ANALYTICAL DETERMINATION OF THE EFFECTS OF PHOSPHATIC FERTILIZERS AND MANURE ON MAIZE YIELDS IN ACIDIC SOILS IN KISII AND RACHUONYO DISTRICTS.

JACOB SOSPETER ADEMBA

A Thesis submitted to Graduate School in Partial Fulfillment of the Requirements for the Award of Master of Science Degree in Chemistry of Egerton University.

EGERTON UNIVERSITY.

September 2009.

DECLARATION AND RECOMMENDATION

Declaration

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

Sign ………………………… Date:…………………..

Jacob Sospeter Ademba

Recommendation

This thesis has been submitted with our approval as supervisors:

Sign: …………………… Date ……………………

Prof. Mwaniki Silas Ngari
Lecturer, Department of chemistry
Egerton University.

Sign: …………………… Date :…………………

Dr. Anthony Obutiatia Esilaba
Soil Scientist,
Kenya Agricultural Research Institute (KARI)
KARI Headquarters Nairobi.

COPYRIGHT

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisors; Professor Mwaniki Silas Ngari and Dr. Anthony Obutiatia Esilaba for their guidance during the entire field and laboratory work, and thesis write-up. It is their encouragement; patience and kindness that made it possible to complete this work.

I wish to thank the Director, Kenya Agricultural Research Institute {KARI}, Dr. Ephraim Mukisira and the KARI / Kisii Centre Director Dr. Felister Makini for permission to use the laboratory facilities. The assistance of Mr. Nelson Kidula on data analysis is highly appreciated. I wish to thank the entire technical staff of KARI- Kisii, especially Mr. Alloys Gesicho, for their assistance and encouragement during my laboratory work. I wish to thank my entire family, my wife Salome and children Emily, Gordon, Apeles, Flora, Amos, Rodgers and Idah for their moral support and encouragement throughout the work. Finally, I wish to thank my colleagues, Opondo, Kariuki, Okello and others for their assistance and encouragement when the going seemed tough.

ABSTRACT

Maize production in sub-Saharan Africa remains low and the yields are on the decline. This has been attributed to a variety of factors which include soil nutrient depletion and *Striga* infestation. Soil phosphorous, nitrogen and *Striga hermonthica* are the major constraints to maize production in Nyanza Province of Kenya. The yields are typical of low input systems ranging below 1.0 t ha^{-1} against a potential of 5.0 t ha^{-1} per season. In an attempt to overcome these constraints, field trials were conducted at two on-farm sites, Bototo in Kisii Central district and Kabondo in Rachuonyo district, in Nyanza Province of Kenya. The trials were conducted during the long and short rains seasons in 2007. The study investigated the effects of phosphatic fertilizers and manure on nutrient uptake, nutrient use efficiency, maize yields and soil nutrients content at harvest in both sites. A Randomized Complete Block Design (RCBD) was used with the farmers as replicates. Farmers in Bototo plant H614 variety while those in Kabondo plant H513 maize variety. Plots were top dressed with Calcium Ammonium Nitrate (CAN) fertilizer at a uniform rate of 30 kg N $ha.^{-1}$ Diammonium Phosphate (DAP), Minjingu Rock Phosphate (MRP) and Triple Super Phosphate (TSP) fertilizers were applied at a rate of 60 kg ha^{-1} P_2O_5 and farmyard manure (FYM) at 10 t ha^{-1}. One rate of P (60 kg ha^{-1} P_20_5) was applied on all the P sources and a no P treatment (check) plus lime only treatment was included in determining the effects due to the applied P in the acidic soils. Complete soil chemical analysis was done in all the plots. To assess the effects of phosphorus fertilizers and manure and estimate the nutrient content and uptake of major nutrients, plant and soil samples were analyzed using standard methods. There were significant ($P \leq 0.01$) crop growth vigor response to the fertilizers and manure due to treatments at both sites. There were significant ($P \leq 0.01$) grain yield, total dry matter yield and harvest index responses to phosphate fertilizers and manure treatments at both sites. Phosphate fertilizers and manure treatments had significant ($P \leq 0.01$) effects on *Striga* emergence at both sites. *Striga* emergence correlated weakly with phosphate fertilizers and manure treatments and strongly with grain yield at both sites. Nutrient uptake and removal by the crop significantly ($P \leq 0.01$) increased due to fertilizers and manure application, with a corresponding reduction in the total soil N, P, K, Ca and Mg. Phosphate fertilizers and manure application significantly ($P \leq 0.01$) increased available soil phosphorus, agronomic phosphorus use efficiency (APUE) and physiological phosphorus use efficiency (PPUE) in both sites. The results indicate that phosphate fertilizers and manure applications are essential to improve maize yield, nutrient phosphorus use efficiency and the applied nitrogen reduced the impacts of *Striga hermonthica* damage to maize yields.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS / ABBREVIATIONS

AEZ	Agro – ecological zone
ANOVA	Analysis of Variance
cmol kg^{-1}	centimol per kilogram
CAN	Calcium Ammonium Nitrate
CEC	Cation Exchange Capacity
CSIRO	Commonwealth Scientific and Industrial Research Organization.
DAP	Diammonium Phosphate
DMRT	Duncan's Multiple Range Test
ECEC	Effective cation exchange capacity
FURP	Fertilizer Use Recommendation Project
FYM	Farmyard manure
ICRAF	International Centre for Research in Agro-forestry
KARI	Kenya Agricultural Research Institute
LM	Low Midlands
m.a.s.l	metres above sea level
MRP	Minjingu Rock Phosphate
NUE	Nutrient Use Efficiency
PRA	Participatory Rural Appraisal
RRC	Regional Research Centre
TSP	Triple Super Phosphate
UM	Upper Midlands
WAC	World Agro forestry Centre

DEFINITION OF TERMS

Adoption: This refers to the acceptance and use of a technology by a farmer after going through a mental process of decision – making.

Agronomic nutrient use efficiency: Indicates the relationship between crop yields per unit of nutrients applied**.**

Extension workers / staff: Any person who delivers extension information or messages to farmers

Farmer empowerment: This is a way of providing farmers with an opportunity to learn and achieve greater control over the conditions that they face every day in their group and farms.

Nutrient recovery efficiency: Indicates the fraction of a nutrient applied by fertilizer that is taken up by the crop.

Physiological/ utilization efficiency is the grain yield per unit of nutrient taken up by the crop.

Smallholder: Farmer with small land parcels of 3 acres or less whose main occupation is farming as a source of livelihood.

Technology: The combination of knowledge, inputs and management practices which are deployed together with productive resources to produce a desired output

CHAPTER ONE

INTRODUCTION

1.1 Background information

Appropriate fertilizer use leads to increased crop yields and high crop recovery of applied nutrients. Some elements may be hazardous to the environment if used in various forms such as nitrates and phosphates. Efficient addition of fertilizers is therefore important in ensuring crops attain maturity within specific growing seasons (Warren. 1962).

A large number of phosphorus compounds are used in the addition of fertilizers to plants; however due to range in characteristics of those materials coupled with the complex nature of fertilizers, soil reaction products have made agronomic evaluation of phosphorus fertilizers complicated. Effectiveness of phosphorus fertilizers therefore depend on the chemical and physical properties, rate and method of application, soil and climatic conditions and the crop species grown (Mokwunye and Bationo, 2002).

In recent years, there has been an increased use of high nutrient fertilizers mainly for economic reasons, for example, Diammonium Phosphate (DAP), Triple Super Phosphate (TSP) and Minjingu Rock Phosphate (MRP) fertilizers (Buresh et al., 1997). Several drawbacks have however been reported in the use of Diammonium Phosphate. This includes young crops that have shown injury (Okalebo, 1977), low availability of soil magnesium, calcium and potassium ions by forming insoluble compounds (Wapakala, 1976).

It is therefore necessary to establish the influence of factors like method and rate of phosphorus fertilizer application and how different fertilizers affect growth and yields of plants in a given area. This is in order to allocate appropriate fertilizers to suit varying agricultural conditions (Russel, 1988).

1.2 Statement of the problem

Maize nutrient (nitrogen, phosphorus, potassium, calcium and magnesium) uptake, use efficiency and yields in Nyanza Province have been on the decline. This maybe associated to inefficiency of the fertilizers and manure currently applied and / or nutrient depletion coupled with lack of suitable fertilizer application rates and soil acidity. The current research recommendations were developed more than two decades ago, hence the extent of nutrient depletion is unknown and phosphate fertilizer and manure application by farmers does not commensurate with the plant requirements and / or nutrient levels in the soil.

1.3 Overall objective

To determine suitable phosphorous fertilizers and manure at the application rate and their effects on maize yields in acidic soils.

1.3.1 Specific objectives

- To determine concentration levels of phosphorus, nitrogen, potassium, calcium and magnesium in the soils.
- To assess the effects of phosphorus fertilizers and manure on concentration levels of phosphorus, nitrogen, potassium, calcium and magnesium uptake and grain and dry matter yields on maize.
- To assess the effects of phosphorus fertilizers and manure on soil acidity.
- To establish the efficiency of currently used phosphorous fertilizers and manure.

1.4 Alternative hypotheses

- There is no residual phosphorus, nitrogen, potassium, calcium and magnesium in the soils.
- Applications of phosphorus fertilizers and manure have no effect on maize phosphorus, nitrogen, potassium, calcium and magnesium content and uptake and grain and dry matter yields.
- Applications of phosphorus fertilizers and manure have no effect on soil acidity.
- Phosphorous fertilizers and manure currently applied are efficient.

1.5 Justification of the study

Twenty years have elapsed since the last fertilizer use recommendation project was carried out in Kisii and Rachuonyo districts (FURP, 1994). Declining yields of maize, which accounts for a significant proportion of the food diet for smallholder mixed farms of Kisii and Rachuonyo districts, has raised concerns about food security. There is therefore need to determine the nutrient residue upon application of different phosphatic

fertilizers and manure, and their effects in acidic soils of smallholder mixed farms of Kisii and Rachuonyo districts to determine whether this rate is still applicable.
There is need for recommendation for the right fertilizers in different soils and climatic conditions. This may help check this decline and improve food security**.**

This study analyzed the soils and plants with the purpose of quantifying the phosphorus, nitrogen, potassium, calcium and magnesium contents and uptake and the phosphorus use efficiency to meet the crop requirements.

1.6 Purpose of the study

To determine recommendation that will increase maize production through use of appropriate rate of phosphorus fertilizers and manure under different soil and climatic conditions. These factors depend on chemical and physical properties of the fertilizers, soil and climatic conditions and crop species grown.

1.7 Assumptions

The following were the assumptions of the study.

- Farmers will volunteer to participate in the experiment freely and will avail their plots for implementation.
- The farmers will report their true experiences of working within the group during implementation of the experiment.
- The weather conditions will be favorable during implementation of the experiment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background information

Of the world's major cereal crops, maize is of greatest importance in terms of tonnage, consumption and financial value (Ferrar, 1995). Maize production in sub-Saharan Africa in general and Kenya in particular still remains low and the yields are declining. This has been attributed to a variety of factors, the prominent being soil nutrient depletion (Stoorvogel et al., 1993; Sanchez et al., 1997) and *Striga* infestation (Esilaba and Ransom, 1997). Generally, throughout sub-Saharan Africa, the predominant low-input agriculture results in a net depletion of nutrients. The depletion of nutrients has been calculated at 22 kg N, 2.5 kg P and 15 kg K ha^{-1} per year (Stoorvogel et al., 1993) with higher values for Kenya. *Striga* infests an estimated 21 million hectares of maize and sorghum in Africa causing an estimated yield loss of 4.1 million tons of grain yield per year (Mumera and Below, 1993). The major *Striga* species affecting cereals in Africa and Kenya are *S. hermonthica* and *S. asiatica*. Smallholder farmers are the worst hit as they have few resources to purchase inputs and little flexibility in their cropping systems, as they mainly produce maize, sorghum and millet for subsistence. Yield losses of up to 70% are common in Africa while complete maize losses and field abandonment are frequent under heavy *Striga* infestations in south western Kenya (Odongo, 1995). *Striga* is particularly a pest of low - fertility soils, the infestation being less severe on fertile soils (Ransom and Odhiambo, 1994). Investment in soil fertility replenishment especially nitrogen would, therefore, be essential in order to reduce *Striga* damage to the crop and increase food production.

2.2 Nutrient uptake and use efficiency

2.2.1 Phosphorus

Phosphorus is one of the major essential elements in maize production. It is the most commonly limiting nutrient element in the tropics after water and nitrogen. Many tropical soils have extremely high capacities to immobilize phosphorus (Sanchez et al, 1997). In the maize plant, phosphorus principally stimulates early root formation and growth, hastens crop maturity and affects the grain yield (Marschner, 1995). The P is taken up from the soil in $H_2PO_4^-$ and HPO_4^{2-} forms by plants, and unless the soil contains adequate P or it is supplied from external sources, plant growth is restricted. Phosphorus losses through leaching and crop removal are generally small (Tisdale et al., 1990). Plant available P levels can undergo gradual decline where losses through crop removal exceed input through fertilizers, animal manure and crop residue (Tisdale et al., 1990). Phosphorus is continuously taken up by maize from the seedling stage to maturity, with its maximum uptake during the third and sixth week of growth (Tisdale et al., 1990). Bekunda (1990) observed that P accumulation increased rapidly from vegetative to silking stages and dropped thereafter up to harvest. The drop in P accumulation partly unaccounted for in old maize leaves is lost through senescence (Keulen, 1983) and in empty cobs. Up to the commencement of flowering, only 15% of the quantity of P required is observed. The largest P requirement occurs after flowering and during ripening periods. During grain formation, translocation of P to the grain is smaller compared to that of N. At maturity, about 75% of the total P in the above ground parts of the plant should be in the grain (Keulen, 1983). Under P deficiency, the amount available to the plant during grain formation definitely influences the P content of the grain.

