COMPARATIVE EFFECTS OF KRAAL MANURE AND PHOSPHORUS FERTILIZER ON SOIL ACIDITY AND PHOSPHORUS AVAILABILITY TO MAIZE *(Zea mays L.)*

BY
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A THESIS SUBMITTED TO THE UNIVERSITY OF ZAMBIA IN PARTIAL FULFILMENT OF THE REQUIMENT FOR THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY

THE UNIVERSITY OF ZAMBIA
Lusaka
2011

DECLARATION

I, **Kelebonye Bareeleng**, do hereby declare that this dissertation represents my own, independent work. I further certify that it has not previously been submitted for a degree or any other award to this or another university

Signed: _______________ Date:_________________

APPROVAL

The University of Zambia approves this dissertation of **Mrs Kelebonye Bareeleng** as fulfilling part of the requirements for award of the degree of Master of Science in Agronomy.

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ABSTRACT

Soil acidity is a major constraint to crop productivity and lime, the primary amendment, is seldom effective when applied alone and it is not easily accessed by resource-poor farmers. Organic residues around the farm are seldom used as soil amendments. This study was conducted at the University of Zambia Farm to determine the comparative effects of kraal manure and phosphorus fertilizer on soil acidity and phosphorus availability to maize. The site is situated at an altitude of 1140 m a.s.l (15˚21`-15˚24` S and 20˚27`-20˚28` E). The soil was classified as mixed, fine-loamy, isohyperthermic Oxic Paleustalf . Treatments comprised of two levels of lime (0t/ha and 3t/ha), three levels of phosphorus (0kgP/ha, 20kgP/ha and 30kg/P/ha and four levels of kraal manure (0t/ha, 2.5t/ha, 5t/ha and 10t/ha).The treatments were replicated three times in a split- split plot design. Lime levels as main plot treatments, four organic amendment levels for Kraal manure as sub plot and three phosphorus levels as sub-subplot treatments. Maize was the test crop. Selected soil chemical properties and plant tissue analysis were determined at the start of the experiment and after crop harvest. Addition of agricultural lime rapidly increased soil pH, concentrations of Ca, Mg and extractable P. Kraal manure additions increased concentrations of Ca and Mg, organic matter and plant available P, but it had a small effect on increasing soil pH (11%). Applied lime increased available P in the soil by unlocking the residual P. The increase in plant available P when kraal manure was applied was expected because the extra P was derived from the kraal manure which contained 1.18% of P. When P fertilizer is applied in combination with lime or kraal manure, the application rates for P would be lower than to when P is applied alone. The increase in grain yield was due to addition of amendments and optimal P fertilizer to ameliorate soil acidity and increase nutrient uptake. Application of 3t/ha lime and 20kgP/ha may be recommended for increasing maize yield on acid soils particularly in the study area. It was concluded that kraal manure alone may be used as amendment to overcome poor soil fertility and increase crop yield on acid soils were lime is expensive and not easily accessed by farmers.

DEDICATION

This dissertation is dedicated to my family. They have been a source of joy, support and encouragement to complete my studies.

ACKNOWLEDGEMENTS

I wish to express my appreciation to the SADC/SCARDA for funding my studies and to the University of Zambia for accepting my application. I am grateful to my supervisors Professor O. I. Lungu and Dr K. Munyinda for their support, patience, guidance, encouragement and understanding provided a conducive environment for me to complete my project. Thanks are extended to Dr D. Lungu for his important administrative role he played and his office is always open for students to consult, thank you very much Dr. I would like also to thank Soil Science Lab Technicians for the good work they have done and field staff for their technical support.

A special thanks to Basotho students who were like my family away from home for their support and encouragements. Special thanks to my daughter, son and their father for the love they gave me every time. Above all I thank my almighty God for giving me knowledge, wisdom and understanding throughout my studies.

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Chapter 1

1.0 INTRODUCTION

Maize *(Zea mays)* is an important food crop which possesses a high calorific value for human beings. It is the major staple crop grown in South Africa Development Community regions. (SADC). Due to high yield potential and easy sowing compared to other cereal crops it is gaining popularity. Maize is eaten boiled or roasted and the stalks can be used as fodder. In Zambia bulk of maize produced is used for human food. However, the production of maize is constrained by among other factors low soil fertility and unfavorable soil chemical properties.

Increases in soil P availability due to liming have been reported in a number of glasshouse and field trials (Adams, 1984). Application of lime to acid soil can stimulate crop growth by eliminating toxicities (particularly of Aluminum and Iron) and increasing the availability of certain plant nutrients such as Calcium, Nitrogen and Molybdenum (Adams, 1984). The supply of Phosphorus to plants is largely controlled by adsorption-desorption reactions which regulate the concentration of Phosphorus in the soil solution. These reactions may be influenced by lime-induced increases in pH and Calcium (Barrow, 1984; Curtin et al., 1993; Agbenin, 1996). The addition of lime not only replaces hydrogen ions and raises soil pH thereby eliminating most major problems associated with acid soils, but it also provides calcium and magnesium that are deficient in acid soil.

Schulte et al., (1996) reported that at a low pH (4.0-5.0) more iron and aluminum are soluble and form insoluble phosphate compounds, therefore, less phosphate is available. On these soils, maize yield was reduced due to Al or Mn toxicity and Ca, Mg, P and Mo deficiencies (Aldrich et al.,1975). Lorry (1999) stated that the solubility of the compound holding phosphorus is directly related to the soil pH. Any factor that affects root growth will affect the ability of plant to explore more soil volume and get adequate phosphorus. Mckelvey, (1973) reported that the ability the of a plant to take up phosphorus is largely due to its root distribution relative to phosphorus location in soil. Soil acidity affects mineral solubility and influences sorption or precipitation of nutrients with Al and Fe (Hue, 1992). Increasing the pH of acidic soils improves plant-availability of some nutrients while reducing the solubility of elements such as Al and Mn (O'Hallorans et al., 1997; Hue and Licudine, 1999).

Soil acidity problems are commonly corrected by applying agricultural lime. However, there is evidence that organic residues from green and animal manures can also increase the pH of acid soils and improve soil fertility by enhancing supply of nutrients for crop production (Hue, 1992; Warren and Fonteno, 1993; Iyamuremye et al., 1996; O'Hallorans et al., 1997; Wong et al., 1998). The effect of animal manure on soil pH may persist over several years. Bickelhaupt (1989) found that the application of composted lime-treated horse manure to a slightly acidic soil (pH 5.7) increased soil pH to between 6.7 and 7.3, and the effect was undiminished 12 years after manure application.

Livestock manure is rich in plant nutrients. Studies have shown that about 70 - 80% of the nitrogen (N), 60 - 85% of the phosphate (P_2O_5), and 80% of the potassium (K_2O) fed to animals are excreted in the manure (Klausner et al. 1984). Along with nutrients, manure supplies valuable organic matter that helps to improve soil physical properties and increase the activity of beneficial soil microbes. Eghball and Power, (1987) noted that applying enough manure or compost to meet the nitrogen requirements of corn may greatly increase the levels of P and other nutrients in the soil. They also found that the phosphorus content (measured by Bray-1) increased by 81 mg/kg after a single application of manure based on nitrogen requirements and by 114 mg/kg after a similar application of compost. Therefore, animal manure could be substituted for agricultural lime to improve production on acids soils. A high level of phosphorus in the soil is an environmental concern. The risk of pollution of surface water bodies with P originating from agricultural land is known to be greater in soils with more, than less, plant-available P, but depends on many factors including climate, soil type and hydrology, agronomic practices and landscape (Lemunyon and Gilbert, 1993; Heathwaite, 1997).

One of the reasons that P management is difficult is the sensitivity of many water bodies to very low concentrations of dissolved P. For many lakes, streams, reservoirs, and estuaries concentrations of total P as low as 20 $\mu g l^{-1}$ may cause entrophic conditions (Correll, 1998). Nutrient management will play a key role in decrease of P inputs to surface waters. Sims et al., (1998) reported that high levels of P in soils are common due to many years of P fertilizer applications. Understanding the soil processes by which solid phase soil P becomes available for uptake by plants will improve the ability to manage residual soil P and potentially allow a significant decrease in the use of P fertilizer.

Soil acidity has been reported to be a major constraint to crop production and causes great losses in yield. In Zambia soil acidity is common in the high rainfall areas on Oxisol, Ultisols and on intensively cultivated light-textured and poorly buffered soils (Lungu et al., 1993). Soil analysis results from the University Zambia Farm in this study shows low soil pH ranging from 3.8-5.1. Major problem that can militate against the effective use of lime are high cost of commercial liming materials for small scale farmers. They lack financial resource to purchase adequate amounts of inorganic fertilizers, so they can use what they have around the farm to ameliorate soil acidity and to make phosphorus available for plant uptake.

Organic material like kraal manure is a promising liming source, can be used to reduce exchangeable Al of acid soils and improve soil fertility. Kraal manure is not fully integrated into crop production as organic amendment but is used as organic fertilizer. The use of agricultural lime is costly and it reacts more slowly with the soil colloids than animal manure. Brady,(1999) reported that limestone reacts more slowly, taking up to a year and even longer to react fully with soil colloids. Phosphorus deficiency has been reported to by widespread in Sub Sahara Africa soils. P deficiency severely limits crop yields in some of Zambian soils. Phiri (2008) reported that where P fertilizer is not applied, yields of grain crops are reduced by as much as 50% from the optimal yields obtained with adequate fertilization.

Turtle-Agro Mining Ltd, (2009) stated that most of the soils used for crop production in Zambia need lime for optimum yield. Soil analysis results from studies done by Soil Science Department, University of Zambia between 1998 and 2003, revealed that although soil acidity is higher in the high rainfall regions of Zambia, the problem is widespread in all parts of the country and the soils will benefit from liming. The extent of the problem varies from field to field, therefore, the amount of lime required also varies. A proper liming strategy combined with other sound agronomic practices will increase crop productivity. According to Lungu and Chinene, (1993), studies in zambia have shown that crop yields on acid and unlimed soils have declined even with the application of adequate amounts of inorganic fertilizers. The research is therefore designed to determine the effects of kraal manure and phosphorus fertilizer on soil acidity and phosphorus availability to improve soil fertility.

Chapter 2

2.0 LITERATURE REVIEW

2.1 Characteristics of acid soils

Soils become acid when a large proportion of the cations held at the exchange sites of soil colloids are occupied by hydrogen ions, as well as various forms of hydrated aluminum. When water is introduced into soil, for example as rain or through irrigation, equilibrium is established such that a large quantity of the hydrogen ions becomes distributed in the soil solution, making the soil solution acidic (Adams, 1984). Carl and David, (2003) defined soil acidity as the term used to express the quality of hydrogen and aluminum cations in soils, and soil pH is an indicator of acidity. Studies carried in Zambia by Lungu and Chinene , (1993) have revealed that crop yields on acid and unlimed soils have declined even with the application of adequate amounts of inorganic fertilizers.

Soil acidity is widespread in the tropics and could be partially responsible for low bean and maize yield in Sub -Saharan region. According to Mbakaya, 2007, soils in SSA have low organic matter contents and soil acidity also contribute to low crop yields. In acid soils, there are problems of both plant nutrient deficiencies and toxicity of three elements (Aluminium (Al) Manganese (Mn) and Hydrogen (H^+)

2.2 Causes of soil acidity

Spies and Harms, (2007) stated that some soils are acidic because of the composition of the parent material (minerals and rocks) from which they were formed. In Zambia, soil acidity could be due to parent material, application of inorganic nitrogenous fertilizer application, leaching of bases and accumulation of Fe, H and Al ions or a combination of these factors.

