The nine samples were taken along the two of the diagonals of the plot by taking one sample at the centre of the plot and the remaining in all directions from the center. Subsequently, and at the same depth, soil samples were collected at 4 stages of crop growing after planting (4 weeks - vegetative, 8 weeks - flowering, 12 weeks - podding and 17 weeks - harvest). The soil samples were taken to the laboratory for determination of texture, pH, exchangeable cations (Ca, Mg, K, Na), exchangeable acidity, extractable P, total carbon (C) and nitrogen (N), and mineral N (NO_3^-, NH_4^+). The soil samples were then air-dried and ground to pass through a 2 mm sieve. Total N and C were analyzed only before planting and after harvesting. The goat manure was also analyzed for macronutrients and pH.

3.4.2. Soil analysis and chemical properties determination

Soil texture was determined by the hydrometer method (Okalebo *et al.*, 2002). Soil pH water was measured in a 1:2.5 soil water ratio (Ryan *et al.*, 2001) that is adding 25 ml of distilled water to 10 g of soil in a 50 ml beaker and measured after standing for 30 minutes, using a pH measure model AD 1000. Soil pH_{KCl} was measured in a suspension of soil and 1M KCl in a 1:2.5 soil to solution ratio (Ryan *et al.*, 2001; Okalebo *et al.*, 2002). Exchangeable acidity was determined using titration method according to Okalebo *et al.* (2002), Sark & Hader (2005). A subsample of soil (5 g) was extracted with 25 ml of 1M KCl. The resulting solution was filtered using filter paper No 42 and leached 5 successive times with 25ml of 1M KCl, after left to stand for 30 minutes. It was followed by titration (0.1M NaOH) after adding 3 drops of phenolphthalein indicator solution. The exchangeable acidity was calculated by the following formula:

$$\text{Exchangeable acidity } (\text{cmol}(+)\ \text{kg}^{-1} = (\text{ml NaOH}_{\text{sample}} - \text{ml NaOH}_{\text{blank}}) * 10 \qquad (1)$$

Soil extractable P and exchangeable cations were determined by Mehlich 1 method (Mehlich, 1953). After extraction of 5 g of air dried soils with 25 ml of a mixture solution of 0.1M HCl and 0.025M H_2SO_4 the suspension was shaken for 60 minutes in automatic shaker, centrifuged and then filtered using filter paper No. 42. The extractable P was determined colorimetrically using a spectrophotometer (430 nm wavelength) after adding 1ml of ammonium molybdate and ammonium vanadate mixture to 5 ml of the extraction for color development, after standing for 1 hour. Calcium (Ca), Sodium (Na) and Potassium (K) were determined by flame photometry. Magnesium (Mg) was determined by atomic absorption spectrophotometry (540 nm wavelength), after mixing 1ml of the extract with 5 ml of Mg compensating solution, plus 2 ml of both titan yellow and 8% NaOH solutions were left to stand for 1 hour.

The soil organic C and total N were determined by dry combustion method (Ukovich *et al.*, 2008) in an automatic CHN elemental analyzer. Approximately 20 mg soil samples were weighed using sensitive balance, folded in a tin capsule and subjected to elemental analysis (EA) procedures where the weight of percent of C and N in the sample were determined through a complete oxidation process.

3.4.3. Determination of plant height

To evaluate the effect of the treatments on soybean development, ten plants per plot were randomly selected before harvest and their heights measured using a tape measure. Plants were measured between the highest photosynthetic tissue and ground level (Cornelissen *et al.*, 2003).

3.4.4. Harvesting and yields determination

The crop was harvested in the four central lines per plot equivalent to 6m^2 of the plot, which made the harvested area. Plants were cut at the ground level. Fallen leaves were collected and weighed in the field using weighing balances. Subsequently pods were separated and sun dried before being threshed. After threshing, the moisture content of the grains was determined using a moisture meter. The Dry Matter (DM) weight was determined as well as weight of 100 seeds. Thereafter, the yields (ton ha^{-1} basis) were calculated and adjusted to 12% (standard) of moisture content using the following formulas (2, 3, and 4).

$$\mathrm{DM(kg)} = \frac{\text{Sample fresh Weight (g) - Sample Dry Weight(g)}}{1000} \tag{2}$$

$$\text{Yield (ton ha}^{-1}) = 10 * \frac{\mathrm{DM(kg)}}{\text{Harvested area(m2)}} \tag{3}$$

$$\text{Yield}_{\text{adjusted}} \text{ (ton ha}^{-1}) = \text{Measured yield} * \frac{(100-\text{Sample moisture content})}{(100-\text{Standard moisture content})} \tag{4}$$

Harvest Index (HI), which expresses the efficiency of a crop variety to convert the dry matter into economic yield was also determined by the use of the following formula.

$$\text{Harvest Index } = \frac{\text{Grain yield(kg)}}{\text{Total Dry Matter yields(kg)}} \tag{5}$$

3.4.5. Plant tissues sampling, preparation and analysis for N and P

Plants were sampled for N and P content in tissues. Ten plants were randomly sampled, packed in paper sample bags and transported to the laboratory. At the vegetative stage, 4 weeks after planting (4WAP) the plants were sampled by cutting at the ground level. At flowering and podding plants were sampled by collecting the third or fourth trifoliate leaves from the top, while at harvesting, different parts of the plant (stem, leaves, pods, grain) were included.

The collected samples were washed with distilled water to remove any contamination and were oven-dried at 65°C for 48 hours. Dried samples were ground to pass through a 0.5 mm sieve. Thereafter, subsamples of 5 mg were subjected to N content determination in a CN analyzer. Phosphorus concentration was determined colorimetrically in a spectrophotometer (590 nm wavelength) by vanado-molybdate method, after the samples were digested in acid at high temperatures (Ryan *et al*, 2001; Okalebo *et al*., 2002; Sark & Hader, 2005). The N and P uptake on kg ha^{-1} basis was calculated according to the following formula:

$$\text{Nutrient uptake } (\text{kg ha}^{-1}) = \frac{\text{Nutrient concentration } (\%) * \text{Dry Matter Yield } (\text{kg ha}^{-1})}{100} \qquad (6)$$

3.5. Determination of N_2 fixation in soybean

To assess N_2 fixation, plants were sampled at 8 WAP from the second last row of each plot. These plants were collected from a regular area of 30 cm x 30 cm. The soil around the roots of plants to be sample was loosened to a depth of about 20 cm. The plants were then carefully removed from the soil, and any attached soil removed by washing with distilled water. Thereafter the number of nodules per plant was counted. Roots and shoots were separated oven dried at 65°C for 48 hours, and ground to pass through a 0.5 mm sieve. Plant samples were analyzed for total N in a automatic CN analyzer as described in section 3.4.5. Subsequently soil samples were collected within 15 cm depth for mineral N analysis by extracting with 2M KCl followed by NO_3-N and NH_4-N determination by flow injection system according to Sark and Harder (2005). Total soil mineral N was calculated as the sum of soil nitrates and ammonium N. To assess mineral N in a ton.ha^{-1} basis the following formula was used (Ukovich *et al*., 2008):

$$\text{Nsoil}(\text{kg N ha}^{-1}) = \text{Soil N}(\text{mg kg}^{-1}) * \text{bulk density}(\text{g cm}^{-3}) * \frac{\text{sampling depth}(\text{cm})}{10} \qquad (7)$$

Therefore, the amount of N_2 fixed was determined by the Nitrogen difference method (Peoples *et al*., 1989; Hardarson & Danso, 1993; Ukovich *et al*., 2008) which consists of the difference between N content in the soybean crop and the reference crop plus the difference in mineral

N in the soil where these (soybean and reference crop) are grown. A non-nodulating soybean variety was used as the reference crop to enable N fixation assessment.

$$N_{fixed}\,(\text{kg ha}^{-1}) = (N_{soybean} - N_{reference}) + (Nsoil_{soybean} - Nsoil_{reference}) \qquad (8)$$

3.6. Determination of Soil Microbial Biomass

Soil samples were collected at the harvest of 2012 SR and 2013 LR season at 15 cm depth, using soil auger. Fresh soil samples were packed in a cooler box and transported to the laboratory. Soil microbial biomass N was determined by chloroform fumigation-extraction method (Okalebo *et al.* 2002; Sark & Hader, 2005). Three subsamples of 10 grams each were obtained from the soil samples. For the first sub-sample, soil moisture content was determined gravimetrically by drying it for 48hours at 105°C (Okalebo *et al.*, 2002). Dry soil was used to express MBN in a soil dry weight basis. The remaining 2 samples were analyzed for total N after subjecting one of the subsamples (10g) to chloroform fumigation. Thereafter the subsamples were extracted using 0.5M K_2SO_4. Total N was determined by Kjeldahl method whereby N was determined colorimetrically after acid digestion (Ryan *et al.*, 2001; Okalebo *et al.*, 2002; Sark & Hader, 2005). The microbial biomass nitrogen was estimated as the difference in total N content between the fumigated and the non-fumigated (control) samples.

$$\text{Microbial Biomass N} = N_{fumigated} - N_{control} \qquad (9)$$

3.7. Statistical data analysis

Data generated was prepared using Microsoft Excel and subjected to analysis of variance (ANOVA) using SAS version 8 (SAS Institute, 1999). Means were separated using Least Significant Difference (LSD) of means. The means were subjected to *t-student* test at 95 percent of significance level ($p < 0.05$), to test means differences. Nitrogen and Phosphorus uptake, N_2 fixed and soil microbial biomass were subjected to Pearson correlation coefficient to establish their relationship with grain yield.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Effects of manure, lime and P fertilizer on soil chemical properties

4.1.1. Soil pH and exchangeable acidity

Soil pH values were not significant at the start of the experiment but were observed to be significantly different ($p < 0.0001$) after harvest of 2012 SR and 2013 LR cropping seasons (Tables 4.1 and 4.2). In both seasons, the application of lime alone recorded the highest value for soil pH water of 5.83 (2012 SR) and 5.91 (2013 LR) which corresponded, respectively, to an increase of 15.4% and 15.9% over the control. This was followed by the application of combined manure with lime plus P fertilizer with 5.79 in 2012 SR and 5.82 in 2013 LR. The soil pH KCl was also higher under application of lime alone with pH 4.76 (13.6% increase) in 2012 SR and 4.80 (9.9% increase) in 2013 LR. Meanwhile, application of P fertilizer alone consistently recorded the lowest values over the controls for both pH water and KCl in both seasons.

Relative to the preseason, soil pH water significantly increased in all treatments except in the control in both seasons (Table 4.1). Lime alone increased significantly 0.72 units ($p = 0.0019$) and 0.8 units ($p = 0.0011$) in 2012 SR and 2013 LR, respectively. This was followed by ½Manure+Lime+½ P which increased soil pH by 0.68 units ($p = 0.0116$) in 2012 SR and 0.71 ($p = 0.0098$) in 2013 LR. A similar scenario was observed for soil pH in KCl (Table 4.2). However, P fertilizer alone did not record a significant increase while the control recorded reduced soil pH in KCl.

Table 4.1: Changes in soil pH water (0-15 cm depth) under various treatments.

Treatments	**pH water** (1:2.5)						
	Initial	2012SR	Change	*t*-test, *p*	2013LR	Change	*t*-test, *p*
Manure	5.10^{a}	5.62^{ab}	+0.52	0.0025	5.72^{bc}	+0.62	0.004
Lime	5.11^{a}	5.83^{a}	+0.72	0.0019	5.91^{a}	+0.8	0.0011
P fertilizer	5.07^{a}	5.26^{cd}	+0.19	0.0321	5.26^{e}	+0.19	0.0358
½Manure+Lime	5.02^{a}	5.64^{ab}	+0.62	<0.0001	5.65^{c}	+0.63	<0.0001
½Manure+½ P	5.10^{a}	5.46^{bc}	+0.36	<0.0001	5.50^{d}	+0.4	<0.0001
½Manure+Lime+½P	5.11^{a}	5.79^{a}	+0.68	0.0116	5.82^{ab}	+0.71	0.0098
Lime+½ P	5.01^{a}	5.59^{ab}	+0.58	0.0014	5.70^{c}	+0.69	0.0005
Control	5.00^{a}	5.05^{d}	+0.05	0.7924	5.10^{f}	+0.1	0.4329
***p*-value**	**0.5718**	**<0.0001**			**<0.0001**		
LSD$_{(0.05)}$	**0.15**	**0.27**			**0.1**		

Means followed by the same letter(s) are not significantly different for the specified parameter (p<0.05)

Table 4.2: Changes in soil pH KCl (0-15 cm depth) under various treatments.