The total phosphorus content of the soil is of no direct practical importance, but it has often been used as a weathering index. Total phosphorus in the topsoil decreases with increasing weathering intensity (Sanchez et al, 1997).The transformation of one form of phosphate into another is controlled mainly by soil pH. As soils become more acidic, the reaction of iron and aluminium increases and the relatively soluble calcium phosphate are converted into less soluble aluminium and iron phosphates. These processes are slow enough to permit considerable quantities of calcium phosphates to be present in acid soil with pH values below 5.5. In highly weathered soils, most of the inorganic phosphorous is in the occluded or reductant – soluble form because of the formation of iron and aluminium oxide coatings. In acidic soils aluminium and iron are most abundant and react with phosphorus to form relatively insoluble aluminium and iron phosphates. In Calcareous soils the phosphate ions are precipitated by calcium and magnesium as relatively insoluble compounds. The higher the content of iron and aluminium oxides, the larger is the phosphorus – fixing capacity of the soil. Also, the higher the exchangeable aluminium content, the larger the phosphorous fixing capacity. Organic phosphorus normally accounts for 20 to 50 percent of the total topsoil phosphorus. Resource poor farmers consider organic phosphorus to be the main source of phosphorus for plants in no - fertilizer agriculture. Its maintenance, therefore, is of great practical significance in traditional agricultural systems.

The solid inorganic forms of phosphorus are usually divided into three active fractions and two relatively inactive fractions. The active fractions can be grouped into calcium-bonded phosphates (Ca-P), aluminium bonded phosphates (Al–P), and iron bonded phosphates (Fe –P). Calcium phosphates are present as films or as discrete particles, while Al -P and Fe-P occur as films or are simply adsorbed on clay or silt surfaces. The relatively inactive fractions are the occluded and reductant soluble forms. Occluded phosphorus consists of Fe-P and Al-P compounds surrounded by an inert coat of another material that prevents the reaction of these phosphates with the soil solution. Calcium phosphates are more soluble than aluminium phosphates, which are in turn more soluble than iron phosphates.

Residual phosphorus, phosphate from a fertilizer or manure application not used by a crop, continues to be of value to succeeding crops, although the uptake each year is usually less than that of the first year (Russell, 1988).

Anderson et al. (1974) found that P fertilization can markedly affect P concentration in the soil solution by influencing competition for adsorption sites between organic P compounds and orthophosphates. Evans (1985) reported that competition between inorganic and organic P for soil sorption sites could take place and presumably result in the increase of dissolved organic phosphorus directly after fertilizer application.

2.2.2 Nitrogen

Nitrogen is a component of proteins and nucleic acids, and when N is sub-optimal growth is reduced (Marschner, 1995). Maize is able to utilize either NH_4^+ or NO_3^- as N source and grows best when both are present (Schrader et al., 1972). The most practical way of application of any fertilizer is to broadcast it and incorporate it into the soil surface before planting. For nitrogen this procedure is efficient only if the NH_4^+ and NO_3^{--} ions released stay in the root zone and are not leached or denitrified to a considerable extent. Since crop nitrogen requirements are low at early growth stages, the optimum timing is that which ensures a good nitrogen supply at the two critical growth stages of the maize at the lowest possible cost (Sanchez et al, 1997). Plant N uptake has been shown to vary with the type of crop and stage of crop growth (Norman et al., 1992; Guindo et al., 1994). Guindo et al., (1995) reported that fertilizer N uptake and accumulation in wheat increased steadily prior to heading and then decreased thereafter. The pattern of N accumulation in plant parts differs at various stages of growth. A study by Norman et al. (1992) on N distribution in rice plant indicated that the total plant N in stems and leaf sheaths increased steadily up to heading after which the panicle had the highest N content. Nitrogen in the panicle continued to increase at the expense of other plant parts such that by maturity, it contained two thirds of the total plant N. Ta and Weiland (1992) observed that though N absorption continued during grain filling, there was substantial mobilization of N from vegetative organs (shoot and leaves) to the ear. Fertilizer N rate has been reported to affect the amount of N remobilized within a plant, with high N rates being inhibitory to the remobilization of vegetative N to the grains (Bulman and Smith, 1993). Nitrogen uptake and utilization by plants varies depending mainly on the nutrient levels in the soil. Power (1983) also showed that N fertilizer increased N concentration in plant material during the period of fertilizer application and thereafter up to 2 to 3 years. Correlation between N concentration in plants and fertilizer N applied was found to be inconsistent by Binford et al. (1992) in maize. These authors attributed this to the fact that N concentration in plant was greatly influenced by other factors that have little effect on final yields and thus cannot be a reliable indicator of N availability in maize. Intensive nitrogen fertilization for several years can create marked residual effects. They include high inorganic nitrogen contents in some profiles and, when ammonium sulphate is used, a drastic decrease in pH and base saturation in the profile (Buresh et al, 1997).

A number of experiments associated with increasing soil N availability, have documented increases in crop growth rates and yields (Odhiambo, 1989). However, due to low concentration of mineral nitrogen in acid soils, N uptake is limited and hence affects crop yields (Alexander, 1977). Nitrogen is important in increasing maize yields but the abundance of Al, Fe, and exchangeable H^+ in acid soils lead to poor N mineralization hence low yields (Gonzaletez – Prieto et al., 1992).

2.2.3 Nutrient use efficiency

The efficiency with which plant nutrients are used is of considerable interest. The concept of fertilizer nutrient use efficiency (NUE) could be conceptualized in three aspects: yield (agronomic), recovery and physiological (utilization) efficiencies. Agronomic NUE indicates the relationship between crop yield per unit of nutrients applied; nutrient recovery efficiency indicates the fraction of a nutrient applied by fertilizer that is taken up by the crop, while physiological/ utilization efficiency is the grain yield per unit of nutrient taken up by the crop. It is an indication of the availability of a particular nutrient in relation to other growth factors. Nutrient use efficiency is influenced by the nutrient and its source, rate, time and method of fertilizer application, plant genotype, soil and climatic conditions during the growing season (Fan and Mackenzie, 1994). Genotypic differences in nutrient utilization in maize have been attributed to differences in efficiency in acquisition by the roots, transport and utilization by the crop (Elliot and Lauchli, 1985). Plant P uptake, immobilization by microbes and increased P sorption in limed soils could have resulted in lower P levels in soils after these treatments. Brady (1984) found that P supplied to soils as fertilizer was converted to less available inorganic pool. Similarly, Yang and Jacobsen (1990) reported that fertilizer P applied to similar soils was rapidly converted to relatively insoluble forms. This followed a trend of decreasing soil available P towards a stable value with time. The efficiency in acquisition and internal utilization in turn depends on level of nutrients supplied and the plant age (Marschner, 1995). Information on nutrient use efficiency in the region is meagre, and was restricted to the report by Sigunga et al. (2002). The authors reported nutrient use efficiency by maize grown on Vertisols. This study, the analytical determination of the effects of phosphatic fertilizers and manure on maize yields in acidic soils in Kisii and Rachuonyo districts was focused on maize agronomic and physiological nutrient use efficiencies on Nitisols and Chromoluvic Phaeozems.

Jones (1973) reports a 70 percent recovery for maize under conditions of no leaching, with the nitrogen applied before seeding or side–dressed. Nitrogen recovery by rice ranges from 30 to 50 percent under constant flooding and from 20 to 30 percent under water management practices conducive to leaching and denitrification. In the latter case use of sulphur- coated area may increase the recovery rate to 30 or 40 percent (Sanchez et

al, 1973 b). Nitrogen recovery by wheat may be as high as 50 percent with the best rate, timing and placement practices (Hamid, 1972).
The relationship between the amounts of inorganic phosphorus added to the soil is a good parameter for determining how much fertilizer phosphorus should be added to arrive at a desired level of soil solution phosphorus.

2.2.4 Nitrogen-phosphorus interaction

Dual N and P application has been reported to enhance P fertilizer use efficiency. Olsen et al., (1962) did a study demonstrating the interaction of P and N fertilizers in maize. They found that mixing sulphate muriate of potash and 20% super phosphate and applying it in one band near the seed was more effective for early P utilization than applying the N and K salts in one band and P in another band on the opposite side of the seed. Statistically significant increase in height, a higher percentage of fertilizer derived P in the plant and a higher percentage recovery indicated a benefit from the mixing of the three elements. Olsen et al., (1962) suggested that the N-P interaction was as a result of complex biological, chemical and physical factors functioning in the fertilized zone of the soil and resulting in increased P absorption.

Miller (1971) suggested that increased root growth into the fertilizer zone due to presence of N intimate to P fertilizer caused increased P uptake. Several hypotheses have been put forward to explain the N stimulation of P uptake. Leonce and Miller (1966) attributed the phenomenon to NH_4^+ -N enhancement of P absorption by the root. They observed that preloading roots with NH_4^+ -N increased the rate of P uptake by roots, and suggested that increased N metabolism is associated with increased P uptake. Barneix (1981) suggested that preloading roots with NH_4^+-N induces the synthesis of carriers that transport P across membranes into root cells. Rhizocylinder acidification due to NH_4^+ -N has also been found to influence P uptake by inhibiting Ca-P precipitation on root surfaces and by increasing the $H_2PO_4^-/HPO_4^{2-}$ ratio in soil solution (Miller, 1971).

Raju et al; (1982) showed that maize absorbed more P from DAP than from single super phosphate (SSP), this could be due to the N associated with phosphate in the case of DAP that enhanced P uptake. Fan and Mackenzie (1994) also observed an increased P uptake efficiency when P was applied with N- fertilizer. The effect of added N may be physiological enhancement of P uptake when applied in a band with N (Miller, 1965) or NH_4^+ induced acidification near the root and an increase in the concentration of $H_2PO_4^-$ compared with HPO^{2-}_4 (Gahoonia et al., 1992). A decrease in the precipitation of fertilizer P when banded with $(NH_4)_2$ SO_4 was attributed to the same NH_4^+ induced acidification (Gahoonia et al., 1992). It is thus apparent that maize P use efficiency from fertilizer may be enhanced if there is some nitrogen in the ammonium form with the phosphorous. In dual N and P treatment, there are high P uptake by the maize plant and high P supply by soil. Thus, combined N and P application enhances P uptake and use efficiency, and improves yields.

Banded application of low rates of urea with acidic phosphates increased P fertilizer efficiencies and corn grain yields by improving P availability in two acid Canadian soils (Fan and Mackenzie, 1994). Banding of low rates of urea with P fertilizer resulted in greater beneficial residual effects on grain yield and P uptake in the following year. Thus, urea application with acidic P fertilizer has intrinsic value in improving maize yield and P- use efficiency (Fan and Mackenzie, 1994). Hikwa et al., (1990) however noted only few situations that showed significant N and P interaction on grain yield. Some sites with combinations of 30 to 60 kg N ha $^{-1}$ and 20 to 40 Kg P_2O_5 ha $^{-1}$ seemed to have yield advantages over other combinations. Dadi and Gedeno (1990) when studying maize production under different N-P levels reported that the highest maize mean yield of 5 t ha $^{-1}$ was obtained from 100 N and 50 P_2O_5 kg ha $^{-1}$ a and on average there was a 9 kg grain increment for each Kg of nutrient (N and P combined) used. Muchdar and Dahlan (1988) found that N had a consistent effect on yield as it increased due to N, P, and S application on young volcanic soils. Application of 92 kg ha $^{-1}$ of N (Urea), 1/3 at seedling and 2/3 at 30 days after planting was recommended. The effect of P alone and combination of P with N varied between test sites.

Starter fertilizers containing N and P applied to corn and grain sorghum are intended to serve various functions. They may be used to hasten maturity, or to give the quick start in out distancing weeds, or to assist in obtaining an adequate stand under adverse weather conditions (Olsen et,. al, 1962). Schlegel and Havlin (1995) reported that with optimal N, fertilizer P doubled apparent N fertilizer recovery. Fertilizer P decreased grain moisture at maturity and increased grain yields by 48% averaged over 10 year period when applied

with optimal N. A reduction in grain moisture decreases drying costs, reduces crop loss potential, and allows for earlier harvest.
To realize maximum crop production, the acid infertile soils have to be corrected through application of soil amendments (Juric et al, 1986), use of organic manures (Hue et al, 1986) or high application rates of P and N fertilizers (Yamoah et al, 1996).

Much of the literature relating to nitrogen – phosphorous interactions is concerned with the gross effects of fertilizer additions on soil fertility and relatively few attempts have been made to characterize the chemical composition of soil solutions following these applications (Simard et al, 1988).

2.2.5 Farmyard manure

For centuries the use of farmyard manure (FYM) has been synonymous with a successful and stable agriculture. Not only does it supply organic matter and plant nutrients to the soil but also it is associated with animal agriculture and with forage crops, which are generally soil protecting and conserving (Brady, 1984).

Manure as it is applied in the field is a combination of faeces, urine and bedding (litter) and feed waste. As might be expected, the chemical composition of this material varies widely from place to place depending upon factors such as animal species, age and condition of the animals, nature and amount of litter and the handling and storage of the manure before it is spread on the land (Brady, 1984).

Manure, plant and animal wastes used as fertilizer, is rich in humus. It releases many important nutrients into the soil. However, it is deficient in three important nutrients: nitrogen, phosphorus and potassium. A commercial fertilizer has about 20 times as much nitrogen, phosphorus and potassium as manure. For this reason, manure is often used in conjunction with other fertilizers. Manure also helps to loosen the soil and retain water (Russell, 1988). Because of its low nutrient content and great bulk, the cost of transporting and handling manure generally makes it uneconomical in comparison with commercial inorganic fertilizers. Manure regulates acidity through release of organic molecules that bind exchangeable and hydroxyl Al, the key P fixers in acid soils (Hue et al, 1986). Organic manures also supply nutrients to plant and the carbon containing compounds provide substrates for soil animals and microorganisms (Cooke, 1982).