2.2.1 Soil Organic Matter (SOM)

As microorganisms decompose soil organic matter (O.M), they release carbon dioxide that quickly reacts with water (H_20) to produce H^+ and HCO^{3-}. Decomposition of organic residues and root respiration increases carbon dioxide in soil air to about ten times the atmospheric carbon dioxide, thus, acidity produced from carbon dioxide in soil air is greater than that produced in the atmosphere. In addition, microorganisms produce organic acids. Soil OM content varies with the environment, vegetation and soil, thus its contribution to soil acidity varies accordingly. Mineral soils containing large amounts of OM and organic acids contribute significantly to soil acidity (Havlin et al, 2005). Decaying of organic matter produces hydrogen which is responsible for acidity.

2.2.2 Crop removal

Harvesting of crops has its effect on soil acidity development because crops absorb the exchangeable bases elements, as cations, for their nutrition. When these crops are harvested and the yield is removed from the field, then some of the basic material responsible for counteracting the acidity developed by other processes is lost, and the net effect is increased soil acidity. High yielding forages, such as bermudagrass or alfalfa, can cause soil acidity to develop faster than with other crops (Zhang and Johnson, 1972). Calcium, magnesium and potassium are essential nutrients for plant growth and their uptake by plants and subsequent removal through harvest can have an acidifying effect on soils. The amount of these nutrients removed by cropping depends on a) crop grown, b) part of crop harvested and c) stage of growth at harvest (Spies and Harms, 2007).

2.2.3 Fertilizers

Nitrogen fertilizers have a greater acidifying effect on soils than other fertilizers. Two processes are involved. First, commonly used nitrogen fertilizers contain ammonium nitrogen. Soil bacteria convert ammonium to nitrate through a biochemical process called nitrification. The second acidifying effect comes from nitrate that is not taken up by the growing crop (Spies and Harms, 2007). Lungu and Chinene, (1993) reported that the amount of N fertilizers applied to soils in Zambia varies depending on the cropping system. If the NH_4^+ is taken up by the plant before nitrification takes place and in quantities greater than the accompanying anion, soil acidity will results from proton release from roots. However, nitrification takes place rapidly in most soils so that the window of opportunity for NH_4^+ plays a role in soil acidification, and theoretically two moles of H^+ are released per mole of NH_4^+ converted to nitrate (Jolley and Pierre, 1977). The study done by Lungu and Dynoodt, (2008) have shown that long-term annual application of urea resulted in soil acidification and decreases in exchangeable Ca and Mg, especially if these were already low in the soil.

2.2.4 Rainfall

Excessive rainfall is an effective agent for removing basic cations over a long time period. Rainfall is the most effective in causing soils to become acidic if a lot of water moves through the soil rapidly. Sandy soils are often the first to become acidic because water percolates rapidly, and sandy soils contain only a small reservoir of bases (buffer capacity) due to low clay and organic matter contents. Soils can become acid even in the absence of crop removal or fertilizer application, (Spies and Harms, 2007). In Zambia soil acidity is common in the high rainfall areas (annual >1000 mm) on oxisols, Ultisols and on intensively cultivated light-textured and poorly buffered soils where heavy rates of acid-forming fertilizers have been used.

2.3 Effects of soil acidity on crop growth

Acid soils are not productive for most crops, except those that are acid-tolerant like tea or coffee. This is due to one or more of the following:

1. Al, Mn and Fe toxicity due to the increased concentrations of these ions as a result of increased solubility of their respective minerals under acidic conditions.
2. Ca, Mg and Mo deficiency due to their increased solubility and leaching.
3. N, P and S deficiency due to their slow release as a result of reduced rate of organic matter decomposition at low pH soils, for the microorganisms responsible are negatively affected by strong acidity.
4. P deficiency due to its fixation by Fe and Al to form insoluble Fe and Al phosphates.

Schwab et al., (1990) stated that acidification or lowering of soil pH has a negative impact on crop growth and occurs as a direct result of application of specific types of fertilizers. Crop growth is severely affected by high levels of Al which causes direct injury to the plant root system. Soil solution Al concentration above one part per million (1ppm) often causes direct yield reduction. Certain soils, especially the majority of Oxisols common to Sub Sahara Africa (SSA) have higher levels of Al than others, making them more amenable to Al toxicity problems.

According to Sanchez, (1976) the other serious negative impact of acidification in SSA is increased limitation on the availability of P, already the most common limiting factor in SSA soils. At low pH common in African soils, P is complexed with hydrous oxides of iron (Fe) and Al or reacts with silicate minerals. Phosphorus is most available at neutral levels (pH 6-7). However, liming to increase soil pH above 6.5 may do more harm than good. It may reduce the availability of phosphate and cause deficiencies of micro-nutrients such as manganese and zinc . Overliming may also increase the loss of sulphate if the excess calcium is leached. Liming to increase soil pH above 6.5 should only be taken for crops known to grow best at these pH values.

Spies and Harms, (2007) reported that soil microorganisms do not function effectively in acid soils. As soil pH levels decline so does the activity of the organisms which decompose organic matter, releasing nutrients to plants. Although these organisms function best at soil pH levels of 8.0, their effectiveness does not drop rapidly until pH levels drop below 6.0. Decomposition of organic matter also contributes to aggregation of soil particles which provides for good soil tilth, aeration and drainage. Effectiveness of the bacteria which enter legume roots and fix nitrogen is optimal at pH levels of 6.5 to 7.0 and declines rapidly when pH levels reduce below to 6.0.

2.4 Beneficial effects from liming soil

Dudal, (2002) reported that organic inputs are not substitutes for inorganic fertilizers as both inputs fulfill different functions. As a matter of fact, by definition, the term fertilizer applies to materials which contain at least 5% of one or more of the three primary nutrients in available form excluding most organic resources. While the main role of mineral inputs is to supply nutrients or correct unfavorable soil pH conditions, organic resources contain C, which drives finally replenishes the soil organic matter (SOM) pool.

2.4.1 Supply of nutrients from organic matter

Soil organic matter (SOM) is the most important indicator of soil quality and productivity and consists of a complex and varied mixture of organic substances. Organic matter increases soil porosity, thereby increasing infiltration and water-holding capacity of the soil, providing more water availability for plants and less potentially erosive runoff and agro-chemical contamination (Lal et al.,1998). Structure of the fine-textured soils may be improved by liming, as a results of increased soil organic matter content and enhanced flocculation of Ca- saturated clays.

Microbial activity and the cycling of nutrients through soil organic matter substantially impacts plant nutrient availability. The soil solution concentration of N, S, P and several micronutrients are intimately related to the organic fraction in soils (Havlin et al., 2005). Erich et al., (2002) noted that carbon (C)- containing residual materials, such as compost, biosolid, or manure, have the potential to increase soil organic matter levels to these and improve soil quality when added to these soils in significant quantities.

Phosphorus is a macronutrient that plays a number of important roles in plants. It plays a key role in energy transfer and thus it is essential for photosynthesis and other chemio-physiological processes in plants. Adequate phosphorus results in higher grain production, improved crop quality, greater stalk strength, increased root growth and early crop maturity (Havlin, et al., 2005). Lorry, (1999) stated that maximum availability of phosphorus generally occurs in a pH range of 6.0 to 7.0. Maintaining a soil pH in this range also favors the presence of $H_2P0_4^-$ ions which are more readily absorbed by plants. Lime also makes phosphorus that is added to the soil more available for plant growth and increases the availability of nitrogen by hastening the decomposition of organic matter (Adams, 1984).

Mitchell, (2000) stated that soils are limed to reduce the harmful effects of low pH (aluminum or manganese toxicity) and to add calcium and magnesium to the soil. The amount of lime needed to achieve a certain pH depends on the pH of the soil and the buffering capacity of the soil and also neutralizing value and particle size of lime. The buffering capacity is related to the cation exchange capacity (CEC). The higher the CEC, the more exchangeable acidity (hydrogen and aluminum) is held by the soil colloids. As with CEC, buffering capacity increases with the amounts of clay and organic matter in the soil. Soils with a high buffering capacity require larger amounts of lime to increase the pH than soils with a lower buffering capacity.

Crozier and Hardy (2003) also stated that increased soil CEC occurs, as well as reduced leaching of basic cations, particularly potassium. The soil CEC includes a number of pH-dependent sites that become available to hold cations as the pH increases. When these sites are occupied by strongly attached aluminum (low pH), any potassium added in fertilizer is more susceptible to leaching.

The research conducted by Whalen et al., (2002) revealed that the uptake of N, K, S, Ca and Mg in Canola grain and straw was greater from soils receiving lime and manure than fertilized soils, and the P uptake was higher in manure-amended soils than in soils that received lime or fertilizer only. The P uptake in wheat was greater in manure-amended soils than in fertilized or limed-amended soils than manure-amended and fertilized soils. Green and animal manures can increase P availability in soils and consequently improve P uptake by crops (Ohno and Crannell, 1996). According to Crozier and Hardy, (2003) plants develop healthier roots because they are exposed to reduced toxicity of aluminum and manganese. Better root growth may improve nutrient uptake and enhance drought tolerance. Optimal pH is conducive to the breakdown of some herbicides, preventing damage to rotational crop. Tendon, (1992) reported that animal manure neutralized soil acidity and supplied essential micronutrients. Carbon (C) containing residual materials , such as compost, biosolids or manure, have the potential to increase soil organic matter levels and improve soil quality when added to these soils in significant qualities. There is considerable evidence in the literature to suggest that the application of organic material to soil increase P solubility (Sanyal and De Datta, 1991).

Organic matter may be sorbed to soil particles at non-specific sorption sites, which would increase the surface negative charge of the particle. This would reduce the electrostatic attraction of P to the soil and keep more P in solution. In general, manure application increases both inorganic and organic soil P levels; many types of manure have a relatively high percentages of their total Pin inorganic forms. The research conducted by Erich et al., (2002) revealed that both amended and unamended soils contained levels of plant-available P within the range considered optimum for crop production, 7.5-20 mg/P/kg.

2.4.2 Phosphorus from kraal manure

Animal manures contain significant concentration of nitrogen (N) and phosphorus (P), and their utilization for crop production is beneficial in terms of nutrient recycling and reducing commercial fertilizer use. Manure serves both as a source of subsurface P and an effective mobilizing agent. Blockage of P sorption sites by organic acids, as well as complexation of exchangeable Al and Fe in the soil, are potential causes of this mobilization. Both added manure or litter and native organic matter have significant effects on subsurface P retention (Wandruszka, 2006). The application of manure is widely practiced to increase the productivity of soils that contain inadequate levels of organic carbon. The effects of manure on P availability in various soils has been widely studied, and the general conclusion has been that it is a source of P; interacts with soil components in a manner that increases P recovery by crops; and enhances the effectiveness of inorganic P fertilizer. P added from manure and other sources, however, tends to become less available to plants with the passing of time (Sample et al., 1980). As regards the eventual status of fertilizer P in soil, it is interesting to note that manure and mineral (KH_2PO_4) fertilizer appear to contribute to different P pools (Griffin and Honeycutt, 2003).