Treatments	**pH KCl** (1:2.5)						
	Initial	2012SR	Change	*t*-test, *p*	2013LR	Change	*t*-test, *p*
Manure	4.26^{a}	4.53^{bc}	+0.27	0.0126	4.57^{bc}	+0.31	0.0063
Lime	4.25^{a}	4.76^{a}	+0.51	0.0362	4.80^{a}	+0.55	0.0255
P fertilizer	4.22^{a}	4.31^{de}	+0.09	0.2688	4.32^{d}	+0.1	0.2387
½Manure+Lime	4.14^{a}	4.58^{abc}	+0.44	<0.0001	4.61^{bc}	+0.47	<0.0001
½Manure+½ P	4.21^{a}	4.43^{cd}	+0.22	0.0309	4.49^{c}	+0.28	0.0104
½Manure+Lime+½P	4.25^{a}	4.67^{ab}	+0.42	0.0046	4.71^{ab}	+0.46	0.003
Lime+½ P	4.20^{a}	4.51^{bc}	+0.31	0.0415	4.55^{c}	+0.35	0.0263
Control	4.17^{a}	4.19^{e}	+0.02	0.8317	4.16^{e}	-0.01	0.9089
***p*-value**	**0.5373**	**<0.0001**			**<0.0001**		
LSD$_{(0.05)}$	**0.13**	**0.19**			**0.15**		

Means followed by the same letter(s) are not significantly different for the specified parameter (p<0.05)

Overall, the treatments reduced soil exchangeable acidity in both seasons (Table 4.3). In the 2012 SR season all treatments reduced significantly ($p = 0.0138$), the exchangeable acidity compared with the control. The treatment of ½Manure+Lime+½ P fertilizer and Lime alone was most effective in reducing exchangeable acidity and recorded 1.75 cmol (+) kg^{-1} and 2.0 cmol (+) kg^{-1}, respectively. The highest values of exchangeable acidity in 2012 SR were observed for control (4.0 cmol (+) kg^{-1} soil) and P fertilizer alone (3.0 cmol (+) kg^{-1} soil). During 2013 LR the application of treatment ½Manure+Lime+½P gave the highest reduction ($p = 0.0006$) of exchangeable acidity (4.2 fold reduction) compared with the control, this was followed by Lime and Lime+½ P (3.2 fold reduction) treatment. However, application of P fertilizer alone did not reduce soil exchangeable acidity after season 2013 LR (Table 4.3).

During the 2012 SR soil exchangeable acidity was significantly reduced (-2.0 units) following the application of ½Manure+½ P ($p = 0.0284$) over the preseason (Table 4.2). Meanwhile, in 2013 LR the exchangeable acidity was reduced significantly under Lime alone (-2.0 units; $p = 0.0211$) and ½Manure+½ P (-1.75 units; $p = 0.0483$). Contrary, P fertilizer alone and control increased soil exchangeable acidity but not significantly.

Table 4.3: Changes in soil exchangeable acidity (0-15 cm depth) under the treatments.

	Exchangeable Acidity (cmol(+) kg^{-1} soil)						
Treatments	Initial	2012SR	Change	*t*-test, *p*	2013LR	Change	*t*-test, *p*
Manure	4.00^{a}	2.25^{bc}	-1.75	0.1563	2.00^{b}	-2.00	0.1053
Lime	3.50^{a}	2.00^{bc}	-1.50	0.0659	1.50^{b}	-2.00	0.0211
P fertilizer	3.50^{a}	3.00^{ab}	-0.50	0.7737	4.25^{a}	+0.75	0.5778
½Manure+Lime	3.00^{a}	2.00^{bc}	-1.00	0.4762	1.75^{b}	-1.25	0.3364
½Manure+½ P	4.00^{a}	2.00^{bc}	-2.00	0.0284	2.25^{b}	-1.75	0.0483
½Manure+Lime+½P	3.25^{a}	1.75^{c}	-1.50	0.3194	1.25^{b}	-2.00	0.1655
Lime+½ P	4.00^{a}	2.25^{bc}	-1.75	0.3393	1.50^{b}	-2.50	0.1497
Control	4.50^{a}	4.00^{a}	-0.50	0.8617	5.25^{a}	+0.75	0.7227
***p*-value**	**0.8598**	**0.0138**			**0.0006**		
LSD(0.05)	**2.15**	**1.19**			**1.75**		

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

Soils with low pH (pH < 5) are usually of high concentration of H^+ and Al^{3+} ions in the solution, which affect negatively the availability of other nutrients (basic) for the crops. It was noted that application of lime combined with manure increased soil pH but reduced exchangeable acidity. The combination of manure with lime plus P fertilizer mostly increased soil pH and reduced exchangeable acidity than the combination of lime with manure, P fertilizer alone and lime+½ P over the control. The increase was attributed in part to the displacement of Al^{3+} and H^+ ions from soil sorption sites by Ca^{2+} cations content in lime. In addition to that the OH^- ions and Mg^{2+} ions released through manure decomposition may have also contribute to the complexation of Al^{3+} and H^+ ions in the soil. Similar observations were made by Kanyanjua *et al.* (2002), Khoi *et al.* (2010), Kisinyo *et al.* (2012) who reported that application of lime combined with manure, P fertilizer or both increased soil pH.

Lime alone increased soil pH and reduced soil exchangeable acidity when compared to the pre-season and to the control. The increase in soil pH under lime treatment was due to addition of CaO which reacts with water leading to production of OH^- ions which forms $Al(OH)_3$ and H_2O thus raising the soil pH and decreasing exchangeable acidity. Elsewhere, studies conducted revealed also that lime application lead to increased soil pH and decreased soil exchangeable acidity (The *et al.*, 2001; Nekesa *et al.*, 2005). In addition, Kisinyo *et al.* (2012) attributed the soil pH increase in lime treatment as a result of H^+ and Al^{3+} ions displacement from soil adsorption sites by Ca^{2+} ions contained in lime.

Manure increased soil pH and decreased exchangeable acidity. Manure used in this study was of pH 9.3 (Table 3.1), therefore alkaline and the OH^- ions may have contributed to reduce Al^{3+} and H^+ ions in the soil. It may have also added exchangeable cations that replaced the acidic cations in the exchangeable soil sites. Increase in soil pH over the control as result of application of organic manures as reported in this study is in agreement with the findings of several other researchers (Awodun *et al.*, 2007; Adeniyan *et al.*, 2011; Kheyrodin & Antoun, 2012). According to Nyambati *et al.* (2003) alkaline pH manure could improve the pH of moderately acid infertile soil if applied repeatedly over season. On the other hand applied manure through its decomposition releases exchangeable cations to the soil solution, which replace the Al^{3+} and H^+ ions in the soil sorption sites (Crawford *et al.*, 2008). It in return lowers their concentration, thereby increasing soil pH (Kanyanjua *et al.*, 2002; Repsiene & Skuodiene, 2010) and reducing exchangeable acidity (Whalen *et al.*, 2000; Khoi *et al.*, 2010). However, the effectiveness of manure on soil pH depends on its quality (Gitari & Friesen, 2001), which may explain the slow increase of soil pH by manure when compared with lime.

Solely application of P fertilizer did not increase the soil pH neither reduce soil exchangeable acidity over the control. Other researchers (Kisinyo *et al.*, 2005; 2012) reported similar results and attributed this situation to the release of H^+ ions during P fertilizer dissolution. According to Harter (2007) phosphoric acid, phosphorus based fertilizer, has an acidifying effect on the soil whereby the phosphoric acid releases H^+ ions progressively to the soil therefore acidifying the soil surrounding the band.

4.1.2. Soil exchangeable cations

The treatments had significant influence on soil exchangeable cations except for Na (Table 4.4). During 2012 SR the treatments increased significantly ($p = 0.0477$) exchangeable Ca values in the order of treatments: ½Manure+Lime+½P (1.01 cmol (+) kg^{-1}), Manure (0.73 cmol (+) kg^{-1}), corresponding to an increase of 2.97 and 2.15 times respectively, over the control. In the same period application of ½Manure+½P less increased exchangeable Ca by 1.26 times. In the 2013 LR the application of ½Manure+Lime+½P and sole Lime significantly increased ($p = 0.0491$) soil exchangeable Ca by 1.87 and 1.64 times, respectively in relation to the control. During the same period, the P treatment recorded the lowest increase in soil exchangeable Ca (1.07 times) relative to the control.

Manure and lime applied separately increased soil exchangeable Ca over the control. However, the most effective and significant increase was observed when manure was combined with lime plus P fertilizer. The increase was attributed to the release of Ca^{2+} ions content in lime through its dissolution, and to mineralization of manure with release of mineral nutrients in it. Manure used in the current study had 0.92 % of Ca (Table 3.1), which was high and able to supply 9.2 g Ca kg^{-1} to the soil. Elsewhere The *et al.* (2001) and Caires *et al.* (2006) also reported significant increase of exchangeable Ca after application of manure alone or combined with lime and P fertilizer. Similarly, Awodun *et al.* (2007), Phengsouvana *et al.* (2009), Odedina *et al.* (2011) also found significant increase in soil exchangeable Ca with application of manure, lime or their combination. On the other hand the liming effect of manure and when combined with lime improved soil condition such as pH, Ca and microbial activity, which enhanced soil exchangeable Ca (Kisinyo *et al.*, 2005; 2012; Hassan *et al.*, 2010; Adeleye *et al.*, 2010; Chimdi *et al.*, 2012). These interactive effects are clear in this study as it was found that soil exchangeable Ca was positively and significantly correlated (Figure 4.1) to soil pH during 2012 SR ($R^2 = 0.62$; $p = 0.0209$) and 2013 LR ($R^2 = 0.68$; $p = 0.0113$). This, means that Ca availability much more affected soil pH which was in agreement with reports from Rahman *et al.* (2002), Repsiene and Skuodiene (2010).

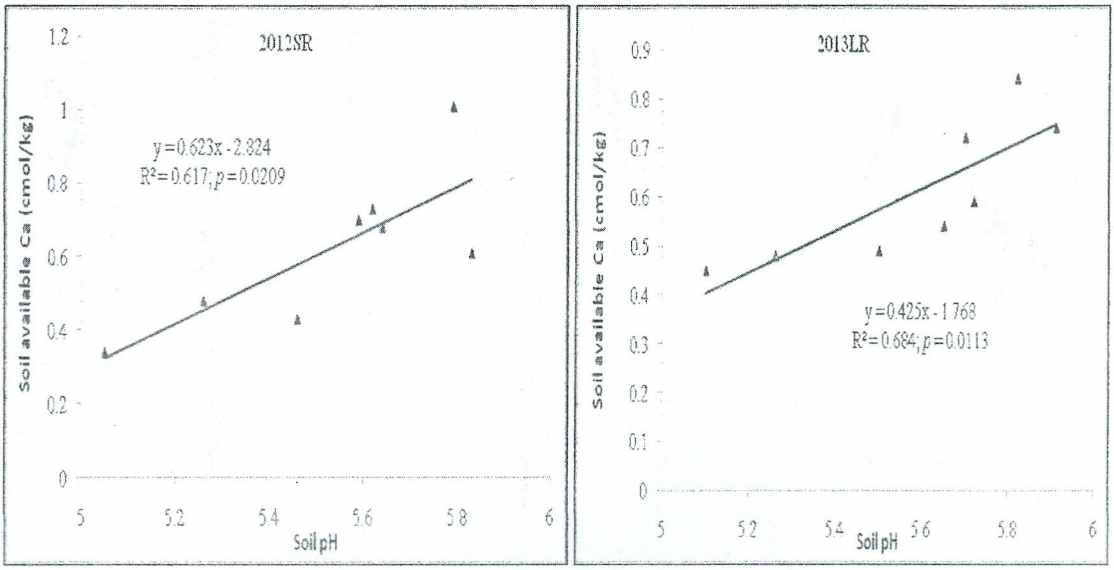

Figure 4.1: Relationship between soil pH and soil exchangeable Ca.

Soil exchangeable Mg was significantly increased in the 2012 SR ($p = 0.0229$) and 2013 LR ($p = 0.024$) seasons as a result of the treatment application (Table 4.4). The increase of soil exchangeable Mg was in the order of treatments: ½Manure+Lime (0.34 cmol (+) kg^{-1}), Lime (0.33 cmol (+) kg^{-1}) in 2012 SR and Lime+½P (0.34 cmol (+) kg^{-1}), ½Manure+Lime+½P (0.32 cmol (+) kg^{-1}) and L (0.32 cmol (+) kg^{-1}) in the 2013 LR. The lowest was recorded in the control and P treatments, 0.26 cmol (+) kg^{-1}.

Table 4.4: Soil exchangeable cations and CEC (cmol(+) kg^{-1} soil), 0-15 cm depth in various treatments.