Besides nutrient supply, organic manure may also exhibit a positive effect on soil structure; water holding capacity, aeration and soil fauna (KARI, 1993).

Numerous researchers have reported increase in crop yields due to manure application. Studies on the response of cabbages to P, N and manure application in Kenya by Kanyanjua and Schnier (1994) showed that cabbages responded well to FYM. Between 23 and 100% of 50 Kg P_2O_5 ha $^{-1}$ ha $^{-1}$ could be substituted by applying 5t ha $^{-1}$ FYM. Besides nutrients supply, significant increase in cabbage yield has been attributed to the complexion of aluminium in the soil by organic acids released by FYM (Hue et al., 1986). Higher maize yields have also been reported after manure application (Yamoah et al; 1996).

Marthers et al; (1980) reported that manure is a good fertilizer on soil that requires P and N to provide high yields. This is attributed to manure's slow release of plant nutrients and contents of N and P. Application of farmyard manure (FYM) may affect available P level considerably (KARI, 1993). This is due to manures chelating effects on Fe, Al, and Mn ions (Hue et al, 1986), hence nutrients released from manure are kept in available forms for subsequent crop uptake. They documented increased crop growth and yields associated with increasing soil N availability. They reported that manure and fertilizer application lead to increased microbial populations resulting to a higher turnover of soil organic N.

Cattle manure is an integral component of soil fertility management in many areas of the tropics and its importance as a source of nutrients for crop production is widely recognized (Bationo and Mokwunye, 1991). Participatory rural appraisal surveys conducted in western Kenya shows that farmers rely on organic manures as low cost and easily available alternative to inorganic fertilizers (KARI, KISII, 1979). The quantity and quality of manures available on smallholder farms are the major factors limiting its contribution (Table 2.1).The Research Recommended Rate of farmyard manure is 10 t ha $^{-1}$.

Table 2.1. Range of nutrient content of commonly used manure types

Type of manure	Percent N	Percent P_2O_5	Percent K_2O	Percent CaO	Percent MgO
Farmyard	1.0-2.7	0.4-1.5	1.2-8.4	0.3-2.7	0.3-1.4
Pig	1.5-2.4	0.9-4.5	1.4-3.8	0-1.3	0-0.7
Poultry	2.3-2.5	2.3-3.9	1.0-3.7	0.6-4.0	0.9-1.6
Cattle	1.7-2.6	0.5-3.7	1.3-2.5	0-0.9	0-1.0
Sheep/ Goat	1.5-1.8	0.9-1.0	1.4-1.7	0.9-1.0	0.6-1.0
Sewage sludge	2.9-4.2	0.3-3.6	0.4-2.9	2.0-4.3	0.5-0.8

Source: KARI (National Agricultural Research Laboratories)

2.2.5.1 Farmyard manure utilization

Biologically, manure has many attributes. It supplies a wide variety of nutrients along with organic matter for improving the physical characteristics of soils and their water–holding capacities. Its beneficial effects on plant growth are sometimes difficult to duplicate with other materials. At the same time its bulkiness and low analysis reduces its competitive economic value. High labour and handling costs and relatively cheap inorganic fertilizers are responsible for this unfortunate situation. Even so, manure remains a most valuable soil organic resource. Economic considerations merely make it necessary to choose more carefully the soil and crop situation wherein manure is applied (Brady, 1984).

2.2.5.2 Long term effects of farmyard manure.

The total benefits from manure utilization are sometimes not apparent from crop yields during the first or even second or third year following application. Manure along with crop residues, is a primary means of replenishing soil organic matter. Although a portion of the nutrients and organic matter in manure is broken down and released during the first year or two, some is held in humus-like compounds subject to very slow decomposition. Its effect is long standing not only on future nutrient supplies but also on the physical condition of the soil i.e. aggregate stability, pore space, bulk density and available water range (Sanchez 1997).

When manure or crop residues are added to soil, a portion of the organic carbon, nitrogen, sulphur and perhaps other elements are converted to humus. In this form, the elements are released only very slowly with rates of 2-4 percent per year being common thus, the components of manure which are converted to humus will have continuing effects on soil years after their application (Brady, 1974).To realize maximum crop production, the acid infertile soils have to be corrected through application of soil amendments (Juric et al, 1986), use of organic manures (Hue et al, 1986) or high application rates of P and N fertilizers (Yamoah et al, 1996).

2.2.6 Effects of fertilizer application on soil properties

Fertilizer application has been reported to influence both soil physical and chemical fertility, the effect varying with fertilizer nutrient source and rate, soil and climatic factors. Wapakala (1976) reported that continued use of Di-Ammonium Phosphate depressed soil pH and available Ca, Mg and K. But when the N source was Calcium Ammonium Nitrate, there was a build up of Ca, a rise in pH and an increase in Ca-P and a depression of occluded Al-P and Fe –P in the inorganic soil fraction. Thus, the long- term maintenance of high crop yield under fertilizer treatments may eventually require alleviation of soil acidification. Evans (1985) reported a significant increase in soil solution P concentration due to inorganic P application. He attributed this to the influence of the applied P on the competition for sorption sites between the organic and inorganic P compounds. The gradual net depletion of soil cations in both low and high input treatments if not compensated by additions, would eventually affect crop yield, quality, and plant resistance to diseases and pests (Welch et al., 1991).

2.3 Constraints to maize (Zea mays L.) production in Nyanza Province of Kenya

2.3.1 Nitrogen and phosphorus

Widespread N and P deficiencies exist in the tropics in general (Sanchez et al., 1997; Smalling et al., 1997) and in agricultural soils in Kenya in particular (KARI, 1991; Okalebo et al., 1979). In Kenya, these deficiencies have been demonstrated in the low soil N and P test levels across croplands (FURP, 1994) and from the economic responses to N and P fertilizers, particularly with maize (Okalebo et al., 1994). Nutrient N and P deficiency in those soils has been attributed to nutrient depletion through decades of continuous cropping without commensurate fertilizer inputs (Sanchez et al., 1997; Smalling et al., 1997). Phosphorus deficiency particularly, has been attributed to low inherent native soil P (Nyandat, 1981), P fixation, soil erosion and leaching among others (Okalebo et al., 1993). The maximum yield obtained with P application however, has been shown to differ largely between sites and soil types, most likely due to differences in rooting depth of the sub-soil, available soil moisture and rainfall distribution. An increase in crop yield would have a substantial impact on reducing food insecurity of rural households. Fertilizer N and P inputs, therefore, are needed to improve the maize yield agronomically and economically.

2.3.2 Striga infestation

Striga represents one of the largest single biological constraints to food production in Africa. *Striga* in Kenya is found mainly in the Western part of the country in the lower sections of the Lake Victoria Basin and to a lesser extent in the Coastal strip, frequently on subsistence farms. *Striga* is abundant in soils with low organic matter content. The use of organic manure is an effective method of *Striga* control (Ransom and Odongo, 1994).

The occurrence of *Striga* is associated with low soil fertility (Ransom and Odhiambo, 1994, Esilaba et al, 1997) with high infestation occurring in less fertile soils. Owing to the complex *Striga* problem, a number of approaches have been explored in an attempt to control the weed. These include deep cultivation to burry *Striga* weeds, hand weeding of *Striga* plants, rotating cereals with trap crops such as cowpeas, groundnuts and cotton, the use of *Striga* seed germination stimulants such as ethylene, ethephon, strigol and strigol analogues, the use of herbicides including dicamba, bromoxymil, titfluralin and imazapyr. Host plant resistance is considered to be the most feasible control measure for poor farmers.

2.4 Liming

Liming is the process of neutralizing soil acidity (raising soil pH) by using liming materials. Common liming materials available in the market include: Agricultural lime ($CaCO_3$), slaked lime ($Ca(OH)_2$), and dolomite lime ($CaMgCO_3$) or magmax. In addition to neutralizing the acidity of the soils, agricultural lime and slaked lime supply Ca^{2+} while dolomite lime supplies both Ca^{2+} and Mg^{2+}. Over-liming should be avoided because Ca^{2+} and Mg^{2+} can precipitate P thereby rendering it unavailable for plant uptake. Liming materials are supplied primarily to alleviate soil acidity and not to supply nutrients. An adequate supply of nutrients should be facilitated through fertilizer addition. Soils with a pH below 5.0-5.5 (depending on the soil) can adversely affect crop growth. Aluminium, manganese and iron increase in solubility as soil pH drops and may actually become toxic to plants at pHs below 5.0-5.5. Beans are especially sensitive to aluminium toxicity, which is the crops most yield limiting factor in some areas. Many soil laboratories routinely test for soluble aluminium levels in very acid soil samples. Manganese and iron toxicities can be serious, too, but usually are not a problem unless the soil is also poorly drained. Very acid soils are usually low in available P and have a high capacity to tie up added P by forming insoluble compounds with iron and aluminium. Although very acid soils usually have enough calcium to supply plant needs (except for peanuts), they are likely to be low in magnesium and available sulphur and molybdenum. Low soil pH depresses the activities of many beneficial soil microbes such as those that convert unavailable N, P, and S to available mineral forms. Anderson and Domsch (1980) reported that acid soils limit microbial growth.

Maize and cowpeas may tolerate soil acidity in the pH 5.0-5.5 range depending on the soil's soluble aluminium content. Sorghum is somewhat more tolerant than maize to soil acidity. Peanuts commonly do well down to pH 4.8-5.0 since they have comparatively good aluminium tolerance. Beans are the most sensitive of the reference crops to soil acidity, and yields usually decline below a soil pH of 5.3-5.5.

Acid soils give poor crop performance in terms of crop yields. This is due to unavailability of P and N resulting from P fixation and slowing down of nitrification rates (Stevenson, 1986). Liming acid soils improves yields because of the rise in soils pH, which is conducive for plant growth and microbial organic matter decomposition, and mineralization of nutrients (N, P, and S). The mineralized nutrients are then made available for crop uptake, thus contributing to the yield increase.

Juric et al (1986) showed that liming of acid soils increased maize yields. Acid soils limed to pH values of 5.0 and 6.0 maintained high yields of Soybeans, maize and cotton for up to six years (Freitas and Van Ray, 1974). Similar yield increases have been observed in pastures and soybean due to liming (Smith et al, 1994). They reported that mineralization of organic P is generally stimulated by higher pH. Liming increases soil pH, which as a result decreases the solubilities of Al and Fe- hydroxides in the soil solution (Smith et al, 1994). Anderson (1980) explains that lime and fertilizer additions increase the solubility and availability of some organic phosphate esters. Kunishi (1982) also observed that liming generally increases the mineralization of organic phosphates.

2.4.1 Correcting acidity by liming.

The acid or very acid conditions of many tropical soils do not suit most crops. Liming is therefore a prerequisite for most agricultural practices (FAO, 1988). Many crops require a pH of over 4.5 for optimum growth. The amount of lime required depends on the natural acidity of the soil and the specific requirement of the crop. It is impossible to indicate specific lime requirements for the great variety of crops, which can be grown on different soils.

2.4.2 Location of acid soils in Nyanza.

Soils in higher rainfall areas are likely to be slightly acid to strongly acid since large quantities of calcium and magnesium may have been leached out over time by rainfall. Those of drier regions are likely to be alkaline or only slightly acid due to less leaching. Continued use of nitrogen fertilizers, whether chemical or organic will eventually lower soil pH enough to require liming. Calcium nitrate, potassium nitrate, and sodium nitrate are the only exceptions and are usually too expensive or unavailable.

2.4.3 Determination of soil liming requirements

Soil pH can be measured fairly accurately in the field with a liquid indicator kit or a portable electric tester. These are useful for troubleshooting but have two drawbacks. Soil pH is not the sole criteria for determining if liming is needed. The soil’s content of soluble aluminium (called “exchangeable” aluminium) is probably more important, and the portable pH kit cannot measure this. A soil with a pH of 5.0 or lower might still be satisfactory for the growth of most crops if its exchangeable aluminiun content is low. On the other hand, another soil with a pH of 5.3 might need liming because of too much aluminium.

The amount of lime needed to raise the soil pH by one unit varies greatly with the type of soil involved. One soil may require 8-10 times more lime than another to achieve the same rise in pH even though both have the same initial pH. The amount of lime needed

depends on the soil's amount of negative charge, which varies with its texture, type of clay minerals, and amount of humus. Only soil laboratory analysis can determine this.
Many soil-testing laboratories use buffer solutions to help estimate lime requirements; some of these solutions are not suitable for organic soils as they were developed for mineral soils with different exchange characteristics.

Lime was recommended if soil in the buffer was less than pH 5.5 (Lucas 1982). Lime recommendation also depends on the crop grown. Several factors modify the critical pH for good plant growth, including the crop sensitivity to active calcium content. In general,

organic soils with low Fe and Al contents can have an optimum pH value as low as 5.0 for certain crops, whereas soils containing appreciable amounts of Fe and Al have an optimum pH value approaching 6.0 for the same crops.
Liming to neutral state is expensive and unnecessary. It may affect the availability of trace elements and over liming may influence denitrification, producing low level of nitrate- nitrogen. Over liming an acid soil appreciably depresses the phosphate recovery and large quantities of calcium, and in the case of dolomite application also magnesium, may interfere with the absorption of potassium by the plants (FAO, 1988). In many cases, therefore, liming is a prerequisite for profitable farming.

The optimum pH values and rates of application to achieve this vary considerably from crop to crop and between different types of soil. When assessing adequate levels of liming, local experimentation is important as optimum pH levels are partly dependent on local economic factors. There are two main materials used for liming; limestone, which is relatively pure $CaCO_3$ with less than 1 percent MgO, and dolomite, a $CaCO_3$ and $MgCO_3$ mixture containing over 15 percent MgO. The pure materials act faster to raise the pH than the dolomitic ones though the latter supply Mg, which is deficient in many soils. Proximity to source and transport costs of these bulky materials often determine the local choice of materials. Occasionally marl, which usually has admixtures of mineral material, and coral lime, are used locally. In all cases, to be effective, the limestone and related materials need to be finally ground to pass through a 100-mesh sieve.

