

**LIME AND MANURE APPLICATION TO ACID SOILS AND THEIR
EFFECTS ON BIO-CHEMICAL SOIL PROPERTIES AND MAIZE
PERFORMANCE AT KAVUTIRI - EMBU COUNTY**

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DECLARATION

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

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DEDICATION

This work is dedicated to all optimists who not just view soil as an agent soiling their hands but as a God given natural resource that since time in memorial has undergone serious degradation under man's inappropriate exploitation and more so, are willing and ready to revitalize its fertility and productivity. This will increase crop yields to feed the ever-rising human population through proper utilisation of this scarce resource.

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ABBREVIATIONS AND ACRONYMS

ANOVA	- Analysis of Variance
CAN	- Calcium Ammonium Nitrate
CEC	- Cation Exchange Capacity
CRD	- Complete Randomised Design
DAP	- Di-ammonium phosphate
DM	- Dry Matter
DOC	- Dissolved Organic Carbon
DON	- Dissolved Organic Nitrogen
FURP	- Fertilizer Use Recommendation Project
FYM	- Farm Yard Manure
Hp	- Exchangeable acidity
KARI	-Kenya Agricultural Research Institute
LSD _{5%}	- Least Significance Difference between means at 5 %
SED	-Standard Error of Differences between means
SSA	- Sub-Saharan Africa
TSP	- Triple Supper Phosphate
WAP	- Weeks after planting

ABSTRACT

Soil acidity is widespread globally, accounting for about 40% of total arable soils. In Kenya, acid soils cover about 13% of total land area and are distributed widely in the croplands of central and western Kenya regions, covering over one million hectares. The main limitation of crop productivity in Kavutiri, Embu, is soil acidity and more specifically aluminium toxicity. The objective of this study was to determine the effects of agricultural lime in combination with farmyard manure (FYM) on soil properties (exchangeable acidity, pH, and microbial biomass) and maize growth. The treatments include: goat manure at 3 levels (0, 5 and 10 Mg ha⁻¹) and agricultural lime (CaCO₃) at 6 rates (0, 2.5, 5, 7.5, 10, and 12.5 Mg ha⁻¹). The study was carried out in two phases. Phase 1 was carried out at the greenhouse with pots arranged in a complete randomised design (CRD) and replicated thrice while phase 2 was carried out on a farmer's field at Kavutiri where the soil samples for phase 1 were taken. Only the best three performing treatments in phase 1 were selected and verified during phase 2 in a complete randomised block design (CRBD) with three replicates. In each phase, maize was the test crop and was grown for a period of 8 weeks. The biophysical data generated from the study was analysed using Analysis of Variance (ANOVA) in Genstat statistical package. Treatment means were compared at probability $p < 0.05$ using Fischer's least significant difference (L.S.D). Results of this study indicate that soil acidity decreased with increase in manure and lime levels. The treatment M₁₀L_{12.5} –with 10 Mg ha⁻¹ of manure and 12.5 Mg ha⁻¹ of lime - recorded the highest pH of 6.3 and 5.9 for greenhouse and field trials, respectively. Maize growth parameters (root length, height and biomass dry weight) were found to increase significantly as levels of manure and lime increased. Treatment M₁₀L_{12.5} from greenhouse trial recorded the highest values for root length (41.3 cm), height (150.3cm) and dry biomass weight of 755.4 Kg ha⁻¹. Microbial biomass was found to be higher in the field than in greenhouse trials with the highest value of 28.8×10^5 and 26.7×10^3 Colony forming units (CFU) for bacteria and fungi, respectively. This marked significant increases ($P < 0.05$) of 772.7 and 86.6% for bacteria and fungi, respectively above the control. From the study, it was concluded that combining 10 Mg ha⁻¹ of FYM and 12.5 Mg ha⁻¹ of agricultural lime could be a promising alternative amendment for acid soil management strategy for increased maize production at Kavutiri and other related soils in Kenya.

CHAPTER ONE

INTRODUCTION

1.1 Background Information of the Study

Over half of the world population currently lives in regions dominated by acid soils (Yang *et al.*, 2004) whose productivity is on the decline to meet the food requirements of the ever increasing population, especially in the tropics (Hartemink, 2002). Soil acidity is a major yield-limiting factor for crop production worldwide. The land area affected by acidity is estimated at 4 billion hectare, representing approximately 30 % of the total ice-free land area of the world (Sumner and Noble, 2003). In Kenya, acid soils cover about 13 % of total land area and are distributed widely in the croplands of central and western Kenya regions. They cover over one million hectares under maize, legume, tea and coffee crops, grown by over 5 million smallholder farmers (Gudu *et al.*, 2007).

In the tropics, substantial weathering of soils over millennia has resulted in the leaching of crop nutrient bases (mainly K, Mg and Ca). This is followed by replacement by H, Al and Mn cations that contribute to acid related stresses on crop production (Okalebo *et al.*, 2009). Acid infertility factors limit crop growth and yield as well as soil productivity in highly weathered soils of humid and sub-humid regions of the world due to deficiency of essential nutrient elements (Akinrinade *et al.*, 2006)

Crop production is low and declining on such acid soils, particularly where acid forming fertilizers, such as di-ammonium phosphate (DAP), have been applied continuously to already acidic soils over years (Nekesa, 2007). As these soils suffered multi-nutrient deficiencies, application of mineral fertilizers has become

mandatory to increase crop yields. However, mineral fertilizers are commonly scarce, costly; having imbalanced nutrition and their use could exacerbate the problem of soil acidity (Oguike *et al.*, 2006; Nottidge *et al.*, 2006). The practice of liming acid soils is not common in Sub-Saharan Africa (SSA), perhaps because of limited knowledge on lime effectiveness, availability and high hauling costs of liming materials (Okalebo *et al.*, 2009).

Continuous cropping with incorrect fertilizer type application has intensified chemical degradation of arable lands resulting in reduced capacity of soils to produce crops sustainably (Nandwa, 2003; Ayuke *et al.*, 2007; Mugendi *et al.*, 2007). According to Kisinyo *et al.*, (2005), continuous cropping has led to development of soil acidity due to toxic levels of aluminium (Al) and the concomitant phosphorus (P) deficiency that hinders plant growth.

Liming is the most important and most effective practice to ameliorate soil acidity constraints for optimal crop production (Haynes, 1984). The practice of well-planned and execution of liming under these situations is fundamental to improve soil fertility and for increasing crop yields on acid soils. This in turn helps to reduce crop production risks associated with soil acidity, as liming promotes nutrients use efficiency especially phosphorus.

Proper liming of the acid soils has the potential of contributing to an overall increase of maize yields cultivated in such soils because of reducing exchangeable acidity and increasing pH. Reduction of acidity in soils also improves the microorganisms' proliferation and hence their activity in soils (Onwonga *et al.*, 2010). The magnitude of the soil acidity problem and the potential that these soils

offer in increasing the production of food and fiber provided a focus for the objectives of this study.

1.2 Problem Statement

Soil acidity is a major constraint to maize (*Zea mays*) production on tropical soils due to toxic levels of aluminium (Al) and the concomitant phosphorus (P) deficiency that hinder plant growth (Kisinyo *et al.*, 2005). The Fertilizer Use Recommendation Project (FURP) carried out trials between 1986 and 1991 and published area- and crop-specific fertiliser recommendations for various AEZ (KARI, 1994). However, it was established that 29 % of the trial sites could not be conclusively used to give fertiliser recommendations. All these sites had acidic soils with a pH less than 5.5 (KARI, 1994).

Following the inconclusive results obtained by FURP in some acidic soils in Kenya (Mochoge, 1992), Kanyanjua *et al.*, (2002), carried a liming study on a nitisols acid soil (pH 4.6), of Chehe-Nyeri Kenya and came up with fertilizer and lime recommendations for acid soils. The rates they recommended are rather high that most resource poor farmers in the region cannot afford to purchase. Nevertheless, there is a research gap in that no specific research has been carried out that combines lime and manure treatments on the amendment of acid soils.

The soils at Kavutiri are Ando-humic Nitisols but with pH levels comparable to that at Chehe (4.6). Therefore, to increase maize production in this area, there was need to research on the role of lime and manure in alleviating acidity problem. This was to ensure that farmers only apply economical levels of lime and manures in their farms to reap optimum benefits.

1.3 Research Questions

The study was guided by the following research questions:

- 1) What are the effects of adding agricultural lime and farmyard manure to acid soil on exchangeable acidity and pH?
- 2) How does agricultural lime and farmyard manure application to acid soils influence maize growth?
- 3) Is bacteria and fungi population in acid soils also affected by application of agricultural lime and farmyard manure?

1.4 Research Objectives

The broad objective of this study was to determine the effect of amending acid soils of Kavutiri-Embu with agricultural lime and farmyard manure (FYM) to improve soil productivity.

Specific objectives

These include:

- 1) To determine the effect of amending acid soils with agricultural lime and farmyard manure on exchangeable acidity and pH.
- 2) To evaluate the effect of amending acid soils with agricultural lime and farmyard manure on maize growth.
- 3) To determine the effect of agricultural lime and farmyard manure application on the bacteria and fungi population in acid soils.

1.5 Research Hypotheses

The research hypotheses of the study were:

- 1) Amending acid soils with agricultural lime and farmyard manure significantly lowers exchangeable acidity and raises the pH.
- 2) Amending acid soils with agricultural lime and farmyard manure significantly improves maize growth.
- 3) Incorporation of agricultural lime and farmyard manure significantly enhance micro- organisms (bacteria and fungi) population in acidic soils.

1.6 Justification for the Study

To increase crop yields and reduce crop production risks associated with soil acidity, there is need to focus on soil amendment practices that target efficiency of nutrients use in soils especially phosphorus that is made unavailable chemically for plant uptake. Proper liming of the acid soils together with use of manure has the potential of contributing to an increase of overall yield of maize cultivated in acid soils because of reducing exchangeable acidity and raising pH in acid soils. For example dry matter yield increase of maize from 18.1 to 36.2g per plant has been reported by use of both manure and lime (Kanyanjua *et al.*, 2002). Use of manure and agricultural lime do not only improve soil productivity but also stabilize yields over time and encourages farmers to invest more in maize cultivation. Reduction of acidity in soils also improves the microbial status and hence their activity in soils. Because field studies on such acid soils are usually expensive and time consuming, it is necessary that controlled experiments are carried out first before verification of best treatments

in the field. This is the case in this study because there is little research done in Kenya specifically on acid soils improvement using manure and lime.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Overview

Vast areas of tropical lands that were once fertile have been rendered unproductive due to continuous cultivation and erosion which has caused physical soil degradation, loss of soil organic matter and a decrease in Cation exchange capacity (CEC) as well as increased Al and Mn toxicity (Mba, 2006). It is increasingly evident that declining soil fertility because of acidity is the most widespread, dominant limitation on yields of maize (*Zea mays*) and on the sustainability of maize-based cropping systems in southern and eastern Africa (Kumwenda *et al.*, 1996).

According to Fageria and Baligar (2008), soil acidity produces complex interactions of plant growth-limiting factors involving physical, chemical, and biological properties of soil. Soil erosion and low water-holding capacity are major physical constraints for growing crops on tropical soils. Calcium, magnesium, and phosphorous deficiencies or unavailability, and aluminium toxicity are considered major chemical constraints that limit plant growth on acid soils. Among biological properties, activities of beneficial microorganisms are adversely affected by soil acidity, which has profound effects on the decomposition of organic matter, nutrient mineralization, and immobilization, uptake and utilization by plants, and consequently on crop yields (Fageria and Baligar, 2008).

Acid soils are highly weathered and contain large quantities of Al and Fe hydrous oxides that have the ability to adsorb major elements onto their surfaces such that much of added nutrients are fixed instead of being made available for crop

use (Akinrinade *et al.*, 2006). Soils, especially, in the humid tropics, become acidic when basic cations are removed through leaching, plant uptake and plant harvest (Wild, 1993). Addition of acid and acid forming chemicals like ammonium compounds through nitrification process, and microbial production of organic acids (Wild, 1993) are other factors that lead to the development of soil acidity. Soils tend to become acidic as a result of: (1) rainwater leaching basic ions (calcium, magnesium, potassium and sodium); (2) carbon dioxide from decomposing organic matter and root respiration dissolving in soil water to form a weak organic acid; (3) formation of strong organic and inorganic acids, such as nitric and sulphuric acid, from decaying organic matter and oxidation of ammonium and sulphur fertilizers (Donald, 2011).

According to Chude *et al.*, (2005), soils with pH values of less than 5.5 are considered as acidic. Soil acidity, the domain of H^+ and Al^{3+} cations in the soil solution, as reflected in soil pH levels generally below 5, is widespread in the highly weathered and leached soils of the humid tropics (Gachene and Kimaru, 2003).

2.2 Soil exchangeable acidity (Hp)

Soil exchangeable acidity is the total amount of the Cation Exchange Capacity (CEC) of a soil that is due to H^+ and Al^{3+} ions (FAO, 1995). It indicates soil disturbances due to high Al concentrations (which are toxic to plants and soil organisms). Exchangeable acidity is measured only if the pH value drops under 7 because only then does the concentration of exchangeable H^+ and Al^{3+} ions becomes significant. Soil exchange acidity does not vary much under natural conditions. Abrupt changes may however be found after land use changes (e.g. deforestation,

liming etc.), and such changes are used for monitoring land use changes (FAO, 1995). Frequent measurements of soil exchange acidity may be conducted if land use changes have been detected in order to evaluate its effect on soil properties.

In acid soils, biological activities decline, soil aggregation becomes poorer and availability of nutrients to plants is affected. These soils usually have low contents of calcium and magnesium, and in extreme conditions, the supply of these nutrients to plants may be deficient (Wild, 1993). The most common problem in acid soils is however, the toxicity of aluminium (Al^{3+}) to plants, and for some species the toxicity of manganese (Mn^{2+}) (Nekesa *et al.*, 2005). Acid soils are also associated with Phosphorous fixation because of increased iron, aluminium and manganese in the soils. All these factors contribute to severe reduction of maize crop yields (Nekesa *et al.*, 2005).

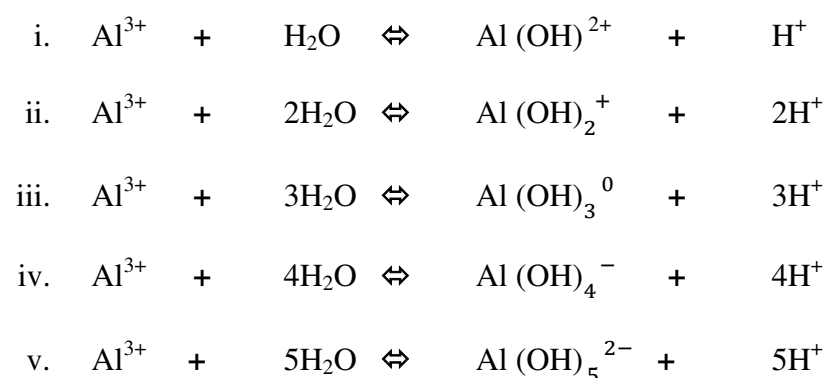
2.3 Chemical explanation of how soil acidity develops.