Chapter 3

3.0 MATERIALS AND METHODS

3.1 Site description

The field experiment was conducted at University of Zambia Farm (15˚21`-15˚24` S and 20˚27`-20˚28` E) during the 2010 and 2011 academic year. The site is situated at an altitude of 1140 m a.s.l. The soil is classified as mixed, fine-loamy, isohyperthermic Oxic Paleustalf (Verbruggen, 1984)

3.2 Treatments and experimental design

The experiment was in a split-split plot design laid out as 2 x 3 x 4 factorial . Two soil amendments were applied (agricultural lime, and kraal manure). Lime (dolomitic limestone) was applied at two rates 0 t/ha and 3 t/ha and for kraal manure the rates were 0 t/ha, 2.5 t/ha, 5 t/ha and 10 t/ha. Three levels of phosphorus as MAP (Mono Ammonium Phosphate) was applied in bands at rates of 0 kg/ha, 20 kg/ha and 30 kg/ha.

Lime levels (L0 and L3) as main plot treatments, four organic amendment levels for Kraal manure (K0, K2.5, K5 and K10) as sub plot and three phosphorus levels as sub-subplot treatments. Treatments were replicated three times. Maize was used as a test crop an inter row spacing of 0.75m by 0.30m intra-row. Individual plots (main plot) sizes was 180m^2 (9m x 20m) and the subplot measured 45m^2 (9m x 5m), and the total experimental area was 20m x 31m with 2m borders between the replications.

3.3 Data collection

Prior to planting initial levels of P, exchangeable bases (Ca^{2+} and Mg^{2+}) and Al^{3+}, organic carbon and soil pH were determined in soil.

At harvest plant height (cm), grain yield (kg/ha) and 100 seed weight; soil available P, exchangeable bases, Al, soil pH and plant analysis tissues were determined.

3.4 Soil Analysis

A composite sample from each treatment plot was then used in the analysis of soil pH, exchangeable Al, extractable P, organic matter and exchangeable bases (Ca and Mg). Soil reaction (soil pH) was measured in 0.01 M $CaCl_2$ at a soil: solution ratio of 1:2:5(Karla et al, 1991). Extractable P was extracted with Bray No: 1 method (Bray and Kurtz, 1945). Soil organic carbon was determined by using the Walkly-Black method (Walkley-Black, 1935). Exchangeable bases were extracted with a solution of neutral ammonium acetate and then measured in the filtrate by Atomic Absorption Spectroscopy (Kalra and Maynard, 1991). Exchangeable Al was measured in 1.0 M KCl (Black et al., 1978)

3.5 Kraal manure analysis

Kraal manure sample used was then analyzed for macronutrients, organic matter content, extractable P and exchangeable bases (Ca and Mg). Macronutrients in kraal manure were determined by wet destruction (Cottenie et al, 1982). Organic matter, extractable P and exchangeable bases were determined as for soils.

3.6 Plant analysis

Macronutrients in plant tissues were determined by wet destruction (Cottenie et al, 1982).

3.7 Analysis of data

All the data were subjected to analysis of variance (ANOVA) using the GenStat 13 edition discovery stastical package. The least significant difference (LSD) was used to separate the treatment means where there were significant differences.

Chapter 4

4.0 RESULTS

4.1 Introduction

Relevant chemical properties of the soil and kraal manure samples used in study are shown in Table 1. The soil was very acid (pH 3.88) and the soils were also characterized by low levels of calcium (0.56 cmol/kg) and magnesium (0.45 cmol/kg) and high concentration of exchangeable Al (0.92 cmol/kg). The kraal manure used in the study contained high amount of organic carbon (20.10 %), with optimum levels of calcium (7.50 %) and magnesium (3.25 %) and low P concentration (1.18 %).

A summary of analysis of variance for chemical soil properties is presented in Table 2. The results showed that there were significant treatments effects ($p<0.001$). The effect of interactions among the three treatments were varied. Lime x kraal manure interaction showed a highly significant increase in soil pH ($p<0.001$). The interaction of lime x P fertilizer was significant ($p<0.01$), while that between kraal manure x P fertilizer and the three way interactions were not significant. There were significant treatment effects of lime, kraal manure and P on soil Al. The interactions of lime x kraal manure, lime x P, kraal manure x P were significant ($p<0.01$) and three way interaction lime x kraal manure x P were significant ($p<0.05$). The results showed that there were significant treatment effects of lime x kraal manure ($p<0.05$), the interaction of kraal manure x P were significant ($p<0.001$), while there was a non significant difference on lime x P interaction and three way interaction on soil organic matter content. There were significant treatment effects of lime, kraal manure and P on soil calcium. The interaction of lime x P was significant ($p<0.05$), while there was a non significant difference of lime x kraal manure, kraal manure x P and three way interactions. The results showed that there was significant treatment effects of kraal manure x P ($p<0.01$) and three way interactions ($p<0.05$) on magnesium concentration, however there were non significant differences of lime x kraal manure and lime x P interactions.

Table 1: Initial soil and kraal manure analysis

Parameters	Soil	Kraal manure
Soil pH ($CaCl_2$)	3.88	-
Exchangeable Al (cmol/kg)	0.92	-
Calcium (cmol/kg)	0.56	0.08%
Magnesium (cmol/kg)	0.45	3.25%
Available P (mg/kg)	17.15	1.18%
Organic carbon (%)	0.72	20.1

Table 2: Summary of analysis of variance for some selected soil chemical properties

Source	df	pH	Al	O.M	Soil P	Ca	Mg
			(cmol/kg)				
Reps	2	ns	ns	ns	ns	ns	ns
Lime	1	***	***	ns	*	*	*
Error (a)	2	0.4183	0.001	0.346	1.86	0.41	
Kraal	3	***	***	***	***	**	***
Error (b)	12	0.069	0.0014	0.0169	37.66	0.3455	
Lime x krl	3	***	**	*	ns	ns	ns
Error(c)	32	0.0075	0.0004	0.01	17.71	0.06	
P	2	***	**	***	***	***	***
Lime x P	2	ns	**	***	ns	ns	**
Krl x P	6	***	***	ns	**	ns	*
Limex krlxP	6	ns	*	ns	ns	ns	*

ns= non significant, *=significant at 5% probability,**=significant at 1% probability, ***=significant at 0.1% probability level

4.2. The effects of amendments and P fertilizer on soil pH

Soil pH was significantly different ($p<0.001$) between lime levels. Soil pH at 0 t/ha of lime was 4.2 and application of lime at 3 t/ha increased the soil pH to 6.02. Significant differences ($p<0.001$) were observed among kraal manure levels on soil pH. Soil pH was higher (5.6) in plots amended with high level of kraal manure (10 t/ha) than with low (4.6) level (2.5 t/ha). Application of P fertilizer at 30 kg/ha increased soil pH up to 4 % compared to control.

The changes in soil pH depended on the addition of kraal manure and lime application rates as presented in Table 3. The result showed a significant increase in soil pH when kraal manure was applied alone at 10 t/ha. There was no increase in soil pH when kraal manure was applied at 2.5 t/ha and 5 t/ha compared to control. Lime applications of 3t/ha alone, or in combination with kraal manure increased soil pH. Soil pH varied with lime application. There was slight increase of soil pH with application of P at 20-30 kg/ha (Table 4). The data showed that addition of lime alone or in combination with P application rates gave a greater increase of soil pH than when P applied alone. Lime applied alone had an increase of soil pH up to 40%. Even though lime applied alone increased soil pH, the increase in soil pH when in combination with P at high rates showed that the increase was the effect from P fertilizer applied.

Table 3: Interaction of lime and kraal manure on the soil pH

Lime rates	**Kraal manure rates**				
	0t/ha	2.5t/ha	5t/ha	10t/ha	Mean
0t/ha	4.046	4.19	4.281	4.53	4.26175
3t/ha	5.21	5.848	6.218	6.746	6.0055
Mean	1.16	1.66	1.94	2.22	1.745
Interactions					
CV: 3.0 %					
Lsd(0.05) 0.504					

Table 4: Mean of soil pH for lime and phosphorus fertilizer application interaction at harvest.

Treatments	soil pH levels	Increase in %
control	4.18	0
0t/ha lime x 20kgP/ha	4.27	2.15
0t/ha lime x 30kgP/ha	4.34	3.83
3t/ha lime x 0kgP/ha	5.86	40.19
3t/ha lime x 20kgP/ha	5.99	43.3
3t/ha lime x 30kgP/ha	6.16	47.39
Lsd (0.05) =0.63		-

4.3 Effects of lime and kraal manure on Al

Lime reduced exchangeable Al. The reduction at higher level was up to 100 % compared to control. Kraal manure significantly decreased exchangeable Al up to 100 % at highest rate (10 t/ha). Addition of P fertilizer decreased exchangeable Al up to 0.01 cmol/kg at 20 kg/ha and 0.02 cmol/kg at 30 kg/ha. The changes in exchangeable Al that occurred in the soil after the application of kraal manure and lime are given in Table 5. Lime and kraal manure reduced the levels of exchangeable Al in the soil. The results showed a reduction in exchangeable Al with more than 2.5 t/ha of kraal manure, while there was no further significant decrease on exchangeable Al at 5 t/ha and 10 t/ha. Lime applied alone or in combination with kraal manure reduced exchangeable Al compared to control. Lime application alone was more effective in reducing exchangeable Al (greater than 100 % reduction).

4.4 The effects of Lime and P fertilizer application on exchangeable Al

Exchangeable Al varied with rates of lime and P fertilizer application (Figure 1). The reduction of exchangeable Al was more at the higher rates of P fertilizer application compared to control. With 3 t/ha of lime, the reduction in exchangeable Al compared to fertilized plot was more than 100 % compared to kraal manure. These data show that the effect of lime alone in reducing the level of exchangeable Al in the soil was significant. The changes in exchangeable Al that occurred in the soil after the application of kraal manure and P fertilizer are given in Figure 2. Kraal manure and P fertilizer significantly reduced the levels of exchangeable Al compared to control. At the rate of 20 kg/ha the reduction was 40 % and 75 % at the rate of 30 kg/ha compared to control. These data showed that P fertilizer alone was also effective in reducing the level of exchangeable Al.

Table 5: Effect of kraal manure and lime interaction on exchangeable Al in soil solution.