Lime, when applied to soils is relatively immobile and a thorough mixing to the required depth is therefore important. This is laborious to achieve manually and even with mechanized means several diskings will be necessary. In the tropics, the low level of mechanization leads to inefficient liming at the field scale. Where deep mixing is necessary, split applications can be given, one half ploughed under, the other top dressed after ploughing. Split applications also allow the use of both pure and dolomitic limestone (FAO, 1988).

2.4.4. Lime - fertilizer – plant interactions in acid soils

Soils of the humid regions have developed under conditions in which rainfall exceeds evaporation during most of the year. Under this condition there has been a gradual depletion of soil bases and the development of soil acidity. The soil clays often contain coatings of Fe and hydroxyl Al. These materials significantly affect the retention and availability of fertilizer cations and anions in acid soils. The capacity of these soil materials to fix P, Mo and B are influenced by liming.

Acid mineral soils at pH 5 and below often contain appreciable amounts of Al and Mn in the soil solution that are detrimental to plant growth. Optimum growth and efficient use of fertilizer nutrients in acid soils require the addition of lime to neutralize the toxic concentrations of Al and Mn. Acid soils have high P fixing capacity due to either precipitation of P as insoluble Fe/Al phosphates or chemisorptions due to Fe/Al–oxides and clay minerals. Soil pH and previous liming influence P sorption by acid soils (Smyth and Sanchez, 1980).

Liming has been suggested as a method of dealing with acid infertility and P availability (Hue, 1989). Maximum phosphate availability to plants occurs when soil pH is maintained in the range of 6.0 to 7.0 (Eghball et al; 1990). Liming has been found to increase plant growth at low pH (Nurlaeny et al; 1996). It also encourages formation of calcium phosphate, increase mineralization of organic phosphates, and decreases phosphorus fixation and thereby availing more P to plants (Miranda and Rowell, 1987). In addition detoxification of Al, and thus enhancement of root growth is another means by which liming may enhance P uptake and growth (Haynes, 1984).

Inorganic P fertilization and lime additions have been found to increase the organic P content in the soil (Dalal, 1977). Further, P fertilization usually increases dry matter production of crops and ultimately the organic matter content in soils. Lime and fertilizer additions will tend to increase plant yield, exudation of carbon, organic matter turnover, microbial activity and solubility and availability of some organic phosphate esters (Anderson and Domsch, 1980). Competition between inorganic and organic P compounds for soil sorption sites may also occur and result in a substantial increase in dissolved organic phosphorous directly after fertilizer application (Evans, 1985).

There are conflicting views on the effects of liming on P availability in highly weathered acidic soils. Liming can increase (Dalal, 1986), decrease (Anjos and Rowell, 1987) or have no effect (Miranda and Rowell, 1987) on the extractability or availability of soil P. They found that liming decreases the P in solution and labile P, and increased the P sorption capacity of the soils. This was attributed to increased sorption capacity to reactions of the added P with freshly precipitated iron and aluminium hydroxides. The effects of liming on P availability therefore may depend on the extent to which P is sorbed by reactions with exchangeable Al and absorbing surfaces. Small additions of lime to acid Hawaaian latosols greatly increased the uptake of fertilizer P but liming to pH 7, drastically reduced P uptake from acid Al latosols . Liming has no effect on P uptake when the initial pH is 5.8 (Reeve and Summer, 1970). It is important to find the best P rate to apply when lime is used. Tisdale et al, (1990) revealed that the basic ingredient in most phosphatic fertilizers is monocalcium phosphate, which contains calcium. Ordinary super phosphate and TSP has 15-21 and 12-14% Calcium, respectively implying that large doses of P fertilization is synonymous to liming.

Yamoah et al., (1996) observed a decline in yields in the presence of lime. They found that yield increases of potatoe, maize and beans due to liming were highest where no P was applied and diminished with increasing rates of P. Lime – P interactions are not only influenced by soil properties such as Al concentration and pH, but also by the sequence of lime and P supply to soil and by cycles of wetting and drying after liming (Adams, 1984). Fageria and Baligar (1989) suggested that high P rates might cause yield reduction by limiting the uptake of other nutrients such as potassium and zinc.

Level of available P in the soil, pH value of the soil, form and method of fertilizer P application, influence phosphorus uptake by crops (Bekunda, 1990). Acid soils render P and N unavailable through P fixation and slowing down of nitrification rates, respectively (Stevenson, 1986). Micro- organisms that are important in solubilization of organic P compounds, N mineralization and organic matter decomposition are also inhibited in acid soils (Stevenson 1986).

Bonde and Rosswall (1987) reported that both seed and straw yield of manure oilseed rape plants were significantly increased by N application. Bareto and Raun (1995) observed significant linear grain yield response in maize to TSP application. Low value of % P in the control plot could be due to low available P in soil and / or poor rooting, which resulted in low uptake. Deleterious effects of soil acidity on maize also include impairment of root development. Yamoah et al., (1996) observed that maize root weights positively correlated significantly ($P<0.01$) with P. Silberbush and Barber (1993) found that the rate of growth and fineness of roots and root hairs to be the most effective factors influencing P uptake. Wright et al; (1989) noted that under acidic conditions, increased amounts of exchangeable Al could cause shallow rooting.

Generally, residual P was highest where manure was applied. This is attributed to the slow but continuous release of nutrients by manure. Microbial immobilization, synthesis of organic P compounds and mineralization of organic P can be expected to influence P availability by changing the amount of sorbed inorganic P and releasing organic P compounds into solution (Seeling and Zasoski, 1993). They observed that much of the P supplied to soils is converted to less available inorganic pool with time.

2.5 Spectrophotometry in analysis of soil and plant samples

2.5.1 Flame photometry

Flame photometry is concerned with quantitative analysis. The function of the spectrometer in quantitative emission spectroscopy is to isolate the spectral lines. In the case of simple flame spectra it is possible to separate the lines by means of narrow band-pass filters (see figure 1).

A flame photometer is a simple though effective, accurate and inexpensive instrument, similar in many respects to an absorptiometer. The sample is prepared as a solution and sprayed by means of an atomizer into a flame of meker-type burner.

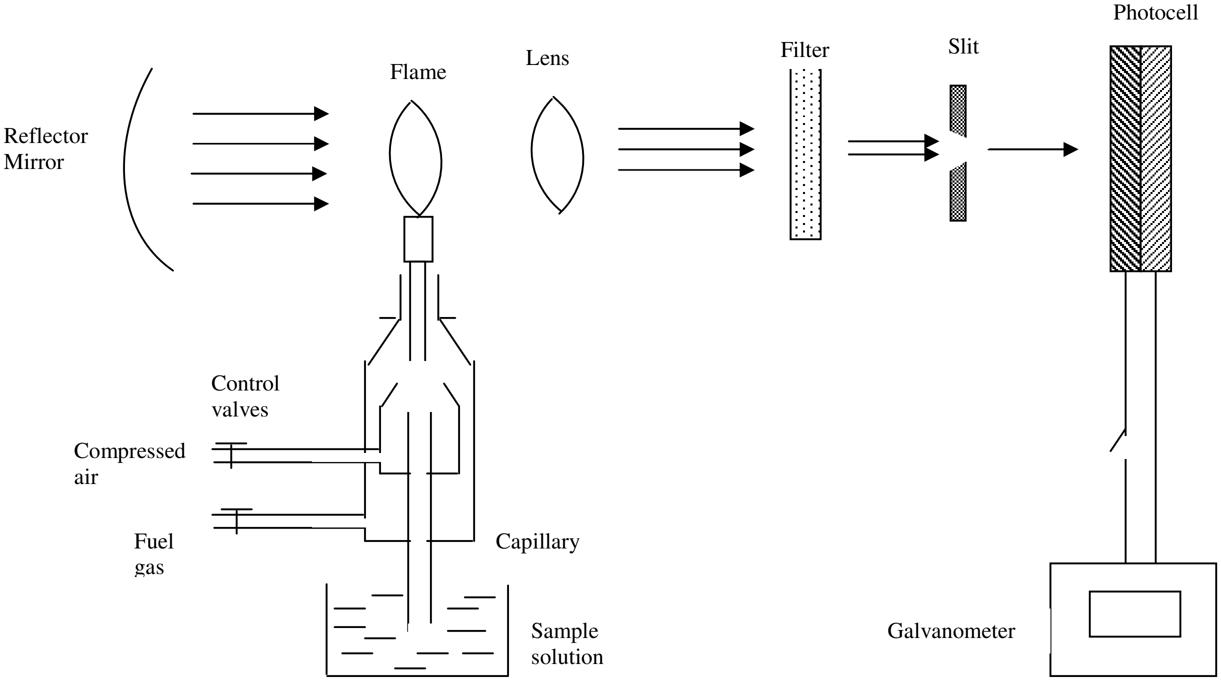

Fig1. Schematic diagram of a flame photometer.

Air together with the entrained spray is blown through the throat of the burner where it mixes with the fuel gas (e.g. coal gas or butane). The radiation emitted is passed through a filter and the intensity of the selected band measured with a photocell detector. Filter flame photometers by their very nature cannot resolve closely-spaced lines; hence their use is restricted to a few elements with strong well defined lines, mainly Na, K, Li and Ca.

The method has wide spread use in pathological laboratories for the determination of Na, K, and Ca in clinical samples. The recent availability of interference filters, which have a much narrower band pass, has extended the range of such instruments to include further elements as Mg.

Other elements require high temperature flames (e.g. air/acetylene, Ca. 2700 ^{0} C, Oxygen / acetylene, Ca. 3050 ^{0} C, and a dispersing Monochromator and thus more costly instrumentation.

2.5.1.1 Qualitative analysis

Elements which produce relatively few but intense lines at the temperature (Ca. 2000 ^{0}C) of a combustion flame e.g. the alkali metals, require relatively simple means of determination

The characteristic colored flames of elements such as sodium and potassium are well known in qualitative analysis. Their flame emission lines in the visible region are readily observed through a spectroscope as a means of qualitative analysis.

2.5.2 Atomic absorption spectroscopy

In atomic absorption spectroscopy measurement is made of the specific absorption of light by the unexcited atoms, i.e. the atoms which remain in the ground state.

A hollow cathode lamp containing the element to be excited is used to produce a beam of radiation characteristic of the element. The beam is split by a rotating sector mirror into the sample and reference beams which respectively bypass and traverse the flame, into which is spayed the sample solution of the element. The ground state atoms absorb the resonance frequencies and the fraction of incident radiation absorbed obeys Beers law (over a limited concentration range) and is a measure of the concentration of the ground state atoms in the flame.

The flame acts merely as vaporizer and is not required as in flame photometry, to excite the atoms to higher energy levels. Any radiation emitted from the flame appears as continuous signals and is distinguished from the alternating signal of the lamp by the amplifier of the photomultiplier detector. This is tuned to the frequency of the rotating sector.

The method is virtually specific for these elements and can be used for trace analysis as it can easily operate in the range 0.01 to 10 ppm.

Atomic absorption is now widely used in metallurgical, biochemical and general inorganic analysis.

2.5.3 Ultraviolet and visible spectroscopy.

Spectra in the UV and visible regions are concerned with electronic transition and in particular, transitions involving outer electrons. For an atom a single change in electronic energy gives rise to a spectral line. For a molecule, however, such a change is, in general accompanied by simultaneous vibration and rotation changes so that the number of absorption lines is very large and the lines crowd together, forming bands.

2.5.3.1 Chromophores

Early in the history of molecular spectroscopy selective absorption in the UV and visible region was attributed to the presence of unsaturated groups known as chromophores (color carriers) and is largely independent of the rest of molecular frame work.

2.5.3.2 Inorganic systems

Characteristic absorption in the visible and near UV are also found in ionic systems, especially those ions possessing unfilled, closely – spaced, inner energy levels (d and f) between which transition can occur. This is why transition metals and rare earth metals usually have colored salts although the molar absorptivities of most are so low that must be complexed for spectrophotometric determination. The outer electron levels of these elements can be stabilized by coordination with groups or molecule (ligands) able to donate lone-pair electrons such as chloride, ammonia or water, or act as π electron acceptors such as cyanide, phenanthroline e.t.c.

For example, in ferricyanides, $[Fe(CN)_6]^{3-}$, the twelve electrons coordinated by the six cyanide groups are divided between the stable outermost level and the incomplete 3d level. The wavelength of absorption is influenced by the valence state of the central element (e.g. in ferri and ferro cyanides) and the nature of the coordinating group (ligand – field effect).

2.6 Soil organic matter (Walkley and Black)

Soil organic matter (humus) contents are estimated from the determination of carbon, which is made by oxidation under standardized conditions sulphuric acid medium.

The principal of this method is formulated as follows:-

$4(Cr^{6+}+3e \longrightarrow Cr^{3+})$

$3(C-4e \longrightarrow C^{4+})$

$4(Cr^{6+} + 3C \longrightarrow 4Cr^{3+} + 3C^{4+}$

$2K_2Cr_2O_7+3C + 8H_2SO_4 \longrightarrow 2K_2SO_4+2Cr_2 (SO_4)_3+3CO_2+8H_2O$

Normally 1g air-dry soil is being used, but if the soil is poor or high in organic carbon more or less can be taken. The soil sample is treated with a measured amount of $K_2Cr_2O_7$ in excess in the presence of H_2S0_4 - H_3PO_4 is added in order to complex the Fe^{3+} ions which are liberated.

After 30 minutes, diphenylamine indicator is added and the excess $K_2Cr_2O_7$ titrated with a ferrous solution. As soon as ferrous ions are added in excess, the indicator turns from blue to a brilliant green color.