Theoretically, soil acidity is quantified on the basis of hydrogen (H^+) and aluminum (Al^{3+}) concentrations of soils (Fageria and Baligar, 2008). For crop production, however, soil acidity is a complex of numerous factors involving nutrient/element deficiencies and toxicities, low activities of beneficial microorganisms, and reduced plant root growth which limits absorption of nutrients and water (Fageria and Baligar, 2003a). In addition, acid soils have low water-holding capacity and are subject to compaction and soil erosion (Fageria and Baligar, 2003a). Various publications have thoroughly discussed the complex components of the soil acidity (Kamprath and Foy, 1985; Tang and Rengel, 2003).

Soils become acidic for several reasons. The most common source of hydrogen is the reaction of aluminum ions with water. According to Fageria and Baligar (2008), the equation for this reaction in very acid soils (pH < 4.0) is:



The species of aluminum ions present vary with pH. Potassium chloride extracted Al and Al saturation has an inverse relationship with pH (Kariuki *et al.*, 2007). Increased soil acidity causes solubilization of Al, which is the primary source of toxicity to plants at pH below 5.5 (Bohn *et al.*, 2001; Ernani *et al.*, 2002; Kariuki *et al.*, 2007). The forms of aluminum are mostly exchangeable Al^{3+} under very acidic conditions (pH < 4.5) to aluminum-hydroxyl ions at higher pH (4.5–6.5) (Carson and Dixon, 1979). In general, the net positive charges of the hydroxyl aluminum species decreases as the pH increase and then becomes negative in the alkaline pH range. The species of aluminum ions generate hydrogen ions through a series of hydrolysis reactions as shown in the following equations by Lindsay (1979):



The exchangeable Al^{3+} precipitates as insoluble Al hydroxyl species as the pH increases and is reported to decrease 1000-fold for each unit increase in pH (Lindsay, 1979). However, at pH values greater than 6.5, Al becomes increasingly soluble as negatively charged aluminates form (Haynes, 1984).

The $\text{Al}(\text{OH})_2^+$ species is of minor importance and exists over only a narrow pH range. The Al^{3+} ions are predominant below pH 4.7 while $\text{Al}(\text{OH})_2^+$ ions are between pH 4.7 and pH 6.5, $\text{Al}(\text{OH})_3^0$ ions between pH 6.5 and pH 8.0, and $\text{Al}(\text{OH})_4^-$ ions above pH 8.0. $\text{Al}(\text{OH})_5^{2-}$ species occurs at pH values above those usually found in soils (Bohn et al., 2001).

Soils become acidic due to the parent material being acidic and naturally low in the basic cations such as Ca^{2+} , Mg^{2+} , K^+ , and Na^+ or due to leaching of these elements down the soil profile by excess rains. This situation is common in high rainfall areas, where precipitation exceeds evaporation, and leads to leaching. Soil acidity may also be produced by long-term use of ammonium fertilizers, removal of cations in the harvested portion of crops and leaching process, and release of organic acids in decomposition of crop residues and added organic wastes (Sparks, 2003).

Use of adequate amounts of nitrogen fertilizer is fundamental for higher yield of crops under all ecosystems. Urea and ammonium sulphate are dominant nitrogen carriers used for crop production around the world. The acidification of soils by using the ammonium form of nitrogen fertilizers can be explained by the following equation:



The oxidation of NH_4 in the above equation is known as nitrification and heterotrophic and autotrophic bacterias can carry it out. The most important autotrophic genera of bacteria are *Nitrosomonas* and *Nitrobacter* (Sparks, 2003).

2.4 Farming practices that contribute to soil acidity

Use of legume crops continuously or in rotation can increase soil acidity. Bolan and Hedley, (2003) found that continuous cultivation of legume crops decreased the pH of agricultural soils. Other researchers have found that legume based pastures also increases soil acidification (Williams, 1980). Williams (1980) reported that even the normal growth of clover pasture for 50 years decreased the pH of an Australian soil from 6.0 to 5.0 at a depth of 30 cm. Legumes also increase soil acidification in arable cropping systems due to their high absorption of basic cations and the release of H^+ ions by the roots to maintain ionic balance (Bolan and Hedley, 2003). According to these authors, for different legume species, about 0.2–0.7 mole of H^+ were released per mole N_2 fixed. In addition, they state that the amount of H^+ ions released during N_2 fixation is really a function of carbon assimilation and hence depends mainly on the form and amount of amino acids and organic acids synthesized within the plants. Soil acidification is also caused by the release of protons (H^+) during the transformation and cycling of carbon, nitrogen, and sulfur in the soil–plant–animal system (Bolan and Hedley, 2003).

2.5 Impact of soil acidity to root development and soil microorganisms

Soil microbiological properties can serve as soil quality indicators because soil microorganisms are the second most important (after plants) biological agents in the agricultural ecosystem (Fageria, 2002; Yakovchenko *et al.*, 1996). Soil microorganisms provide the primary driving force for many chemical and biochemical processes and thus affect nutrient cycling, soil fertility, and carbon cycling (He *et al.*, 2003). Plant roots and rhizosphere are colonized by many plant-

beneficial microorganisms such as symbiotic and non-symbiotic nitrogen (N₂) fixing bacteria; plant growth promoting rhizobacteria, saprophytic microorganisms, bio-control agents, and mycorrhizae and free-living fungi. Soil acidity restricts the activities of these beneficial microorganisms, except fungi, which grow well over a wide range of soil pH (Brady and Weil, 2002).

Acid soils affect plants in several ways. For instance, Al prevents plant root elongation due to its direct effect on metabolism or indirectly by rendering the phosphate in the soil unavailable by binding it to form aluminium phosphates thereby leading to overall low crop yields (Mora *et al.*, 2005). Plant species and varieties differ, in their sensitivity to the conditions in acid soils (Wild, 1993). Maize lies in the medium tolerance range and would do well in the 5.5-6.0 pH range. Among the maize varieties, local cultivars like *Githigu* found in Central Kenya, are adapted to the lower end of the tolerance range (Kanyanjua *et al.*, 2002).

Acidity produces complex interactions of plant growth-limiting factors involving physical, chemical, and biological properties of soil. Among biological properties, activities of beneficial microorganisms are adversely affected by soil acidity, which has profound effects on the decomposition of organic matter, nutrient mineralization, and immobilization, uptake and utilization by plants, and consequently on crop yields (Huber, 2006). Soil microorganisms especially bacteria and fungi have been shown to be sensitive to organic amendments and lime application (Magdoff, 2001). Organic amendments are known to increase the abundance of various components of the soil food web, including the soil fungal and bacterial communities (Forge *et al.*, 2008).

Recent studies have demonstrated that changes in soil microbial communities across space are often strongly correlated with differences in soil chemistry (Nilsson

et al., 2007; Lauber *et al.*, 2008; Jenkins *et al.*, 2009). In particular, it has been shown that the composition, and in some cases diversity, of soil bacterial communities is often strongly correlated with soil pH (Fierer and Jackson, 2006; Hartman *et al.*, 2008; Lauber *et al.*, 2009). This pattern holds both for overall bacterial community composition (Fierer and Jackson, 2006; Lauber *et al.*, 2009) and for the composition of individual bacterial groups (Jenkins *et al.*, 2009).

Many researchers have proved that many microorganisms in soil produce organic acids like carbonic acids, acetic acids, citric acids, etc. These acids create favorable environment for the enhancement of P solubility and uptake by plants (Sharif *et al.*, 2011). Kucey *et al.*, (1989) have shown from liquid medium studies that the microbial solubilization of soil phosphate has often been due to excretion of organic acids. The availability of Phosphorus for plant uptake can therefore be increased by treatment with mineral acids, organic acids, and a mixture of organic materials, biological treatment, etc. Incorporating organic manures and P materials has been shown to enhance the solubility (Sharif *et al.*, 2011).

2.6 Liming as a soil acidity management strategy

According to Sanchez *et al.*, (1997), soil fertility reduction on the smallholder farms remains the central cause of decline in per capita food production in Africa, a situation that threatens food security. The rising rural poverty and the price fluctuations on fertilizer and other farm inputs has led to decline in capacity of farmers in Sub-Saharan Africa to put through necessary fertility measures (Borlaugh, 2003). Nutrient losses in soils is seen as a drawback towards achievement of food security and therefore needs to be addressed.

Nutrient management is a decision-making process with regard to control of nutrient flows in soils to combine an economically viable agricultural production with minimum nutrient losses (NRCS, 2006). The modern agriculture production requires the implementation of efficient, sustainable, and environmentally sound management practices (Fageria and Baligar, 2008). In this context, liming is an important practice to achieve optimum yields of all crops grown on acid soils. Liming materials are used to neutralise soil acidity (Fenton *et al.*, 1993) as liming is the most widely used long-term method of soil acidity amelioration as its success is well documented (Kaitibie *et al.*, 2002; Scott *et al.*, 2001).

Application of lime at an appropriate rate brings several chemical and biological changes in the soils, which are beneficial or helpful in improving crop yields on acid soils. Adequate liming eliminates soil acidity and toxicity of Al, Mn, and H; improves soil structure (aeration); improves availabilities of Ca, P, Mo, and Mg, and N₂ fixation; and reduces the availabilities of Mn, Zn, Cu, and Fe and leaching loss of cations. For several crops, liming results in some chemical changes in the soil such as, increase in pH, effective cation exchange capacity (ECEC), and exchangeable Ca, decrease in toxic elements for example Al³⁺ and Mn²⁺ and changes in the proportion of basic cations in CEC sites (Ezekiel, 2006).

According to Rasnake *et al.*, (2002), an agricultural liming material, or "Aglime," is a material containing calcium (Ca) and/or magnesium (Mg) compounds capable of neutralizing soil acidity. These materials include limestone (both calcitic and dolomitic), burnt lime, slaked lime, marl, and various by-products. Liming materials are carbonates, oxides, or hydroxides of Ca and/or Mg.

Lime is usually added to acid soils to increase soil pH. Its addition not only replaces hydrogen ions and raises soil pH, thereby eliminating most major problems

associated with acid soils but it also provides two nutrients, calcium, and magnesium to the soil. Lime also makes phosphorus that is added to the soil to be more available for plant growth and increases the availability of nitrogen by hastening the decomposition of organic matter (Donald, 2011). Liming materials are relatively inexpensive, comparatively mild to handle and leave no objectionable residues in the soil. Over-liming, however, can significantly reduce the bioavailability of micronutrients (Zn, Cu, Fe, Mn and B), which decrease with increasing pH (Fageria *et al.*, 2002). This can produce plant nutrient deficiencies, particularly that of Fe which is made available at medium acidic conditions.

2.7 Effect of farmyard manure application on soil acidity

It has been perceived for a long time that animal manure lowers soil pH as some commercial nitrogen fertilizers do (Hailin, 1998). Working on a long-term field and greenhouse studies using animal manure as an ameliorating agent on acid and neutral soils, Hailin (1998) found that soil pH was higher by 0.5 units to a depth of 2 feet under littered soils than in un-littered soils. The main reason why manure raises soil pH is due to the presence of calcium and magnesium elements in it and its buffer capacity because of forming complexes with Al and Fe in acid soils (Tang *et al.*, 2007; Hue *et al.*, 1986). Organic matter has been found to increase the soil's ability to hold and make available essential plant nutrients and to resist the natural tendency of soils to become acidic (Reis and Rodella, 2002). As such, applying manure to acid soils not only supplies the much needed nutrients and organic colloids for plant growth but also reduces soil acidity, thus improving phosphorus availability and reduces aluminium toxicity (Hailin, 1998).

Proton exchange between the soil and manure which contains some phenolic, humic-like material makes it capable of raising soil pH (Tang *et al.*, 2007). Another mechanism that has been proposed to explain the increase in soil pH by such materials as farmyard manure is the specific adsorption of humic material and/or organic acids (products of decomposition) onto hydrous surfaces of Al and Fe oxides by the exchange with corresponding release of OH^- (Hue *et al.*, 1986). Returning organic amendments in form of livestock manures and crop residues to soil could be important in supplying crop nutrients as well as improving soil moisture conditions and increasing availability of P by stimulating microorganisms that solubilize soil P (Fankem *et al.*, 2008).

2.8 Way forward in management of acid soils

Soil acidification is an ongoing natural process which can be enhanced by human activities or can be controlled by appropriate soil management practices (Fageria and Baligar, 2008). Acid soils can be managed in two ways, i.e., either by growing suitable crops for a particular soil pH or by ameliorating the soils through application of amendments, which counteract the soil acidity (Biswas and Mukherjee, 1994). Traditionally, methods used to raise soil pH include; use of mulch from agro-forestry tree species, burning of sites to give ash and use of animal wastes although such materials are not available in the right amounts desired and in most cases, they are too bulky (Woomer *et al.*, 1999). The usual agricultural practice for most crops is to maintain a soil pH of 6.0- 6.5 by the addition of lime, applied as calcium carbonate, calcium hydroxide or calcium oxide. However, in many developing countries, where semi subsistence agriculture prevails, the lack and/or

high cost of lime prevent its use. Under such conditions, alternative means of managing soil acidity need to be developed.

Research has shown that additions of green manures, FYM, and composts to acid soils can reduce Al toxicity and increase crop yields (Tejada *et al.*, (2006). An increase in soil pH and/or complexation of soil-solution Al by decomposition products of organic residues (e.g., organic acid anions and soluble humic materials) have been implicated as the main factors in Al detoxification (Haynes and Mokolobate, 2001). The use of FYM as an ameliorating material has therefore, been advocated as a cheap-input strategy for the management of acid soils (Haynes and Mokolobate, 2001). In addition, manures are a waste product of modern intensive methods of housed animal production and such materials are available to resource-poor farmers who are situated close to intensive animal-production units or in their farm in rural areas. A combination of the organic manures and ground lime ameliorate acidity menace greatly.