	Ca^{2+}		**Mg^{2+}**		**K^{+}**		**Na^{+}**		**CEC**
Treatment	2012SR	2013LR	2012SR	2013LR	2012SR	2013LR	2012SR	2013LR	2013LR
Manure	0.73^{ab}	0.59^{abc}	0.28^{b}	0.29^{bc}	0.30^{a}	0.41^{a}	0.10^{a}	0.19^{a}	1.48^{ab}
Lime	0.61^{bc}	0.74^{ab}	0.33^{a}	0.32^{ab}	0.09^{cd}	0.07^{d}	0.09^{a}	0.22^{a}	1.35^{abc}
P fertilizer	0.48^{bc}	0.48^{bc}	0.28^{b}	0.28^{bc}	0.09^{cd}	0.08^{d}	0.09^{a}	0.22^{a}	1.07^{cd}
½Manure+Lime	0.68^{abc}	0.54^{bc}	0.34^{a}	0.29^{bc}	0.13^{bcd}	0.12^{cd}	0.10^{a}	0.25^{a}	1.21^{bcd}
½Manure+½ P	0.43^{bc}	0.49^{bc}	0.28^{b}	0.28^{bc}	0.18^{b}	0.17^{bc}	0.11^{a}	0.21^{a}	1.15^{bcd}
½Manure+Lime+½P	1.01^{a}	0.84^{ab}	0.29^{ab}	0.34^{a}	0.15^{bc}	0.22^{b}	0.11^{a}	0.24^{a}	1.65^{a}
Lime+½ P	0.70^{abc}	0.72^{ab}	0.30^{ab}	0.32^{ab}	0.07^{d}	0.11^{cd}	0.09^{a}	0.23^{a}	1.38^{abc}
Control	0.34^{c}	0.45^{c}	0.26^{b}	0.26^{c}	0.08^{cd}	0.06^{d}	0.10^{a}	0.18^{a}	0.95^{d}
***p*-value**	**0.0477**	**0.0491**	**0.0377**	**0.024**	**<0.0001**	**<0.0001**	**0.1231**	**0.6315**	**0.0139**
$LSD_{(0.05)}$	**0.39**	**0.27**	**0.05**	**0.04**	**0.08**	**0.08**	**0.02**	**0.08**	**0.36**

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

The increased soil exchangeable Mg as a result of lime application was attributed to increase in soil pH which in turn may have increased Mg availability in the soil. The results are in agreement with those of Rahman *et al.* (2002), Repsiene and Skuodiene (2010), Andric *et al.* (2012). When manure was combined with lime and P fertilizer, soil exchangeable Mg was increased and this was attributed to addition of nutrients to the soil through mineralization. In addition, manure by increasing soil pH it reduced Al^{3+} and H^{+} content in soil exchange sites increasing then Mg availability. These findings are in agreement with those of Rahman *et al.* (2002), Escobar and Hue (2008), Shen and Shen (2001) who reported increased available Mg in the soil where manure was applied combined with lime. In the current study, there was a significant, positive relationship between soil pH and soil exchangeable Mg during 2013 LR ($R^2 = 0.71$; $p = 0.0143$), which shows the importance of soil pH improvement to enhance soil Mg availability (Figure 4.2). According to Awodun *et al.* (2007), the availability of Mg in acid soils is reduced. Under low soil pH, the soil exchangeable sites are depleted of Mg creating an imbalance of these nutrient. Therefore, its increase may be a result of improved soil conditions (acidity) and/or microbial activity due to improved organic matter.

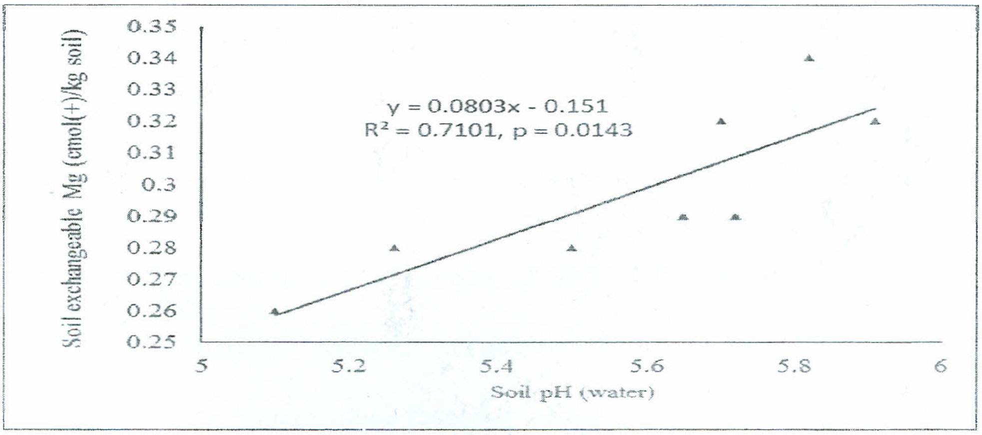

Figure 4.2: Relationship between soil pH and soil exchangeable Mg, 2013 LR.

Application of Manure alone recorded the highest significant ($p < 0.0001$) increase of exchangeable K in soil in both 2012 SR (3.75 fold) and 2013 LR (6.83 folds) over the control. This was followed by treatment ½Manure+½P (2.25 fold) in 2012SR and ½Manure+Lime+½P (3.67 fold) in 2013 LR. The lowest was observed for Lime+½P and Lime alone in 2012SR and 2013 LR respectively (Table 4.4).

There were no observed statistical significant differences in soil for available Na in both 2012 SR ($p = 0.1231$) and 2013 LR ($p = 0.6315$). However, ½Manure+½P and ½Manure+Lime+½P treatments recorded numerically high values (0.11 cmol (+) kg^{-1} soil). Meanwhile, in 2013 LR the highest numerical value was recorded for ½Manure+Lime and ½Manure+Lime+½P with 0.25 cmol (+) kg^{-1} and 0.24 cmol (+) kg^{-1} soil, respectively. The lowest value was observed in the plots receiving Lime alone (0.09 cmol (+) kg^{-1} soils) in 2012 SR and Manure alone treatment (0.19 cmol (+) kg^{-1}) in 2013LR (Table 4.4).

The increase of soil exchangeable K with manure alone or combined with P fertilizer plus lime was due to added K from manure decomposition and mineralization. The manure used in the current study was of 1.69% K (Table 3.1) content which might have added significant amounts of this nutrient to the soil. Many other researchers (Ewulo, 2005; Ayeni & Adetunji, 2010; Adeleye *et al.*, 2010; Adeniyan *et al.*, 2011) reported soil available K increase when manure was applied alone or combined with lime and P fertilizer.

The soil CEC values determined at harvest of 2013 LR season were statistically and significantly ($p = 0.0139$) different (Table 4.4). The application of treatments ½Manure+Lime+½P and Manure alone recorded the highest soil CEC values of 1.65 cmol (+) kg^{-1} and 1.48 cmol (+) kg^{-1}, respectively, while the lower value was recorded for P fertilizer treatment (1.06 cmol (+) kg^{-1}). In relation to the pre-season, the application of treatment ½Manure+Lime+½P mostly increased soil CEC by 16.4%. This increase was due to improved soil conditions such as soil pH, increased soil Ca, Mg and K through mineralization and lime dissolution, reduction of exchangeable acidity which in turn increased the exchangeable sites of the soil.

4.1.3. Soil total carbon, nitrogen and available phosphorus

4.1.3.1. Soil total carbon

Compared to the control, all the other treatments showed significant increase in soil organic carbon (Table 4.5), but with less difference within the treatments. The application of Manure alone recorded the highest soil C (2.59%), while the control recorded the lowest (2.38%). Generally, there was observed an increase in soil organic C relative to pre-season, which might be due to addition of organic matter with manure application, to droppings of leaves and their respective decomposition and to the decomposition of roots left during the first season.

Table 4.5: Soil total C, N and available N (0-15cm depth) in various treatments.

Treatments	C (%)	N (%)	Available N (mg kg^{-1} soil)	
	2013LR	2013LR	2012SR	2013LR
Manure	2.59^{a}	0.27^{a}	22.35^{a}	17.58^{a}
Lime	2.51^{a}	0.25^{bc}	14.95^{b}	13.87^{bc}
P fertilizer	2.53^{a}	0.27^{a}	14.08^{b}	13.74^{bc}
½Manure+Lime	2.51^{a}	0.26^{abc}	17.30^{b}	13.25^{bc}
½Manure+½ P	2.50^{a}	0.26^{ab}	17.25^{b}	14.08^{bc}
½Manure+Lime+½P	2.55^{a}	0.26^{ab}	16.13^{b}	14.30^{bc}
Lime+½ P	2.50^{a}	0.25^{c}	15.78^{b}	14.84^{b}
Control	2.38^{b}	0.25^{bc}	13.76^{b}	12.40^{c}
***p*-value**	**0.0149**	**0.0214**	**0.0238**	**0.0042**
LSD$_{(0.05)}$	**0.10**	**0.01**	**3.79**	**2.16**

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

The higher values of soil organic C observed under manure application may be attributed to added organic matter (Clark *et al.*, 1998; Amba *et al.*, 2011). It was also observed that the application of sole P fertilizer (60 kg ha^{-1}) increased significantly soil organic C. The same results had been reported in northern guinea savanna of Nigeria by Amba *et al.* (2011) who attributed the increase to the dropping of leaves, which added organic C to the soil. The significant increase of soil organic C after lime and manure application, as sole or combined, might be associated with the general improvement of soil condition as result of applied inputs lime, which might have enhanced proliferation of soil microbial biomass and their activity in the soil.

4.1.3.2. Total and mineral soil nitrogen

The application of treatments statistically ($p = 0.0204$) increased soil total N values in the order Manure alone and P fertilizer alone (0.27%); followed by ½Manure+Lime, ½Manure+½P and ½Manure+Lime+½P treatments (0.26%); while the lowest was observed under Lime, Lime+½P and control treatments (0.25%), (Table 4.5). The increase in soil total N when Manure alone was applied may be due to addition of organic matter content (Adeleye *et al.*, 2010; Efthimiadou *et al.*, 2010). Meanwhile, the increase in soil total N observed under sole application of P fertilizer and Lime may be attributed to the addition of organic matter to the soil with the dropping of leaves (Amba *et al.*, 2011) as well to the remaining roots from the first season which undergone decomposition.

Soil available N significantly increased in both 2012 SR ($p = 0.0238$) and 2013 LR ($p = 0.0042$) growing seasons (Table 4.5). The application of Manure alone recorded the highest values for available N of 22.35 mg kg^{-1} in 2012 SR and 17.58 mg kg^{-1} in 2013 LR, which was an increase of 62.4% and 41.8% for 2012 SR and 2013 LR, respectively, above the control. The values of available N during 2012 SR were higher than the 2013 LR in all the treatments. This could be due to good rainfall that was fairly distributed resulting into optimum moisture and adequate organic matter mineralization in 2012 SR. According to Risse *et al*., (2006) climatic conditions, such as rainfall, temperature, moisture, and soil aeration affects the rate of organic matter decomposition where warm and humid climates favour the rapid decomposition.

These results compare well with those of Kapkiyai *et al.* (1999), Whalen *et al.*, (2000), Edmeades (2003), Kihanda *et al.* (2004) who also found that mineral N was high in manured soils than un-manured. Maerere *et al.* (2001) in Tanzania also found that goat manure increased significantly soil available N in a moderately acidic soil after one season and attributed it to mineralization of manure. That is the reason why application of sole manure (10 ton ha^{-1}) recorded the highest soil available N in the two seasons, as compared to treatments of Lime and P fertilizer alone where increase of available N in soil were minimal in both seasons due to diminishing native soil organic matter.

4.1.3.3. Soil available phosphorus

In 2013 LR, application of treatments showed statistical difference in soil available P (p = 0.0119) (Table 4.6). The increase were observed in the various treatments in the order of P fertilizer alone (10.79 mg kg^{-1}), Manure alone (10.05 mg kg^{-1}) and Lime alone (9.85 mg kg^{-1}), which corresponded to 48%, 37.9% and 35.1%, respectively, over the control. The lowest values were recorded for ½Manure+½P (7.29 mg kg^{-1}, a 30.86% increase) and ½Manure+Lime+½P (31.41%) treatments.

At the end of 2012 SR, no significant changes in soil available P under any treatment relative to initial status were observed (Table 4.6). However, in 2013 LR significant increase in soil available P was observed under Lime alone ($p = 0.0023$), followed by Lime+½ P ($p = 0.0002$), ½ Manure+Lime+½ P ($p = 0.0001$) and ½ Manure+½ P ($p = 0.0008$). In the same period there was a decrease in soil available P under the control, but not significant. Generally, soil available P increased from the initial status to the post second season by 43.93% (under sole application of Lime). The increase might be due to residual effect of phosphorus fertilizer because of its low mobility in the soil. In addition, lime and manure applied in both seasons may have also contributed to raising soil pH and consequently increased P availability.

Table 4.6: Changes in soil available P (0 - 15 cm depth) in various treatments.

Treatments	**Available P** (mg kg^{-1} soil)						
	Initial	2012SR	Change	*t*-test, *p*	2013LR	Change	*t*-test, *p*
Manure	7.72^{a}	8.02^{a}	+0.30	0.9572	10.05^{a}	+2.33	0.1509
Lime	6.94^{a}	7.51^{a}	+0.57	0.4966	9.85^{a}	+2.91	0.0023
P fertilizer	8.15^{a}	7.35^{a}	-0.80	0.8073	10.79^{a}	+2.64	0.169
½Manure+Lime	8.45^{a}	7.79^{a}	-0.66	0.8051	9.63^{a}	+1.18	0.5297
½Manure+½ P	7.10^{a}	7.36^{a}	+0.26	0.7108	9.54^{a}	+2.44	0.0008
½Manure+Lime+½P	6.94^{a}	7.32^{a}	+0.38	0.3582	9.58^{a}	+2.64	0.0001
Lime+½ P	7.06^{a}	7.24^{a}	+0.18	0.8108	9.84^{a}	+2.78	0.0002
Control	7.93^{a}	7.20^{a}	-0.73	0.485	7.29^{b}	-0.64	0.5649
***p*-value**	**0.634**	**0.8995**			**0.0119**		
LSD$_{(0.05)}$	**2.05**	**1.36**			**1.57**		

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

The low mobility of P in acid soils is a known fact (Gupta, 2011). Hence, the method of fertilizer application used might have also influenced the values of available P analyzed, since the method of P fertilizer application was band placement while the soil samplings were done between the rows. Kamara *et al.* (2008) stated that the variability of soil available P after application of fertilizer may be due to fertilizer placement. In order to build up soil P the broadcasting is better than band placement, which favours rapid availability of the nutrient to crop uptake. However, under acid soils the band placement is recommended due to P fixation and to increase its availability as well as use efficiency. In the other hand lime and manure effects require time to release soil fixed P and for mineralization to take place. Maerere *et al.* (2001) stated that P mineralization increases with time after the initial application of the organic amendments. The other reason for this observation could be attributed to the uptake of P by the plants. According to Gudu *et al.* (2005) the crop P uptakes is another pathway or sink for the added P. These observations are in agreement with those of Abera *et al.* (2005) and Kamara *et al.* (2008).