$Cr^{6+}+3e \longrightarrow Cr^{3+}$

$3(Fe^{2+}-1e \longrightarrow Fe^{3+})$

$Cr^{6+}+3Fe^{2+} \longrightarrow Cr^{3+}+3Fe^{3+}$

$K_2Cr_2O_7+6FeSO_4+7H_2SO_4 \longrightarrow K_2SO_4+Cr_2 (SO4)_3+Fe_2 (SO_4)_3+H_2O$

2.7 Randomized complete block designs (RCBD)

OBJECTIVE: Collect data to compare <u>a</u> treatment means or to estimate variance components.

EXPERIMENT: Given b groups of at least a units with small within group expected variance, each group can be used to form a COMPLETE BLOCK or replicate. Treatments are assigned at random to units in a block by using random permutations of the numbers 1 to a (Cochran and Cox, 1957).

Linear statistical model:

$$X_{ij} = \mu + T_i + B_j + E_{ij}$$

$i = 1,2, \ldots, a$

$j = 1,2, \ldots, b$

μ represents the overall mean acting on each plot, T_i and B_j are treatment and block effects. E_{ij} will be independent and N $(0, \sigma^2_E)$. σ^2_E represents experimental error arising from a treatment's variation in response across replication. It is an interaction between Blocks and Treatments.

The T_i and B_j may be Model I (FIXED), i.e. selected for inclusion in the experiment. If T_i are model II (random sample from a population of treatment) then they are N $(0,\sigma^2_T)$ variables. Similarly the B_j would be N $(0, \sigma^2_B)$.

If X_{ij} is the mean of several sub-samples, say n, in the block then X_{ij} will be more nearly normally distributed. Further the VAR $(\bar{X}_{ij}) = \sigma^2/n$, smaller than for a single small harvest.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Description of the experimental site at Bototo

Field experiments were conducted at an on – farm site in Bototo. This region has an altitude of 1590 metres above sea level (m.a.s.l) with a precipitation of 1200 – 2100 mm. The soils are mollic Nitisols or sandy loam Nitisols of moderately high fertility. The site is located in upper midland zones (UM_1) with agro climatic conditions suitable for maize, tea, coffee and sweet potatoes production (Jaetzold and Schmidt, 1983). Maize is the leading food crop in the region and is planted twice a year, during the long rains (March – July) and short rains (August – December). The upper midlands (UM_1) lie between 1500 and 1900 m above sea level. It is warm and humid with annual mean temperature of 18 ^{0}C to 25.5 ^{0}C and a mean minimum temperature of 11 to 14 ^{0}C. The annual average precipitation is greater than 80 % of the potential evaporation (E_0).

3.2 Description of the experimental site at Kabondo

Field experiments were conducted at an on – farm site in Kabondo. This region has an altitude of 1450 –1700 metres above sea level (m.a.s.l) with a precipitation of 1598 mm. The soils are chromoluvic Phaeozems located in lower midland zones (LM_1) with agro—climatic conditions suitable for maize, coffee and sweet potatoes production (Jaetzold and Schmidt, 1983). Maize is the leading food crop in the region and is planted twice a year, during the long rains (March –July) and short rains (August – December). The lower midland (LM_1) lies between 800 and 1500 m above sea level. It is warm and humid with annual mean temperature of 21-24 ^{0}C, and a mean minimum temperature of at least 14^{0}C. The annual average precipitation is at least 80 % of the potential evaporation (E_o).

The sites were chosen based on being dominated by acidic soils and agro-ecological differences. The details of the experimental sites; latitude, longitude, altitude, and agro-ecological zones are given in Table 3.1.

Summary of the positional details of the experimental sites (Table 3.1) and long term mean and seasonal climatic data for the study sites (1978 to 1998) (Table 3.2) were also used in the interpretation of the data.

Table: 3.1 Summary of the positional details of the experimental sites.

Site	Administrative district	*AEZ	#Altitude m.a.s.l	# Longitude	# Latitude
Bototo	Kisii central	UM_1	1590	$34^0 44'$E	0^0 39’s
Kabondo	Rachuonyo	LM_1	1450	$34^0 52'$E	0^0 26’s

* Agro – ecological zone (Jaetzold and Schmidt, 1983)

Values obtained using Global positioning tool, GPS 12 X L (1998, Garmin, Olathe, U.S.A).

Table 3.2 Long term mean and seasonal climatic data for the study sites (1978 to 1998).

Climatic parameter	Bototo	Kabondo
Seasonal rainfall {R (mm)}	938	855
Potential Evapotranspiration{ P.E (mm)}	795	849
R/P.E	1.18	1.00
Mean temperature ^{0}C	20.1	20.9
Annual rainfall {R (mm)}	2041	1890
Potential Evapotranspiration {P.E (mm)}	1878	1701
R/P.E	0.92	0.90
Mean temperature ^{0}C	21.8	22.5

Source Corbett et al (2001) Act database Version 3.0

Experimental design and treatments

The experimental design was Randomized Complete Block Design (RCBD) with 40 selected farmers as replicates. Ten men and ten women farmers were involved in each of the sites at Bototo and Kabondo.

The treatments comprised of:

i).	No phosphorus fertilizer used at planting	-0 kg ha^{-1} $P_2 0_5$
ii).	Lime only	- 0 kg ha^{-1} $P_2 0_5$ + 250 kg ha^{-1} lime
iii).	Diammonium Phosphate (DAP)	- 60 kg ha $^{-1}$ $P_2 0_5$
iv).	Minjingu Rock Phosphate (MRP)	- 60 kg ha $^{-1}$ $P_2 0_5$
v).	Triple Super Phosphate (TSP)	- 60 kg ha $^{-1}$ $P_2 0_5$
vi).	Farm Yard Manure (FYM)	-10 t ha $^{-1}$
vii).	½ FYM + ½ DAP	- 5 t ha $^{-1}$ FYM + 30 kg ha $^{-1}$ $P_2 0_5$

3.3 Planting and crop maintenance

Land preparation was done in early March and August prior to the start of the long and short rain seasons respectively. The land was oxen ploughed once and harrowed twice to obtain a fine tilth seedbed. There were seven plots per block each measuring 3.75m wide by 4.8m long giving a net plot area of 18m^2 per plot. Lime was applied in one of the seven plots per block at the rate of 250 kg ha^{-1} $CaCO_3$ two weeks before sowing. Each plot consisted of 5 rows each with 8 hills. Maize hybrid H614 was the test crop in Bototo and H513 the test crop in Kabondo chosen on the basis of being a suitable variety for the study area (Jaetzold and Schmidt, 1983).

At the onset of the seasonal rains, three seeds of maize Hybrid, H614 for Bototo and H513 for Kabondo were sown per hill at a spacing of 0.75m (inter – row) by 0.60m (intra – row), and later thinned to two plants / hill at 21 days after crop emergence. The inter – row spacing of 0.75 m by intra-row spacing of 0.6m was used as the crop was hand planted and this resulted into an optimum plant density of 44 , 444 plants per hectare, which is desirable for low rainfall areas as the study sites. The fertilizers were applied at time of planting along the furrows and mixed with soil to avoid direct contact with the seeds. Planting date was recorded per site. Uniform top dressing with calcium ammonium nitrate (CAN) fertilizer at a recommended rate of 30 kg N ha $^{-1}$ rate so that N is not limiting (KARI, 1993).

Furadan was applied in each planting hole at the rate of 10 kg ha^{-1} to protect the seeds and seedlings against soil borne pests after which the seeds were placed and covered with a small quantity of soil. The crop was protected against stalk borer *(Buseola fusca)* by application of Kombat, a commercial insecticide, applied to the maize funnels at 4 weeks after planting at the rate of 4 kg ha $^{-1}$.

Hand weeding was done once at four weeks after crop germination and thereafter, no further weeding was done to enable accurate assessment of *Striga* infestation. *Striga* emergence counts were conducted every two weeks from the date of planting up to harvesting.

Gladiator, an insecticide, was applied in each trial site to check termite damage to the crop. The crop was harvested at physiological maturity from a net harvest area of 18 m^2 and threshed by hand. Harvesting dates were recorded per site. All ears affected by pests or rotten were excluded in yield measurements. All the consumable grains of a net plot were weighed and then sub – sampled. The stover was cut at about 5cm above the ground level, weighed and sub- sampled for dry matter determination.

3.4 Crop data collection and calculation procedures

The data collected consisted of planting date, emergence date, stand count at 21 days after emergence (DAE), plant stand count at harvest, scores for crop growth vigor on a scale of 1 to 7 at 21 DAE, common diseases, flowering date, *Striga* count at harvest, harvesting date, and yield per plot converted to t ha $^{-1}$. Data collection was done from the net harvest area of 18m^2.

Crop harvest data included field grain, cob and stover weights recorded. Field grain moisture content was recorded using a grain moisture tester (model DjGMTS. N. 0528.) Sub-samples of grain, cobs and stover were then taken for oven drying and subsequent dry matter yield determination. The grain yield (adjusted to 15% moisture content), total above ground dry matter yield, harvest index, and total nutrient uptake and phosphorus use efficiency was calculated using the following formulae by Sigunga, et. al., (2002):

(i) Grain yield (at 15%) = $\frac{GW \text{ x } (100 - MCA)}{100 - MCD}$

(ii) Total dry matter yield (kg ha^{-1}) = GY + SY +CY

(iii) Harvest index = $\frac{\text{GY}}{\text{Total dry matter yield}}$

(iv) Total nutrient uptake = (NCG X GY) + (NCS X SY) + (NCC X CY)

Where:

GY, SY and CY are grain, stover, and cob dry matter yields respectively;

GW, MCA and MCD are fresh grain weight, moisture content of fresh grain and moisture content of grains at 15% moisture respectively;

NCG, NCS and NCC are nutrient (N, P, K, Ca, and Mg) concentrations in grain, stover and cob respectively;

Nutrient phosphorus use efficiency was calculated using the following formulae:

(v) Agronomic P use efficiency = $\frac{Y_f - Y_O}{P}$

(vi) Physiological P use efficiency = $\frac{Y_f - Y_O}{P_{uf} - P_{uo}}$

Where:

Y_f, and Y_o are yields of fertilized and unfertilized crops respectively;

P is the rate of fertilizer P applied, P_{uf} and P_{uo} are P uptake in fertilized and unfertilized crops respectively.

The changes in soil nutrient contents at harvest were determined by difference method:

(vii) Change in soil nutrient content = $P_x - P_o$.

Where:

Px is the nutrient content for a given fertilizer application rate.

Po is the nutrient content for the check (zero) fertilizer treatment.

3.5 Sample collection, preparation, and laboratory analysis

3.5.1 Soil sampling and sample preparation

At the start of the experiment, soil samples were randomly collected from 5 spots at a depth of 0 – 30 cm at each experimental site, using a 5 cm diameter auger. The 0 – 30 cm sampling depth was used as the rooting depth of maize is concentrated, within the same soil depth. Composite soil samples from 5 spots are considered to be good representative of the soil conditions of the experimental plot. The samples were used to assess the initial soil fertility status at the research sites. The soil samples were mixed to obtain a composite sample. About 3 kg sub – samples were obtained from the composite sample, air – dried in a well ventilated room for three days and ground to pass through 2- mm sieve. The soil samples were analyzed for pH (1:2.5) soil: solution (H_20 and 0.01M $CaCl_2$), extractable P, % P, % N, % K, % Ca, % Mg, texture, organic carbon, exchangeable acidity, cation exchange capacity (CEC), and exchangeable bases. At crop harvesting, composite soil samples were collected plotwise at 3 spots per row, to assess changes in soil chemical properties with respect to the fertilizer treatments applied. The samples were analyzed for extractable P, % N, % P, % K, % Ca, and % Mg contents. Samples of farmyard manures which the farmers used in planting were analyzed for pH , N g kg^{-1} ,P g kg^{-1}, Ca g kg^{-1}, Mg g kg^{-1}, K g kg^{-1}, and C g kg^{-1} concentrations .The mean values were calculated and used to determine the approximate farmyard manure rate used in the trials in Bototo and Kabondo.

3.5.2 Plant tissue sampling and sample preparation

Plant samples were separated into stover, cob, and grain. The stover was chopped using a chaff cutter. The stovers, cobs, and grains were sub - sampled, weighed, and oven – dried to a constant weight at 70 ^{0} C for 48 hours for determination of the above ground dry matter yield. The dried plant material was ground using Cromption Willey mill to pass through a 2 mm sieve and sub - sampled for total N, P, K, Ca and Mg determination.

3.5.3. Laboratory analysis of soil and plant tissue samples

3.5.3.1 Soil texture

Soil texture was determined by the hydrometer method (Okalebo et al, 1993). About 50 g of air – dried soil sample (sieved through 2 mm sieve) was mixed with distilled water and dispersed in baffled cup using 10 ml of 10 % sodium Hexametaphosphate solution. After stirring for two minutes, the suspension was transferred into Bouyoucos cylinder (Bouyoucos, 1962) and made to the mark with distilled water.

The amount of soil separated in suspension was measured by stirring the suspension, then taking both hydrometer and thermometer readings after 40 seconds and 2 hours duration. The soil textural class was determined using the textural triangle.

3.5.3. Soil pH

The pH of soil samples was determined electrometrically both in water (pH water) and in 0.01 M $CaCl_2$ (pH $CaCl_2$) at a (1: 2.5) soil: solution ratio (weight /volume) as outlined by Okalebo et. al, (1993). About 10g of air – dry soil samples were added to 25 ml of distilled water and the mixture shaken at 260 reciprocations per minute for 10 minutes and allowed to settle for 30 minutes.

The pH of the soil suspension was recorded thereafter, using a pH meter on a glass electrode.

3.5.3.3 Exchangeable acidity

Exchangeable acidity was determined by the titration method as described by Anderson and Ingram (1993). About 10g of air – dry soil was saturated with 25 ml of 1 M KCl for 30 minutes, filtered (using Whatman No. 42 filter paper) and leached with 5 successive 25 ml. aliquots of 1 M KCl. The concentration of aluminium and hydrogen ions in the filtrate was determined through titration against 0.1M Na0H, and used to quantify the soil exchangeable acidity.