For a long time, acid soils have been considered less suitable for productive agriculture. However, the generation of modern technology, through intensive research, has brought forth a new reality of increased productivity of grains and other food, fiber and feed crops, pastures, and energy products on these soils. Borlaugh and Dowsell (1997) concluded that acid lands are no longer a marginal agriculture frontier, but the most extensive agriculture frontier of the world, providing hope for adequate food supply and a better quality of life for millions of people, especially in the tropics. Within the last few decades, significant advances have been made in the management of acid soils of the tropics for improving pasture for cattle raising and increasing productivity of annual and plantation crops (Fageria and Baligar, 2003a;

Sumner and Noble, 2003). However, there's need to develop technologies that are economically viable, environmentally sound, and socially acceptable.

For increase in food supply on acid soils, sustainable cropping systems are essential for agronomic, economic, and environmental reasons. Sustainable crop production is defined as practice that over the long term enhances environmental quality and the resource base on which agriculture depends, provides for basic human food and fiber needs, is economically viable, is socially acceptable, and improves the quality of life for farmers and society as a whole (White *et al.*, 1994).

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study sites

The research was carried out in two phases each running for eight weeks. The first phase was greenhouse pot experiment taking place at Kenyatta University (KU) in the Department of Plant and Microbial Sciences and the field experiment done at Kavutiri in Embu County (Fig. 1). Kavutiri is located in agro-climatic zones I at an altitude of 1700 m above sea level (Jaetzold *et al.*, 2007) on the eastern slopes of Mount Kenya. It is found at latitude 0° 25' S and longitude 37° 30' E with annual mean temperature of 18 °C and mean annual rainfall ranging from 1200 to 1400 mm.

Like other soils around Mt. Kenya, Kavutiri soils are developed on phonolites whose mineralogy consists of orthoclase feldspars, olivine, augite, nepheline and biotite (Wanjogu *et al.*, 2003). These soils are classified as Ando-humic Nitisols (Jaetzold *et al.*, 2007) and are sandy-clay in nature. The soils are characterised by low exchangeable bases, indicated by the low base saturation, estimated at 23.5 % and low percentage content of N of 0.23 % while C is approximated to be 3.25 %. The soils for the greenhouse experiment were obtained from Kavutiri field site.

3.2 Site selection

Kavutiri the soil-sampling site was chosen because not much of acid soil liming related research activities have been conducted. This site was selected following the information from FURP (1991) trials (conducted between 1986 and 1991) which shown very poor performance of maize crop, just like other sites around Mt. Kenya due to high soil acidity (Mochoge, 1992).

Phase one of this study was carried out at Kenyatta University. This site was chosen based on the availability of the greenhouse facility at the institution and that the experiment could be carried out off-season during the January- March dry period. Above all, it was the best approach to have a better understanding of the behaviour of the treatments in a controlled environment in this acid soil. Phase two was carried in a farmer's field at Kavutiri, and only three best performing treatments in Greenhouse were selected for verification in the field.

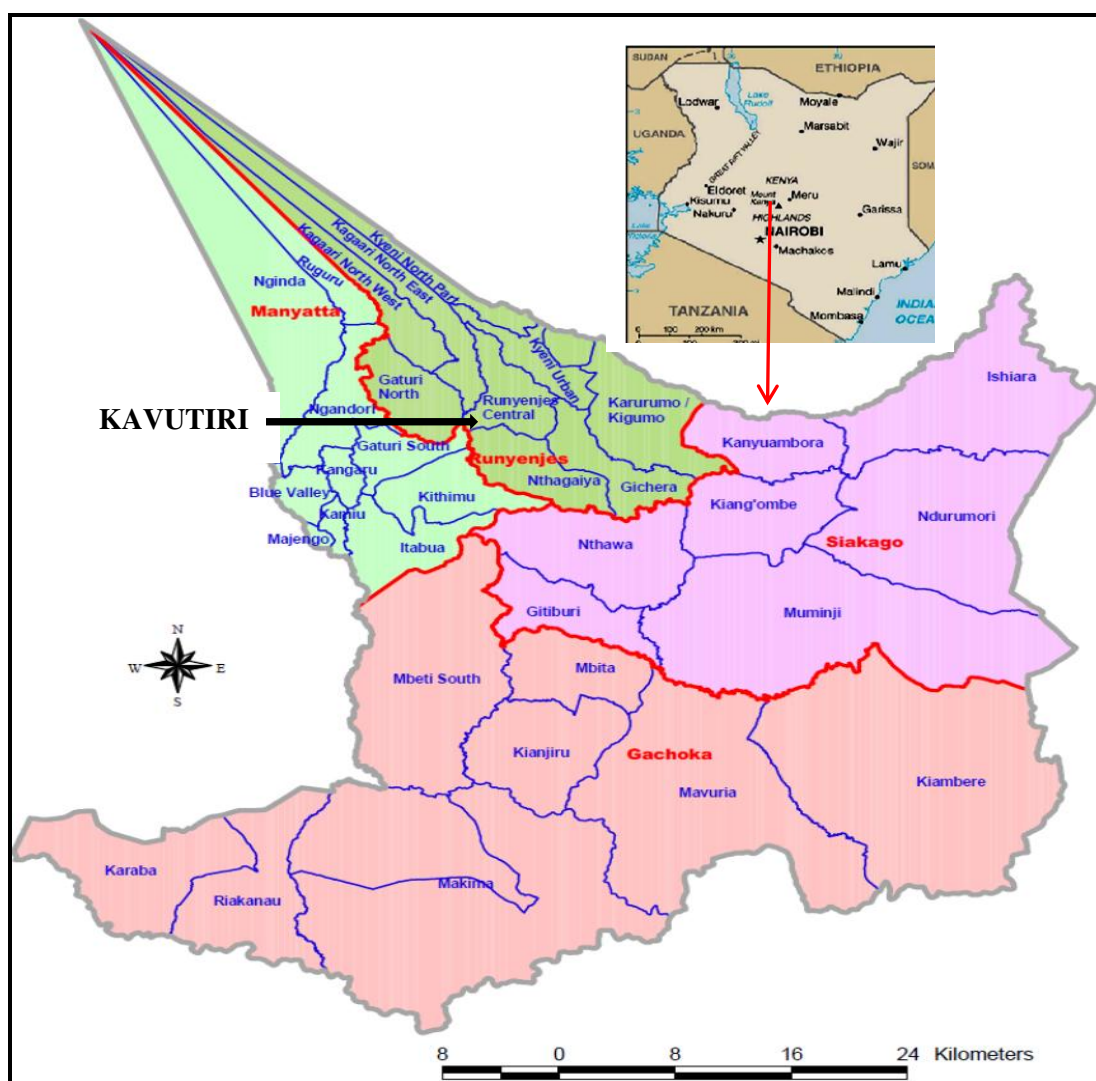


Figure 1: A map of Embu County-Kenya showing the location of Kavutiri- the field study site

3.3 Soil sampling for Greenhouse experiment

Soil sampling for greenhouse experiment and baseline data analysis was done in January 2012 before the planting season at Kavutiri commenced. Soil samples were taken from two profiles to a depth of 20 cm in farmer's field. The two profile samples were then mixed thoroughly and two composite samples derived from them, labelled and packed in cool boxes ready for laboratory analyses. The remaining sampled soil was packed in sacks and transported to Kenyatta University for greenhouse pot experiment.

3.4 Selection and sampling of inputs

The agricultural lime used in this study was sourced from the stockists in Nairobi. It was selected among other lime material due to its availability and affordability in terms of prices (7 US \$ /50 kg bag). Composite samples were taken, packed into labelled sampling papers and taken to laboratory for analysis of CaCO_3 and MgO equivalent. Farmyard manure (FYM), specifically goat manure, was collected from one farmer at Kavutiri where soil sampling was done. Goat manure was selected because of its ample availability at the Kavutiri area and that many farmers in the area use it. The manure was well decomposed for use. Composite samples were taken to the laboratory for analysis.

3.5 Greenhouse Pot Experiments

3.5.1 Design and set up of Greenhouse experiment

Pot experiments were established in January 2012 at the Department of Plant and Microbial Sciences of Kenyatta University. Soil quantities of 4 kg were weighed from the bulk soil sampled from the field and put into each pot.

3.5.2 Treatments and spacing

The treatments included: FYM at three levels (0, 5 and 10 Mg ha⁻¹) and lime at six levels (0, 2.5, 5, 7.5, 10, and 12.5 Mg ha⁻¹) which were added and thoroughly mixed with the soil. The treatment combinations were applied as shown on Table 1 and were replicated thrice. The pot locations in the greenhouse were rotated twice per week to minimize the effect of variations in ambient light and temperature conditions.

Both Phosphorus (TSP) and nitrogen (CAN) fertilizers at the rates of 50 and 70 kg ha⁻¹ respectively were applied as blanket. This was an equivalent of 1.88 and 2.63 g per pot for TSP and CAN, respectively. While TSP was applied at planting, CAN was applied as a topdress at the 4th week after planting. The test crop was maize (*Zea mays* variety H513). Three seeds were sown per pot and thinned to two after emergence.

The pots were arranged in three rows following a Complete Randomised Design (CRD). The spacing between the rows was 0.75 m while between pots in a row was 0.5 m. This was to mimic the field spacing such that one hectare can hold 26,600 pots each with two maize plants (Fig. 2). The crop was watered twice a week. Biomass harvesting and oven drying took place at 4th and 8th weeks after planting.

Table 1: Treatment combination and their actual rates as applied per pot for greenhouse experiment

Treatment code	Treatment Description	Actual amount applied pot ⁻¹ (g)	
		<u>Manure</u>	<u>Lime</u>
M ₀ L ₀	Control (No Manure & Lime)	0	0
M ₀ L _{2.5}	Manure (0 Mg ha ⁻¹) + Lime (2.5 Mg ha ⁻¹)	0	10.0
M ₀ L ₅	Manure (0 Mg ha ⁻¹) + Lime (5.0 Mg ha ⁻¹)	0	20.0
M ₀ L _{7.5}	Manure (0 Mg ha ⁻¹) + Lime (7.5 Mg ha ⁻¹)	0	30.0
M ₀ L ₁₀	Manure (0 Mg ha ⁻¹) + Lime (10.0 Mg ha ⁻¹)	0	40.0
M ₀ L _{12.5}	Manure (0 Mg ha ⁻¹) + Lime (12.5 Mg ha ⁻¹)	0	50.0
M ₅ L ₀	Manure (5 Mg ha ⁻¹) + Lime (0 Mg ha ⁻¹)	188	0
M ₅ L _{2.5}	Manure (5 Mg ha ⁻¹) + Lime (2.5 Mg ha ⁻¹)	188	10.0
M ₅ L ₅	Manure (5 Mg ha ⁻¹) + Lime (5.0 Mg ha ⁻¹)	188	20.0
M ₅ L _{7.5}	Manure (5 Mg ha ⁻¹) + Lime (7.5 Mg ha ⁻¹)	188	30.0
M ₅ L ₁₀	Manure (5 Mg ha ⁻¹) + Lime (10.0 Mg ha ⁻¹)	188	40.0
M ₅ L _{12.5}	Manure (5 Mg ha ⁻¹) + Lime (12.5 Mg ha ⁻¹)	188	50.0
M ₁₀ L ₀	Manure (10 Mg ha ⁻¹) + Lime (0 Mg ha ⁻¹)	376	0
M ₁₀ L _{2.5}	Manure (10 Mg ha ⁻¹) + Lime (2.5 Mg ha ⁻¹)	376	10.0
M ₁₀ L ₅	Manure (10 Mg ha ⁻¹) + Lime (5.0 Mg ha ⁻¹)	376	20.0
M ₁₀ L _{7.5}	Manure (10 Mg ha ⁻¹) + Lime (7.5 Mg ha ⁻¹)	376	30.0
M ₁₀ L ₁₀	Manure (10 Mg ha ⁻¹) + Lime (10.0 Mg ha ⁻¹)	376	40.0
M ₁₀ L _{12.5}	Manure (10 Mg ha ⁻¹) + Lime (12.5 Mg ha ⁻¹)	376	50.0

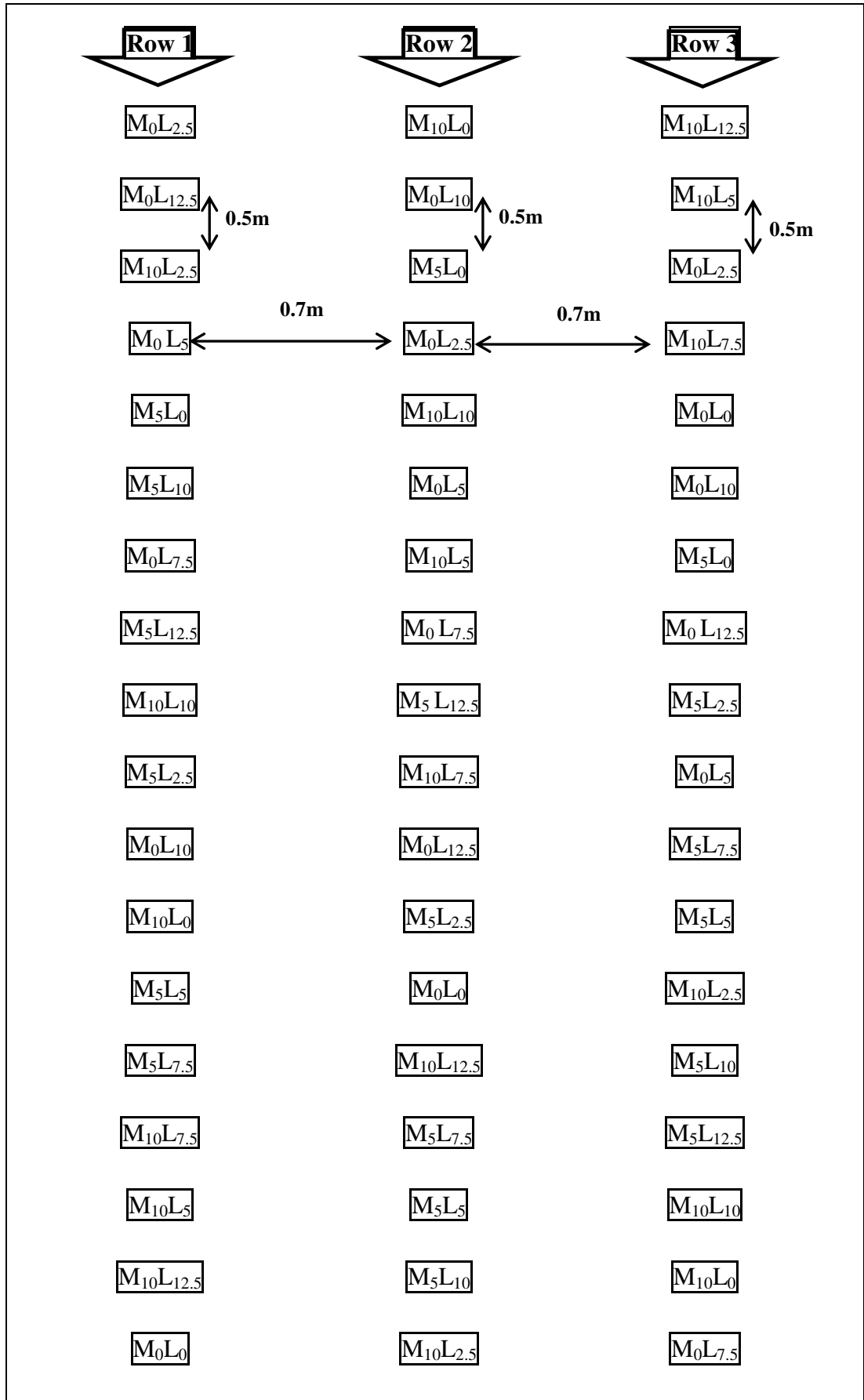


Figure 2: Schematic layout of pot treatments for the greenhouse experiment.