Lime rates	**Kraal manure rates**				
	0t/ha	2.5t/ha	5t/ha	10t/ha	Mean
0t/ha	0.1644	0.1467	0.08	0.08	0.11778
3t/ha	0.05	0.04	0.03	0.02	0.035
Mean	0.11	0.11	0.05	0.06	0.08
Interaction					
CV %=28.1					
Lsd(0.05)=0.04					

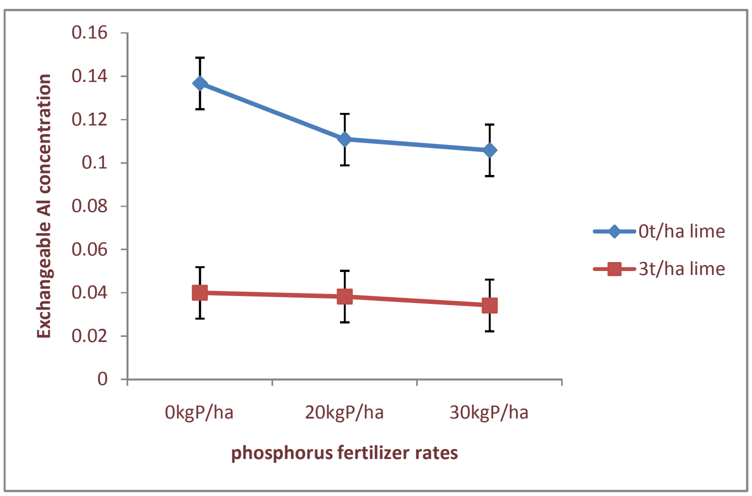

Figure 1: Effect of lime and P fertilizer on exchangeable Al. The bars in the graph represent least significant difference (LSD) at ($p<0.05$)

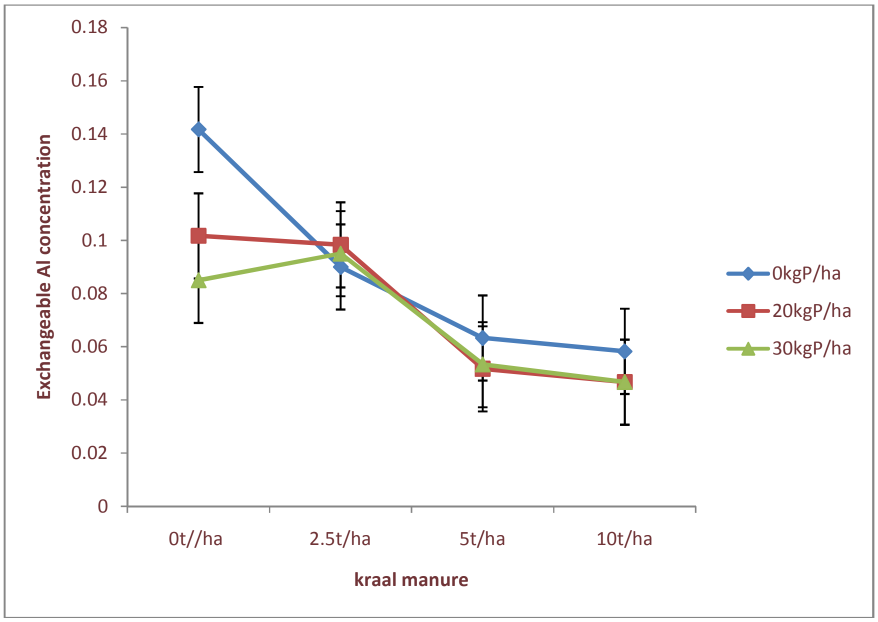

Figure 2: Effect of kraal manure and phosphorus fertilizer interaction on exchangeable Al concentration in the soil. The bars in the graph represent least significant difference (LSD) at ($p<0.05$)

4.5 The effect of amendments and P fertilizer on soil organic matter

Lime had effect on increasing the soil organic matter. Kraal manure and P significantly increased the soil organic matter content. Changes in soil organic matter content depended on the addition of kraal manure and lime rates as shown in Figure 3. There was a significant increase in organic matter content between control and 10 t/ha of kraal manure while there was no increase in organic matter between the 2.5 t/ha, 5 t/ha and 10 t/ha when kraal manure was applied without lime. There was a non significant increase of organic matter content in the soil when lime was combined with kraal manure. Levels of organic matter increased with the level of lime irrespective of kraal manure applied. At a higher rate of lime organic matter increased compared to control. The changes in soil organic matter content that occurred in the soil after application of kraal manure and P are shown in Figure 4. Soil organic matter varied with kraal manure and P application rates. Soil organic matter increased when P was applied together with kraal manure but at higher rate of 10 t/ha.

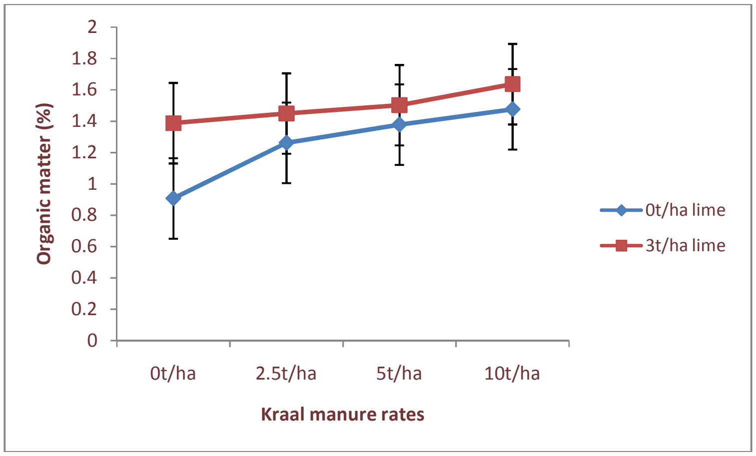

Figure 3: Effect of kraal manure and lime application on organic matter content. The bars in the graph represent least significant difference (LSD) at ($p<0.05$)

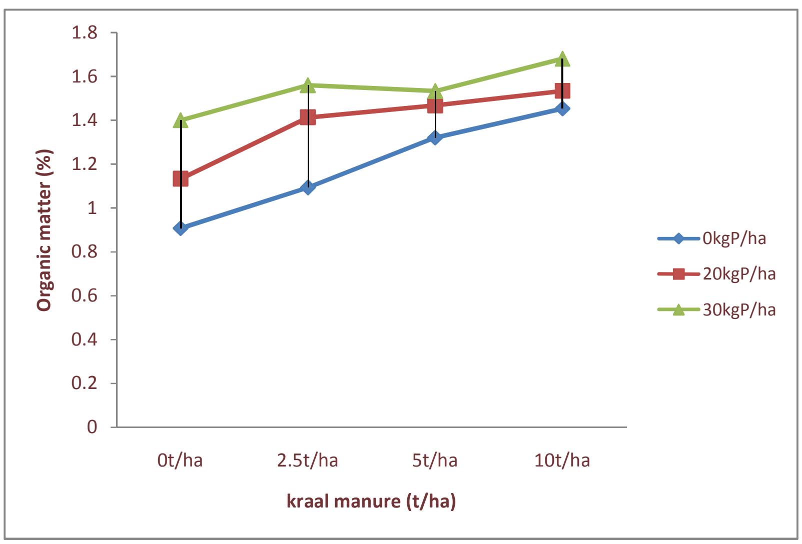

Figure 4: Effect of kraal manure and P application on organic matter content. The bars in the graph represent least significant difference (LSD) at ($p<0.05$)

4.6 Influence of lime, kraal manure and P fertilizer on soil available P

Lime, kraal manure and P fertilizer application rates applied alone significantly increased available P in the soil (Table 6). Applied lime increased available P in the soil by unlocking the residual P. Increase in available P when kraal manure was applied was expected because the extra P came from kraal manure which contained 1.18 % of P (Table 1). There was an increase in available P at 20 kgP/ha and additional in increase at 30 kgP/ha when P was applied alone. There is a significant increase in available P across the levels of kraal manure application. Increase in the rate of P fertilizer resulted in more increase in available P in the soil by 59.78 % at the highest rate which was the highest value compared to that of lime and kraal manure at high rates.

4.7 Effect of kraal manure, lime and P fertilizer combination on calcium availability

Kraal manure increased soil exchangeable calcium at the high rate of application (Table 7). The increase of exchangeable calcium was minimum at 2.5 t/ha compared to the highest rates of kraal manure. Soil exchangeable calcium varied with lime and P application rates. Calcium increased when lime was applied together with high rates of P fertilizer. Calcium content increases only when P was applied in combination with lime (Table 8).

The changes in soil magnesium that occurred after the application of kraal manure and P fertilizer are given in Table 9. Changes in magnesium content increased with the increasing levels of P when combined with kraal manure. When P was applied alone there was a non significant increase in magnesium content irrespective of the application rate. At 2.5 t/ha the higher rate of P applied increases exchangeable magnesium more than the higher rates of kraal manure (5 t/ha and 10 t/ha).

4.6.1: Effects of lime, kraal manure and P fertilizer on exchangeable Al and Mg concentration

The application of lime, kraal manure and P fertilizer decreased exchangeable Al. Lime was used as control, kraal manure and P fertilizer decreased the exchangeable Al without lime, overall there was a decline in Al irrespective of P fertilizer level applied. When no lime was applied there was a sharp decline in exchangeable Al at the high level of P application. There was a reduction in exchangeable Al at high rate of kraal manure irrespective of P fertilizer applied. There was further reduction of exchangeable at the high rate of lime regardless of P fertilizer applied.

Table 6: Mean values for plant available soil P from various treatments of lime, phosphorus fertilizer and kraal manure amendment applied alone

	Available soil P	
Treatments	mg/kg	Increase in %
Lime (0 t/ha)	32.41	0
(3 t/ha)	33.49	3.33
Phosphorus (0kg/ha)	25.31	0
(20 kg/ha)	33.1	30.78
(30 kg/ha)	40.44	59.78
kraal manure(0 t/ha)	25.47	0
(2.5 t/ha)	31.55	23.87
(5 t/ha)	35.31	38.63
(10 t/ha)	39.47	54.97

Table 7: Mean soil exchangeable calcium concentration for kraal manure application rates

Treatments	Calcium concentration	Increase (%)
0 t/ha kraal manure	1.23	0
2.5 t/ha	1.29	4.89
5 t/ha	1.63	32.52
10 t/ha	2.02	64.23
Lsd(0.05)= 0.43		

Table 8: Increase in calcium concentration in the soil due to lime and phosphorus fertilizer interaction.

Lime rates	P fertilizer rates			
	0kg/ha	20 kg/ha	30kg/ha	Mean
0 t/ha	0.874	0.993	0.329	0.73
3 t/ha	1.59	2.072	2.397	2.02
Mean	0.72	1.08	2.07	1.29
Interaction				
Lsd(0.05) = 0.52				

Table 9: Changes in magnesium concentration in the soil due to kraal manure and phosphorus fertilizer interaction.

Lime rates	P fertilizer rates			
	0 kg/ha	20 kg/ha	30 kg/ha	Mean
0 t/ha	0.473	0.555	0.565	0.531
2.5 t/ha	0.583	0.76	1.033	0.792
5 t/ha	0.783	0.95	1.201	0.978
10 t/ha	0.882	1.05	1.167	1.033
Mean	0.68025	0.82875	0.9915	0.8335
Interaction				
Lsd(0.05) :0.22				

4.8 Nutrient concentration in maize grain

The summary of analysis of variance for plant tissues is shown in Table 10. The data showed that there were significant treatment effects of lime and P ($p<0.05$) and highly significant for kraal ($p<0.001$), lime x P ($p<0.05$), kraal manure x P ($p<0.001$) and three way interactions ($p<0.05$). Lime x kraal manure was non significant on grain P. Lime x P fertilizer interaction was significant at ($p<0.01$) and kraal manure x P were significant ($p<0.001$) on calcium uptake by maize grain. However, there were non significant differences on lime x kraal manure and three way interaction. The results showed that there were significant treatment effects on three way interaction on grain magnesium. There were significant treatment effects of kraal manure x P ($p<0.01$) on stover P, while there was non significant differences of lime x kraal manure, lime x P and three way interactions. There were significant effects of kraal manure ($p<0.05$) and P was also significant ($p<0.001$) on stover calcium, while there was no significant difference on interactions. The results showed that there was significant treatment effects on kraal manure x P ($p<0.05$) while there were no significant differences on lime x kraal manure, lime x P and three way interaction on stover magnesium.