In 2013 LR, there was an increase in soil available P relatively to 2012 SR season. This could be a result of the residual effects of the applied P fertilizer in the two seasons. Another reason could be as a result of release of fixed P with increased pH of the soil and get free of P from organic matter mineralization. At the end of the experiment (post second season) manure, lime and P fertilizer applied alone showed high available P over the control. Increased soil available P with application of goat manure has been reported (Maerere *et al.*, 2001; Odedina *et al.*, 2011). Manures applied to the soil affect the soil available P in different ways, which include, forming complex with ions of Fe and Al in soil solution, preventing the precipitation of phosphate (Suge *et al.*, 2011). This gradually neutralizes soil acidity and hence make fixed phosphorus available in the soil solution (Onwonga *et al.*, 2008; Mwangi *et al.*, 2002).

Comparing the initial status with that at the end of the 2013 LR season, lime applied alone, or combined with P fertilizer or with both manure and P fertilizer significantly increased soil available P. Liming of acid soils raises soil pH, which in turn releases phosphate ions precipitated with Al and Fe ions thus making P available for plant uptake (Chimdi *et al.*, 2012). When combined with manure it may even provide more favourable environment for microbial activities and possibly result in net mineralization of soil organic P.

4.2. Effects of manure, lime and P fertilizer on N fixation, N and P uptake by soybean

4.2.1. Soybean nodulation and Nitrogen fixation

The number of nodules per soybean plant determined by counting at 8 WAP (Table 4.7) was not significantly (p = 0.1752) affected by the treatments during 2012 SR. However, during 2013 LR the number of nodules per plant was significantly (p = 0.036) influenced by the treatments. In 2013 LR, application of Manure alone and ½Manure+Lime recorded highest mean number of nodules per plant (20.6) followed by P fertilizer (17.1) and ½Manure+Lime+½P (14.4). The control recorded the lowest number of nodules per plant (7.5).

The application of treatments did not significantly (p = 0.1595) affect the amount of nitrogen fixed during 2012 SR but in 2013LR, the treatments were significantly (p = 0.0498) (Table 4.7) affected. Numerically, application of Manure alone resulted in the highest N fixed by soybean (37.01 kg N ha^{-1}) during 2012 SR. Meanwhile, in 2013 LR and relative to the control sole Manure recorded the highest amount of N fixed (65.13 kg ha^{-1}) by soybean, followed by ½Manure+Lime (35.88 kg N ha^{-1}) and ½Manure+½P (33.47 kg N ha^{-1}). The lowest N fixed was observed in the plots receiving Lime+½P treatment (6.2 kg N ha^{-1}). The amount of N fixed was high and significantly correlated with number of nodules ($R^2 = 0.73, p = 0.0067$) and grain yields ($R^2 = 0.82, p = 0.002$) during 2013 LR (Figure 4.3). This means that N fixation process contributed for the N uptake by soybean and consequently on grain yields.

Table 4.7: Soybean nodulation and N_2 fixation in various treatments.

Treatments	**No. of nodules/plant**		**N_2 fixed** (kg ha^{-1})	
	2012SR	2013LR	2012SR	2013LR
Manure	13.1^{a}	20.6^{a}	37.0^{a}	65.1^{a}
Lime	13.3^{a}	12.3^{bcd}	11.5^{a}	9.9^{b}
P fertilizer	22.0^{a}	17.1^{abc}	20.1^{a}	18.8^{b}
½Manure+Lime	15.5^{a}	20.6^{ab}	47.4^{a}	35.9^{b}
½Manure+½ P	24.6^{a}	16.4^{abc}	38.5^{a}	33.5^{b}
½Manure+Lime+½P	15.6^{a}	14.4^{abcd}	30.4^{a}	22.8^{b}
Lime+½ P	19.1^{a}	10.8^{cd}	11.6^{a}	6.2^{b}
Control	7.7^{a}	7.5^{d}	10.6^{a}	4.4^{b}
***p*-value**	**0.1752**	**0.036**	**0.3962**	**0.05**
LSD$_{(0.05)}$	**12.41**	**8.29**	**65.72**	**37.61**

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

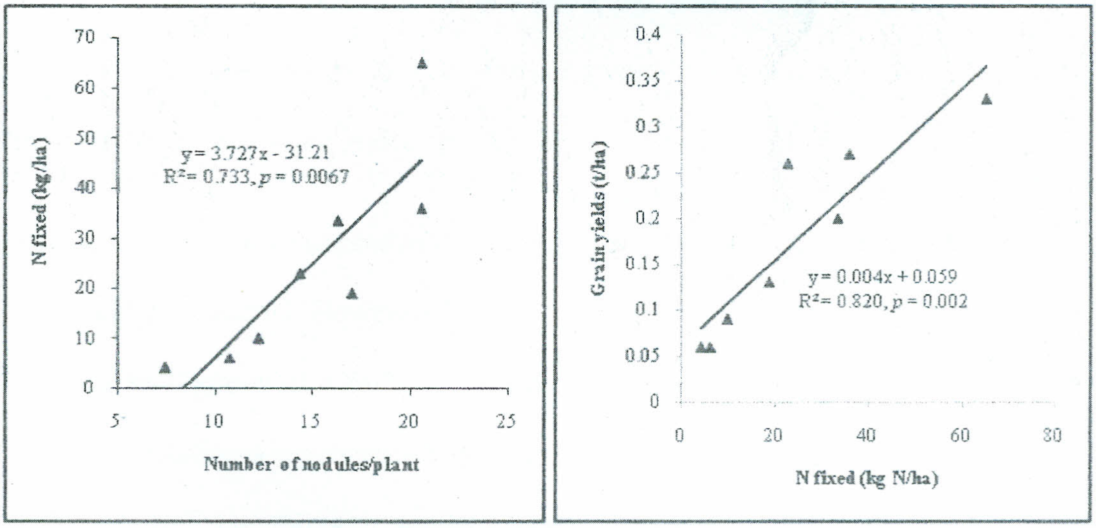

Figure 4.3: Relationship between N fixed with number of nodules and grain yields (2013LR).

The findings showed that there was a positive effect on number of nodules by application of manure alone, manure combined with lime or P fertilizer (Table 4.7). The soils of the experiment site were moderately acidic therefore moderate in N and low in P and other plant nutrients. The application of manure may have contributed not only by supplying nutrients (including N, P, K and micronutrients) through mineralization as also by making available P as result of its liming effect. The increase in P availability as well as N, K and other nutrients enhanced then the nodule formation and N fixation. Furthermore, manure is known by its ability of improving soil physical properties such as structure which in turn improves soil moisture, microbial activity and makes nutrients available (Otieno *et al.*, 2007). The use of manure and its effects in enhancing nodulation and N fixation has been reported elsewhere by several other researchers (Kundu *et al.*, 1996; Schmidt *et al.*, 2000; 2001; Javaid & Mahmood, 2010; Guo *et al.*, 2010; Devi *et al.*, 2013). The better moisture storage also enhances fertilizer and lime dissolution. It was also noted that under sole manure application the N fixation was the highest than other treatments that received manure combined with lime and P fertilizer. These differences can be explained by the amount of manure applied.

Application of P alone or combined with manure also increased number of nodules (2013 LR) but not as high as manure. However, the importance of P in symbiotic N fixation is recognized. According to Tagoe *et al.* (2008), Devi *et al.* (2013), under soil P deficiency the symbiotic process of N fixation is negatively affected resulting in low nodules formation; therefore supply of P is required. These results are similar to those of Ogoke *et al.* (2006), Mugendi *et al.* (2010), Devi *et al.* (2012) who also reported an increased number of nodules per plant with application of P fertilizers. Kumaga and Ofori (2004), Amba *et al.* (2011) found maximum number of nodules at 30 kg P_2O_5 ha^{-1} and 26.4 kg P_2O_5 ha^{-1}, respectively. In the current study P fertilizer at the rate of 30 kg P_2O_5 ha^{-1} combined with manure (5 ton ha^{-1}) increased significantly number of nodules per plant in the 2012 SR season. However, application of sole P enhanced nodulation and N fixation in both seasons, it was, however less than when half the rate was applied combined with manure. Phosphorus is important for initial root development (Better Crops, 1999; Gupta 2011) and population of free-living rhizobia in the rhizosphere and therefore nodulation and N fixation (Danso, 1992; Kisinyo *et al.*, 2005; Fatima *et al.*, 2006; Tagoe *et al.*, 2008).

The application of lime alone was not effective on nodulation than when applied in combination with manure. This may be associated with the fact that lime improved soil environment for microbial activity and manure supply necessary nutrients (N, P, K and Fe) important for nodules formation. Rhizobia bacteria are sensitive to soil acidity and require P, adequate soil moisture for their multiplication (Jones & Giddens, 1985; Bekere *et al.*, 2013). Application of combined manure with lime or P fertilizer improves soil environmental conditions for the development of rhizobial population and root colonization and lastly nodulation (Better Crops, 1999; Fatima *et al.*, 2006).

Generally when comparing the two seasons, the 2012 SR performed better than 2013 LR in both number of nodules and N fixation. The relatively poor performance in the 2013 LR was attributed to the poor rainfall observed during this season. Under drought conditions soybean nodulation and N fixation is negatively affected (Sato *et al.*, 2003; Otieno *et al.*, 2007). Elsewhere, Buttery *et al.* (1998) also reported that the number of nodules was negatively affected by low moisture conditions. According to Imas and Magen (2007), Rotaru (2010) under shortage of water, nodulation is reduced and application of manure improves soil moisture storage and supply nutrients such as N and K, which are synergetic to root development and therefore nodulation and N fixation. This probably explains the significant difference obtained in 2013 LR than 2012 SR. The poor performance under control may be due to prevalence of soil acidity and lower soil fertility status that acts as inhibitors for rhizobial population development and hence their performance. In a study of levels of rhizobial population in semi-arid and semi-humid areas Maingi *et al.* (2006) reported that under acid soil the number of population was affected negatively.

4.2.2. Soybean nitrogen uptake

Nitrogen concentration in the plant was not affected by application of the treatments at 4WAP ($p = 0.5081$), 8WAP ($p = 0.4171$) and 12WAP ($p = 0.9313$) (Table 4.8). Also, there was no significant differences in N harvest by stover ($p = 0.1415$). However, the grain N uptake varied significantly ($p = 0.001$) as result of treatments application. The highest N harvest by the grain was recorded with application of ½Manure+½P (163.33 kg N ha^{-1} and 128.9% increase), followed by ½Manure+Lime (157.68 kg N ha^{-1} and 121.0% increase) and Manure alone (153.03 kg N ha^{-1} and 114.5% increase). Total soybean N uptake (grain + stover) was significantly influenced by the application of the treatments ($p = 0.0012$) where the highest N uptake was observed under ½Manure+½P (197.18 kg N ha^{-1} and 99.2% increase), Manure alone (196.19 kg N ha^{-1} and 98.2% increase) and ½Manure+Lime (190.96 kg N ha^{-1} and 92.9% increase) against the control. The application of P fertilizer alone did not affect significantly N uptake both in the grain and crop (total plant N) over the control, which recorded the lowest values of 71.38 kg N ha^{-1} and 99.01 kg N ha^{-1} for grain and, grain plus stover, respectively.

Table 4.8: Soybean N uptake (2012 SR) under various treatments.