3.5.3 Greenhouse Data Collection and Analyses

Plant tissues sampling for the Greenhouse experiment was done at 4th and 8th week after planting (WAP). One plant per pot was randomly selected and harvested at the 4th week after planting while the remaining one at the 8th week. The plant height was measured from the soil level to the tip of the youngest leaf. At 8th week harvest, the roots were retrieved from the pot by splitting the pot open and soil carefully separated from the fibrous roots. The bare roots were then placed on a table and their lengths measured. The roots average lengths were measured from the main stocks up to the tips and recorded in centimetres. Finally, all the shoots and roots materials of each pot separately were chopped into small pieces, placed in sampling brown paper bags and oven dried at 50 °C for 48 hours. Their dry weight were recorded in grams per pot and converted to kg/ha by multiplying by 53200 (total No. of maize plants per ha).

3.6 The Field Experiments

3.6.1 Design and set up

The field experiment was designed and managed by the researcher and assisted by the farmer. It was conducted during the March –June 2012 long rains on the same farm where soil sampling for the greenhouse experiment was carried out. The objective was to verify the outstanding good results from greenhouse studies, under the real farmer's conditions in the field. However, according to Coe (2002) and Mugwe (2007), there can be high variability in management among farmers, which is known to mask treatment performance, and therefore control of some factors is recommended for providing appropriate biophysical data.

To control variability between greenhouse and field data, similar inputs were used as those of greenhouse experiment. In addition, experimental set up, treatment application and planting was done by both researcher and the farmer. The farmer carried out all other agronomic practices like weeding and thinning in consultation with the researcher. However, all data collection was exclusively done by the researcher. Three out of the 18 best performing treatment combinations ($M_{10}L_{7.5}$, $M_{10}L_{10}$ and $M_{10}L_{12.5}$) were evaluated on farmer's field in a complete randomised block design (CRBD) with three replicates per treatment for precision (Fig. 3). The plots measured 4.5 x 4.0 m with a 1.5 m path between the plots. A control plot was included as well and the maize took eight weeks just as the period taken in the greenhouse for comparison purposes.

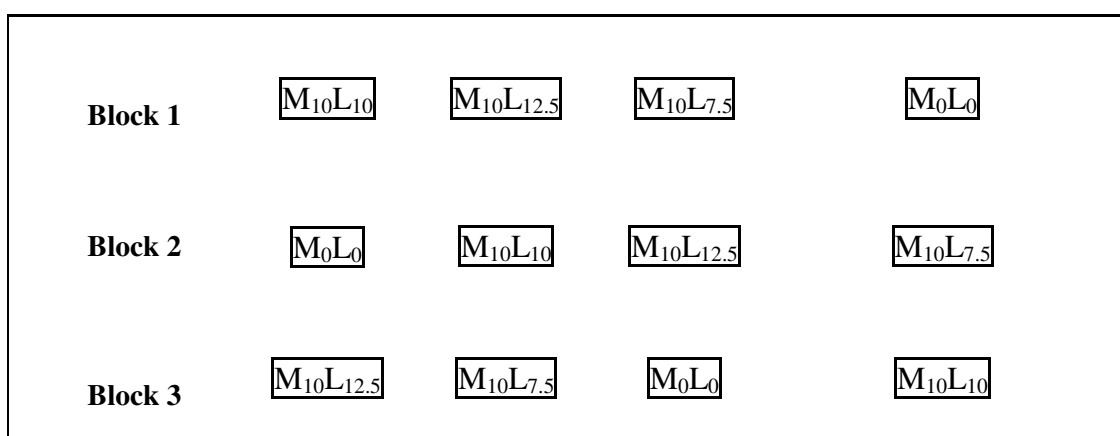


Figure 3: Schematic Layout of the treatments for field experiment at Kavutiri-Embu County.

3.6.2 Land preparation, planting and inputs application

Land was prepared by hand hoeing to satisfactory tilth in February 2012 before onset of long rain. Well decomposed FYM and TSP at the rates of 376 and 1.88 g hole⁻¹, respectively, were added then mixed thoroughly with top soil. Lime was

incorporated to a depth of 0.2 m in a 0.3m wide band along the planting line at the rates of 7.5, 10.0 and 12.5 Mg ha⁻¹ for M₁₀L_{7.5}, M₁₀L₁₀ and M₁₀L_{12.5} treatments, respectively. This was equivalent to 0.75, 1.0 and 1.25 kg m⁻² for M₁₀L_{7.5}, M₁₀L₁₀ and M₁₀L_{12.5} per plot, respectively. Planting holes at a spacing of 0.75 m and 0.5 m for inter and intra-row, respectively, were dug on the lime incorporated band (there were 48 holes per plot). At the onset of the March-June 2012 long rains, three maize (variety H513) seeds were planted per hole after which thinning was done to two a week after germination. Top-dressing with CAN was carried out at the 4th week after sowing.

3.6.3 Sampling and data collection

Initial soil sampling had been done in January 2012 before the greenhouse experiment was established and the soil analyses done. The last soil sampling was carried out in May 2012 at the end of field experiment. In the field experiment, twenty-four (24) holes were selected for samples collection leaving out one row on each side of the plot and the first two hills from either side of the rows to minimise the edge effect. From the 24 holes, a sub-sample of eight was selected at random. Growth parameters were determined from these sampled plants as explained in section 3.5.3

All the data from the eight-planted holes in the field experiment was averaged per plant. In addition, the biomass DM data was further converted to kg per hectare using the formula below.

$$DMWha^{-1} (Kg) = \frac{H \text{ ha}^{-1} \times 2 \times N}{8 \times 1000}$$

Where:

DMWha ⁻¹ (Kg)	= Oven dry weight of biomass ha ⁻¹
H ha ⁻¹	= No. of planting holes ha ⁻¹ at a spacing of 0.75 m by 0.5 m (=26600)
2	= Number of maize plant per hole.
N	= Weight in g of DM from 8 randomly selected plants per plot.
8	= No. of plants randomly selected per plot.
1000	= A factor incorporated to convert g plot ⁻¹ of DM into Kg ha ⁻¹

3.7 Laboratory analysis

Soil, lime and FYM samples were analysed in the laboratory. The soil samples were air dried until a constant weight was obtained, after which they were ground and passed through 2 mm sieve and stored in plastic bags (5 × 7 cm) awaiting analysis. The various analytical procedures employed are described in the sections which follow.

3.7.1 Soil pH determination

Soil pH was measured in a 1:2 (soil: water) ratio using a glass electrode pH meter. Approximately 10 g of soil were weighed into a 60 ml plastic shaking bottles and 20 ml of deionised water was added to the soil with a dispenser. The soil-water solution was shaken thoroughly for 10 minutes after which the suspension was allowed to stand for 20 minutes then re-stirred for another two minutes. The mixture was allowed to settle for 30 seconds before the calibrated pH meter was used to read the pH by immersing the electrode into the upper part of the soil suspension and the

pH values recorded. The glass electrode was then removed from the bottle and rinsed ready for another sample pH reading.

3.7.2 Exchangeable acidity (Hp)

Two and half grams (2.5 g) of soil was weighed and placed in a 60 ml bottle. 25 ml of 1N potassium Chloride was added using a multiple dispenser, stirred for about 10 minutes and then allowed to settle for another 20 minutes after which it was filtered using a whatman No. 5 filter paper. 10 ml of the filtrate was taken and transferred into a 60 ml bottle to where 15 ml of deionised water and 2 drops of phenolphthalein indicator were added. The solution was then titrated with standardized sodium hydroxide until a pale colour appeared persistently for 30 seconds. The volume of NaOH used was recorded. The Hp was then calculated using the formula below:

$$\text{Exchangeable Acidity (me/100 g soil)} = \frac{\text{TVS} - \text{TVB (NNaOH)}}{0.01}$$

Where: TVS = Titration volume for the sample (ml)

TVB = Titration volume for the blank (ml)

NNaOH = Normality of NaOH

3.7.3 Organic Carbon

The modified Walkley-Black method (Nelson and Sommers, 1982) was used in determination of soil organic carbon. Approximately 1.0 g of finely ground air-dried soil was weighed into a clean, dry 250 ml Erlenmeyer flask and 2 ml of water added. A reference sample and a blank were also run. The procedure involved a wet combustion of the organic matter with a mixture of potassium dichromate and

sulphuric acid. After the reaction, the excess dichromate was titrated against ferrous sulphate. A 10 ml of 5 % potassium dichromate ($K_2Cr_2O_7$) solution was accurately dispensed into the flask after which it was swirled gently to form a uniform mixture. Then 20 ml of concentrated sulphuric acid (H_2SO_4) was added slowly into the soil suspension. The mixture was digested at $150^\circ C$ for 30 minutes and then allowed to cool. After cooling, 100 ml of distilled water was added and mixed well. 10 ml of ortho-phosphoric acid and 1 ml of diphenylamine indicator were added. Titration was done using ferrous sulphate ($FeSO_4$) drop-wise from a burette until the solution turned dark green as end-point from an initial purple colour. The volume of $FeSO_4$ solution used was recorded and organic C calculated as shown in the formula below:

$$\text{Soil \% C} = \frac{(V_S - V_B) \times M\text{-}FeSO_4 \times 0.39}{WD\text{-}ODSS}$$

Where:

V_S = volume (ml) of the standard H_2SO_4 used in titrating the sample

V_B = volume (ml) of the standard H_2SO_4 used in titrating the blank

$M\text{-}FeSO_4$ = Molarity of $FeSO_4$ solution

$WD\text{-}ODSS$ = Weight (g) of the digested oven-dried soil sample

0.39 = $3 \times 10^{-3} \times 1.3 \times 100$, where; 3 is the equivalent weight of C and 1.3 is a compensation factor for incomplete oxidation of organic carbon.

3.7.4 Total Nitrogen

About 2 g of soil was weighed into Kjeldahl digestion tubes and 5 ml of distilled water added. After 30 minutes, 0.5 g of selenium (catalyst) and 5 ml of concentrated H_2SO_4 were added to the soil in the tubes then left to stand overnight. The tubes were then placed into block digester and heated initially gently but later vigorously at $300^\circ C$ for at least 3 hours. The tubes were removed and then allowed to cool. About 30

ml of deionised water was added to the digested material and transferred into 100 ml distillation tube and the solution made up to 75 ml mark then allowed to settle. A 10 ml aliquot of the digest was taken and transferred into distillation flask where 10 ml of 40 % NaOH and 10 ml of distilled water were added after which the mixture was distilled using distillation apparatus. The digest was distilled for 4 minutes and the distillate collected in a conical flask containing 20 ml of 4 % boric acid (H_3BO_3).

In order to take care of the traces of nitrogen in the reagents as well as the water used, a blank distillation and titration was carried out. After distillation, the colour changed from pink to green, after which the content of the flask was titrated with 0.005M H_2SO_4 from a burette. At the end-point when the solution changed from weak green to pink the volume of 0.005M H_2SO_4 used was recorded and percentage N calculated as shown in the following formula:

$$\text{The soil \% N} = \frac{(V_S - V_B) \times M\text{-H}_2\text{SO}_4 \times 1.401}{\text{WD-ODSS}}$$

Where:

V_S = volume (ml) of the standard H_2SO_4 used in titrating the sample

V_B = volume (ml) of the standard H_2SO_4 used in titrating the blank

$M\text{-H}_2\text{SO}_4$ = Molarity of standard H_2SO_4

WD-ODSS = Weight (g) of the digested oven-dried soil sample

3.7.5 Exchangeable bases (K, Na, Ca and Mg) and extractable P

The soil exchangeable bases and available P were extracted using Mehlich-3 (M-3) procedures (Mehlich, 1984; Bolland *et al.*, 2003). Approximately 3 g of air-dried soil, ground and passed through 2 mm sieve was weighed into 125 ml

Erlenmeyer flasks and 30 ml of M-3 extraction solution at a ratio of 1:1 (soil: solution) was added. The flask was then corked and shaken on a reciprocating shaker (120-oscillation min⁻¹) for 5 minutes. The suspension was then filtered into a plastic bottle using Whatman filter paper No. 42 that had been rinsed in M-3 extractant. Analysis of the elements was done using a flame Spectrophotometer (Kalra and Maynard, 1991).

3.7.6 Enumeration of bacteria and fungi populations

The dilution and spread plate technique (Thatcher and Clark, 1968) was used to enumerate the number of colonies. In this method, the focus is on the number of colonies rather than the actual number of bacteria/fungi cells. It was therefore assumed that each viable bacteria/ fungi cell in the suspension formed an individual colony (Rangaswami, 1988). One gram of the soil sample from each treatment was suspended in 10 ml of sterilized distilled water. One ml of the soil suspension was then taken and diluted serially (ten-fold). The serial dilution was used in the estimation of microbial population of bacteria and fungi using nutrient agar and potato dextrose agar (PDA) amended with tetracycline (antibiotic), respectively (Kuster and Williams, 1964). Dilution was done up to 10⁵ for bacteria and 10⁴ for fungi .0.1 ml aliquots of the diluted solution were aseptically transferred using a micropipette to the respective sterile culture plates with enrichment media and spread evenly with a sterile bent glass rod.

Media was prepared according to the composition and sterilized in autoclave for 20 minutes. Incubation of the bacterial plates was done at 37 °C for 18 hours and at 25 °C for 5 days for fungal plates. After the incubation period, the colony forming units (CFU) were counted using a colony counter and expressed as CFU g⁻¹ of soil

with consideration given only to the plates that had between 30-300 colonies. Colony forming units, usually abbreviated as CFU, refers to a mass of individual cells of same organism, growing together. It is used as a measure of the number of microorganisms present in or on surface of a sample. The following formula was used for the determination of CFU:

$$\text{CFU/ g of soil} = Cc \times Df \times 10$$

Where:

Cc = Number of colonies counted per plate

Df = Reciprocal of the dilution factor of the tube from which 0.1 ml of the diluent was taken.