Phosphorus content in grain from plots treated with lime and P are given in Figure 5. Application of P increases grain P content as expected on P deficiency soil and, the uptake increases further when lime was applied except at the high rate of P application. The changes in grain P content depended on addition of kraal manure and P application rates as shown in Figure 5. P uptake increases with application of high rates of P when kraal manure was applied compared to when P applied without kraal manure.

Table 10: Summary of analysis of variance for plant tissue composition (%)

Source	df	Grain P	Grain Ca	Grain Mg	Stover P	Stover Ca	StoverMg
Reps	2	ns	ns	ns	ns	ns	ns
Lime	1	*	**	ns	*	ns	ns
Error (a)	2	0.013	0.023	0.089	0.0053	0.0118	0.0777
Kraal	3	**	***	***	**	*	***
Error (b)	12	0.0043	0.0389	0.02	0.0028	0.0037	0.0092
Lime x krl	3	ns	ns	ns	ns	ns	ns
Error(c)	32	0.0081	0.0313	0.008	0.0008	0.0023	0.0054
P	2	*	***	***	***	***	***
Lime x P	2	*	**	ns	ns	ns	ns
Krl x P	6	***	***	ns	**	ns	*
Lime krl xP	6	*	ns	*	ns	ns	ns

ns= non significant, *=significant at 5% probability,**=significant at 1% probability, ***=significant at 0.1% probability level

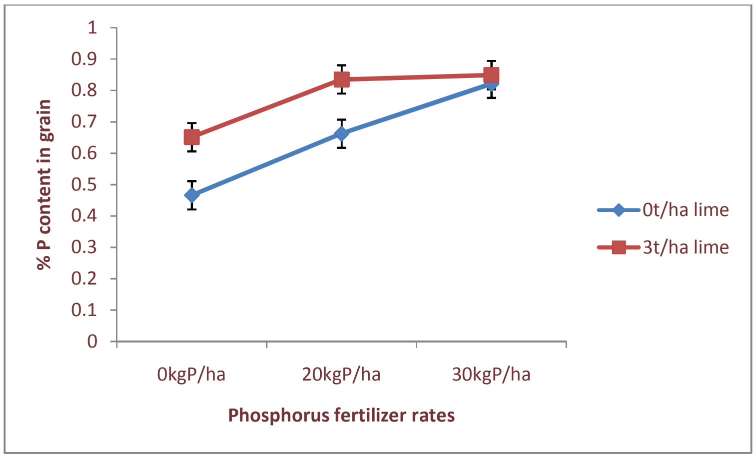

Figure 5: Effect of lime and P fertilizer on phosphorus concentration in maize grain. The bars in the graph represent least significant difference (LSD) at ($p<0.05$)

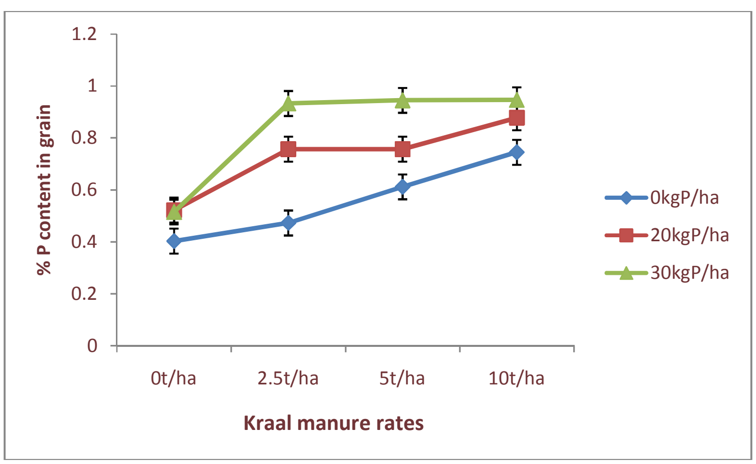

Figure 6: Effect of kraal manure and P fertilizer on phosphorus concentration in maize grain. The bars in the graph represent least significant difference (LSD) at ($p<0.05$)

The increase in grain calcium content depended on the addition of lime and P fertilizer application rates as shown in Figure 7. Application of P at higher rates without lime increased grain calcium uptake, whereas when lime was applied with P at the higher rate (30 kg/ha) there was a non significant increase. Grain calcium content varied with P and kraal manure application rates (Table 11). There was an increase in grain calcium content when P fertilizer was applied alone at 30 kg/ha. The uptake increased further when kraal manure was combined with P application rates. Addition of kraal manure at 10t/ha increases magnesium at lower rate of P (0 kgP/ha).

Kraal manure and P fertilizer application rates increased the P content in stover (Table 12). There was a small increase in P content when P was applied at 20 kg/ha and 30 kg/ha without kraal manure. The applications of P increased the P uptake further when kraal manure was applied specially at the high rate of P application (30 kg/ha). At 0 t/ha there was significant increase of P uptake between 0 kgP/ha and 30 kgP/ha.

The increase in magnesium content in stover depended on the addition of Kraal manure and P application rates as shown in Table 13. There was a slight increase in magnesium uptake when P fertilizer was applied without kraal manure. Magnesium content increased when P was applied together with kraal manure at the high rate of kraal manure. There was no increase in magnesium uptake at the 0 kgP/ha across kraal manure application rates. There was no significant increase between 0 kgP/ha and 20 kgP/ha from 0 t/ha to 5 t/ha of kraal manure.

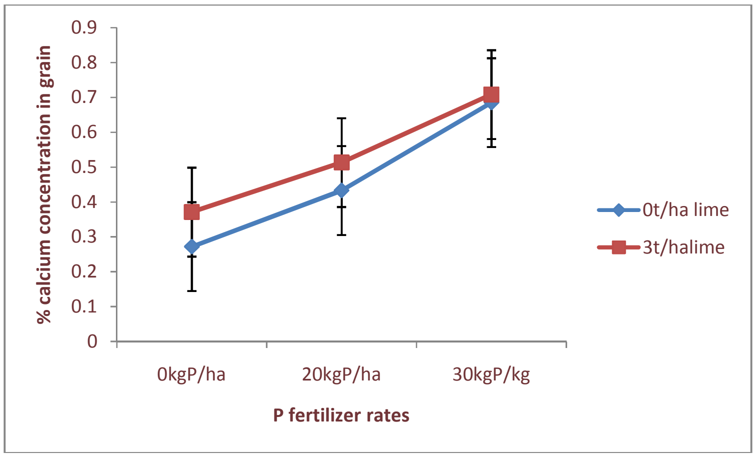

Figure 7: Effect of lime and P fertilizer on calcium concentration in maize grain. The bars in the graph represent least significant difference (LSD) at ($p<0.05$)

Table 11: Effect of kraal manure and P fertilizer on calcium concentration in maize grain.

Kraal manure rates	**P fertilizer rates**			
	0kg/ha	20kgP/ha	30kgP/ha	Mean
0t/ha	0.195	0.27	0.49	0.32
2.5t/ha	0.25	0.47	0.66	0.46
5t/ha	0.318	0.5	0.73	0.517
10t/ha	0.523	0.65	0.90	0.68
Mean	0.32	0.47	0.69	0.497
Interaction Lsd (0.05) = 0.13				

Table 12: Effect of kraal manure and P fertilizer on P concentration on maize stover

Kraal manure rates		**P fertilizer rates**		
	0kg/ha	20kgP/ha	30kgP/ha	Mean
0t/ha	0.081	0.103	0.136	0.107
2.5t/ha	0.08	0.112	0.156	0.116
5t/ha	0.073	0.138	0.185	0.132
10t/ha	0.106	0.163	0.243	0.171
Mean	0.085	0.129	0.180	0.131
Interaction Lsd (0.05) = 0.045				

Table 13: Effect of kraal manure and P fertilizer on magnesium concentration on maize stover.

Kraal manure rates		**P fertilizer rates**		
	0kg/ha	20kgP/ha	30kgP/ha	Mean
0t/ha	0.147	0.19	0.27	0.20
2.5t/ha	0.155	0.25	0.405	0.27
5t/ha	0.22	0.285	0.45	0.320
10t/ha	0.198	0.385	0.575	0.386
Mean	0.180	0.278	0.425	0.295
Interaction Lsd (0.05) = 0.10				

4.9 Effects of amendments and P fertilizer application on yield and yield components

The summary of analysis of variance of yield and yield components is shown in Table 14. The Kraal manure x P fertilizer interaction showed a significant influence on grain yield ($p<0.001$) and the three way interaction was significant ($p<0.001$), while that between lime x kraal manure and lime x P were non significant. The results showed that there were significant treatment effects of lime x kraal manure ($p<0.001$),lime x P ($p<0.001$) and three way interactions ($p<0.001$), while there were non significant treatment effects on kraal manure on plant height. There were significant treatment effects on kraal manure ($p<0.01$) and P ($p<0.001$), while that between interactions were not significant on 100 seed weight.

Grain yields from plots treated with kraal manure and P are given in Figure 8. There was an increase in grain yield with the increase in P application rates when P was applied without kraal manure. At the rate of 2.5 t/ha of kraal manure application there was no increase in grain yields at the higher rates of P (20 kg/ha and 30 kg/ha), while there was an increase in grain yields when 5 t/ha of kraal manure was combined with P application rates. The pattern was the same for 0t/ha and 5 t/ha of kraal manure. However, at 10 t/ha of kraal manure the yield become the same irrespective of P application rate. Kraal manure application at higher rate (10 t/ha) contributed to grain yield. Changes in plant height depended on the applications of lime plus kraal manure plus P fertilizer rates (Table 15). The results show that plant height increased with the increase in kraal manure and P fertilizer rates without lime. Plants were taller at the high rate of kraal manure (10 t/ha) without lime. Plants on the lime-amended plots were remarkably shorter compared to plants on unlimed plot. The effect of P was not seen when lime was applied. The data show that lime was not effective in increasing plant height regardless of kraal manure and P application rates.

Table 14: Summary of analysis of variance for yield and yield components

		kg/ha	cm	kg/ha
Source	**df**	**Grain yield**	**Plant height**	**100 seed weight**
Reps	2	ns	ns	ns
Lime	1	ns	ns	ns
Error (a)	2	2549895	921.5	163.35
Kraal	3	***	ns	**
Error (b)	12	363738	240.3	84.28
Lime x krl	3	ns	***	ns
Error(c)	32	77584	160.1	51.16
P	2	***	***	***
Lime x P	2	ns	***	ns
Krl x P	6	***	ns	ns
Limex krlxP	6	***	***	ns

ns= non significant, *=significant at 5% probability,**=significant at 1% probability, ***=significant at 0.1% probability level

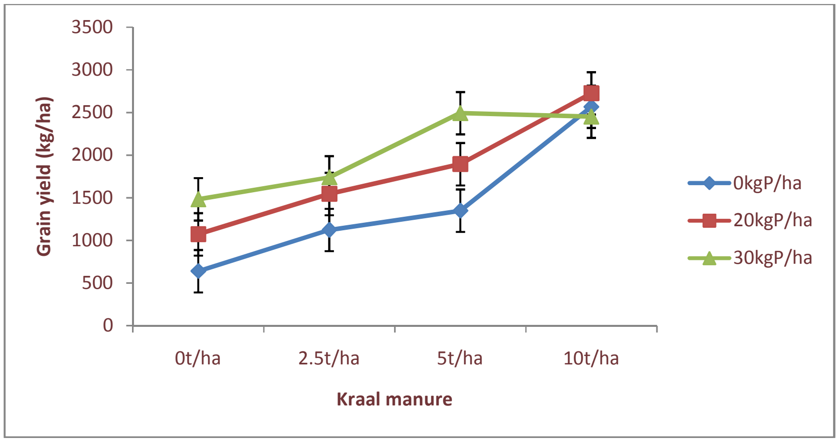

Figure 8: Effect of kraal manure and P fertilizer application on grain yield. The bars in the graph represent least significant difference (LSD) at (p<0.05)

Table 15: Effect of lime, kraal manure and P on plant height.