3.5.3.4 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) was determined using ammonium acetate (NH_4OAc) (pH = 7.0) method as described by Okalebo et al. (1993). About 10g of air- dry soil was saturated with 100ml of 1M NH_4OAc solution at pH 7 by mechanical shaking for 30 minutes. The suspension was filtered (through No. 42 Whatman filter paper) and the soil retained on the filter paper. The leachate was retained for exchangeable bases determination. The ammonium-saturated soil was washed with 50 ml alcohol to remove the interstitial ammonium ions. Soil was then leached with 1M KCl and the amount of ammonium ions in the leachate quantified as the CEC of the soil. The amounts of Calcium and Magnesium in the extract was analyzed on the atomic absorption spectrophotometer (Model CTA –2000 AAS, chem. Tech Analycal,UK). While potassium on a flame photometer (model: EEL, Evans Electroselium, UK) following the procedures described by Okalebo et. al,. (1993).

3.5.3.5 Total organic carbon

Total organic carbon was determined by a modified Walkley – Black “Wet” oxidation method of Allison (1964). About 0.5g of 0.3 mm air – dry soil samples were weighed in triplicate into a block digester tube into which 10ml of 1N potassium dichromate ($K_2Cr_2O_7$) solution and 15ml concentrated sulphuric acid (H_2S0_4) was added. Two reagent blanks were also included. The mixtures were digested at 155 ^{0}C for 30 minutes and then allowed to cool. The digests were transferred quantitatively to 250 ml conical flasks with about 150 ml of distilled water followed by 10 ml of 85% orthophosphoric acid (H_3P0_4). The unreacted dichromate in the digest and the blanks were titrated against 0.5 M Ferrous ammonium sulphate solution. The percentage organic carbon was calculated using the formula:

Organic carbon (%) = $\dfrac{(B-T)\,0.3xV}{\frac{W}{B}}$

Where T = Sample titre (ml)

B = Blank titre (ml)
W = Oven dry sample weight (g)
V = Volume of 1N K_2 Cr_2 0_7 used (ml)
0.3 = 1 ml of 1 N K_2 Cr_2 0_7 = 0.003 g C X 100.

3.5.3.6 Extractable phosphorus

Extractable phosphorus was determined after extraction with Mehlich extractant (a mixture of 0.1 M HCl and 0.025 M H_2S0_4) (Olsen and Sommers, 1982). About 5 g of 2mm air dry soil was weighed and a scoop of activated phosphorus – free charcoal added to absorb organic matter and decolorize extracts. The soil was saturated with 25ml of the extracting solution by mechanical shaking of the mixture for 30 minutes and filtered through Whatman No. 42 filter paper. A blank and a standard sample were included in each series. The P concentrations of the samples were determined calorimetrically following the ammonium molybdate- vanadate procedure on a spectrophotometer (Model: Noraspec ® II, Pharmacia Biotech) at 430 nm after one hour.

3.5.3.7 Total soil and plant tissue analysis

Total soil and plant tissue N, P, K, Ca and Mg was determined following the digestion of 0.2g air dry soil / tissue samples in 4.4 ml H_2S0_4 – H_2O_2 digestion mixture (made of 0.42g selenium powder and 14 g lithium sulphate, 350 ml of 30% hydrogen peroxide and 420 ml of concentrated H_2S0_4 at 360^0 C for 2 hours (Anderson and Ingram, 1993). The digests were allowed to cool and thereafter made up to the 100 ml mark with distilled water for subsequent total N, P, K, Ca, and Mg analyses.

Total (ammonium) N in the digest was determined following the salicylic – hypochlorite colorimetric method (Anderson and Ingram, 1993). About 0.2 ml of the filtrate was put in a test tube, followed by addition of 5ml of colour development reagents N1 (a mixture of sodium salicylate, sodium citrate and sodium tartrate in deionized water) and N2 (a mixture of Na0H and 5% sodium hypochlorite solution). The sample N concentrations were read on a spectrophotometer at 655 nm after one hour. The P concentrations in the sample digests were determined calorimetrically by the ammonium molybdate – vanadate procedure on a spectrophotometer at 430 nm after one hour. Potassium in the digest was determined on a flame spectrometer, while Ca and Mg concentrations were determined using an Atomic Absorption Spectrophotometer (AAS).

3.6 Statistical analysis

Data on growth vigor, Striga emergence, grain yield, total dry matter yield, harvest index, nutrient (N,P,K,Ca, and Mg) uptake, phosphorus use efficiency, soil nutrient contents (extractable P, % P, % N, % K, % Ca) at harvest, plant tissue nutrient contents, was subjected to the standard Analysis of Variance (ANOVA) and mean separation, where necessary using Duncan's Multiple Range Test (DMRT) procedures at $P \leq 0.01$. Regression analysis was carried out to estimate the relationship between the variables.

CHAPTER FOUR

RESULTS

4.1 Maize yields

Visual observations of the maize plants showed P deficiency symptoms (purple/reddish coloration in leaves and over-all stunted growth) in the P control plots (0 kg P/ha) at the early crop growth stages (4 weeks after crop emergence) at both sites. There were significant ($P \leq 0.01$) crop growth vigour responses to fertilizers and manure treatments at both Bototo and Kabondo. Plants that received fertilizer and manure were more vigorous in growth than those in the control (Table 4.1). The mean growth vigour was 3.76 and 3.86 in Bototo and Kabondo respectively.

There were significant ($P \leq 0.01$) grain yield values due to treatments. The mean grain yield values were 3932 kg ha^{-1} at Bototo and 3070 kg ha^{-1} at Kabondo (Table 4.1).

Total dry matter yield was significant ($P \leq 0.01$) at both sites. Bototo had a mean of 11470 kg ha^{-1} while Kabondo had a mean of 10750 kg ha^{-1} (Table 4.1).

The harvest index was significant ($P \leq 0.01$) at both sites, with Bototo having a mean of 0.32 and Kabondo a mean of 0.28 (Table 4.1).

Table: 4.1 Effects of treatments on maize growth vigour scores *, maize grain yield, total dry matter yield and harvest index at the study sites.

Treatment	Maize growth vigour score		Grain yield (kg/ha)		Total dry matter yield (kg/ha)		Harvest Index (HI)	
	Bototo	Kabondo	Bototo	Kabondo	Bototo	Kabondo	Bototo	Kabondo
½ DAP + ½ FYM.	6.95^{a}	6.00^{a}	6244^{a}	4990^{a}	16330^{a}	14200^{a}	0.37^{a}	0.35^{a}
TSP	5.00^{b}	5.70^{a}	4961^{b}	3566^{b}	13610^{b}	11170^{b}	0.35^{b}	0.31^{b}
FYM	4.75^{b}	4.85^{b}	$4274^{b/c}$	$3150^{c.d}$	$12320^{b/c}$	$10710^{b/c}$	$0.33^{b/c}$	$0.29^{b/c}$
DAP	3.95^{c}	4.00^{c}	3995^{c}	$2942^{c/d}$	11690^{c}	$10880^{b/c}$	$0.33^{b/c}$	$0.27^{c/d}$
MRP	2.95^{d}	3.75^{c}	3760^{c}	$2658^{d/e}$	11200^{c}	10010^{c}	0.32^{c}	0.26^{d}
Lime	1.55^{e}	1.40^{d}	2569^{d}	2362^{e}	8680^{d}	9900^{c}	0.30^{d}	0.24^{e}
Control	1.15^{e}	1.30^{d}	1722^{e}	1824^{f}	6490^{e}	8340^{d}	0.26^{e}	0.21^{e}
Mean	3.76	3.86	3932	3070	11470	10750	0.32	0.28
CV %	20.57	28.88	32.52	22.59	22.24	14.62	10.79	14.12
SE ±	0.17	0.25	285.92	155.00	570.00	350.00	0.01	0.01
LSD ($P \leq 0.05$)	0.48	0.70	801.02	434.44	1600.00	980.00	0.02	0.02

The means followed by the same letter for each factor in a column are not significantly different ($P \leq 0.01$) according to DMRT mean separation.
*Growth vigour ranked on a scale of 1-7 (1-least vigorous, 7 –most vigorous.)

(i) Grain yield (at 15%) = $\frac{GW \times (100 - MCA)}{100 - MCD}$

(ii) Total dry matter yield (kg ha^{-1}) = GY + SY +CY
(iii) Harvest index = $\frac{GY}{\text{Total dry matter yield}}$

Where
GY, SY and CY are grain, stover, and cob dry matter yields respectively;
GW, MCA and MCD are fresh grain weight, moisture content of fresh grain and moisture content of grains at 15% moisture respectively

4.2 Plant tissue nutrient content

There were significant effects on plant tissue nutrient content due to treatments (P≤ 0.01) at both sites. Total nitrogen content increased significantly due to the applied fertilizers and manure.

Total nitrogen content in Bototo had a mean of 38.81 kg ha^{-1} N in the stover, 52.69 kg ha^{-1} N in the grain, and 31.28 kg ha^{-1} N in the cob. From the plant tissue nutrient content results, at harvest, the grain (52.69 kg ha^{-1} N) had the highest total nitrogen compared to the stover (38.81 kg ha^{-1} N) and the cob (31.28 kg ha^{-1} N) in Bototo (Table 4.2 a).

Total phosphorus content increased significantly due to fertilizers and manure applied at Bototo. Total phosphorus content had a mean of 4.35 kg ha^{-1} P in the stover, 12.91 kg ha^{-1} P in the grain, and 3.16 kg ha^{-1} P in the cob. From the plant tissue nutrient content results, at harvest, the grain (12.91 kg ha^{-1} P) had the highest total phosphorus compared to the stover (4.35 kg ha^{-1} P) and the cob (3.16 kg ha^{-1} P) in Bototo (Table 4.2 a).

Total potassium content increased significantly due to fertilizers and manure applied at Bototo. Total potassium content had a mean of 125.7 kg ha^{-1} K in the stover, 14.23 kg ha^{-1} K in the grain and 10.09 kg ha^{-1} K in the cob. From the plant tissue nutrient content results, at harvest, the stover (125.7 kg ha^{-1} K) had the highest total potassium compared to the grain (14.23 kg ha^{-1} K) and the cob (10.09 kg ha^{-1} K) in Bototo (Table 4.2 a)

Total calcium content increased significantly due to fertilizers and manure applied at both sites. Total calcium content had a mean of 0.0179 kg ha^{-1} Ca in the stover, 0.019 kg ha^{-1} Ca in the grain, and 0.012 kg ha^{-1} Ca in the cob. From the plant tissue nutrient content results, at harvest, the grain (0.019 kg ha^{-1} Ca) had the highest total calcium compared to the stover (0.0179 kg ha^{-1} Ca) and the cob (0.012 kg ha^{-1} Ca) in Bototo (Table 4.2 a).

Total magnesium content increased significantly due to fertilizers and manure applied at both sites.Total magnesium content had a mean of 0.0116 kg ha^{-1} Mg in the stover, 0.0072 kg ha^{-1} Mg in the grain, and 0.0048 kg ha^{-1} Mg in the cob. From the plant tissue nutrient content results, at harvest, the stover (0.012 kg ha^{-1} Mg) had the highest total magnesium compared to the grain (0.0072 kg ha^{-1} Mg) and the cob (0.0048 kg ha^{-1} Mg) in Bototo (Table 4.2 a).

Table 4 .2a Effects of treatments on plant tissue nutrient content at Bototo

	Stover (kg ha^{-1})					**Grain** (kg ha^{-1})					**Cob** (kg ha^{-1})				
Treatment	**N**	**P**	**K**	**Ca**	**Mg**	**N**	**P**	**K**	**Ca**	**Mg**	**N**	**P**	**K**	**Ca**	**Mg**
½ DAP + ½ FYM.	46.00^{a}	6.00^{a}	146.00^{a}	0.020^{a}	0.015^{a}	56.00^{a}	17.85^{a}	22.00^{a}	0.022^{ab}	0.015^{a}	38.20a	5.00^{a}	20.00^{a}	0.015^{a}	0.009^{a}
TSP	40.15^{c}	4.00^{c}	129.70^{b}	0.021^{a}	0.013^{b}	53.00^{c}	12.00^{d}	15.40^{b}	0.020^{bc}	0.012^{ab}	34.70b	4.05^{b}	10.00^{b}	0.015^{a}	0.008^{ab}
FYM	39.00^{c}	3.40^{d}	144.75^{a}	0.021^{a}	0.010^{e}	51.00^{d}	12.00^{d}	12.05^{d}	0.021^{ab}	0.006^{cd}	34.70b	4.05^{b}	10.00^{b}	0.013^{b}	0.008^{ab}
DAP	42.00^{b}	4.00^{c}	126.00^{c}	0.018^{b}	0.013^{b}	55.00^{b}	15.05^{b}	14.55^{bc}	0.022^{ab}	0.009^{bc}	38.20a	3.65^{b}	9.00^{c}	0.012^{c}	0.004^{bc}
MRP	37.10^{d}	5.00^{b}	125.65^{c}	0.016^{c}	0.012^{c}	53.40^{c}	12.80^{c}	13.55^{c}	0.027^{a}	0.005^{de}	29.20c	2.75^{c}	9.00^{c}	0.010^{d}	0.003^{c}
Lime	34.40^{e}	4.05^{c}	106.45^{d}	0.015^{cd}	0.009^{d}	50.75^{d}	10.60^{e}	11..95^{d}	0.014b^{c}	0.002^{e}	27.20e	1.40^{d}	6.50^{d}	0.010^{d}	0.002^{c}
Control	33.05^{e}	4.00^{c}	101.35^{e}	0.014^{d}	0.009^{d}	49.65^{e}	10.10^{f}	10.10e	0.010^{c}	0.002^{e}	23.25f	1.25^{d}	6.10^{d}	0.008^{e}	0.001^{c}
Mean	38.81	4.35	125.70	0.0179	0.012	52.69	12.91	14.23	0.019	0.0072	31.28	3.16	10.09	0.0118	0.0048
CV %	7.31	9.88	4.645	13.56	16.51	1.81	4.52	11.95	79.71	80.95	2.72	22.23	8.128	10.501	128.67
SE ±	0.63	1.31	0.0005	0.0004	0.004	0.214	0.131	0.380	0.0035	0.0013	0.190	0.157	0.184	0.00028	0.0014
LSD (P≤ 0.05)	1.78	0.27	3.67	0.0015	0.0012	0.60	0.37	1.06	0.0097	0.0037	0.53	0.44	0.52	0.0008	0.0039

The means followed by the same letter for each factor in a column are not significantly different (P=0.01) according to DMRT mean separation.