10 = Multiplication factor for changing CFU/ml into CFU/ g of soil.

3.7.7 Particle size analysis

Hydrometer or Bouyoucos method as outlined by Okalebo *et al.*, (2002), was used in determination of percentage content of sand, silt and clay. 50 g of air-dried soil that had been passed through a 2-mm sieve was weighed and transferred to a 'milkshake' mix cup. Fifty ml of sodium hexameta-phosphate solution and 5 ml of sodium peroxide were added to disperse the soil particles and to destroy organic matter content. The sample was allowed to settle for 30 minutes. The resultant soil suspension was stirred using a multi-mix machine. The suspension was then transferred from the cup to the glass-measuring cylinder. With the hydrometer in the suspension, distilled water was added to the lower blue line mark making the volume rise to 1130 ml and then the hydrometer was removed.

The cylinder was then covered with a tight-fitting rubber band and swirled several times until the suspension was thoroughly mixed. The cylinder was then placed on a bench, time noted after which the soil hydrometer was immediately placed into the soil suspension slowly until it floated. First hydrometer reading was then taken and temperature recorded using a thermometer. After the first hydrometer reading, the suspension was left to stand for 3 hours then a second reading was taken. The first reading measured the percentage of silt while the second one indicated the percentage of 2-micron (total) clay in the suspension.

The temperature readings were converted from degrees centigrade ($^{\circ}\text{C}$) to Fahrenheit scale. For every temperature over 68°C , there was an addition of 0.2 to the hydrometer reading before computation while that for those below 68°C , 0.2 was subtracted to compensate for the added dispersing agent. The suspension was sieved through a 300-mesh sieve to remove sand then dried in the oven at 100°C and sifted to remove any remaining silt before weighing to get the percentage of sand in the soil.

3.7.8 Determination of Calcium Carbonate (CaCO_3) equivalent as lime material

The standard method of analyzing CaCO_3 equivalent as described by Ryan *et al.*, (2001) was used. It involves treating the sample with dilute hydrochloric acid and the residual acid (not used by carbonate) is titrated against sodium hydroxide using phenolphthalein indicator. Exactly 1.0 g of the agricultural lime was weighed and transferred into a 250-ml Erlenmeyer flask and 25 ml of 1.0 N HCl added using a pipette. The suspension was swirled to mix and then the mixture was heated almost to boiling point on a hot plate after which the flask was placed on a steam bath for 30

seconds to complete the reaction to dissolve all of the lime that would be dissolved with dilute acid. Dilution was done using distilled water to 100 ml and boiling done for a minute. The sample was then cooled to room temperature, 5 drops of 1% phenolphthalein indicator added and back titrated with 1.0 N NaOH to a pink colour which persisted for at least 15 seconds upon mixing while swirling. Determinations of the calcium carbonate equivalence of the sample were calculated as follows:

$$\% \text{ CaCO}_3 \text{ equivalent} = \frac{(V - T) \times 5 \times 100}{S}$$

Where:

V = ml of HCl originally added

T = ml of NaOH added

S = the lime sample weight in grams

3.7.9 Dry ashing method for determining manure's P, K, Na, Ca and Mg content

The FYM samples were air dried until a constant weight was obtained, after which they were ground and passed through 2 mm sieve and analysed for P, K, Na, Ca and Mg using the dry ashing method as explained by Kalra and Maynard (1991). Crucibles were heated on a hot plate after being washed in 10 % nitric acid (HNO₃) and dried in an oven at a temperature of 80 °C to ensure cleanliness. Approximately 0.5 g of manure samples were weighed into 30 ml crucibles and then transferred into a muffle furnace. The temperature was gradually increased to 500 °C and then maintained constant for 6 hours until a whitish-grey ash was obtained. The crucibles were then removed from the furnace and the samples moistened with a few drops of water followed by 3 ml of 5M hydrochloric acid (HCl) and allowed to settle after which 0.25 ml of concentrated HNO₃ was added.

The crucibles with the samples were then placed on a hot plate set at 80 °C and heated for one hour raising the temperature gradually to 100 °C to completely precipitate any silica present and solubilize the phosphates. The residues were allowed to cool and then moistened. Three ml of 5N HCl was added, covered and warmed gently for 2 minutes. Ten ml of water was added and the residues heated gently to allow dissolution of salts. The residues were then washed into 50 ml volumetric flasks filtering through a 90 mm Whatman No. 42 filter paper, cooled and diluted to the mark with water. The filtrate was then analysed using automated colorimetry method ICP-AES (Kalra and Maynard, 1991). The potential hydrogen (pH), organic carbon (C) total nitrogen (N) and lime's MgO equivalent were analysed as explained in sections 3.3.1, 3.3.3, 3.3.7, and 3.3.8 respectively.

3.8 Data management and statistical analysis

The biophysical data obtained in this study (biomass yield, plant height, root length, microbial density, soil pH and Hp) was entered into excel spread sheet and subjected to analysis of variance (ANOVA) using GenStat Release 13.3 (PC/Windows 7) statistical software (Genstat, 2010). The data was tested for normality then subjected to ANOVA to separate the treatment means found to be significantly different from each other using least significant difference (LSD) at $p < 0.05$. (Buysse *et al.*, 2004)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Chapter's overview

This chapter presents the findings of the study in four major sections. The first section (4.2) presents the characterisation results of the soil, farmyard manure and lime prior to experimental set up. Section (4.3) presents the results of the effects of manure and lime application on soil pH and Hp. The third section (4.4) reports on the effect of treatments on maize growth (on root length, plant height and biomass production). The last section 4.5 present data on soil bacteria and fungi population density as influenced by treatments in both the greenhouse and the field.

4.2 Soil, manure and lime analytical properties

4.2.1 Initial soil characterization

Initial soil characterizations on selected parameters from the study site are presented in Table 2. In general, the soil was a sandy-clay in textural class with small variations in the chemical soil characteristics of the two samples. The soils were found to have an average pH (water) of 4.21 and a very high exchangeable acidity (2.7 me %). According to Chude *et al*, (2005), soils with pH values of less than 5.50 are considered acidic. Bases were quite low (less than 2 me %) except for Ca that was relatively high (3.6 me %). Total nitrogen and organic carbon averaged 0.135 and 1.5 %, respectively. The extractable (available) P was very low (1.15 Mg kg⁻¹). Soil fauna (bacteria and fungi) density was also quite low estimated at 2.6 x 10⁵ and 4.3 x 10³ colonies/g of soil for bacteria and fungi, respectively.

Table 2: Initial soil physical and bio-chemical properties of Kavutiri soils (at the surface 0 -0.2 m)

Parameter	Sample 1	Sample 2	Mean
pH _(water) (1 :2)	4.12	4.30	4.21
Exchangeable acidity (me %)	2.8	2.6	2.7
Extractable P (Mg kg ⁻¹)	1.09	1.21	1.15
Exchangeable K (me %)	0.6	0.5	0.55
Exchangeable Na (me %)	0.4	0.6	0.5
Exchangeable Ca (me %)	3.6	3.0	3.3
Exchangeable Mg (me %)	1.2	0.9	1.05
Base saturation (%)	24	23	23.5
CEC (me %)	23.6	23.2	23.4
Total N (%)	0.13	0.14	0.135
Organic C (%)	1.4	1.6	1.5
Sand %	48	49	48.5
Silt %	8	7	7.5
Clay %	44	41	42.5
Texture class	SC	SC	SC
Bacteria Density (CFU/g of soil)	3.0 x 10 ⁵	2.2 x 10 ⁵	2.6 x 10 ⁵
Fungi Density (CFU/ g of soil)	4.5 x 10 ³	4.1 x 10 ³	4.3 x 10 ³

Key: SC= Sandy Clay; CFU= Colony forming units; Sample 1 was taken from previously maize planted plot and sample 2 close to tea plantation.

The high acidity reported here agree with the findings of Kanyanjua *et al.*, (2002) and Mugwe (2007) who reported low soil pH (< 4.5) values and high Al saturation (70 %) in some soils of the humid highlands of Kenya. The main cause of acidity is the loss of exchangeable bases through leaching from the top soil and is replaced with Al ions (Gachene and Kimaru 2003). Therefore, under very acidic conditions, the soil solution is occupied mostly by aluminium and hydrogen ions. This has a direct effect on crop growth by suppressing the root development and reducing availability of macronutrients to plants especially phosphorus, which is readily available under medium pH range (Brady and Weil, 2002). Okalebo *et al.*, (2003) and Khan *et al.*, (2009) reported that high aluminium content and acidity in soil could contribute to low amounts of macronutrients such as P. This happens through precipitation of the element into insoluble compounds hence rendering it unavailable to the crops.

The soil's total organic carbon (TOC) and total nitrogen (TN) were also found to below average that is 1.5 % and 0.135 %, respectively (Table 2). These values are critical because N in most cases is required in large quantities for plant growth. The capacity of the soil to supply N to plants is intimately linked to the amount and the nature of soil organic matter which is partly the source of available N in the soil (Giller *et al.*, 2006). Since the Kavutiri soils are low in both organic matter and nitrogen, supplementation with mineral fertilizers, manure or other organic residues is necessary to ensure reasonable crop yields.

Like nitrogen, phosphorus (P) was also found to be very low (1.15 Mg kg^{-1}) which could drastically affect crop production as P is a major plant nutrient needed for numerous plant metabolic processes. It plays a great role in crop maturation and root development. Micheni *et al.*, (2003) and Mugwe (2007) working in the same

region, reported that most farms have low P concentrations which can be attributed to inherent low soil P due to high fixing nature of the nitisols that predominate the area and its (P) depletion due to continuous cropping with minimal replenishment. Farmers can replenish the lost P by using mineral fertilisers and organic manures.

4.2.2 Chemical analytical characteristics of FYM and agricultural lime

The chemical analytical results for manure samples from Kavutiri are shown in Table 3. The manure had low levels of major nutrients: P, K, Na, Ca and Mg at 0.12, 0.95, 1.28, 0.9 and 0.34 %, respectively. However, its pH was high (6.82) and had also very high organic Carbon (25.4 %), fair Nitrogen (1.94 %) leading to a narrow C/N ratio (13:1). The less acidic nature of this manure was desirable in reducing the exchangeable acidity of the Kavutiri soils. The narrow C/N ratio of this manure means well for net mineralization for nutrients such N and p, and therefore their availability in soil for plant use.

Table 3: Chemical analysis of Goat manure from Kavutiri

Fertility index	pH _(water)	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	DM (%)	OC (%)	Total N (%)	C:N (ratio)
	6.82	0.12	0.95	1.28	0.9	0.34	95.4	25.4	1.94	13.1

Table 4 shows the analytical results for agricultural lime. The lime was found to be rich in calcium carbonate (35.2 %) but slightly poor in Magnesium oxide (17.1%) In the UK, it is a legal requirement to state the CaO or CaCO₃ content in lime and the

granular size (Simson, 1986). However, in Kenya this is not the case as there is no standard for liming materials and therefore farmers would go for ground chalk or limestone from deposits close to their locality (Kanyanjua *et al.*, 2002). Since both Ca and Mg are deficient in Kavutiri soils, this agricultural lime could increase their concentrations in the soil and at the same time act as an ameliorant agent. This lime is ideal for farmers to use for it is fairly priced (7 US \$ /50 kg bag) and is readily available in retail shops in the area.

Table 4: Chemical analysis for agricultural lime

Parameter	Total Nutrient Content (%)
Calcium carbonate (CaCO ₃)	35.2
Magnesium oxide (MgO)	17.1

4.3 Effects of lime and manure application on soil acidity indices

4.3.1 Soil pH and Hp change following lime and manure application in the greenhouse experiment

Results of soil pH and exchangeable acidity (Hp) obtained from soil amended with different levels of lime and manure after 8 weeks of experiment are presented in Table 5. The Table also shows the changes in percentages of pH and Hp after 8 weeks of experiment. Treatment M₁₀L_{12.5} recorded the highest pH value of 6.3 which translates to nearly a 50 % increase from the initial soil pH value of 4.2 (Table 2) while the no input treatment (control) recorded the lowest pH value (4.1), which was a 2.6% decline in soil pH compared to initial value (pH= 4.2). Generally, there was a gradual trend of pH increase with lime and manure levels to the highest value of 6.3

obtained at M₁₀L_{2.5} treatment. The pH from the treatments decreased in the order of:

M₁₀L_{12.5} > M₀L_{12.5} > M₅L_{12.5} > M₁₀L₁₀ > M₅L_{7.5} > M₅L₁₀ > M₁₀L_{7.5} > M₀L₁₀ > M₅L₅ > M₅L₅ > M₅L_{2.5} > M₁₀L_{2.5} > M₀L_{7.5} > M₁₀L₀ > M₅L₀ > M₀L₅ > M₀L_{2.5} > M₀L₀.

Table 5: Mean Soil pH and exchangeable acidity (Hp) for the greenhouse experiment at the end of 8 weeks after planting (WAP).

Treatment No.	Treatment Code	pH (H ₂ O) 8 WAP	% Change from the baseline value (4.2)	Hp (me %) 8 WAP	% Change from the baseline value (2.7)
1	M ₀ L ₀	4.1 ^f	- 2.6	2.8 ^a	+3.7
2	M ₀ L _{2.5}	4.4 ^f	4.5	1.4 ^b	-48.1
3	M ₀ L ₅	4.7 ^f	11.6	1.3 ^c	-51.9
4	M ₀ L _{7.5}	5.1 ^e	21.1	1.1 ^d	-59.3
5	M ₀ L ₁₀	5.4 ^d	28.3	1.0 ^e	-63.0
6	M ₀ L _{12.5}	6.0 ^b	42.5	0.8 ^f	-70.4
7	M ₅ L ₀	4.9 ^e	16.4	1.0 ^e	-63.0
8	M ₅ L _{2.5}	5.3 ^{d e}	25.9	0.8 ^f	-70.4
9	M ₅ L ₅	5.4 ^d	28.3	0.7 ^g	-74.1
10	M ₅ L _{7.5}	5.7 ^c	35.4	0.5 ^h	-81.5
11	M ₅ L ₁₀	5.7 ^c	35.4	0.4 ⁱ	-85.2
12	M ₅ L _{12.5}	6.0 ^b	42.5	0.2 ^k	-92.6
13	M ₁₀ L ₀	5.0 ^e	18.8	0.4 ⁱ	-85.2
14	M ₁₀ L _{2.5}	5.2 ^{d e}	23.5	0.3 ^j	-88.9
15	M ₁₀ L ₅	5.4 ^d	28.3	0.2 ^k	-92.6
16	M ₁₀ L _{7.5}	5.7 ^c	35.4	0.1 ^l	-96.3
17	M ₁₀ L ₁₀	5.8 ^{b c}	37.8	0.1 ^l	-96.3
18	M ₁₀ L _{12.5}	6.3 ^a	49.6	0.1 ^l	-96.3
S.E.D	-	0.118	-	0.042	-
L.S.D _{5%}	-	0.238	-	0.084	-
P-Value	-	< 0.001	-	< 0.001	-

* Means not sharing a common letter in a column had significant effect at 5 % Probability level.