Treatments	**N content** (%)			**N uptake** (kg ha^{-1})		
	4WAP	8WAP	12WAP	Stover	Grain	Total
Manure	3.58^{a}	5.38^{a}	2.65^{a}	43.15^{a}	153.03^{a}	196.19^{ab}
Lime	3.95^{a}	4.94^{a}	2.86^{a}	31.10^{a}	102.65^{cd}	133.75^{cd}
P fertilizer	3.70^{a}	5.04^{a}	2.93^{a}	29.82^{a}	76.57^{d}	106.39^{d}
½Manure+Lime	3.59^{a}	5.14^{a}	2.90^{a}	33.28^{a}	157.68^{a}	191.96^{ab}
½Manure+½ P	3.62^{a}	4.83^{a}	2.86^{a}	33.86^{a}	163.33^{a}	197.18^{a}
½Manure+Lime+½P	3.81^{a}	4.73^{a}	2.96^{a}	34.52^{a}	143.25^{abc}	177.77^{abc}
Lime+½ P	3.58^{a}	4.81^{a}	2.87^{a}	37.23^{a}	109.16^{bcd}	146.39^{bcd}
Control	3.69^{a}	4.54^{a}	2.88^{a}	27.63^{a}	71.34^{d}	99.01^{d}
p-value	**0.5081**	**0.1491**	**0.9313**	**0.1415**	**0.0011**	**0.0012**
LSD$_{(0.05)}$	**0.41**	**0.58**	**0.47**	**10.54**	**46.59**	**50.76**

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

During vegetative stage N concentration in the plant increased toward flowering as a result of increased uptake of this nutrient as the dry matter biomass increased. Although the nutrient concentration reduced toward the pod fill stage, which meant that this nutrient was redirected from vegetative parts to the grain and pods, when vegetative stage stopped and the reproductive took over. As proof, there was high N uptake observed in the grain against the stover. Adeli *et al.* (2005) also reported high soybean N removal by grain. The grain N uptake was high in treatments which received manure either alone or combined. Other researchers (Schmitt *et al.*, 2001; Tagoe *et al.*, 2008; Sharma *et al.*, 2011) have also reported high N uptake by soybean under manure application. The increased N uptake may be due to supply of N content in the manure (1.60%) which was released to the soil (Table 3.1) through mineralization. The fact that when manure was combined with lime increased uptake might be associated with the ability of both (manure and lime) to improve soil pH which led to increased availability of this nutrient through mineralization of manure. However, when manure was combined with P fertilizer positive effect on N uptake were also observed. Jahangir *et al.* (2009) reported significant increase of grain N uptake by soybean under application of 30 kg P_2O_5 ha^{-1} than 60 kg P_2O_5 ha^{-1}. In the current study 30 kg P_2O_5 ha^{-1} was effective when applied with manure, and this probably was due to the fact that manure improved soil condition by reducing acidity, increasing conditions for microorganism's development and activity which in turn increased N in the soil from manure. In addition to that, P fertilizer applied at planting enhanced root development which in turn increased nutrient uptake (Sharma *et al.*, 2011). The good nutrient uptake in manured treatments may be a result of the ability of manure to improve soil moisture storage enhancing P dissolution and availability of nutrients (Sukartono *et al.*, 2011; Nwachukwu & Ikeadigh, 2012), therefore enhancing N uptake.

Generally, treatments under manure increased significantly N uptake and this fact can be associated with soil K availability which was found to be adequate in manured soils than non-manured ones. According to Tisdale *et al.* (1985), the total N uptake in K deficient plants tend to be reduced as is the buildup of amino acids. This was supported by the significant ($R^2 = 0.53$, $p = 0.0417$) positive relationship between N uptake and soil available K observed in the current study (Figure 4.4). Furthermore, manure by supplying N, P, and K to the soil and the good rainfall regime observed contributed to high biomass accumulation in the manured treatments which also recorded higher N content in the plant.

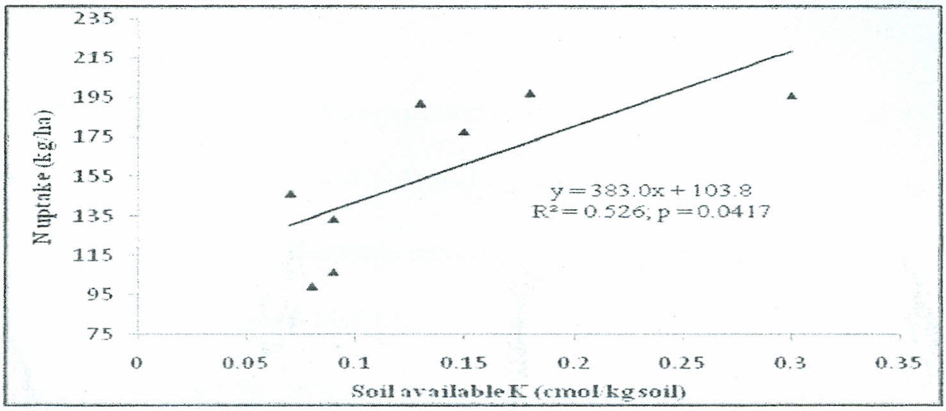

Figure 4.4: Relationship between N uptake with soil available K during 2012 SR

Despite that the N content in the stover and grain did not show statistical difference, irrespective of uptake which was significantly influenced. This suggests that the statistical differences on N uptake observed were due to biomass accumulation rather than the N content in the plant tissues. There was positive and significant relationship between crop N uptake with grain yield ($R^2 = 0.96$, $p < 0.0001$) and soil available N ($R^2 = 0.62$, $p = 0.0204$) (Figure 4.5). This explains the contribution of N in the crop development and yields. Out of total N uptake, the lowest (8.6% for P fertilizer alone) and the highest (35.5% for Manure alone), came from N fixation. This suggests that soybean relied more on soil N than BNF as main N source.

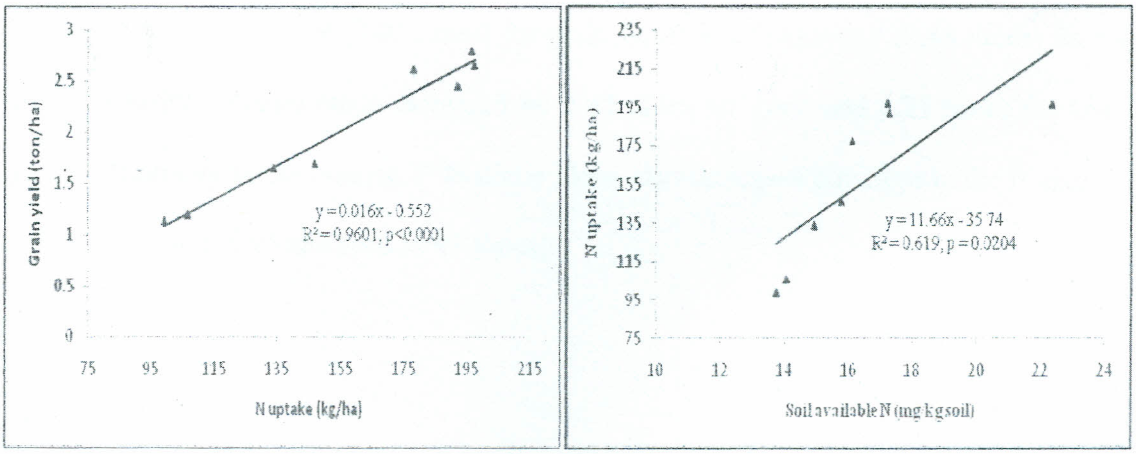

Figure 4.5: Relationship between N uptake with grain yield and soil available N (2012 SR).

4.2.3. Soybean phosphorus uptake

The effects of treatments on P uptake are presented in Table 4.9. There was found no statistical difference in stover P content (*p* = 0.115) and uptake (*p* = 0.1426). However, the treatment application of ½Manure+½P consistently recorded the highest value for P content (0.10%) and uptake (4.58 kg P .ha^{-1}), followed by ½Manure+Lime+½P, which recorded 0.08% for stover P content; and 3.94 kg P ha^{-1} for stover P uptake. On the other hand, the lowest stover P content in tissues and uptake was observed under ½Manure+Lime application, 0.05% and 2.57 kg P ha^{-1} respectively, only above the control.

There was statistical difference observed on grain P content (*p* = 0.0022), where the application of P fertilizer alone recorded the highest significant P content in the grain (0.46%) followed by Lime alone (0.43%), Lime +½P (0.41 %) and ½Manure+Lime+½P (0.39 %). The lowest grain P content was recorded under the control (0.29%).

The treatments affected significantly grain P uptake (*p* = 0.0432) and total soybean P uptake (*p* = 0.0348).The application of ½Manure+Lime+½P increased grain uptake by 3.13 times while ½Manure+½P most increased total P uptake by 2.53 times over the control. This was followed by ½Manure+½P (3.02 times) for grain; ½Manure+Lime+½P (2.48 times) for total uptake. Thirdly, Manure alone increased by 2.92 times for grain and 2.21 times for total P uptake. Relatively to the control, P fertilizer alone also increased but slightly the P uptake in both grain (1.66 times) and crop (1.41 times).

Table 4.9: Soybean P uptake (2012 SR) under various treatments.

Treatment	**P content (%)**		**P uptake** (kg ha^{-1})		
	Stover	Grain	Stover	Grain	Total
Manure	0.06^{a}	0.35^{cd}	3.05^{a}	9.78^{ab}	12.83^{ab}
Lime	0.07^{a}	0.43^{ab}	3.25^{a}	7.18^{abc}	10.43^{abc}
P fertilizer	0.07^{a}	0.46^{a}	2.65^{a}	5.55^{bc}	8.20^{bc}
½Manure+Lime	0.05^{a}	0.34^{cd}	2.57^{a}	8.72^{ab}	11.29^{ab}
½Manure+½ P	0.10^{a}	0.37^{bc}	4.58^{a}	10.13^{a}	14.71^{a}
½Manure+Lime+½P	0.08^{a}	0.39^{abc}	3.94^{a}	10.49^{a}	14.43^{a}
Lime+½ P	0.08^{a}	0.41^{abc}	3.77^{a}	7.07^{abc}	10.84^{abc}
Control	0.07^{a}	0.29^{d}	2.47^{a}	3.35^{c}	5.81^{c}
***p*-value**	**0.115**	**0.0022**	**0.1426**	**0.0432**	**0.0348**
LSD$_{(0.05)}$	**0.03**	**0.07**	**1.66**	**4.54**	**5.38**

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

Phosphorus fertilizer and lime alone enhanced significantly P content in the grain, which may be due to the high rate of P applied associated to its high solubility, which made the nutrient more available. On the other hand, lime may have improved soil acidity, preventing P fixation in the soil thus increasing its uptake. Other researchers (Jahangir *et al.*, 2009; Ogoke *et al.*, 2004; Devi *et al.*, 2012) obtained similar results. According to Caires and Fonseca (2000) the increased grain content even in the soils that have tested low in P, is associated to P release when the pH is increased under lime application. This was supported by a significant relationship ($R^2 = 0.52$; $p = 0.0423$) between grain P uptake and soil pH (Figure 4.6). Despite the high P content observed in the grain when sole P fertilizer and lime alone were applied, the respective grain P uptake was low and this may be attributed to the low dry matter produced under this treatment.

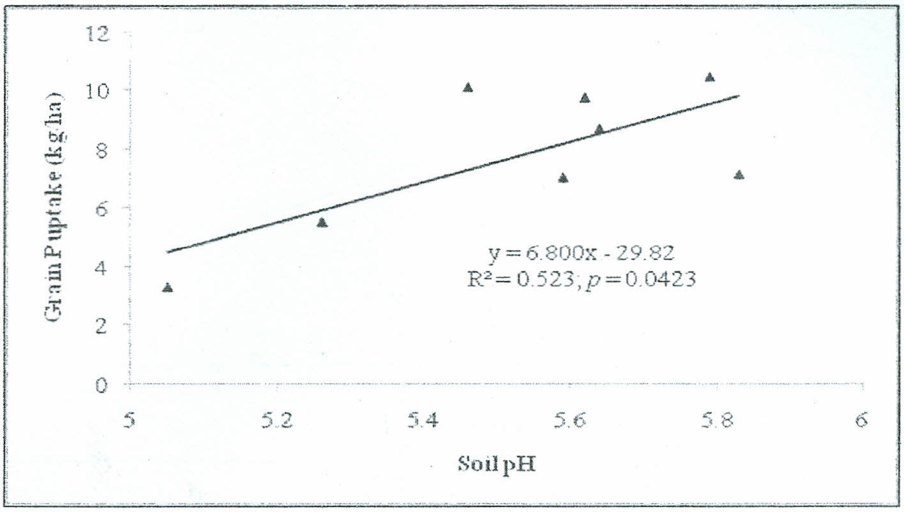

Figure 4.6: Relationship between grain P uptake with soil pH (2012 SR)

Manure alone, manure combined with P fertilizer, lime or both had significant effect on P uptake. Application of manure alone may have influenced P uptake by raising soil pH and acting as nutrient source for the crop. Furthermore, when combined with mineral fertilizer and lime it influenced the availability of nutrients through improved moisture storage, which consequently improved crop growth and greater accumulation of biomass and increased uptake. These results are in agreement with those of Panneerselvam *et al.* (2000); Schmitt *et al.* (2001), Adeli *et al.* (2005) which also found increased P uptake with application of manure alone or combined with mineral fertilizers. According to Schmitt *et al.* (2001) and supported by Hanway and Weber (1971), nutrient accumulation differences can be caused either by dry matter accumulation and or by plant nutrient concentration differences. The different trends observed in grain P concentration and grain yields suggest that the P crop harvest was a function of dry matter accumulation whereby P uptake was high under higher dry matter. There was significant relationship ($R^2 = 0.83$; $p = 0.0017$) between P uptake and grain yields (Figure 4.7), which emphasized the role of P on grain formation and yields.