Total nitrogen content increased significantly due to fertilizers and manure applied in Kabondo. Total nitrogen content had a mean of 16.17 kg ha^{-1} N in the stover, 17.79 kg ha^{-1} N in the grain, and 15.08 kg ha^{-1} N in the cob. From the plant tissue nutrient content results, at harvest, the grain (17.79 kg ha^{-1} N) had the highest total nitrogen content compared to the stover (16.17 kg ha^{-1} N) and the cob (15.08 kg ha^{-1} N) in Kabondo (Table 4.2 b).

Total phosphorus content increased significantly due to fertilizers and manure applied at Kabondo. Total phosphorus content had a mean of 3.21 kg ha^{-1} P in the stover, 6.59 kg ha^{-1} P in the grain, and 3.14 kg ha^{-1} P in the cob. From the plant tissue nutrient content results, at harvest, the grain (6.59 kg ha^{-1} P) had the highest total phosphorus content compared to the stover (3.21 kg ha^{-1} P) and the cob (3.14 kg ha^{-1} P) in Kabondo (Table 4.2 b)

Total potassium content increased significantly due to fertilizers and manure applied at Kabondo. Total potassium content had a mean of 60.21 kg ha^{-1} K in the stover, 7.77 kg ha^{-1} K in the grain and 6.54 kg ha^{-1} K in the cob. From the plant tissue nutrient content results, at harvest, the stover (60.21 kg ha^{-1} K) had the highest total potassium content compared to the grain (7.77 kg ha^{-1} K) and the cob (6.54 kg ha^{-1} K) in Kabondo (Table 4.2 b).

Total calcium content had a mean of 0.011 kg ha^{-1} Ca in the stover, 0.017 kg ha^{-1} Ca in the grain, and 0.013 kg ha^{-1} Ca in the cob -at Kabondo. From the plant tissue nutrient content results, at harvest, the grain (0.017 kg ha^{-1} Ca) had the highest total calcium contents compared to the stover (0.011 kg ha^{-1} Ca) and the cob (0.013 kg ha^{-1} Ca) (Table 4.2 b).

Total magnesium content had a mean of 0.0047 kg ha^{-1} Mg in the stover, 0.0012 kg ha^{-1} Mg in the grain, and 0.003 kg ha^{-1} Mg in the cob. From the plant tissue nutrient content results, at harvest, the stover (0.0047 kg ha^{-1} Mg) had the highest total magnesium content compared to the grain (0.003 kg ha^{-1} Mg) and the cob (0.003 kg ha^{-1} Mg) in Kabondo (Table 4.2 b)

Table 4 .2b Effects of treatments on plant tissue nutrient contents at Kabondo

	Stover (kg ha^{-1})					**Grain** (kg ha^{-1})					**Cob** (kg ha^{-1})				
Treatment	**N**	**P**	**K**	**Ca**	**Mg**	**N**	**P**	**K**	**Ca**	**Mg**	**N**	**P**	**K**	**Ca**	**Mg**
½DAP+ ½ FYM	23.00^{a}	5.00^{a}	70.95^{a}	0.019^{a}	0.008^{a}	20.00^{b}	10.00^{a}	9.90^{a}	0.024^{a}	0.006a	20.15^{a}	4.00^{a}	9.50^{a}	0.018^{a}	0.007^{a}
TSP	20.00^{b}	4.00^{b}	65.95^{b}	0.016^{b}	0.007^{b}	17.00^{d}	7.95^{b}	7.85^{c}	0.024^{a}	0.005b	17.2^{b}	4.00^{a}	7.50^{b}	0.014^{ab}	0.005^{b}
FYM	17.90^{c}	4.00^{b}	69.95^{a}	0.012^{c}	0.005^{c}	15.00^{f}	7.95^{b}	7.15^{d}	0.018^{ab}	0.002	16.20^{c}	3.10^{b}	7.50^{b}	0.014^{b}	0.003^{c}
DAP	17.00^{c}	4.00^{b}	60.55^{c}	0.010^{c}	0.005^{c}	21.00^{a}	7.00^{c}	8.15^{c}	0.021^{a}	0.004c	20.15^{a}	3.10^{b}	9.50^{a}	0.013^{bc}	0.003^{c}
MRP	17.00^{c}	3.00^{c}	54.35^{d}	0.009^{d}	0.004^{d}	19.00^{c}	5.30^{d}	8.85^{b}	0.018^{b}	0.003d	15.30^{d}	2.70^{c}	4.30^{c}	0.012^{bc}	0.002^{d}
Lime	10.00^{d}	1.30^{d}	51.85^{e}	0.005^{e}	0.002^{e}	17.10^{d}	4.00^{e}	6.40^{e}	0.011b	0.0014e	8.40^{e}	2.60^{c}	3.90^{c}	0.011^{bc}	0.001^{e}
Control	8.30^{e}	1.20^{d}	47.85f	0.006^{e}	0.002^{f}	15.40^{e}	3.95^{e}	6.10^{e}	0.006^{c}	0.0012e	8.15^{e}	2.50^{c}	3.55^{c}	0.010^{c}	0.001^{e}
Mean	16.17	3.21	60.21	0.011	0.0047	17.79	6.59	7.77	0.017	0.003	15.08	3.14	6.54	0.013	0.003
CV %	16.65	14.89	3.18	33.27	30.52	2.23	10.86	13.92	80.53	24.97	3.01	14.99	18.89	49.15	32.17
SE ±	0.60	0.11	0.43	0.0008	0.0003	0.089	0.16	0.24	0.0031	0.00019	0.101	0.105	0.276	0.0014	0.0002
LSD (P≤ 0.05)	1.69	0.30	1.20	0.0023	0.0009	0.25	0.45	0.68	0.009	0.0005	0.28	0.30	0.77	0.004	0.0006

The means followed by the same letter for each factor in a column are not significantly different (P=0.01) according to DMRT mean separation.

4.3 Nutrient uptake

There were significant treatment effects on nutrient uptake ($P \leq 0.01$) which indicates significant N responses to fertilizers and manure at both sites (Table 4.3). Nitrogen uptake was highly correlated ($r = 0.96$) with total dry matter yield at both sites. The mean values for nitrogen uptake were 49.83 and 28.17 kg ha^{-1} N in Bototo and Kabondo respectively.

There were significant phosphorus uptake responses to the fertilizers and manure (Table 4.3). Phosphorus uptake correlated strongly ($r = 0.91$) with grain and total dry matter yields at both sites. The mean values for phosphorus uptake were 47.35 and 35.73 kg ha^{-1} P in Bototo and Kabondo respectively.

Potassium uptake increased significantly due to the application of fertilizers and manure in both the sites (Table 4.3). The mean values for potassium uptake were 77.27 and 32.39 kg ha^{-1} K in Bototo and Kabondo respectively.

Calcium uptake increased significantly due to the fertilizers and manure in both Bototo and Kabondo (Table 4.3). The mean values for calcium uptake were 5.78 and 4.55 kg ha^{-1} Ca in Bototo and Kabondo respectively.

Magnesium uptake increased significantly due to fertilizers and manure in Bototo but the results were not significant in Kabondo (Table 4.3). The mean values for magnesium uptake were 3.23 and 1.74 kg ha^{-1} Mg in Bototo and Kabondo respectively.

Table 4.3 Effects of treatments on nutrient uptake at the study sites.

Treatment	Nitrogen uptake (kg ha^{-1} N)		Phosphorus uptake (kg ha^{-1} P)		Potassium uptake (kg ha^{-1} K)		Calcium uptake (kg ha^{-1} Ca)		Magnesium uptake (kg ha^{-1} Mg)	
	Bototo	**Kabondo**	**Bototo**	**Kabondo**	**Bototo**	**Kabondo**	**Bototo**	**Kabondo**	**Bototo**	**Kabondo**
½ DAP + ½ FYM.	67.80^{a}	31.70^{b}	63.50^{a}	47.90^{a}	105.10^{a}	44.40^{a}	8.25^{a}	5.76^{b}	4.12^{a}	2.20^{a}
TSP	47.80^{d}	44.10^{a}	43.30^{d}	47.50^{a}	82.90^{b}	38.70^{d}	5.06^{d}	6.09^{a}	2.99^{c}	2.26^{a}
FYM	67.30^{a}	25.30^{d}	59.60^{b}	35.20^{b}	80.60^{c}	34.50^{c}	8.17^{a}	4.82^{d}	3.49^{b}	1.98^{b}
DAP	56.30^{b}	27.50^{c}	51.60^{c}	35.20^{b}	86.00^{b}	34.40^{c}	6.74^{b}	5.08^{c}	3.98^{a}	1.95^{b}
MRP	50.80c	21.70^{e}	56.80^{b}	33.40^{c}	80.20^{c}	28.20^{e}	6.33^{c}	3.85^{f}	3.44^{b}	1.60^{c}
Lime	37.70^{e}	28.40^{c}	38.40^{e}	32.90^{c}	59.50^{d}	29.50^{d}	3.56^{e}	4.19^{e}	2.69^{b}	1.47^{b}
Control	21.10^{f}	18.60^{f}	18.30^{f}	18.00^{d}	46.70^{e}	17.10^{f}	3.34^{f}	2.08^{g}	1.9^{e}	0.75^{e}
Mean	49.83	28.17	47.35	35.73	77.27	32.39	5.78	4.55	3.23	1.74
CV %	7.68	10.39	11.35	4.79	8.85	5.99	8.36	2.89	12.89	10.37
SE ±	0.86	0.65	1.20	0.38	1.53	0.43	0.11	0.03	0.09	0.04
LSD ($P \leq 0.05$)	2.40	1.84	3.37	1.07	4.29	1.22	0.30	0.08	0.26	0.11

The means followed by the same letter for each factor in a column are not significantly different (P=0.01) according to DMRT mean separation.

Total nutrient uptake = (NCG X GY) + (NCS X SY) + (NCC X CY)

Where:

GY, SY and CY are grain, stover, and cob dry matter yields respectively;

NCG, NCS and NCC are nutrient (N, P, K, Ca, and Mg) concentrations in grain, stover and cob respectively;

4.4 Nutrient use efficiency

There were significant improvements in nutrient use efficiency (NUE) due to treatments ($P \leq 0.01$) as indicated by Agronomic Phosphorus Use Efficiency (APUE) responses to fertilizers and manure treatments in Kabondo and Bototo (Table 4.4).

The mean values for Agronomic phosphorus use efficiency were 32 kg grain per kg P and 29 kg grain per kg P in Bototo and Kabondo respectively. Control and lime treatments had no applied P and thus no data on nutrient use efficiency was calculated.

Physiological Phosphorus Use Efficiency (PPUE) significantly responded to fertilizers and manure in Bototo and Kabondo (Table 4.4). The mean values for Physiological Phosphorus Use Efficiency were 36 kg grain per kg P and 42 kg grain per kg P in Bototo and Kabondo respectively.

Table 4.4: Phosphorus agronomic use efficiency and physiological use efficiency

Treatment	Agronomic phosphorus use efficiency (kg grain/kg P)		Physiological phosphorus use efficiency (kg grain/kg P)	
	Bototo	**Kabondo**	**Bototo**	**Kabondo**
½ DAP + ½ FYM.	29^{b}	76^{a}	39^{b}	38^{c}
TSP	24^{c}	29^{b}	42^{a}	37^{d}
FYM	42^{a}	7^{e}	36^{c}	38^{c}
DAP	43^{a}	24^{c}	38^{b}	40^{d}
MRP	21^{d}	11^{d}	29^{d}	46^{a}
Lime	-	-	35^{c}	46^{a}
Control	-	-	29^{d}	46^{a}
Mean	31.85	29.48	35.53	41.56
CV %	6.80	5.90	6.02	2.38
SE $\pm$	0.49	0.22	0.48	0.22
LSD ($P \leq 0.05$)	1.36	1.10	1.74	0.62

The means followed by the same letter for each factor in a column are not significantly different ($P \leq 0.01$) according to DMRT mean separation.

$$\text{Agronomic P use efficiency} = \frac{Y_f - Y_O}{P}$$

$$\text{Physiological P use efficiency} = \frac{Y_f - Y_O}{P_{uf} - P_{uo}}$$

Where:

Y_f, and Y_o are yields of fertilized and unfertilized crops respectively;

P is the rate of fertilizer P applied; P_{uf} and P_{uo} are P uptake in fertilized and unfertilized crops respectively

4.5 Soil nutrient content

Initial soil analysis indicated that the soils at the sites were low in fertility, acidic, with low amounts of total N, organic carbon, total and extractable phosphorus and exchangeable bases (Table 4.5a).

Table 4.5a Soil chemical and physical properties of the study sites (0-30cm).