In case of exchangeable acidity (Hp), the values decreased with increase in lime and manure levels. Treatments; $M_{10}L_{7.5}$, $M_{10}L_{10}$, and $M_{10}L_{12.5}$, had the lowest Hp value of 0.1 each which was a decrease of 96.3% from the baseline value of 2.7 (Table 2). A gradual increase in Hp was noticed as lime and manure decreased, with the highest value in the control treatment (M_0L_0) of 2.8. This was a 3.7 % increase from the initial baseline value. The order in which Hp decreased was: $M_0L_0 > M_0L_{2.5} > M_0L_5 > M_0L_{7.5} > M_5L_{10} > M_5L_0 > M_0L_{12.5} > M_5L_{2.5} > M_5L_5 > M_5L_{7.5} > M_5L_{10} > M_{10}L_0 > M_{10}L_{2.5} > M_5L_{12} > M_{10}L_5 > M_{10}L_{7.5} = M_{10}L_{10} = M_{10}L_{12.5}$ (Table 5a).

4.3.2 Soil pH and Hp change following lime and manure application in the field experiment

For the field experiment, treatment $M_{10}L_{12.5}$ recorded the highest pH of 5.9 which was equivalent to a 40.1 % increase from that of 4.2 before experimental set up. The pH decreased significantly ($P < 0.05$) to the lowest (4.1) in the control plot, which was a decrease of 2.6% from the base line pH (4.2). The order in which pH decreased was: $M_{10}L_{12.5} > M_{10}L_{10} > M_{10}L_{7.5} > M_0L_0$ (Table 6).

On the other hand, Hp declined significantly in all plots except the control that recorded 2.8 me percentage making a 3.7 % increase above the baseline value of 2.7. In all the other plots, there was a significantly Hp decrease from 0.5 to 0.3 me % for $M_{10}L_{7.5}$ and $M_{10}L_{12.5}$ treatments, respectively. This was equivalent to 85.2 % and 88.9 % decrease for $M_{10}L_{7.5}$ and $M_{10}L_{12.5}$ treatments, respectively.

Table 6: Mean Soil pH and exchangeable acidity (Hp) changes following lime and manure application for the field experiment at the end of 8 weeks after planting (WAP).

Treatment No.	Treatment Code	pH (H ₂ O) 8 WAP	% Change from the baseline value (4.2)	Hp (me %) 8 WAP	% Change from the baseline value (2.7)
1	M ₀ L ₀	4.1 ^d	-2.6	2.8 ^a	+3.7
2	M ₁₀ L _{7.5}	5.0 ^c	18.8	0.5 ^b	-81.5
3	M ₁₀ L ₁₀	5.5 ^b	30.6	0.4 ^b	-85.2
4	M ₁₀ L _{12.5}	5.9 ^a	40.1	0.3 ^b	-88.9
S.E.D	-	0.0827	-	0.0991	-
L.S.D _{5%}	-	0.2024	-	0.2424	-
P-Value	-	< 0.001	-	< 0.001	-

* Means not sharing a common letter in a column had significant effect at 5 % Probability level.

In comparison, it was observed that application of equal amount of FYM and lime to acid soils in greenhouse and field, led to slightly higher pH in the greenhouse as compared to the field. The two control treatments from greenhouse and field experiments, recorded equal Hp of 2.8 me % each. The rest of greenhouse treatments (M₁₀L_{7.5}, M₁₀L₁₀ and M₁₀L_{12.5}) recorded a constant Hp of 0.1 me % each whereas for the field trial, they had higher values that decreased from 0.5 to 0.3 in the order M₁₀L_{7.5} > M₁₀L₁₀ > M₁₀L_{12.5}. In general, it was found that greenhouse trial treatments had lower soil acidity as portrayed by higher pH and lower Hp in comparison to their field counterparts.

In all the treatments except the control, pH progressively increased while the Hp decreased with increase in manure and lime application. The pH increase with manure application corresponds with the findings by Egball, (2002) and Mucheru, (2003). It could be attributed to reduction of Al³⁺ ions concentration in soil solution

and in exchangeable sites because of lime and manure application (Pearce and Sumner, 1997). Wong and Swift, (2003) in their findings also reported that addition of organic manures to acid soils increased soil pH, decreased Al saturation, and thereby improved conditions for plant growth.

The rise of soil pH through addition of FYM corroborate with the findings of Mokolobate and Haynes, (2002) and could have been caused by consumption of H^+ by the humic-type substances which have a large number of carboxyl, phenolic and enolic functional groups as proposed by Wong *et al.*, (1998). These substances are formed during decomposition processes and are relatively stable against further decomposition. Their capacity to consume H^+ therefore, indicates their buffer characteristics and their ability to neutralize soil acidity.

In another study by Noble *et al.*, (1996), it was found that additions of organic manures to acid soils improve soil fertility not only by adding organic matter and nutrients but also by increasing soil pH and decreasing concentrations of phytotoxic Al in exchangeable and/or soluble form. Certainly, the manure used in this study had a higher pH than the study soil so their addition is likely to have contributed to the slight raise of pH of this soil as seen in tables 5 and 6.

The rise in pH and reduction of soil exchangeable acidity can also be associated with the presence of basic cations (Ca^{2+} and Mg^{2+}) (Fageria, *et al.*, 2007) and anions (CO_3^{-2}) in lime that are able to exchange H^+ from exchange sites to form $H_2O + CO_2$. Cations occupy the space left behind by H^+ on the exchange leading to the rise in pH. The change in soil pH within the eight weeks concurs with the findings by Fageria, (2001a) who reported that significant chemical changes could take place within 4–6 weeks after applying liming materials if soil has sufficient moisture.

The lower pH in the control treatment than the baseline value is because of oxidation of the NH_4 ions from the added DAP and CAN and absence of the buffer to reduce the activity of the released H^+ due to nitrification process in the soil (Sparks, 2003). The effectiveness of lime to neutralize H^+ concentrations as compared to manure contribution is quite evident from the pH changes in the interaction treatments where the changes were almost similar (Tables 5 and 6). According to Kaitibie *et al.*, (2002), liming is the most widely used long-term method of soil acidity amelioration as its success is well documented. However, this study has shown that combining lime with manure in the long term lead to higher pH changes. The buffering capacity of FYM ensures that the soil pH does not fluctuate steeply within a short period (Wong *et al.*, 1998). This is good for maintaining a favourable environment for plant nutrient uptake.

4.4 The effect of the lime and manure amendments on maize growth parameters.

The second objective of this study aimed at evaluating the combined effect of lime and manure on maize growth parameters (height, dry matter and root length). This section discusses the results of these parameters from greenhouse and field experiments.

4.4.1 Change in maize growth parameters following lime and manure application in the greenhouse experiment

Photos of nine randomly selected greenhouse pots with maize 4 WAP are shown in plate 1. Within the first four weeks, there were no major observable differences among the treatments. However, treatments in which 10 Mg ha^{-1} (376 g pot^{-1}) of

manure was applied ($M_{10}L_{2.5}$, $M_{10}L_{7.5}$ and $M_{10}L_{12.5}$) were seen to have more vigorous maize plants than those with less or no manure (M_0L_5 and $M_0L_{12.5}$).

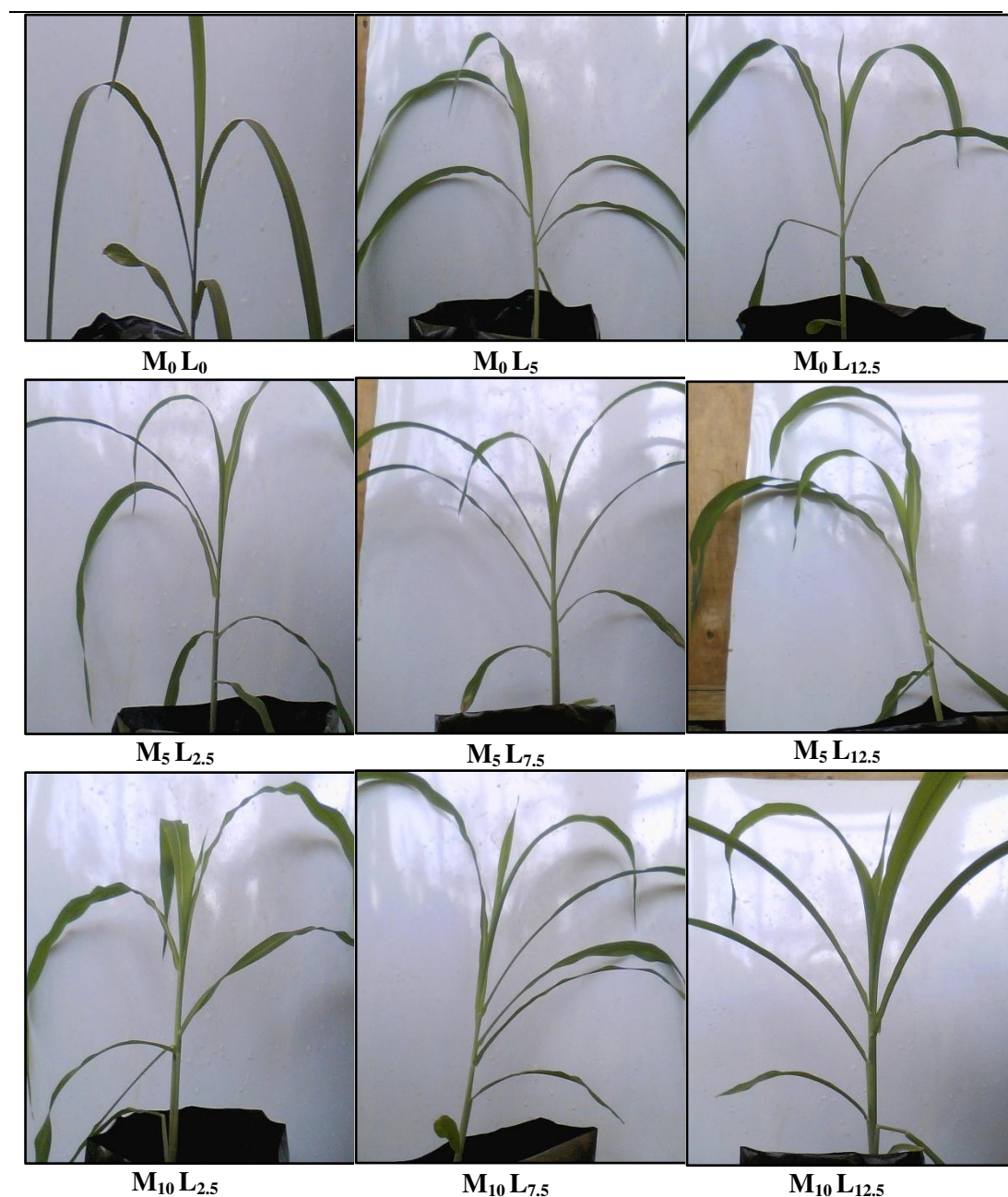


Plate 1: Photos taken 4 WAP showing the performance of maize from selected treatments in the greenhouse pots experiment.

The results of plant height, dry matter and root length for greenhouse experiment are presented in Table 7. Analyses of variance indicate that there was a significant difference ($P < 0.05$) among treatments.

Table 7: Mean plant height and dry matter (DM) weight - 4 and 8 weeks after planting (WAP) and root length 8 WAP in the greenhouse and field experiments

Treatment No.	Treatment Code	<u>... Plant height...</u>		<u>..... DM weight</u>				<u>Root length</u>
		4 WAP	8 WAP	<u>....4 WAP....</u>		<u>...8 WAP...</u>		<u>..8 WAP..</u>
				(g/plant)	(kg/ha)	(g/plant)	(kg)	(cm)
1	M ₀ L ₀	34.0 ^j	89.7 ^h	1.2 ⁱ	63.8	6.7 ^k	356.4	6.3 ^j
2	M ₀ L _{2.5}	39.0 ⁱ	115.0 ^g	1.8 ^h	95.8	7.4 ^j	393.7	9.3 ⁱ
3	M ₀ L ₅	42.0 ^h	116.3 ^f	2.3 ^g	122.4	7.9 ⁱ	420.3	13.3 ^h
4	M ₀ L _{7.5}	44.0 ^{g h}	119.0 ^f	2.7 ^f	143.6	8.4 ^h	446.9	14.7 ^h
5	M ₀ L ₁₀	45.0 ^{g h}	124.3 ^e	2.9 ^f	154.3	9.0 ^g	478.8	17.7 ^g
6	M ₀ L _{12.5}	47.3 ^{f g}	124.0 ^e	2.9 ^f	154.3	9.0 ^g	478.8	19.0 ^{f g}
7	M ₅ L ₀	47.0 ^{f g}	126.3 ^e	2.8 ^f	149.0	8.9 ^h	473.5	20.0 ^f
8	M ₅ L _{2.5}	49.0 ^{e f}	132.7 ^d	3.4 ^e	180.9	9.4 ^g	500.1	23.3 ^e
9	M ₅ L ₅	51.3 ^{d e}	135.7 ^{c d}	3.3 ^e	175.6	9.9 ^f	526.7	27.0 ^e
10	M ₅ L _{7.5}	53.3 ^d	139.0 ^{b c}	3.7 ^d	196.8	10.3 ^f	548.0	30.0 ^d
11	M ₅ L ₁₀	56.3 ^{c d}	140.7 ^b	3.9 ^d	207.5	11.3 ^e	601.2	31.7 ^d
12	M ₅ L _{12.5}	54.7 ^{cd}	136.7 ^c	4.0 ^d	212.8	11.9 ^d	633.1	34.3 ^c
13	M ₁₀ L ₀	55.3 ^c	139.3 ^{bc}	3.9 ^d	207.5	11.9 ^d	633.1	35.3 ^c
14	M ₁₀ L _{2.5}	58.3 ^{bc}	141.3 ^b	4.3 ^c	228.8	12.4 ^c	659.7	37.0 ^{b c}
15	M ₁₀ L ₅	61.3 ^a	143.7 ^b	4.7 ^b	250.0	13.0 ^b	691.6	38.0 ^b
16	M ₁₀ L _{7.5}	62.3 ^{ab}	146.3 ^{ab}	4.7 ^b	250.0	13.8 ^a	734.2	38.0 ^b
17	M ₁₀ L ₁₀	63.7 ^a	150.3 ^a	5.0 ^a	266.0	14.2 ^a	755.4	39.7 ^a
18	M ₁₀ L _{12.5}	61.0 ^{ab}	148.7 ^a	5.1 ^a	271.3	14.1 ^a	750.1	41.3 ^a
S.E.D	-	1.746	1.771	0.104	-	0.243	-	1.030
L.S.D _{5%}	-	3.542	3.591	0.219	-	0.493	-	2.090
P-Value	-	< 0.001	< 0.001	< 0.001	-	< 0.001	-	< 0.001
* Means not sharing a common letter in a column had significant effect at 5 % Probability level.								