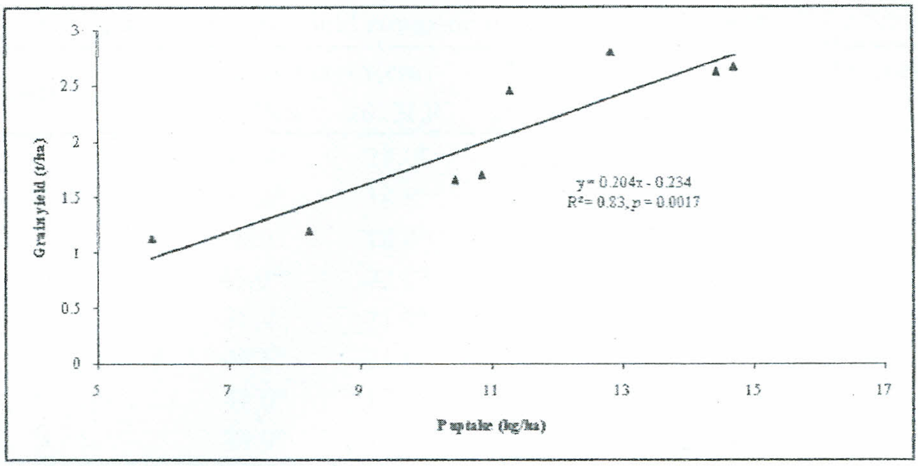

Figure 4.7: Relationship between grain yields with P uptake (2012 SR).

4.3. Effects of manure, lime and P fertilizer on soybean growth and yields

4.3.1. Plant height, number of pods and seed weight

Table 4.10 shows the effects of various treatments on growth performance and yields components of soybean. Plant height was significantly affected by the treatments in both seasons. During 2012 SR, application of ½Manure+½P and Manure alone treatments recorded significantly (*p* = 0.0044) the highest plant height of 50.4 cm and 49.9 cm respectively. P treatment resulted in no difference with the control and had the lowest plant height of 40.2 cm. The comparison between treatments showed that ½Manure+½P produced statistically (*p* = 0.00399) higher growth than P treatment. Meanwhile in 2013 LR season the application of Manure alone and ½Manure+Lime treatments recorded significantly (*p* = 0.0005) the highest plant heights of 23.0 cm and 22.2 cm, respectively. These were closely followed by ½Manure+Lime+½P (21.9 cm) and ½Manure+½P (21.9 cm), whereas the lowest plant height was observed under Lime+½P treatment (17.1 cm).

Table 4.10: Soybean growth and yield components in various treatments.

Treatments	**Plant height(cm)**		**Number of pods**		**100 seed (g)**	
	2012SR	2013LR	2012SR	2013LR	2012SR	2013LR
Manure	49.9^{a}	23.0^{a}	35.0^{a}	7.3^{a}	18.4^{ab}	11.9^{ab}
Lime	42.4^{b}	18.8^{b}	23.0^{b}	3.0^{c}	18.4^{bc}	11.1^{bc}
P fertilizer	40.2^{b}	18.8^{b}	22.6^{b}	4.4^{bc}	18.1^{bc}	12.3^{a}
½Manure+Lime	45.0^{ab}	22.2^{a}	26.2^{b}	6.5^{ab}	18.1^{bc}	11.5^{abc}
½Manure+½ P	50.4^{a}	21.9^{a}	25.6^{b}	7.0^{a}	19.1^{a}	12.3^{a}
½Manure+Lime+½P	48.6^{a}	21.9^{a}	23.8^{b}	6.2^{ab}	18.6^{ab}	11.8^{abc}
Lime+½ P	42.0^{b}	17.1^{b}	22.7^{b}	3.8^{c}	18.1^{bc}	10.8^{bc}
Control	39.9^{b}	17.2^{b}	22.3^{b}	2.9^{c}	17.7^{c}	10.8^{c}
***p*-value**	**0.0044**	**0.0005**	**0.0006**	**0.0013**	**0.0238**	**0.0389**
$LSD_{(0.05)}$	**6.17**	**2.81**	**5.02**	**2.31**	**0.75**	**1.11**

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

The treatments significantly affected the number of pods per plant both in 2012 SR ($p = 0.0006$) and 2013 LR ($p = 0.0013$) (Table 4.10). During 2012 SR and 2013 LR the manure alone mostly increased the number of pods per plant by 1.57 folds (2012 SR) and 2.55 folds (2013 LR) against the control, followed by ½Manure+Lime (1.17 folds) in 2012 SR and ½Manure+½P (2.43 folds) in 2013 LR. In contrast, the P fertilizer alone did not increase the number of pods over the control. Moreover, the inter-comparison amongst the treatments, during 2012 SR, showed that the number of pods per plant observed under Manure treatment were significantly different than Lime ($p = 0.0015$), P fertilizer ($p = 0.001$), ½Manure+Lime ($p = 0.0275$), ½Manure+½P ($p = 0.0156$), ½Manure+Lime+½P ($p = 0.0031$) and Lime +½P ($p = 0.0011$) treatments. But in the 2013 LR the difference was found to be significant between Manure and Lime alone ($p = 0.0164$) as well as between Lime and ½Manure+½P ($p = 0.031$) treatments.

The weights of 100 seeds were significantly affected by the treatments in both seasons (Table 4.10). During 2012 SR the highest 100 seed weight was recorded under ½Manure+½P treatment with 19.1 g, followed by ½Manure+Lime+½P (18.6 g) and Manure (18.4 g) treatments. The lowest 100 seed weight was recorded under Lime+½P treatment (18.1 g). In the 2013 LR season the application of P fertilizer and ½Manure+½P treatments recorded significantly higher 100 seed weight of 12.3 g and 12.3 g respectively; while the lowest was recorded under the control (10.8 g).

Manure alone or combined with lime and P fertilizer increased soybean growth and yield components (pods and seed weight) in both seasons. It shows the importance of combining nutrient sources to enhance crop development. Manure may have provided different nutrients and together with lime improved soil environment and enhanced mineralization. These results are similar with the results reported by several other researchers (Umoetok *et al.*, 2007; Javaid & Mahmood, 2010). Manure is a reservoir of nutrients that are released through mineralization and are availed for plant growth (Chiezey & Odunze, 2009), and when combined with P fertilizers it increases nutrient supply which in this study may have enhanced vegetative growth, affecting therefore and indirectly plant height (Umoetok *et al.*, 2007). The nutrient content of the goat manure was fair (Table 3.1), and the quantity applied must have supplied the important nutrients such as N, P and K which are critical for soybean growth. In addition the good performance of manure combined with lime and P fertilizer may be due to the improvement in soil conditions and increased availability of nutrients through manure and lime application; and also to the addition of P which is important during initial root growth, nutrient uptake and therefore plant development (Abbas *et al.*, 2011). A positive significant relationship was found between plant height and soil available K ($R^2 = 0.69$, $p = 0.0109$) and N uptake (R^2

= 0.83, p = 0.0015), Figure 4.8. These nutrients (N and K) are taken up by soybean in relatively high amount (Imas & Magen, 2007) and are directly involved on photosynthesis and therefore plant growth (Tisdale *et al.*, 1985; Sharief *et al.*, 2010; Gupta, 2011).

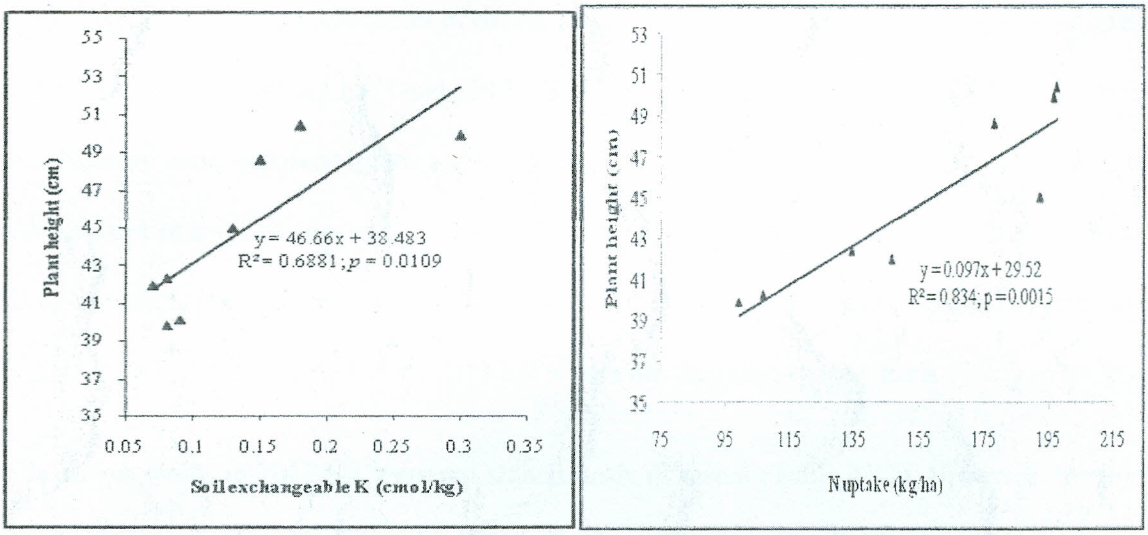

Figure 4.8: Relationship between plant height with soil exchangeable K and N uptake (2012SR)

Combining manure with P fertilizer resulted in the significant increase in plant height and 100 seed weight. Manure as organic resource requires microorganism decomposition to release nutrients to the soil from where plants take up. On the other hand, the mineral nutrients are of ready availability and provide nutrients for both microorganism and crop. Manure also may have improved soil physical conditions such as structure (moisture) which favoured microbial activity and root development. However, the crop did not respond to combined application of lime and P fertilizer and that may be associated with low supply of nutrients such as N and K which are provided by manure.

4.3.2. Soybean dry matter and grain yields

The mean weights of dry matter and grain yields (in ton ha^{-1}) are shown in Table 4.11. The grain yields values were significantly different in both 2012 SR ($p = 0.0011$) and 2013 LR ($p < 0.0001$) seasons. The application of Manure alone recorded the highest and significant grain yield in 2012 SR (2.80 ton ha^{-1}) and 2013 LR (0.36 ton ha^{-1}). The higher yield observed under sole Manure were followed by the application of ½Manure+½P (2.66 ton ha^{-1}) in 2012 SR and ½Manure+Lime (0.29 ton ha^{-1}) in the 2013 LR. The lowest increase was observed for P fertilizer and Lime+½P treatments in 2012 SR and 2013 LR, respectively. The grain yield was higher in the 2012 SR season than 2013 LR where the decrease ranged from 87.1% to 94.7%.

The stover yields in 2012 SR were not significantly different (Table 4.11). However, the total dry matter yields were significantly different in both 2012 SR ($p = 0.0085$) and 2013 LR ($p = 0.004$) seasons. The highest dry matter yields were recorded for Manure applied alone in both 2012 SR (8.32 ton ha^{-1}) and 2013 LR (4.32 ton ha^{-1}) seasons. These were followed by ½Manure+Lime+½P (7.46 ton ha^{-1}) in 2012 SR and ½Manure+Lime (3.72 ton ha^{-1}) in 2013 LR. The control recorded the lowest in both seasons.

The harvest index (HI) which relates the economic yield to the total dry matter yield was found to be statistically different in the both seasons (Table 4.11). In the 2012 SR season, ½Manure+Lime+½P and ½Manure+½P recorded significantly ($p = 0.0037$) higher HI (0.35) than other treatments. Whereas in the 2013 LR the application of Manure alone had significantly ($p = 0.0002$) higher HI (0.24), followed closely by ½Manure+Lime and ½Manure+Lime+½P (0.23). The lowest HI was observed under the control in the both seasons with 0.23 (2012 SR) and 0.09 (2013 LR).

The drastic reduction of grain yields in 2013 LR against 2012 SR was mainly attributed to the poor rainfall observed during 2013 LR. During the 2013 LR season the rains had very poor temporal distribution where most of it (64.6% of the total rainfall observed in the season) occurred during the first 25 days after planting followed by low amounts of rainfall (varying from 30 to 66 mm per month). May (41.6 mm) and June (66 mm) were the months with lowest rainfall, which affected plant growth during half part of vegetative stage and all of the flowering and podding stages. The monthly rainfall distribution during the study period in 2012 SR and 2013 LR at Embu is presented in Figure 3.1. Rainfall scarcity affects directly soil moisture and consequently fertilizer and lime dissolution, therefore reduces microorganism's activity, availability of nutrients and its uptake with main negative effects on crop development, lastly and most important crop yields. The decrease in grain yields ranged from 87.1% to 94.7% while stover yields ranged from 80.6% to 89.1%. Elsewhere, Kamara *et al.* (2011) found reduced grain yields up to 74.05%, number of pods by 57.89% as result of relatively low rainfall observed.

Table 4.11: Soybean grain and dry matter yields and Harvest Index (HI) under different treatments.