Lime rates	**Kraal manure rates**	**Phosphorus fertilizer rates**			
0t/ha	0 t/ha	0 kg/ha	20 kg/ha	30kg/ha	Mean
	2.5 t/ha	122	124	141.8	129.26
	5 t/ha	96.5	125.8	130.2	117.5
	10 t/ha	115	133.2	140.7	129.63
2t/ha	0 t/ha	109.7	140.9	170.7	140.4
	2.5 t/ha	142.3	153	142.3	145.8
	5 t/ha	133.2	132.5	154	139.9
	10 t/ha	127.7	156.8	135.3	139.9
	Mean	120.91	138.02	145	134.64
	Interaction CV: % 9.6 Lsd(0.05)= 39.07				

4.10. Relationship of Grain yield to Exchangeable Al, Soil pH, Ca, Mg, Soil available P and Organic Matter

The relationship between grain yield and some selected soil parameters are highly significant at ($p<0.001$) probability level. The increase in organic matter and soil pH had a positive relationship on increasing yield, while exchangeable Al and Ca had a negative effect, data presented in Table 16.

Table 16: The correlation between grain yield (kg/ha) and selected soil parameters.

Parameters	Correlations
Exchangeable Al	-0.795***
Soil pH	0.529***
Exchangeable Ca	-0.547***
Soil Organic Matter	0.072***

Chapter 5

5.0 DISCUSSION

In acid soil with low soil pH, P is fixed by other elements (iron and aluminum). When P is fixed is not available for plant uptake. Available P in this study was adequate in unamended soils, reflecting long-term additions of P to these relatively acid soils. The plant available P for the soil used was 17.15 mgP/kg, reflecting accumulation from long term additions of P to these relatively acid soils. Whalen et al., (2001) reported that optimum plant available P within for crop production ranged between 7.5-20 mgP/kg.

Amelioration of acid soils by liming or incorporating organic matter is an accepted agronomic practice for the tropical soils. Application of amendments on acidic soils increased soil pH and reduced aluminiumaluminum toxicity. The increase in soil pH as a result of liming would improves the soil environment for crop growth (Curtin and Smillie, 1995). Liming is a common method for raising soil pH and ameliorating phytotoxicity in acid soils. Effects of liming on soils include, increased soil pH, Ca and Mg saturation, decrease concentration of aluminum, increased P availability and nutrient uptake by plants (Oluwatoyinbo et al., 2009). The application of a combination of kraal manure and lime at high rates of 10t/ha kraal manure and 3t/ha lime increased soil pH by to 73.86% compared to lime alone (54.76%) or kraal manure (45%) alone.when they were applied alonetoto Addition of soil amendments to acid soil increased plant growth and resulted in yield increase. Anetor et al., (2006) also observed favorable pH changes in soil when lime was applied to soya bean. These results showed that the combination of lime and kraal manure at the high rates of 3t/ha lime and 10t/ha kraal manure can be effective in improving soil quality and benefit farmers through increased yield of crops.

There was an increase in soil pH in combination of the lime and P. when lime was interacted with P fertilizer. LanderenLime plus P does not add any organic matter in to the soil, these results had negative influence on available P. Treatments weretpreviouslyissThere was a general increase in soil pH fromby application of lime and P either alone or in combination. Lime application alone increased the soil pH from an initial 3.88 to pH 6.0 while addition of P fertilizer increased it to pH 5.2. The combination increased soil pH to 6.2. Liming has been reported to be a common practice of raising soil pH and ameliorating element phytotoxicity in acid soils. Adams, (1984) reported that lime also madekes phosphorus that wasis added to the soil more available for plant growth and increase the availability of nitrogen by hastening the decomposition of organic matter. The result showed that P fertilizer can have a positive effect when used as inorganic amendment to ameliorate soil acidity.

The significant decrease in exchangeable Al that occurred in acid soil used in this study were the soil was a result of addition of calcium and magnesium from lime and kraal manure. Hue, (1992); Warren and Fonteno, (1993); Iyamuremye et al., (1996); O'Hallorans et al., (1997); Wong et al., (1998) reported that there wasis evidence that organic residues from green and animal manures couldcan also ameliorate soil acidity and increase pH of acid soils and improve soil fertility by enhancing the supply of nutrients for crop uptake.

Addition of kraal manure to soils resulted in an initial decrease in exchangeable Al concentration. Haynes and Mokolobate (2000) reported that the decrease in exchangeable Al was not necessarily a function of the rise in pH. This is consistent with the result of this study as there was a slight increase in soil pH up to 11% at 10t/ha kraal manure and the decrease in Al concentration was more than 100%. Patiram (1996) observed that application of farmyard manure, in a field experiment, decreased exchangeable Al during the first 75 days after application but soil pH was, however, unaffected by this treatment. The effects of kraal manure and lime were similar in reducing the exchangeable Al up to 100% at high rates. The results were consistent with those obtained by Hue (1990) who reported that the effects of manure and lime were similar in all soils, reducing the exchangeable Al up to 100% in all acid soils. The reduction in exchangeable Al concentration is explained partly by the increase kraal manure and P application rates in soil pH but the greater part was due to lime application.

Addition of P fertilizer alone also had a significant reduction on reducing exchangeable Al. Application P fertilizer greater than 20 kgP/ha decreased exchangeable Al by 26%. The reduction of exchangeable Al was also observed when P was incorporated toecorded seedlings by Havlin et al., (2005) who reported that one short-term management strategy for reducing Al^{3+} toxicity to seedlings was tois band application of P fertilizer in the seedbed. Band application of P at the time ofwheat planting wheat dramatically reduceds Al^{3+} toxicity and increased wheat yield. These findings were not in agreement with The et al., (2001) who observed that the application of soil amendment with phosphorus tended to increase in Al and H and a decrease in CEC. Matsumoto et al., (1976) have shown that P and Al are localized in the same sites in roots of plants suffering from Al toxicity. The accumulation of Al and P within the root-free space suggests precipitation of aluminophosphates within the free space and/or adsorption of phosphates by hydroxyl-Al polymers already precipitated. However, application of high amount of P fertilizer in the acid soils can be associated with the ability of the roots to uptake P more than Al for root growth and development. In our situation where acid soils are also deficient in P, it may be prudent to increase P fertilizer rates which will reduce Al toxicity.

The combination of lime and kraal manure increased soil organic matter content. These results confirmed that the combination of the kraal manure and lime resulted in significantly increased soil organic matter content at higher rates. Erich et al., (2002) also observed that the addition of compost, animal manure and green manure to the amended soil increased the level of soil organic matter. Application of kThis showed thatkraal manure can beis important strategy to increase the soil organic matter content especially at high rate (10 t/ha). Other researchers have reported that organic matter increases the fertility of the soil, lowers soil bulk density, improves water infiltration, aeration and have positive influence on soil structure. Moshi et al., (1974) reported that organic matter also inhibits P fixation by either physically blocking adsorption sites or through the competition for adsorption sites by organic anions. Therefore, soil organic matter can be an effective organic amendment to avail P for plant uptake as it blocks P fixation sites at higher rates of application.

Lime increased soil organic matter by creating a favorable environment for microorganism to decompose the plant residues. Spies and Harms, (2007) reported that soil microorganisms do not function effectively in acid soils. As soil pH becomes acid so does the activity of the organisms which decompose organic matter, releasing nutrients to plants. The results also confirm the importance of increasing soil organic matter in agricultural production systems especially for acid soils in the tropics. Management of soil organic matter include addition of manures to the soil, return of crop residues after harvest and avoiding bush burning. There are, however , challenges to address this issue where there is competition for crop residues with livestock.

Liming the soil unlocked residual P for plant uptake. Agricultural~~Dolometic~~ lime ~~-~~contains calcium and magnesium and this explains the observed increased in Ca and Mg in limed plots. However, increased~~in~~ P was clearly the result of unlocked~~ P~~ residual P from~~in~~ the soil after application of lime. When the soil is acid P is fixed and is not available for plant uptake. Haynes and Mokolobate (2000) reported that highly weathered acid soils often have deficient levels of plant available P and also contain large quantities of Al and Fe hydrous oxides, resulting in the ability to adsorb large quantities of added P. The results of this~~e~~ study have shown that soil reaction (pH) is the single most important management factor for~~of~~ controlling~~ the~~ available P in soil. In most tropical soils more than half of the applied fertilizer is P as most soils are deficient in it. These results suggest that most of P fixed by Al can be unlocked by application of 3t/ha of lime and this practice can result in reducing the cost of purchasing phosphate fertilizer.

Additions of kraal manure to acid soils in order to minimize the need for lime and fertilizer P would be of considerable benefit to resource- poor farmers at greater than 2.5 t/ha. Kraal manure generally contains significant quantity of P which is released through mineralization of soil organic matter during the decomposition. However, the data showed that 10t/ha kraal manure did increase available P at harvest more than 50%. Ohno and Crannel (1996) reported that green and animal manures could increase P availability in soils and consequently enhance P uptake by crops. The results suggest that increasing soil pH is responsible for improving crop production on acid soils, and manure application helps to maintain soil organic matter content and improve soil physicochemical properties for optimum plant growth. Animal manures contain significant concentration of nitrogen (N) and phosphorus (P), and their utilization for crop production is beneficial in terms of nutrient recycling and reducing commercial fertilizer use (Wandruszka,2006).

Phosphorus deficiency in most tropical soil has influenced the use of phosphate fertilizers. The use of P fertilizer in acid soils is the common practice as the soils are low in plant available P being fixed by Al and Fe. The results obtained from this study showed that different application rates of phosphorus fertilizer significantly increased available P. At the high rate 30 kgP/ha the increase in available P was 59.77%. Similar results were obtained by Beckie and Ukrainetz, (1995) reported that soil P levels were highest in those plots that had received the highest rate of P fertilizer in the past cropping year and lowest in the unfertilized plots. In acid soils to provide an adequate supply of P to crops, high inputs are needed, which is not an economically viable option for resource poor farmers. When P fertilizer is applied with lime or kraal manure, application rates for P will be lower compared to when applied alone.

Lime and P fertilizer combination increased the exchangeable Ca by more than 100%. The agricultural lime used in the study contained Ca and Mg. Havlin et al, (2005) reported that the primary Ca sources are liming materials such as $CaCO_3$, $CaMg(CO_3)_2$ and others that are applied to neutralize soil acidity. The overall effects of lime on soils include among other, increase in soil pH, Ca and Mg saturation increase in P availability and improved nutrient uptake by plants (Oguntoyinbo et al., 1996).