It was observed that treatment M₁₀L₁₀ recorded the highest plant height both at 4 and 8 WAP of 63.7 and 150 cm, respectively whereas, plant heights in control pots were 34.0 and 89.7 cm as measured in 4th and 8th WAP, respectively, which were significantly different ($P < 0.05$) from the highest heights in the greenhouse experiment. The order in which plant height decreased was M₁₀L₁₀ > M₁₀L_{12.5} > M₁₀L_{7.5} > M₁₀L₅ > M₁₀L_{2.5} > M₅L₁₀ > M₁₀L₀ > M₅L_{7.5} > M₅L_{12.5} > M₅L₅ > M₅L_{2.5} > M₅L₀ > M₀L₁₀ > M₀L_{12.5} > M₀L_{7.5} > M₀L₅ > M₀L_{2.5} > M₀L₀.

Dry matter weight recorded at the two intervals i.e. 4 and 8 weeks after planting (WAP), the control treatment recorded the lowest dry matter weight (1.2 and 6.7g plant⁻¹) at 4 and 8 WAP, respectively, which correspond to 63.8 and 356.4 kg ha⁻¹. Thereafter, weights increased steadily with the treatments up to treatments M₁₀ L₁₀ and M₁₀L_{12.5} which had the highest weights of 5.1 and 14.2g/plant, respectively at 4th and 8th WAP (Table 7).

At 8 WAP weight of dry matter increased with increase in lime and manure application in the order: M₀L₀ < M₀L_{2.5} < M₀L₅ < M₀L_{7.5} < M₅L₀ < M₀L₁₀ < M₀L_{12.5} < M₅L_{2.5} < M₅L₅ < M₅L_{7.5} < M₅L₁₀ < M₅L_{12.5} < M₁₀L₀ < M₁₀L_{2.5} < M₁₀L₅ < M₁₀L_{7.5} < M₁₀L_{12.5} < M₁₀L₁₀.

In case of roots, the mean root lengths as influenced by lime and manure application (Table 7) increased with increase in inputs levels. Treatment M₁₀L_{12.5} had the longest roots with mean average of 41.3 cm, which was 555.5 % longer than the control (6.3 cm). The order from the longest root length to the shortest was as follows: M₁₀L_{12.5} > M₁₀L₁₀ > M₁₀L₅ > M₁₀L_{7.5} > M₁₀L_{2.5} > M₁₀L₀ > M₅L_{12.5} > M₅L₁₀ > M₅L_{7.5} > M₅L₅ > M₅L_{2.5} > M₀L_{12.5} > M₀L₁₀ > M₀L_{7.5} > M₀L₅ > M₀L_{2.5} > M₀L₀.

Plate 2 shows photos of maize roots as affected by manure and lime application for the greenhouse experiment.



Plate 2: Photos showing maize roots at 8 WAP from randomly selected pots in greenhouse experiment

It is evident from the photos that treatments with 10 Mg ha⁻¹ of manure had longer and stronger healthy roots followed closely by those with 5 Mg ha⁻¹ while those with no manure were short and looked unhealthy, which is an indication of manure effect on rooting as compared to liming.

4.4.2 Performance of Maize growth parameters following lime and manure application in the field experiment

At the 4th week, treatment M₁₀L₁₀ recorded the highest height (71.7 cm), 115.3 % higher than control. But at the 8th week, treatment M₁₀L_{12.5} had the highest height of 140.7 cm, a 80 % higher than that of no input treatment (Table 8). Other treatments, that is M₁₀L₁₀ and M₁₀L_{7.5} had heights of 136.7 and 132.3 cm, respectively. The control continued to exhibit significantly ($P < 0.05$) the lowest height (64.7 cm).

In terms of dry matter weights, the control treatment recorded the lowest weight (1.4 and 6.1g plant⁻¹ at 4 and 8 WAP, respectively, translating to 74.5 and 324.5 kg ha⁻¹, respectively. The rest of the dry matter weights rose significant ($P < 0.05$) to the highest weight of 5.2 g plant⁻¹ (276.6 kg ha⁻¹) for treatment M₁₀L_{12.5} and 13.1 g plant⁻¹ (694.1 kg ha⁻¹) for treatment M₁₀L₁₀ at 4 and 8 WAP, respectively.

For the root lengths, treatment M₁₀L_{12.5} recorded the longest root length (41.7 cm), a 379 % longer than that of control (8.7 cm). The order of the root lengths was as follows: M₁₀L_{12.5} > M₁₀L₁₀ > M₁₀L_{7.5} > M₀L₀.

Table 8: Mean plant height and dry matter (DM) weight - 4 and 8 weeks after planting (WAP) and root length 8 WAP in the field experiments

Treatment		<u>... Plant height...</u>		<u>..... DM weight</u>				<u>Root</u>
Treatment								<u>length</u>
No.	Code	4 WAP	8 WAP4 WAP....	...8 WAP...	..8 WAP..		
				(g/plant)	(kg/ha)	(g/plant)	(kg	(cm)
1	M ₀ L ₀	33.3 ^b	64.7 ^b	1.4 ^c	74.5	6.1 ^b	324.5	8.7 ^b
2	M ₁₀ L _{7.5}	67.7 ^a	132.3 ^a	4.8 ^b	255.4	12.4 ^a	660.0	39.0 ^a
3	M ₁₀ L ₁₀	71.7 ^a	136.7 ^a	5.1 ^a	271.3	13.1 ^a	694.1	40.3 ^a
4	M ₁₀ L _{12.5}	71.0 ^a	140.7 ^a	5.2 ^a	276.6	13.0 ^a	692.7	41.7 ^a
S.E.D	-	2.156	6.37	0.060	-	0.295	-	1.851
L.S.D _{5%}	-	5.275	15.59	0.146	-	0.722	-	4.529
P-Value	-	< 0.001	< 0.001	< 0.001	-	< 0.001	-	< 0.001
* Means not sharing a common letter in a column had significant effect at 5 %								
Probability level.								

The increase in plant height, dry matter weight and root length with decrease in soil acidity can be attributed to improved root environment for nutrient availability (mostly H₂PO₄⁻, HPO₄²⁻) as well as uptake by plants as a result of lime and manure application (Fageria *et al.*, 2004; Mora *et al.*, 2005). This could have been the reason for poor performance in the control (M₀L₀) treatment.

The significant increases in maize growth with application of lime and farmyard manure could be attributed to the general improvement of the soil environment in terms of decreased acidity, increased availability of plant nutrients and enhanced microbial activities especially at the rhizosphere. Addition of manure to soil is especially attributed to its effectiveness in acidity regulation and binding of exchangeable Al in acid soils. Tejada *et al.*, (2006) reported that manure is a good fertilizer on soil that requires P and N to produce high yields. This was however, not

the case with the control where manure and mineral fertilizers were not applied. Yamoah *et al.*, (1996) attributed 44 % reduction in maize yield due to acidity in soils.

Liming acid soils result in the release of P for plant uptake; an effect often referred to as ‘‘P spring effect’’ of lime (Bolan *et al.*, 2003). These authors reported that in soils high in exchangeable acidity, liming might increase plant P uptake by decreasing Al, rather than by increasing P availability per se. This may be due to improved root growth where Al toxicity is alleviated, allowing a greater volume of soil for root elongation. Similar findings have been reported by other researchers (Onwuka *et al.*, 2009; Gudu *et al.*, 2007 and Okalebo *et al.*, 2009). Onwuka, *et al.*, (2009) reported that working with 2, 4, 6 and 8 mega grams per hectare of CaCO₃ increased the soil pH from 5.02 to 8.04. In field experiments reported from western Kenya, it was found that agricultural lime (Gudu *et al.*, 2007) and Minjingu rock phosphate (Okalebo *et al.*, 2009) significantly raised soil pH and maize yields. Dierolf, *et al.*, (1997) reported that application of lime to maize allowed the roots of maize to extend up to 15 to 30 cm of depth in an acid soil.

The improved soil environment due to the inputs, also favours optimal functional of microbial activities such as mineralisation process (Jones *et al.*, 2005; Harrison *et al.*, 2008). Bado and Batiano (2004) reported that integration of organic and inorganic fertilizer sources result into synergy, and improved conservation and synchronization of nutrient release, and crop demand leading to higher yields.

4.4.3 Relationships between maize growth parameters and soil acidity indices

The relationship between soil pH and maize growth parameters (dry matter and plant height) are shown in Fig 4a. A highly significant and positive correlation

relationship was observed between soil pH and the maize growth parameters. Dry matter showed a high correlation of $r^2 = 0.622$ with pH changes in soil while that of plant height with pH was $r^2 = 0.7244$.

Plant height had a negative linear correlation with soil Hp ($r^2 = -0.9517$) while that between dry matter and Hp was also high and negative with a coefficient of determination (r^2) of -0.7588 (Fig 4b).

In Fig. 4(c and d), relationship between soil acidity indices and root length had a positive linear correlation with soil pH ($r^2 = 0.6598$) and a negative non- linear relationship with Hp ($r^2 = 0.969$). This trend agrees with Comin, *et al.*, (2006) who observed in their work, on the effects of soil acidity on the adventitious root system in the field, that acidity negatively affected the root branching and root length of maize crop.

The positive correlation of soil pH with the maize growth parameters implies that as the pH increased the growth parameters were also increasing. As such, addition of the lime and manure, which were found to increase the levels of the parameters, influenced positively on the growth of maize in the soils. As the exchangeable acidity is reduced, the plant roots performances are enhanced (Le Van, *et al.*, 1994).

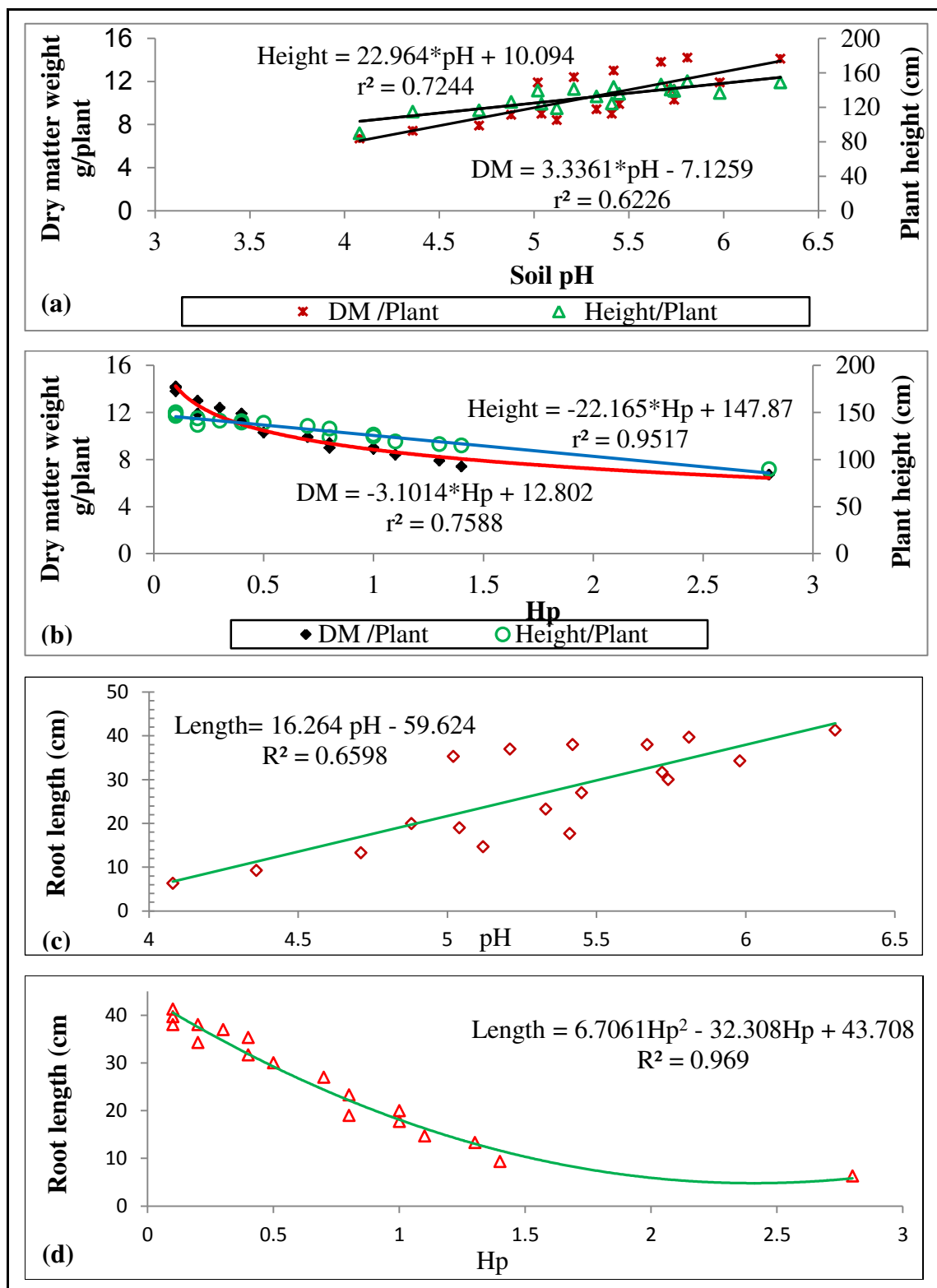


Figure 4: Relationship between maize growth parameters and soil acidity (Hp and pH) in the greenhouse experiment at 8 weeks after planting; dry matter weight and plant height (a-b) and maize root length (c-d).