Treatments	**Grain yield** (ton ha^{-1})		**Stover yield** (ton ha^{-1})		**Total dry matter yield** (ton ha^{-1})		**HI**	
	2012 SR	2013 LR	2012 SR	2013 LR	2012SR	2013LR	2012 SR	2013 LR
Manure	2.80^{a}	0.36^{a}	5.52^{a}	1.04^{a}	8.32^{a}	4.32^{a}	0.34^{ab}	0.24^{a}
Lime	1.66^{bc}	0.09^{d}	4.42^{ab}	0.62^{cde}	6.07^{bc}	3.14^{bc}	0.27^{bc}	0.10^{c}
P fertilizer	1.20^{c}	0.14^{cd}	3.78^{b}	0.70^{bcde}	4.98^{c}	2.95^{c}	0.24^{c}	0.13^{bc}
½Manure+Lime	2.45^{ab}	0.29^{ab}	4.70^{ab}	0.91^{ab}	7.14^{ab}	3.72^{ab}	0.34^{ab}	0.23^{a}
½Manure+½ P	2.66^{a}	0.22^{bc}	4.81^{ab}	0.87^{abc}	7.46^{ab}	3.71^{b}	0.35^{a}	0.18^{ab}
½Manure+Lime+½P	2.62^{a}	0.28^{ab}	4.84^{ab}	0.80^{abcd}	7.46^{ab}	3.62^{b}	0.35^{a}	0.23^{a}
Lime+½ P	1.70^{bc}	0.06^{d}	4.86^{ab}	0.53^{e}	6.57^{abc}	3.22^{bc}	0.26^{c}	0.09^{c}
Control	1.14^{c}	0.06^{d}	3.76^{b}	0.55^{de}	4.9^{c}	2.7^{c}	0.23^{c}	0.09^{c}
***p*-value**	**0.0011**	**<0.0001**	**0.0937**	**0.003**	**0.0085**	**0.004**	**0.0037**	**0.0002**
LSD$_{(0.05)}$	**0.86**	**0.1**	**1.21**	**0.25**	**1.86**	**0.61**	**0.07**	**0.07**

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

Manure alone increased yields more than when it was combined with P fertilizer, lime or both. However, this was in contrast with the expectation that manure applied together with both lime and P fertilizer would result in the highest yields. Although, the yields obtained were similar. Application of fertilizer P makes nutrient readily available from the early growth stage of the crop and that promotes nutrient and water uptake. Thus, manure when combined with mineral fertilizer P it contributed improve soil physical conditions and nutrient use efficiency (Danga *et al.*, 2009) and soybean yields. Therefore, in the current study the relative higher yields recorded under sole application of manure (10 ton ha^{-1}) might be due to the amount of nutrients availed than when it was combined.

The manure used in this study was fair in macro nutrients (Table 3.1) and must have supplied the important nutrients such as C, N, K and P which are critical for soybean growth and yields. Manure might have also contributed for improved soil microbial biomass and activity resulting in organic matter decomposition and nutrients release. Moreover, the high yields observed under manure application may be as a result of its ability to improving soil physical properties such as structure, which increase soil water retention and enhances nutrients uptake (Ghosh *et al.*, 2004; Sukartono *et al.*, 2011; Nwachukwu & Ikeadigh, 2012). Elsewhere several other researchers have reported significant increase on soybean grain yield with application of farm yard manure and poultry manure (Mekki & Ahmed, 2005; Tagoe *et al.*, 2008; Javaid & Mahmood, 2010). Similarly, it has also been reported significant increase in soybean yields when manure was applied in combination with mineral fertilizers than mineral fertilizers alone (Zingore & Giller, 2012; Peter & Ayolagha, 2012).

During both seasons, symptoms of K deficiency were observed in the non-manure plots. According to the law of minimum, it is suggested that the low yields observed under non manure treatments are probably due to soil K deficiency. Potassium is an essential macronutrient very important to plants and it is involved in cell division, water and nutrient uptake (Tisdale *et al.*, 1985; Gupta, 2011). Therefore, its deficiency negatively affects shoot and root growth as well as water and nutrients uptake. In addition, K is the second nutrient mostly taken up by soybean after N and its deficiency greatly affects negatively crop development and yields (Imas & Magen, 2007). Thus, the low yields observed under the non-manure treatments could be caused by the low soil K (< 0.20 cmol(+) kg^{-1}) (Table 4.4) as well as poor N fixation (Table 4.7) and NP uptake (Tables 4.8 and 4.9). Therefore, it suggests that the use of manure combined with lime, P fertilizer or both enhanced good soil conditions, which in turn contributed to relatively high yields. The positive and significant relationship between grain yield with N fixed ($R^2 = 0.67, p = 0.0135$), soil exchangeable K ($R^2 = 0.62$, $p = 0.02$) during 2012 SR and 2013 LR (Figures 4.9 and 4.10), respectively, evidenced the role of manure in contribution to soil improvement and yields.

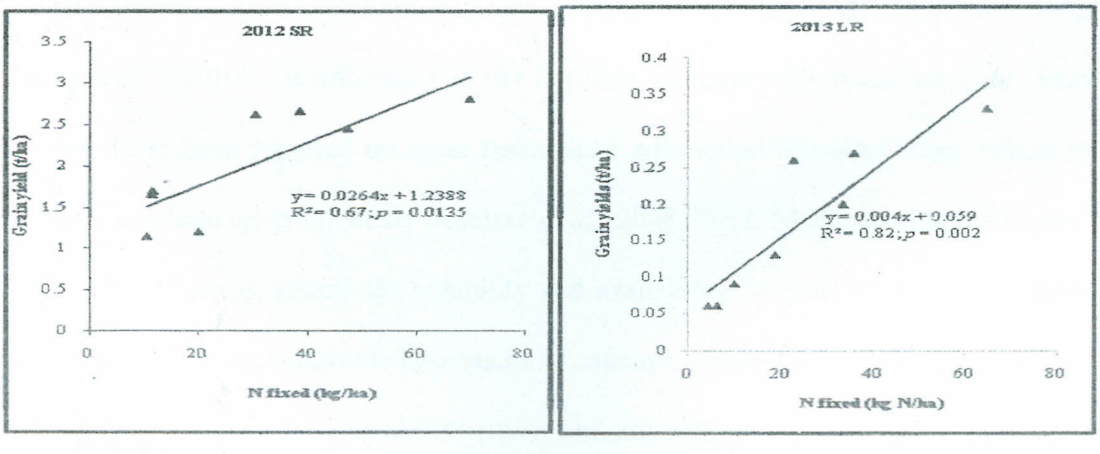

Figure 4.9: Relationship between grain yields with N fixed during 2012 SR and 2013 LR.

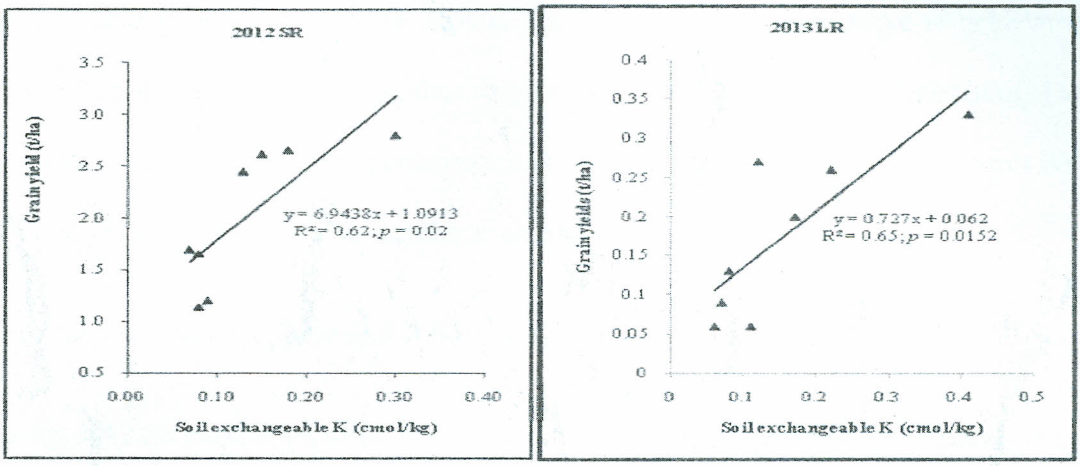

Figure 4.10: Relationship between grain yields with soil exchangeable K during 2012SR and 2013LR.

Application of P fertilizer alone increased grain yields by 5.36% (2012 SR) and 33.3% (2013 LR) while for lime alone the increments were 45.6% in 2012 SR and 50% in 2013 LR. However, the observed increases were not significant. In the current study, the significant response of grain yield to P application was observed when 30 kg P_2O_5 ha^{-1} was combined with 5 ton ha^{-1} of manure. Other researchers reported that application of P not exceeding 20 to 40 kg P_2O_5 ha^{-1} or application of full rate of manure with regard to its quality significantly increased soybean grain yields (Barbagelata *et al.*, 2002; Kamara *et al.*, 2011). According to Danga *et al.*, (2010), the efficiency of any fertilizer decrease with increasing dose. Similar findings have been reported by other researchers who found non-significant effects of P fertilizer and lime on grain yields (Kamara *et al.*, 2008, 2011; Mabapa *et al.*, 2010; Andric *et al.*, 2012). Liming affects the solubility and availability of most of the plant nutrients, raises the level of exchangeable base status of calcium, neutralize the effect of Al^{3+} and H^{+} (raising the soil pH), improves soil structure, and promotes root distribution (Nekesa *et al.*, 2005). These yields trend also to explain that liming alone cannot serve to achieve the maximum potential of an acid soil, thus suggesting that the soils are more depleted of N and K, which clearly influence crop performance as, was observed when these amendments (lime and P fertilizer) were applied in combination with manure.

4.4. Effects of manure, lime and P fertilizer on Soil Microbial Biomass (SMB)

During 2012 SR significant differences in soil microbial biomass among the treatments (p = 0.0335) as result of treatments application (Table 4.12) were observed. The application of Lime alone recorded significantly the highest value of microbial biomass of 48.59 mg kg^{-1} soil. This was a 2.1 fold increase compared to the control. This was followed by ½Manure+½P (1.8 fold increase) and Manure alone (1.7 fold increase), while the lowest microbial biomass increase was observed under ½Manure+Lime and P fertilizer treatment (1.2 folds) over the control.

In the 2013 LR season the microbial biomass values showed significant differences (p = 0.0308) as a result of treatments application. During the same period, the application of Manure alone recorded the highest value of 74.99 mg kg^{-1} soil, which corresponded to an increase of 75.55% over the control. This was followed by the application of ½Manure+Lime+½P (68.85 mg kg^{-1} soil) and Lime alone (66.89 mg kg^{-1} soil) treatments which increased by 59.34% and 54.80%, respectively. However, there were not significant differences amongst them and against Manure alone. The lowest microbial biomass increases were observed in treatment ½Manure+½P (31.36%) and P fertilizer (35.76%) relative to the control.

In 2012SR, the treatment lime alone increased significantly soil microbial biomass by 21.39 units relative to the pre-season. But in 2013LR the treatment manure alone increased microbial biomass significantly by 47.79 units followed by treatment ½Manure+Lime+½P with 41.65 units increase over the pre-season.

Table 4.12: Soil Microbial Biomass (0 - 15 cm depth) in various treatments

Treatments	**Microbial Biomass N (mg kg^{-1} soil)**						
	Initial	2012 SR	Change	*t*-test, *p*	2013 LR	Change	*t*-test, *p*
Manure	27.2	39.23^{ab}	+12.03	0.4892	74.99^{a}	+47.79	*0.0071*
Lime	27.2	48.59^{a}	+21.39	*0.0048*	66.89^{ab}	+39.69	*0.0002*
P fertilizer	27.2	28.41^{bc}	+1.21	0.9799	58.66^{abc}	+31.46	*0.006*
½Manure+Lime	27.2	27.09^{bc}	-0.11	0.9998	65.13^{ab}	+37.93	*0.0016*
½Manure+½ P	27.2	41.40^{ab}	+14.2	0.4531	56.76^{bc}	+29.56	0.0821
½Manure+Lime+½P	27.2	30.44^{bc}	+3.24	0.8108	68.85^{ab}	+41.65	*0.0005*
Lime+½ P	27.2	27.48^{bc}	+0.28	0.9992	64.31^{ab}	+37.11	*0.0066*
Control	27.2	23.26^{c}	-3.94	0.7354	43.21^{c}	+16.01	0.0671
***p*-value**		**0.0335**			**0.0308**		
LSD$_{(0.05)}$		**15.54**			**16.81**		

Means followed by the same letter(s) are not significantly different for the specified parameter ($p<0.05$)

Soil microbial biomass, a living part of soil organic matter, is an agent of transformation for added and native organic matter, and acts as a labile reservoir for plant available nutrients such as nitrogen, phosphorus and sulphur (Logah *et al*., 2010). This, therefore, can be used as an indicator of the soil microbial status characterization (Nannipieri *et al*., 1990). The application of lime alone increased significantly microbial biomass in both seasons and this may be a result of increased soil pH and nutrient availability, which in turn improved soil conditions for microorganism's development. However, when lime was combined with either manure or both manure plus P fertilizer increased microbial biomass slightly in the

2012 SR. Meanwhile, in 2013 LR the same treatments increased significantly microbial biomass, and this fact may be explained by the lime effect on reducing soil acidity over the time. The results are in agreement with those of Fuentes *et al.* (2006), Filep and Szili-Kovács (2010) who also reported increased soil microbial biomass when lime was applied. Furthermore, the soil pH was strongly and significantly correlated ($R^2 = 0.74$; $p = 0.0065$) with microbial biomass in 2013 LR (Figure 4.11). This suggested that the soil acidity plays an important role on microorganism's survival. Several other researchers have reported decreased microbial biomass due to application of lime (He *et al.*, 1997; Lorenz *et al.*, 2001). This probably explains the poor response in plots that received lime combined with manure and P fertilizer in the 2012 SR and possibly due to poor distribution of lime in soil. However, this was not expected, and could be associated with short period of time of which lime was exposed for dissolution and equilibration in soil.