Application of kraal manure as organic amendment help in increasing soil pH which resulted in addition of Ca and Mg in the soil. When the soil is acid there is low content of exchangeable Ca and Mg in the soil. The reduction of exchangeable Al which occurred after the application of kraal manure also has an influence on increase in Ca content in the soil more especially at high rate. In Top Crop Manager (2010) they have found that increased in soil pH by applying cattle manure is due to the presence of calcium carbonates and organic acid in manure. Kraal manure is a source of most essential plant nutrients and , hence it is a complete fertilizer for sustainable production of maize and other crops provided conditions are favorable for the release of these nutrients in simple inorganic ionic forms for plant uptake. In this study the application of kraal manure alone increased exchangeable Ca by 64% at higher rate 10 t/ha. There was significant increase in exchangeable calcium across the kraal manure application rates. This may be due to extra Ca in the kraal manure applied. The chemical composition of kraal manure can be variable and depends on the ration and additives added to livestock feed and so these results are not a prescription for all situations.

The response of ~~M~~maize ~~hasded~~ to phosphorus fertilizer was greater when P was combined at the highest rate of kraal manure. The significant response of maize to application of kraal manure suggests that there are other beneficial effects of kraal manure besides the supply of P. The ~~R~~response of maize to phosphorus also varied depending upon the rate of application.

Combination of kraal manure and P fertilizer resulted in greater yield increase~~ at the higher rates as the yield decreased at the high rate of phosphorus (30kgP /ha)~~. These results showed that application of P fertilizer above 20 kgP/ha was not necessary when 3 t/ha of lime and 10t/ha of kraal manure were combined. However, in this study, application of 10 t/ha of kraal manure alone had a markedly beneficial effect on P uptake. The results were consistent with the results obtained by Whalen et al., (2002) who reported that the P uptake in wheat was greater in manure-amended soils than in soils that received lime or fertilizer only. The beneficial effect of kraal manure is largely related to reduction of exchangeable Al which otherwise tend to restrict phosphate uptake by plants and also increased marginal soil pH (11%). Kraal manure was an adequate substitute for nutrient element P. The results are not in line with what Goss and Stewart (1979) observed in their study that plants grown in superphosphate-amended soil removed a higher percentage of added P than in manure-amended soil.

The application of different levels of kraal manure and P fertilizer significantly influenced the calcium and magnesium uptake by plants. Higher uptake was observed with 10 t/ha of kraal manure and 20 kgP/ha than other levels. Maize is a heavy feeder of calcium and magnesium, and it responded well to the increase of exchangeable cations in soil solution. Spies and Harms, (2007) reported that calcium, magnesium and potassium are essential nutrients for plant growth and their uptake by plants and subsequent removal through harvest can have an acidifying effect on soils.

The P application had much greater effect on maize grain yield than on nutrient concentration in the grain. Russell (1973) has stated that the concentration of cations in most plant tissues was~~is~~ a function of the crop itself and fairly independent of the soil or fertilizer. It was observed in this study that P, Mg and Ca accumulation in the maize ~~grain~~ was greater in grain than in the stover. The increase in uptake of the nutrient elements was due to the reduction of exchangeable Al toxicity in the soil. Hue (1990) reported that inorganic P fertilizer was utilized more effectively by crops when applied in conjunction with organic inputs such as green manure and animal waste, probably by reducing P sorption capacity and increasing P concentration in the equilibrium solution.

The increase in grain yield was due to addition of amendments and optimal P fertilizer to ameliorate soil acidity and increase nutrient uptake. The results of this study were consistent with those reported by Tasneem et al, (2004) showed that use of farmyard manure and sometimes in combination with inorganic fertilizers gave maximum grain yields. The combination of kraal manure and P fertilizer resulted in increased in grain yield of the maize crop and improved uptake of mineral nutrients by the plants. In comparison, on this soil the application of 20 kgP/ha in combination with 10 t/ha of kraal manure produced more than 100% increase in grain yield. The application of 20 kgP/ha alone increased yielded by 67.5% while 10 t/ha of kraal manure alone gave 75%. These yield increases suggest that the greatest effect was from kraal manure which is expected from degraded soils, as at 10t/ha the yield was the same irrespective of P fertilizer application rate.

There was a significant treatment effect on crop height. The small effect of lime combined with kraal manure and P fertilizer on plant height is not in line with the results obtained by Oluwatoyinbo et al., (2005) which showed that plant height was significantly increased by the application of all rates of lime and P applied either singly or in combination in the field study. Plants from lime-amended soils were remarkably shorter than from manure-amended and P fertilized plants. It was observed that combination of 30 kgP/ha with 10 t/ha of kraal manure without lime increased plant height significantly. This is a confirmation that abundant nutrient supply especially N, P and K is directly correlated to growth. Soil amended with kraal manure and inorganic P fertilizer produced taller plants. The results are consistent with Akinride et al 2004 who conducted research on Nigerian Alfisols and found that farmyard manure and inorganic fertilizers produced taller plants.

Plant height increased with increase levels of phosphorus as P is essential for vigorous growth and development of reproductive parts. Similar results were obtained by Arya and Singh (2001) and Bakhsh (1997) who reported that plant height increased with increased level of phosphorus. Change in exchangeable Al and soil pH were more correlated to grain yield than change in soil organic matter and exchangeable Ca. Soil data taken at harvest revealed that grain yield increased was attributed to the significant decrease in exchangeable Al and to the increase in soil pH and soil organic matter after application of lime, kraal manure and P fertilizer either alone or in combination. This results are in line with what Raij and Quaggia (1997) observed that change in exchangeable Al was more correlated to grain yield than Ca content and soil pH. Correlation analysis showed that maize yield was highly correlated with exchangeable Al and soil pH.

However, exchangeable Al and soil pH were found to be the most dominant soil variables for maize yield prediction on acid soils of the University of Zambia Farm.

Chapter 6

6.0 CONCLUSION AND RECOMMENDATIONS

Soil acidity and the associated Al toxicity, P, Ca and Mg deficiencies are the major constraints to increased crop production in the tropics. Agricultural lime alone is effective in ameliorating these constraints. ~~Kraal manure is a source of organic matter, which can improve soil physical and chemical properties for better crop production conditions.~~ Application of lime alone at 3 t/ha or in combination with kraal manure at 10 t/ha was the most effective strategy to ~~as soil amendment to~~ increasing~~e~~ soil pH and ameliorat~~e~~e ~~alu~~aluminum~~nimium~~ toxicity and this result in vigorous ~~on the~~ growth of maize in acidic soil. Al~~Even~~ though kraal manure alone has a positive effect on soil properties, lime ~~still stands a better chance to be~~is better as it quickly increases the soil pH to the levels where plants are able to uptake most essential nutrient elements for plant growth. Furthermore, the results showed that application of 20 kgP/ha and 3 t/ha lime in combination may be recommended for increasing maize yield on acid soils particularly in the study area. Application of 20 kgP/ha and 10 t/ha kraal manure in combination can also increase the yield of maize but the high rate of manure may not be attainable on smallholder farms. Use of kraal manure will greatly benefit farmers in areas where supply of P fertilizer is low or in cases where farmers cannot afford the cost of high fertilizer input.

The results of the study have shown that lime can increase soil pH to 6.0 while kraal manure could only increase soil pH to 4.8, at this pH there is a reduction of uptake nutrient elements specially P at optimum levels. However, kraal manure can be used partially to substitute agricultural lime where lime is far from the farmers and kraal manure is locally available as it can reduce Al concentration to lower levels. The regular use of animal manure is a practical alternative for smallholder cattle-rearing farmers, whilst lime and fertilizer P are expensive inputs that can only be used judiciously.

Programmes of educating resource -poor farmers about the extent to which application of animal manure can reduce lime and fertilizer P dependency are needed because it would greatly benefit them to at least produce a reasonable crop on acid and P-deficient soils compared to total failure without lime and P fertilizer. The most appropriate timing of application of lime and kraal manure to quantify their potential benefits are important practical considerations that need further investigation.~~Timing of application of manure and lime is not known as for lime application has to be done some months before planting to allow it to react with soil colloids because it reacts slowly.~~

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APPINDICES

2a: ANALYSIS OF VARIENCE FOR GRAIN Ca (%)

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151...................................................................
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***** Analysis of variance *****

Variate: GRCa_%

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2    0.82859    0.41430   18.00

Rep.Lime stratum
Lime                       1    0.62907    0.62907   27.33  0.035
Residual                   2    0.04604    0.02302    0.59

Rep.Lime.Krl stratum
Krl                        3    0.94271    0.31424    8.08  0.003
Lime.Krl                   3    0.01165    0.00388    0.10  0.959
Residual                  12    0.46652    0.03888    1.24

Rep.Lime.Krl.P stratum
P                          2    3.59967    1.79983   57.51  <.001
Lime.P                     2    0.18465    0.09233    2.95  0.067
Krl.P                      6    0.81278    0.13546    4.33  0.003
Lime.Krl.P                 6    0.16765    0.02794    0.89  0.512
Residual                  32    1.00148    0.03130
```

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Total                        71    8.69082
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2b. ANALYSIS OF VARIENCE FOR GRAIN P(%)

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151.....................................................................
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***** Analysis of variance *****

Variate: GRP_%
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Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.193176	0.096588	7.46	
Rep.Lime stratum					
Lime	1	0.297092	0.297092	22.94	0.041
Residual	2	0.025905	0.012952	2.98	
Rep.Lime.Krl stratum					
Krl	3	1.481748	0.493916	113.59	<.001
Lime.Krl	3	0.025915	0.008638	1.99	0.170
Residual	12	0.052181	0.004348	0.54	
Rep.Lime.Krl.P stratum					
P	2	0.960380	0.480190	59.22	<.001
Lime.P	2	0.092259	0.046130	5.69	0.008
Krl.P	6	0.210934	0.035156	4.34	0.003
Lime.Krl.P	6	0.137088	0.022848	2.82	0.026
Residual	32	0.259489	0.008109		

```
Total                      71   3.736166
```

2c: ANALYSIS OF VARIANCE FOR GRAIN YIELD

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151.......................................................................
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***** Analysis of variance *****

Variate: Gwt

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2   4416518.   2208259.    0.87

Rep.Lime stratum
Lime                       1   5127875.   5127875.    2.01  0.292
Residual                   2   5099790.   2549895.    7.01

Rep.Lime.Krl stratum
Krl                        3  22770141.   7590047.   20.87  <.001
Lime.Krl                   3   1224250.    408083.    1.12  0.379
Residual                  12   4364859.    363738.    4.69

Rep.Lime.Krl.P stratum
P                          2   4738978.   2369489.   30.54  <.001
Lime.P                     2    357221.    178610.    2.30  0.116
Krl.P                      6   2730112.    455019.    5.86  <.001
Lime.Krl.P                 6   1134444.    189074.    2.44  0.047
Residual                  32   2482701.     77584.

Total                     71  54446889.
```

2d: ANALYSIS OF VARIANCE FOR GRAIN Mg (%)

```
GenStat Release  7.22 DE  (PC/Windows)            18 August 2010 16:00:56
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***** Analysis of variance *****

Variate: GRMg_%

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2   0.624353   0.312176    3.51

Rep.Lime stratum
Lime                       1   0.081339   0.081339    0.91  0.440
Residual                   2   0.177919   0.088960    4.45

Rep.Lime.Krl stratum
Krl                        3   1.259686   0.419895   21.02  <.001
Lime.Krl                   3   0.080936   0.026979    1.35  0.305
Residual                  12   0.239694   0.019975    2.53

Rep.Lime.Krl.P stratum
P                          2   1.708044   0.854022  108.36  <.001
Lime.P                     2   0.018344   0.009172    1.16  0.325
Krl.P                      6   0.044256   0.007376    0.94  0.483
Lime.Krl.P                 6   0.152722   0.025454    3.23  0.014
Residual                  32   0.252200   0.007881

Total                     71   4.639494
```