4.5 Effect of manure and lime application on bacteria and fungi biomass in soil

4.5.2 The laboratory results on soil bacteria and fungi population in greenhouse experiment.

Influence of lime and manure application on microbial population density was investigated and results were as presented (Table 9). In the greenhouse experiment, the highest bacterial count of 24.9×10^5 Colony forming units (CFU) was obtained from treatment $M_{10}L_{12.5}$. This is 654.5% higher than the control (3.3×10^5 CFU). With the rest of the treatments, a decreasing trend was observed ($M_{10}L_{12.5} > M_{10}L_{10} > M_{10}L_{7.5} > M_{10}L_5 > M_{10}L_{2.5} > M_3L_0 > M_5L_{12.5} > M_5L_{10} > M_5L_{7.5} > M_5L_5 > M_5L_{2.5} > M_5L_0 > M_0L_5 > M_0L_6 > M_0L_{7.5} > M_0L_5 > M_0L_{2.5} > M_0L_0$).

For fungi, significant ($P < 0.05$) difference was noted with the control recording 8.8×10^3 CFU while treatment $M_{10}L_{10}$ exhibited the highest value (17.1×10^3 CFU), a 94.3% higher than control. The order in which CFU decreased was: $M_{10}L_{10} > M_{10}L_{7.5} > M_{10}L_5 > M_{10}L_{12.5} > M_{10}L_0 > M_{10}L_{2.5} > M_5L_{12.5} > M_5L_{10} > M_5L_{7.5} > M_5L_5 > M_5L_{2.5} > M_5L_0 > M_0L_{10} > M_0L_{12.5} > M_0L_{7.5} > M_0L_5 > M_0L_{2.5} > M_0L_0$.

Table 9: Mean bacterial and fungal biomass in the greenhouse experiment at 8 weeks after planting (WAP).

Treatment No.	Treatment Code	Bacteria (CFU/g) \times 10^5	% Change from the control treatment	Fungi (CFU/g) $\times 10^3$	% Change from the control treatment
1	M ₀ L ₀	3.3 ^j	0	8.8 ^f	0
2	M ₀ L _{2.5}	4.2 ⁱ	27.3	10.1 ^e	14.8
3	M ₀ L ₅	4.9 ^h	48.5	9.8 ^e	11.4
4	M ₀ L _{7.5}	5.3 ^{hi}	60.6	9.3 ^{ef}	5.7
5	M ₀ L ₁₀	6.6 ^{gh}	100.0	10.6 ^e	20.5
6	M ₀ L _{12.5}	6.4 ^h	93.9	11.2 ^{de}	26.1
7	M ₅ L ₀	7.8 ^{gh}	136.4	10.8 ^e	22.7
8	M ₅ L _{2.5}	8.3 ^{fgh}	151.5	11.7 ^{de}	33.0
9	M ₅ L ₅	8.8 ^{fg}	166.7	11.0 ^{de}	25.0
10	M ₅ L _{7.5}	9.3 ^{fg}	181.8	12.1 ^d	37.5
11	M ₅ L ₁₀	9.9 ^f	200.0	14.0 ^c	59.1
12	M ₅ L _{12.5}	12.4 ^e	275.8	14.2 ^{bc}	61.4
13	M ₁₀ L ₀	14.6 ^d	342.4	14.7 ^{bc}	67.0
14	M ₁₀ L _{2.5}	15.8 ^d	378.8	14.7 ^{bc}	67.0
15	M ₁₀ L ₅	20.1 ^c	509.1	15.4 ^b	75.1
16	M ₁₀ L _{7.5}	21.0 ^b	515.2	16.2 ^{ab}	84.1
17	M ₁₀ L ₁₀	23.8 ^a	621.2	17.1 ^a	94.3
18	M ₁₀ L _{12.5}	24.9 ^a	654.5	15.3 ^b	73.9
S.E.D	-	0.934	-	0.691	-
L.S.D _{5%}	-	1.895	-	1.101	-
P-Value	-	< 0.001	-	< 0.001	-

* Means not sharing a common letter in a column had significant effect at 5 % Probability level.

4.5.3 The results on soil bacteria and fungi population in the field experiment.

Field treatments; M₁₀L_{12.5}, M₁₀L₁₀ and M₁₀L_{7.5} exhibited 28.8, 28.5 and 26.0 × 10⁵ CFU respectively (Table 10). This translates to 433.3, 427.8 and 381.5% increase above the control treatment (5.4 × 10⁵ CFU).

Table 10: Mean bacterial and fungal biomass in the field experiment at 8 weeks after planting (WAP).

Treatment No.	Treatment Code	Bacteria (CFU/g) × 10 ⁵	% Change from the control	Fungi (CFU/g) × 10 ³	% Change from the control
1	M ₀ L ₀	5.4 ^c	0	8.4 ^c	0
2	M ₁₀ L _{7.5}	26.0 ^b	381.5	22.2 ^b	164.3
3	M ₁₀ L ₁₀	28.5 ^{ab}	427.8	27.0 ^a	221.4
4	M ₁₀ L _{12.5}	28.8 ^a	433.3	26.7 ^a	217.9
S.E.D	-	1.368	-	0.3955	-
L.S.D _{5%}	-	2.795	-	0.8021	-
P-Value	-	< 0.001	-	< 0.001	-

*Means not sharing a common letter in a column had significant effect at 5 % Probability level.

A similar trend was observed with fungal colony count whereby treatment M₁₀L₁₀ had the highest CFU count (27 × 10³), 221.4% above the control. Fungal colony count followed the order: M₁₀L₁₀ > M₁₀L_{12.5} > M₁₀L_{7.5} > M₀L₀.

The field experiment indicated that at all levels of manure and lime, microbial population was higher in the field than in greenhouse. This is an indication of the actual habitat of the strains as compared to greenhouse environment where disturbed soils were used. However, with addition of FYM and lime, this might have given rise

to more favourable environment for microbial proliferation in terms of food supply, hence energy increase for the heterotrophic microflora (Naramabuye *et al.*, 2007). The addition of agricultural lime would have also increased microbial activity by increasing pH and possible addition of Ca and Mg.

In general, these results are consistent with research that suggests microbial communities respond quickly to substrate availability (Austin *et al.*, 2004; Schwinning and Sala 2004). According to Liu, (2005) organic manures could improve soil physical properties (soil moisture and structural stability), and consequently benefit soil microbial mediated processes. The microbial count increase as from treatment M_0L_0 to $M_{10}L_{12.5}$ is attributable to microbial proliferation (Onwonga *et al.*, 2010). It is a well-known fact that soil organic C strongly affects the amount and activity of soil microbial biomass (Francisco *et al.*, 2005).

The observations on long-term treatments with FYM to enhance soil microbial activities and to increase microbial biomass (Saviozzi *et al.*, 2002; Böhm *et al.*, 2005; Kandeler and Eder, 1993) concur with the findings of this study.

The high microbial densities recorded in the field can be attributed to large volume of soil hence more substrate in form of C and N that the microbial had to explore and that they were in their native environment as compared to the limited soil volume with pot experiment.

4.5.3 Relationship between soil microbial biomass and soil acidity parameters (pH and H_p).

Bacterial and fungal population biomass in the soil correlated positively with pH. There was a non-linear relationship between fungal population and soil pH ($r^2 = 0.5057$) as described by a regression equation in the fourth polynomial order (Fig.

5a) while bacterial colony count portrayed an exponential regression ($r^2 = 0.5978$). However, the correlation was negative and high ($r^2 = -0.7731$ and -0.9321) for bacteria and fungi, respectively, with exchangeable acidity though in a non-linear pattern (Fig. 5b).

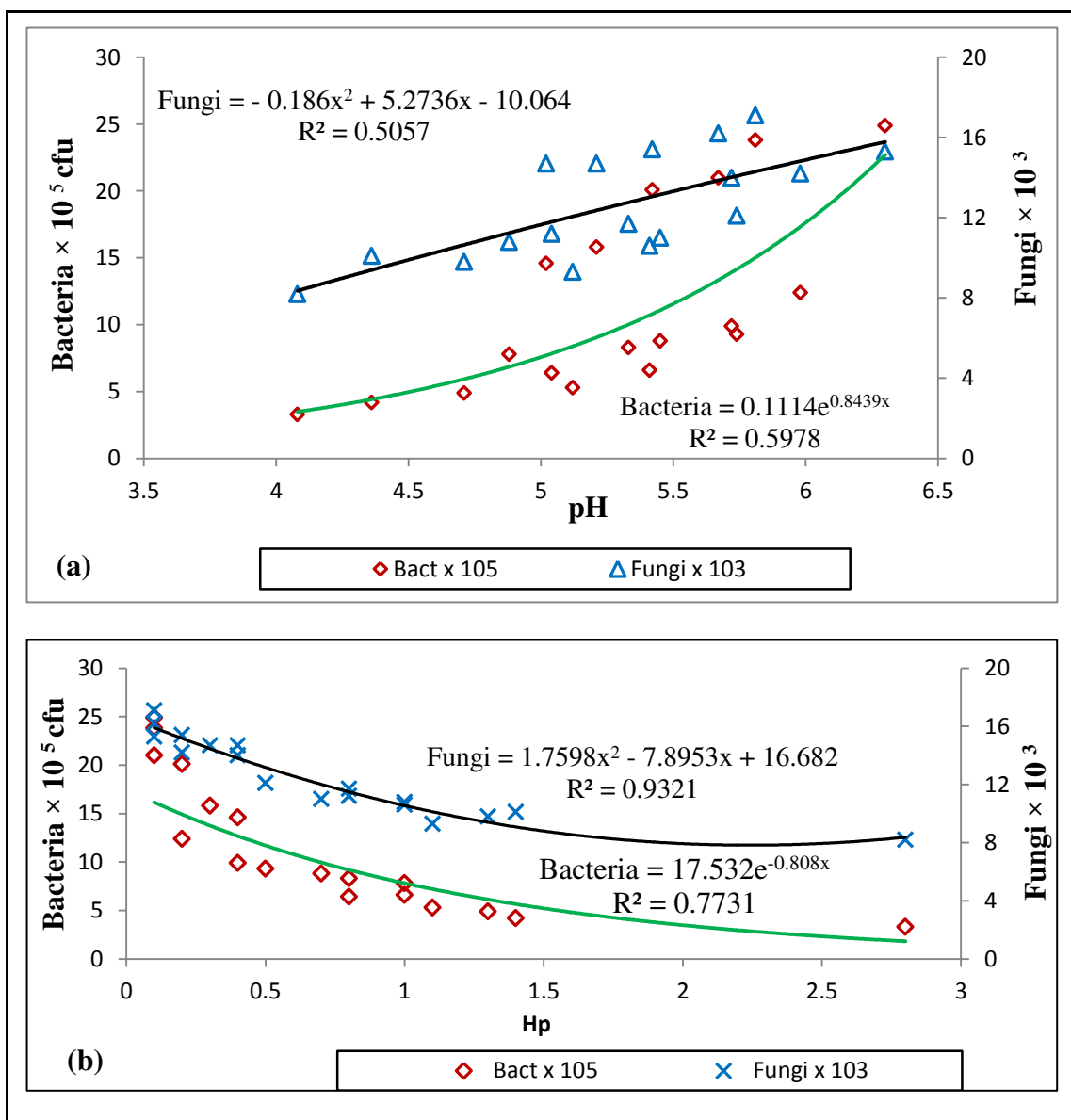


Figure 5: Relationship between soil microbial (bacteria and fungi) biomass and soil acidity indices in the greenhouse experiment at 8 weeks after planting (WAP). (a) pH and (b) Hp

The bacterial abundance in the kavutiri acid soils was sharply defined by soil pH. This corroborates the results by Lauber *et al.*, (2009), which included a wide range of soil types, and suggested that pH is more important overall for structuring soil communities. Fungal population density did not show wide fluctuations with change in pH and lime levels in various treatments (Fig.5a). This is an indication that fungi are able to thrive in a big range of pH levels.

Haynes and Naidu, (1998), found that repeated applications of organic material to acid soil will increase organic matter content with consequent improvements in soil biological activity and structural conditions. This explained further why microbial population increased with addition of manure.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

There was a significant increase ($P < 0.05$) in soil pH with the highest value (6.3) recorded from greenhouse treatment $M_{10}L_{12.5}$ -with 12.5 Mg ha^{-1} of lime and 10 Mg ha^{-1} of manure. Exchangeable acidity decreased significantly ($P < 0.05$) with increase in manure and lime application to as low as 0.1 me %. Increasing the pH and lowering Hp of acidic soils improved maize plant height, dry matter yield and root length as well as soil microbial count. It was found that application of 10 Mg ha^{-1} of lime in combination with 12.5 Mg ha^{-1} of agricultural lime reduced soil acidity to a pH of 6.3 hence promoting plant growth and performance especially for acid sensitive crops like maize.

In the evaluation of the bacterial and fungal population density following incorporation of agricultural lime and farmyard manure in acid soils, the study found that bacterial colonies increased progressively with increase in manure and lime levels. This was accredited to favourable pH levels and presence of organic matter that supplied the microorganisms with necessary carbon for energy. However, for fungal population, it was found to be high even at low pH and increased only gradually with increase in manure and lime levels. This is an indication that fungi are able to thrive better in high acidic soils by utilising the organic materials available than bacteria strains.

On the verification of the best three greenhouse treatments in the farmer's field, the greenhouse trials performed better in terms of biomass production, plant height and root length than field trials. This phenomenon was attributed to better mix

of the inputs in pots in greenhouse compared to what happens in the field. Better mix of lime and manure with acid soil improves soil acidity and microbial environment. On the other hand the field trials recorded higher microbial populations in comparison to greenhouse ones. This could be a reflection of their actual habitat as compared to pot environment. More so, better environmental conditions such as temperatures and food regimes must have played a role in shaping the microbial proliferation.

Results from the present study have demonstrated that application of manure and lime to acid soils has a profound influence on soil pH, exchangeable acidity and microbial populations. Combining 10 Mg ha⁻¹ of manure and 12.5 Mg ha⁻¹ of agricultural lime treatments was more effective in reducing soil acidity, increasing soil fungal and bacterial population and consequently enhancing root length, dry matter and plant height. Thus, the acid soils of Kavutiri-Embu County need manure in combination with lime to improve their chemical and biological properties and consequently their productivity. This would be a promising alternative in developing more affordable acid soil management strategy.

5.2 Recommendations

Based on the findings of this study, the following recommendations are made that give a guideline for further research.

- A long term study needs to be considered since the results reported here were of a short duration and were mainly looking at the soil acidity constraints that affect rooting and maize growth in general without grain forming phase.

- The study tested only agricultural lime and one type of manure, the goat manure. Therefore, more research needs be carried out using other types of farmyard manure and lime.
- Farmers in the study area and other similar areas in the country should be encouraged to use lime and manure to increase maize yield.

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