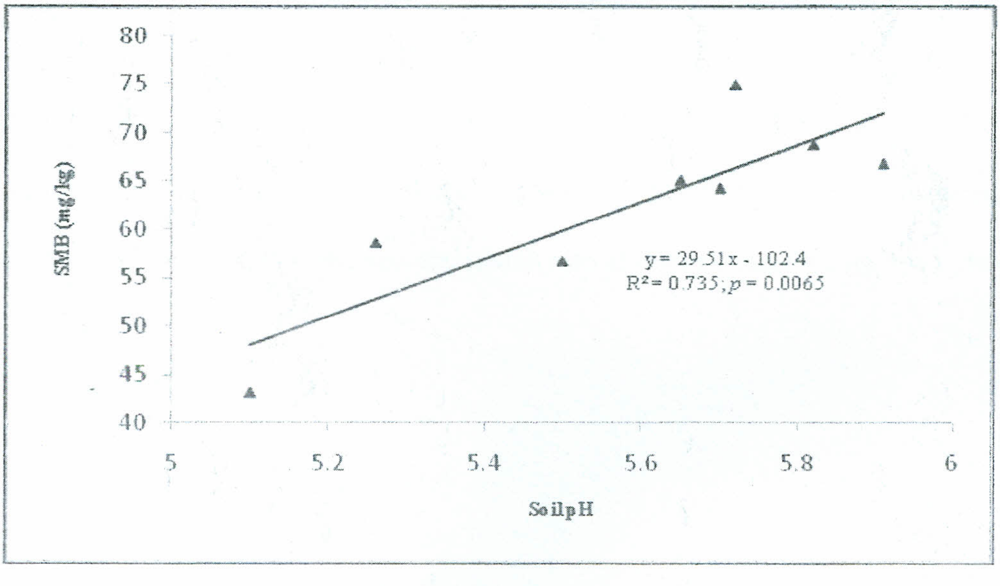

Figure 4.11: Relationship between SMB and soil pH, 2013 LR.

Application of manure alone and when combined with P fertilizer increased microbial biomass significantly during the 2012 SR, while Manure alone, combined with lime and with both lime plus P fertilizer increased MB significantly in the 2013 LR. This, therefore, shows effect of lime application was felt in season two of the experiment (2013LR). These results are similar to those of Tennakoon (1990), Černý *et al.* (2008), Mohammadi (2011) who had also reported significant effects of manure on SMB. The positive effect of full rate of manure can be due to the rate of manure, which contributed to increased soil pH and supply of nutrients in relatively high amount than when it was combined. Additionally, it can be stated that when manure was applied in combination with P fertilizer and lime there was a synergetic effect in providing nutrient P, which is much vital for microorganism survival and development, hence significant increase on MB. The increase can also be a result of greater amounts of biogenic materials like mineralizable nitrogen (Mohammadi, 2011), soil moisture, temperature and availability of substrate provided by application of manure (Logah *et al.*, 2010). On the other hand, application of P fertilizer alone did not increased significantly SMB and this maybe associated to poor labile N and other nutrients present in the soil that may be also related to the lower soil pH, which hindered microorganism's survival and activity as well as the decomposition rate of organic material applied to the soil.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The first objective of the study was to determine the effect of manure, lime and P fertilizer on soil chemical properties and soybean yields. The findings showed that combining 5 ton ha^{-1} of goat manure with 2 ton ha^{-1} lime plus 30 kg P_2O_5 ha^{-1} as P fertilizer was the best practice and increased soil CEC by 73.7%. This closely followed by manure at the rate of 10 ton ha^{-1} which increased CEC by 55.8% against the control. In a comparison with initial soil status lime alone was the best treatment in increasing soil available P by 41.9% in 2013 LR, and soil pH by 14.1% and 15.7% in 2012 SR and 2013 LR, respectively. Relative to the control, manure at the rate of 10 ton ha^{-1} emerged as the best soil amendment increasing soybean yields by 145.6% and 500% in 2012 SR and 2013 LR, respectively.

Accounting for the second objective of this study that was to determine the effects of different soil amendment on soybean N and P uptake and N fixation, the results showed that application of 5 ton ha^{-1} of goat manure + 30 kg P_2O_5 ha^{-1} was the best soil amendment. It increased N and P uptake by 99.2% and 153.2%, respectively, when compared to the control. Amending the soil with 10 ton ha^{-1} also increased 14.8 times N fixed by soybean relative to control and showed to be the best practice.

The third objective was to evaluate the effects of different soil amendment on soil microbial biomass. The findings showed that the best soil amendment in 2012 SR was 10 ton ha^{-1} of goat manure that increased by 108.9% over the control. In 2013 LR, soil amendment with

2 ton ha^{-1} of lime emerged to be the best and increased microbial biomass by 78.0% over the control.

Results from this study shows that, manure alone (10 ton ha^{-1}) was the best soil amendment in terms of soybean N fixation, grain yields and microbial biomass increment. Lime alone (2 ton ha^{-1}) emerged the best amendment in terms of soil pH and available P increment. Integrated application of 5 ton ha^{-1} of goat manure with 30 kg P_2O_5 ha^{-1} was the best amendment in increasing soybean N and P uptake. The integrated application of 5 ton ha^{-1} of goat manure with 2 ton ha^{-1} of lime and 30 kg P_2O_5 ha^{-1} emerged as the best amendment to promote soil CEC, pH, available P and soybean grain yields increase. Goat manure proved to be an important soil amendment therefore, it can substitute or supplement the inorganic fertilizers in Embu County, Central Highlands of Kenya.

5.2. Recommendations

The following recommendations were made, according to the results from this study:

- For improved soil chemical properties and enhanced soil microbial biomass, smallholder farmers are advised to adopt integrated application of goat manure with lime and P fertilizer.
- To increase soybean grain yields, smallholder farmers should adopt use of goat manure alone or integrate it with lime and P fertilizer.
- Further research to evaluate the economic, water use efficiency and crop response to soybean K fertilization in the region.

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APPENDICES

Appendix 1: Anova procedures for soil properties parameters

```
Soil exchangeable Mg
          Source                   DF          Anova SS     Mean Square     F Value      Pr > F

          Treat                     7        0.00315370      0.00045053        3.00      0.0240
          Block                     3        0.00021562      0.00007187        0.48      0.7008
```

```
Soil exchangeable Ca
          Source                   DF          Anova SS     Mean Square     F Value      Pr > F

          Treat                     7        0.58465075      0.08352154        2.50      0.0491
          Block                     3        0.02319367      0.00773122        0.23      0.8734
```

```
Soil exchangeable K
          Source                   DF          Anova SS     Mean Square     F Value      Pr > F

          Treat                     7        0.38932600      0.05561800       20.33      <.0001
          Block                     3        0.02064369      0.00688123        2.52      0.0860
```

```
Soil exchangeable Na
          Source                   DF          Anova SS     Mean Square     F Value      Pr > F

          Treat                     7        0.01605795      0.00229399        0.75      0.6315
          Block                     3        0.03557453      0.01185818        3.89      0.0234
```

```
Soil CEC
          Source                   DF          Anova SS     Mean Square     F Value      Pr > F

         Treat                      7        1.30402949      0.18628993        3.30      0.0159
         Block                      3        0.12724188      0.04241396        0.75      0.5344
```

```
Soil available P
          Source                   DF          Anova SS     Mean Square     F Value      Pr > F

          Treat                     7       28.18421797      4.02631685        3.51      0.0119
          Block                     3        1.36839184      0.45613061        0.40      0.7559
```

```
Soil pH water
          Source                   DF          Anova SS     Mean Square     F Value      Pr > F

          Treat                     7        2.17759688      0.31108527       69.41      <.0001
          Block                     3        0.00490938      0.00163646        0.37      0.7789
```

Soil pH KCl

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	1.20712188	0.17244598	17.01	<.0001
Block	3	0.02123438	0.00707813	0.70	0.5635

Exchangeable acidity

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	60.21875000	8.60267857	6.09	0.0006
Block	3	4.09375000	1.36458333	0.97	0.4271

Soil available N

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	65.30001172	9.32857310	4.31	0.0042
Block	3	14.81937109	4.93979036	2.28	0.1086

Total soil Nitrogen

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	0.00119688	0.00017098	3.08	0.0214
Block	3	0.00010938	0.00003646	0.66	0.5877

Total soil Carbon

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	0.09908750	0.01415536	3.34	0.0149
Block	3	0.02026250	0.00675417	1.59	0.2205

Appendix 2: Anova procedures for plant growth, yield component and yields

Grain yield 2013LR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	0.30999712	0.04428530	10.92	<.0001
Block	3	0.03706590	0.01235530	3.05	0.0513

Grain yield 2012SR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	12.90941036	1.84420148	5.45	0.0011
Block	3	0.74451282	0.24817094	0.73	0.5440

Stover yield 2012SR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	9.72643622	1.38949089	2.07	0.0937
Block	3	0.24367090	0.08122363	0.12	0.9468

Stover yield 2013LR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	0.95428611	0.13632659	4.61	0.0030
Block	3	0.13720069	0.04573356	1.55	0.2322

Total Dry Matter 2012SR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	42.04513307	6.00644758	3.77	0.0085
Block	3	0.61867982	0.20622661	0.13	0.9416

Total Dry Matter 2013LR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	7.55324656	1.07903522	6.32	0.0004
Block	3	0.34658855	0.11552952	0.68	0.5761

Harvest index 2012SR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	0.07470843	0.01067263	4.42	0.0037
Block	3	0.01261277	0.00420426	1.74	0.1893

Harvest index 2013LR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	0.11318619	0.01616946	6.98	0.0002
Block	3	0.02488423	0.00829474	3.58	0.0310

Appendix 3: Anova procedures for soybean nodulation and N fixation

Number of nodules

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	603.3746875	86.1963839	2.71	0.0360
Block	3	238.9134375	79.6378125	2.51	0.0868

Nitrogen Fixation

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	11388.68002	1626.95429	2.49	0.0500
Block	3	3350.58257	1116.86086	1.71	0.1961

Appendix 4: Anova procedures for nutrients uptake

Nitrogen uptake

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	45214.74798	6459.24971	5.42	0.0012
Block	3	4216.40414	1405.46805	1.18	0.3414

Phosphorus uptake

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	256.0928039	36.5846863	2.74	0.0348
Block	3	30.8598805	10.2866268	0.77	0.5240

Appendix 5: Anova procedures for soil biologic properties

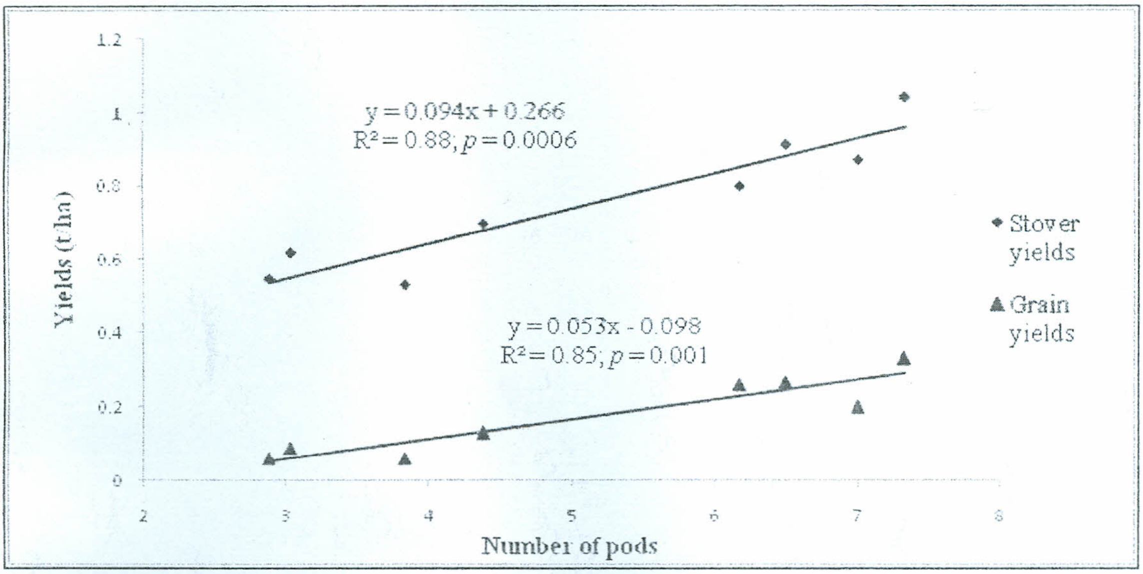
SMB 2012SR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	2158.765021	308.395003	2.76	0.0335
Block	3	2287.829594	762.609865	6.83	0.0022

SMB 2013LR

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Treat	7	2581.739485	368.819926	2.82	0.0308
Block	3	629.239494	209.746498	1.60	0.2184

Appendix 6: Relationship between number of pods with stover and grain yields during 2013LR.



Appendix 7: Relationship between plant height with stover and grain yields during 2013LR.