2e: ANALYSIS OF VARIENCE FOR 100 SEED WEIGHT

```
GenStat Release  7.22 DE  (PC/Windows)            16 August 2010 23:12:22
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***** Analysis of variance *****

Variate: HSW

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2    1222.97     611.48    3.74

Rep.Lime stratum
Lime                       1     630.24     630.24    3.86  0.188
Residual                   2     326.70     163.35    1.94

Rep.Lime.Krl stratum
Krl                        3     915.62     305.21    3.62  0.045
Lime.Krl                   3     102.52      34.17    0.41  0.752
Residual                  12    1011.34      84.28    1.65

Rep.Lime.Krl.P stratum
P                          2    1327.42     663.71   12.97  <.001
Lime.P                     2     410.92     205.46    4.02  0.028
Krl.P                      6     595.65      99.27    1.94  0.104
Lime.Krl.P                 6     383.45      63.91    1.25  0.308
Residual                  32    1637.25      51.16

Total                     71    8564.09
```

2 f: ANALYSIS OF VARIANCE FOR PLANT HEIGHT

```
GenStat Release  7.22 DE  (PC/Windows)            17 August 2010 16:38:36
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  16  FACTOR [modify=yes;nvalues=72;levels=4;reference=1] Krl

..........................................................

***** Analysis of variance *****

Variate: Plth

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2      684.8      342.4    0.37

Rep.Lime stratum
Lime                       1      787.4      787.4    0.85  0.453
Residual                   2     1842.9      921.5    3.83

Rep.Lime.Krl stratum
Krl                        3     1414.1      471.4    1.96  0.174
Lime.Krl                   3    12766.0     4255.3   17.71  <.001
Residual                  12     2883.5      240.3    1.50

Rep.Lime.Krl.P stratum
P                          2     4770.1     2385.0   14.90  <.001
Lime.P                     2     3539.8     1769.9   11.06  <.001
Krl.P                      6      813.7      135.6    0.85  0.543
Lime.Krl.P                 6     5231.3      871.9    5.45  <.001
Residual                  32     5122.8      160.1

Total                     71    39856.4
```

2g: ANALYSIS OF VARIANCE FOR SOIL Ca

```
GenStat Release  7.22 DE  (PC/Windows)            17 August 2010 08:56:47
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***** Analysis of variance *****

Variate: SLCa

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2    0.14194    0.07097    0.17

Rep.Lime stratum
Lime                       1   16.38781   16.38781   39.97  0.024
Residual                   2    0.82003    0.41002    1.19

Rep.Lime.Krl stratums
Krl                        3    7.15518    2.38506    6.90  0.006
Lime.Krl                   3    1.49564    0.49855    1.44  0.279
Residual                  12    4.14589    0.34549    5.75

Rep.Lime.Krl.P stratum
P                          2    4.77921    2.38961   39.80  <.001
Lime.P                     2    0.51163    0.25582    4.26  0.023
Krl.P                      6    0.20442    0.03407    0.57  0.753
Lime.Krl.P                 6    0.23707    0.03951    0.66  0.684
Residual                  32    1.92127    0.06004

Total                     71   37.80010
```

2h: ANALYSIS OF VARIANCE FOR SOIL Mg

```
GenStat Release  7.22 DE  (PC/Windows)            17 August 2010 09:00:22
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***** Analysis of variance *****

Variate: SLMg

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2    0.71180    0.35590    4.87

Rep.Lime stratum
Lime                       1    6.85734    6.85734   93.91  0.010
Residual                   2    0.14604    0.07302    0.97

Rep.Lime.Krl stratum
Krl                        3    2.72549    0.90850   12.02  <.001
Lime.Krl                   3    0.08367    0.02789    0.37  0.777
Residual                  12    0.90687    0.07557    6.21

Rep.Lime.Krl.P stratum
P                          2    1.20675    0.60338   49.58  <.001
Lime.P                     2    0.01304    0.00652    0.54  0.590
Krl.P                      6    0.27529    0.04588    3.77  0.006
Lime.Krl.P                 6    0.14696    0.02449    2.01  0.093
Residual                  32    0.38946    0.01217

Total                     71   13.46271
```

2i: ANALYSIS OF VARIANCE FOR SOIL O.M

```
GenStat Release  7.22 DE  (PC/Windows)            17 August 2010 09:03:32
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***** Analysis of variance *****

Variate: SLO_M
```

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.427378	0.213689	0.62	
Rep.Lime stratum					
Lime	1	1.017689	1.017689	2.94	0.228
Residual	2	0.691911	0.345956	20.41	
Rep.Lime.Krl stratum					
Krl	3	1.608089	0.536030	31.63	<.001
Lime.Krl	3	0.360800	0.120267	7.10	0.005
Residual	12	0.203378	0.016948	1.72	
Rep.Lime.Krl.P stratum					
P	2	1.475378	0.737689	74.77	<.001
Lime.P	2	0.002311	0.001156	0.12	0.890
Krl.P	6	0.241244	0.040207	4.08	0.004
Lime.Krl.P	6	0.047467	0.007911	0.80	0.576
Residual	32	0.315733	0.009867		
Total	71	6.391378			

2j: ANALYSIS OF VARIANCE FOR SOIL P

```
GenStat Release  7.22 DE  (PC/Windows)           17 August 2010 09:07:17
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***** Analysis of variance *****

Variate: SLP

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2     289.15     144.58   77.59

Rep.Lime stratum
Lime                       1      21.23      21.23   11.40  0.078
Residual                   2       3.73       1.86    0.05

Rep.Lime.Krl stratum
Krl                        3    1907.43     635.81   16.88  <.001
Lime.Krl                   3     137.81      45.94    1.22  0.345
Residual                  12     451.98      37.66    2.13

Rep.Lime.Krl.P stratum
P                          2    2744.63    1372.31   77.50  <.001
Lime.P                     2       6.11       3.05    0.17  0.842
Krl.P                      6     154.05      25.68    1.45  0.227
Lime.Krl.P                 6      11.48       1.91    0.11  0.995
Residual                  32     566.65      17.71

Total                     71    6294.25
```

2k: ANALYSIS OF VARIANCE FOR Al

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151.....................................................................
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***** Analysis of variance *****

Variate: Al3

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2  0.0034111  0.0017056    1.78

Rep.Lime stratum
Lime                       1  0.1160014  0.1160014  121.40  0.008
Residual                   2  0.0019111  0.0009556    0.67

Rep.Lime.Krl stratum
Krl                        3  0.0448375  0.0149458   10.47  0.001
Lime.Krl                   3  0.0134153  0.0044718    3.13  0.066
Residual                  12  0.0171222  0.0014269    3.40

Rep.Lime.Krl.P stratum
P                          2  0.0043694  0.0021847    5.21  0.011
Lime.P                     2  0.0024194  0.0012097    2.88  0.071
Krl.P                      6  0.0070417  0.0011736    2.80  0.027
Lime.Krl.P                 6  0.0051472  0.0008579    2.05  0.088
Residual                  32  0.0134222  0.0004194

Total                     71  0.2290986
```

2I: ANALYSIS OF VARIENCE FOR SOIL pH

```
GenStat Release  7.22 DE  (PC/Windows)            17 August 2010 08:46:27
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***** Analysis of variance *****

Variate: Ph

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2   0.071386   0.035693    0.09

Rep.Lime stratum
Lime                       1  54.723235  54.723235  130.82  0.008
Residual                   2   0.836603   0.418301    6.06

Rep.Lime.Krl stratum
Krl                        3   9.659337   3.219779   46.65  <.001
Lime.Krl                   3   2.712615   0.904205   13.10  <.001
Residual                  12   0.828256   0.069021    9.16

Rep.Lime.Krl.P stratum
P                          2   0.621411   0.310706   41.25  <.001
Lime.P                     2   0.068544   0.034272    4.55  0.018
Krl.P                      6   0.056433   0.009406    1.25  0.308
Lime.Krl.P                 6   0.029389   0.004898    0.65  0.690
Residual                  32   0.241022   0.007532

Total                     71  69.848232
```

2m: ANALYSIS OF VARIENCE FOR STALK Ca (%)

```
GenStat Release  7.22 DE  (PC/Windows)            17 August 2010 09:12:24
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***** Analysis of variance *****

Variate: STCa_%

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2   0.088269   0.044135    3.74

Rep.Lime stratum
Lime                       1   0.066006   0.066006    5.60  0.142
Residual                   2   0.023586   0.011793    3.17

Rep.Lime.Krl stratum
Krl                        3   0.065606   0.021869    5.87  0.010
Lime.Krl                   3   0.019983   0.006661    1.79  0.203
Residual                  12   0.044678   0.003723    1.73

Rep.Lime.Krl.P stratum
P                          2   0.289411   0.144706   67.30  <.001
Lime.P                     2   0.002178   0.001089    0.51  0.607
Krl.P                      6   0.013044   0.002174    1.01  0.435
Lime.Krl.P                 6   0.008633   0.001439    0.67  0.675
Residual                  32   0.068800   0.002150

Total                     71   0.690194
```

2n: ANALYSIS OF VARIENCE FOR SOIL Mg(%)

```
GenStat Release  7.22 DE  (PC/Windows)            17 August 2010 09:16:29
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***** Analysis of variance *****

Variate: STMg_%

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2   0.116103   0.058051    0.75

Rep.Lime stratum
Lime                       1   0.146701   0.146701    1.89  0.303
Residual                   2   0.155369   0.077685    8.44

Rep.Lime.Krl stratum
Krl                        3   0.323182   0.107727   11.70  <.001
Lime.Krl                   3   0.006937   0.002312    0.25  0.859
Residual                  12   0.110506   0.009209    1.71

Rep.Lime.Krl.P stratum
P                          2   0.729969   0.364985   67.74  <.001
Lime.P                     2   0.019536   0.009768    1.81  0.180
Krl.P                      6   0.102997   0.017166    3.19  0.014
Lime.Krl.P                 6   0.006075   0.001013    0.19  0.978
Residual                  32   0.172422   0.005388

Total                     71   1.889799
```

2o: ANALYSIS OF VARIENCE FOR STALK P(%)

```
GenStat Release  7.22 DE  (PC/Windows)            17 August 2010 09:19:43
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***** Analysis of variance *****

Variate: STP_%

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rep stratum                2  0.0144111  0.0072056    1.37

Rep.Lime stratum
Lime                       1  0.0480500  0.0480500    9.12  0.094
Residual                   2  0.0105333  0.0052667    1.91

Rep.Lime.Krl stratum
Krl                        3  0.0431444  0.0143815    5.22  0.016
Lime.Krl                   3  0.0041611  0.0013870    0.50  0.687
Residual                  12  0.0330778  0.0027565    3.65

Rep.Lime.Krl.P stratum
P                          2  0.1087694  0.0543847   71.98  <.001
Lime.P                     2  0.0014250  0.0007125    0.94  0.400
Krl.P                      6  0.0122639  0.0020440    2.71  0.031
Lime.Krl.P                 6  0.0054972  0.0009162    1.21  0.325
Residual                  32  0.0241778  0.0007556

Total                     71  0.3055111
```