Parameter	**Bototo**	**Kabondo**
Texture:		
Sand (%)	26	55
Silt (%)	28	23
Clay (%)	48	22
Textural class	Clay	Sandy clay loam
Soil pH 1:2.5 (soil: solution)		
H_2O	4.8	5.7
$CaCl_2$	4.5	5.4
Organic carbon (%)	0.7	0.7
Total nitrogen (%)	0.1	0.2
Available phosphorus (mg kg^{-1} soil)	3.0	2.8
Exchangeable bases (cmol (+) kg^{-1})		
K	4.9	8.7
Mg	0.8	0.8
Ca	1.1	3.2
Exchangeable acidity (cmol (+) kg^{-1})		
CEC pH 7 cmol (+) kg^{-1}	4.5	0.7
Base saturation (%)	24	16
Aluminium (%)	49	79
	15.8	4.8

Exchangeable acidity = Al + H

Exchangeable bases = K + Mg + Ca

Effective cation exchange capacity = exchangeable acidity + exchangeable bases

ECEC =Al + H + K + Mg + Ca

% Al = (Exchangeable acidity / effective cation exchange capacity) X100

$$\% \text{ Al} = \left\lfloor \frac{Al+H}{Ca+Mg+K+Al+H} \right\rfloor \text{ x } 100$$

$$\text{Base saturation } (\%) = \left\lfloor \frac{K+Mg+Ca}{Ca+Mg+K+Al+H} \right\rfloor \text{ x } 100$$

There were significant treatment effects on soil nutrient content at both sites. Fertilizers and manure application significantly increased the extractable soil P content above the control at both sites. The mean values for extractable soil P content were 5.43 and 2.20 mg P/kg in Bototo and Kabondo respectively. Minjingu Rock Phosphate and the ½ DAP + ½ FYM treatments significantly increased extractable P than the control at Bototo. In both sites the application of lime significantly increased extractable P as compared to the control (Table 4.5b).

Total soil P contents were significantly different in both sites. The mean values for total soil P were 2.2 and 3.12% P in Bototo and Kabondo respectively. The total soil P contents differed because of the pH changes that occurred in the soil due to fertilizers and manure (Table 4.5b). When the ½ DAP + ½ FYM and TSP treatments are applied N and P nutrients become readily available from the fertilizer and manure because P fixation and slowing down of nitrification rates does not occur. Manure effectively regulates soil acidity and exchangeable Al by binding Fe and Al ions in the acidic soils. TSP contains Ca (12-14%) and hence large doses of P from TSP are similar to liming, thus neutralizing the exchangeable Al and Fe ions.

The fertilizers and manure had no significant effect on total N in both sites. The total N% was approximately 0.01% for Bototo and 0.016% for Kabondo. The fertilizers and manure had no effect on the total N in the soils because there was a blanket application of 30 kg ha^{-1} N so that it was not limiting to the maize crop (Table 4.5b).

Total soil potassium (K) changed significantly with the different fertilizers and manure applied. The mean values for total soil potassium were 2.63 and 8.65% K in Bototo and Kabondo respectively (Table 4.5b). The total soil potassium (K) is less in the ½ DAP + ½ FYM treatments than in the control because of the increased crop nutrients removal following fertilizer and manure application.

Total soil calcium was significantly different in the fertilizers and manure treatments in both Bototo and Kabondo. The mean values for total soil calcium were 0.003 and 0.002 % Ca in Bototo and Kabondo respectively (Table 4.5b).

Total soil magnesium (Mg) changed significantly with the different fertilizers and manure applied. The mean values for total soil magnesium were 0.03 and 0.02 % Mg in Bototo and Kabondo respectively (Table 4.5b).

Table 4.5b Effects of treatments on soil extractable P, total phosphorus, nitrogen, potassium, calcium and magnesium.

Treatment	Extractable P (mg P /kg)		Phosphorus (%)		Nitrogen (%)		Potassium (%)		Calcium (%)		Magnesium (%)	
	Bototo	**Kabondo**	**Bototo**	**Kabondo**	**Bototo**	**Kabondo**	**Bototo**	**Kabondo**	**Bototo**	**Kabondo**	**Bototo**	**Kabondo**
½ DAP + ½ FYM.	6.80^{b}	2.20^{c}	2.10^{c}	2.20^{d}	0.01^{a}	0.013^{a}	2.02^{e}	7.20^{d}	0.0020^{d}	0.001^{b}	0.020^{f}	0.010^{e}
TSP	5.90^{c}	2.00^{d}	2.10^{c}	3.20^{b}	0.01^{a}	0.016^{a}	2.15^{d}	8.10^{c}	0.0027^{b}	0.002^{a}	0.027^{c}	0.020^{b}
FYM	3.50^{e}	1.80^{e}	2.20^{b}	3.20^{b}	0.01^{a}	0.014^{a}	2.86^{b}	8.90^{d}	0.0024^{c}	0.002^{a}	0.024^{d}	0.019^{c}
DAP	4.70^{d}	3.10^{a}	2.20^{b}	3.30^{b}	0.01^{a}	0.015^{a}	2.77^{c}	8.70^{b}	0.0023^{c}	0.001^{b}	0.024^{d}	0.010^{e}
MRP	7.60^{a}	2.20^{c}	2.20^{b}	3.20^{b}	0.01^{a}	0.016^{a}	2.87^{b}	8.60^{b}	0.0022^{a}	0.001^{b}	0.022^{e}	0.012^{d}
Lime	5.90^{c}	2.50^{b}	2.30^{b}	3.00^{c}	0.01^{a}	0.022^{a}	2.88^{a}	8.90^{b}	0.0029^{a}	0.003^{a}	0.035^{a}	0.029^{a}
Control	3.70^{e}	1.60^{f}	2.50^{a}	3.70^{a}	0.01^{a}	0.018^{a}	2.88^{a}	10.10^{a}	0.0028^{a}	0.003^{a}	0.029^{b}	0.020^{b}
Mean	5.43	2.20	2.22	3.12	0.01	0.016	2.63	8.65	0.0025	0.0019	0.026	0.017
CV %	7.94	8.26	6.43	8.57	0.00	114.04	8.40	8.86	6.18	17.51	110.20	115.75
SE ±	0.096	0.041	0.032	0.06	0.00	0.004	0.04	0.17	0.00003	0.0006	0.005	0.004
LSD(P≤ 0.05)	0.27	0.11	0.09	0.17	0.00	0.01	0.10	0.48	0.0001	0.0002	0.001	0.002

The means followed by the same letter for each factor in a column are not significantly different (P≤ 0.01) according to DMRT mean separation.

Hand weeding was done once at four weeks after crop germination and thereafter, no further weeding was done to enable accurate assessment of *Striga* infestation. *Striga* emergence counts were conducted every two weeks from the date of planting up to harvesting.

4.6 Striga emergence

There were significant fertilizers and manure effects on *Striga* emergence at both sites. Bototo had a mean of 15 plants / m^2 while Kabondo had 19 plants / m^2. However, there was no consistent trend in *Striga* emergence response to fertilizers and manure applications at both sites (Table 4.6)

Table 4.6 Effects of treatment on striga counts

Treatment	***Striga* count** Plants per m^2 plot **Bototo**	 **Kabondo**
½ DAP + ½ FYM.	12^{c}	20^{ab}
TSP	11^{c}	18^{d}
FYM	11^{c}	15^{c}
DAP	15^{b}	19^{c}
MRP	17^{a}	20^{ab}
Lime	18^{a}	20^{ab}
Control	18^{a}	21^{a}
Mean	15	19
CV %	14.306	7.63
SE $\pm$	0.47	0.32
LSD($P \leq 0.05$)	1.32	0.91

4.7 Farmyard manure nutrient content of samples from farmers' fields in Bototo and Kabondo.

The mean value for pH in farmyard manure at Bototo was 8.6. The mean values for N, P, Ca, Mg, K and C in farmyard manure at Bototo were 11.6, 2.2, 8.8, 2.6, 7.8 and 116 g kg^{-1} (Table 4.6).

The mean value for pH in farmyard manure at Kabondo was 8.5. The mean values for N, P, Ca, Mg, K and C in farmyard manure at Bototo were 4.3, 1.7, 10.9, 1.0, 5.9 and 42.5 g kg^{-1} (Table 4.6).

Table 4.7. Nutrient concentration of farmyard manures in farmers fields in Bototo and Kabondo

Site	pH	N	P	Ca	Mg	K	C
		←		g kg^{-1}			→
Bototo	8.6	11.6	2.2	8.8	2.6	7.8	116
	8.1-9.0	6.2-13.8	1.2-2.9	4.7-11.5	0.94-4.0	6.9-14.2	62-138
Kabondo	8.5	4.3	1.7	10.9	1.0	5.9	42.5
	8.0-8.9	3.9-5.6	0.02-3.1	0.2-20.8	0.3-1.5	0.04-10.3	39-56

CHAPTER FIVE

DISCUSSION

5.1 Effects of treatments on maize yield

Initial soil analysis indicated that the soils at the sites were low in fertility, acidic, with low amounts of total N, organic carbon, total and extractable phosphorus and exchangeable bases (Table 4.5a). This could be attributed to the continuous cropping of land with little or no nutrient returns, thus resulting into nutrient depletion and decline in soil fertility (Smalling et al, 1997; Sanchez et al, 1997). The crop response to fertilizers and manure application in these soils was therefore expected.

There were P deficiency symptoms in plants that did not receive P treatments which indicated that P limited crop growth at these sites. At three weeks after seedling emergence, plants that received the fertilizers and manure treatments were more vigorous than the control. The significant growth vigour response to fertilizers and manure (Table 4.1) could be attributed to the fact that maize depends on fertilizer P at its early stages of growth and this might have stimulated root proliferation and acquisition of nutrients for growth. The significant relationship between growth vigour and grain yield at the sites shows that early growth strongly influences grain yield production, particularly in soils low in available N and P. Bonde and Rosswall (1987) reported increased crop growth and yields associated with increasing soil N availability. Riley et al (1993) also reported increased early growth of wheat due to P application.

There was no definite pattern in growth vigour and maize yield for all treatments in both sites. This could be attributed to irregular N uptake, even when soil N levels were almost the same. However, other factors that influence uptake such as moisture content and acidity, could have also contributed to the pattern. At the same time plants will finally take up not all the N in available form since some considerable quantities are bound to be lost through processes such as denitrification, leaching and volatilization (Bonde and Rosswall, 1987).

The significant grain yield response to fertilizers and manure application at the sites (Table 4.1) is attributed to the low soil fertility (N and P) status of these soils. The increase in yield is therefore, attributed to the increased availability of N and P due to fertilizers and manure application. For acidic soils, acidification by NH_4^+ - N is not likely to be the explanation for the enhanced P uptake but probably the stimulation of NH_4^+-N on root growth (Fan and Mackenzie, 1994). This is because high P supply is particularly important in stimulating early root formation and growth. Njui and Musandu (1994) have reported similar observations. The significant P effect on harvest index could be attributed to the significant P effect on grain yield.

The mean grain yield at Bototo (3932 kg ha^{-1}) and Kabondo (3070 kg ha^{-1}) were generally below the estimated potential maize grain yield of 5 t ha^{-1} (5,000 kg ha^{-1}) per season for the region (Sanchez et. al 1997). The total above ground dry matter yield followed a similar trend to grain yield being 11470 and 10750 kg ha^{-1} for Bototo and Kabondo respectively. The relatively low yield response could possibly be due to inadequate P supply, from the applied fertilizers and manure thereby limiting crop performance at the sites. Fixation of P in these acidic soils could have limited P availability to the maize crop, resulting into low crop yields.

The inconsistent crop response trends (Table 4.4) could be attributed to the high variability, in *Striga* infestation, which masks the crop response to applied fertilizers, thus resulting into a high variability in crop response observed. The potential P fixation in these acid soils could partly account for the low and inconsistent crop response. Level of available P in the soil, pH value of the soil, form and method of fertilizer P application, influence phosphorus uptake by crops (Bekunda, 1990). Acid soils render P and N unavailable through P fixation and slowing down of nitrification rates, respectively (Stevenson, 1986). Micro-organisms that are important in solubilization of organic P compounds, N mineralization and organic matter decomposition are also inhibited in acid soils (Stevenson 1986).

Bonde and Rosswall (1987) reported that both seed and straw yield of oilseed rape plants were significantly increased by N application. Bareto and Raun (1995) observed significant linear grain yield response in maize to TSP application. The control gave lowest yields, probably because of reduced nitrification rates and fixation of P in the acidic soil that rendered N and P unavailable hence limited uptake of the maize crop and consequently poor performance. Low yields could also be attributed to Al saturation. Yamoah et al, (1996) attributed 44% reduction in maize yields to Al saturation in an acidic soil of North West Cameroon. Interactions involving manure and DAP gave high grain yields. This underlines the importance of integrated nutrient management (FYM and DAP) in crop performance and more so for these acidic soils.The low yields due to lime may be attributed to the fact that application was done two weeks before planting and might have been ineffective in its neutralizing activity and / or application was not homogeneous thus creating pockets of Fe, Al and Mn toxicities which could have affected rooting and nutrition of the maize crop because the soils were dry. Reactions of P with freshly precipitated Fe and Al hydroxides after liming may have occurred thus limiting availability to the maize crop and hence low dry matter yield of maize due to N application, which is also reflected in this study. High yields of maize are observed in TSP plots because it contains Ca (12- 14%) and hence large doses of P are similar to liming.

Lack of significant difference in N content between the control and lime treatments in all the plots was due to the blanket application of the recommended N rate. Lemcoff and Loomis (1986) found that maximum N content in tissue may be constrained by soil N availability and plant N uptake functions.

5.2 Effects of treatments on plant tissue nutrient content.

The plant tissue nutrient content pattern generally followed that of the dry matter yield at both sites. Plant tissue nutrient content was in the order K > N> P > Ca > Mg in the stover at Bototo and N> K> P > Ca > Mg in the grain and cob at both sites. The relative differences in nutrient (N, P, K Ca, and Mg) content in the plant tissues between the sites were related to differences in dry matter yield production at the sites and partly due to the *Striga* parasitism, which masked the crop response to fertilizers and manure. The higher plant tissue nutrient (N, P, K Ca, and Mg) content with combined N and P than the sole P application at the sites could be attributed to the synergistic N enhancement of P uptake (Teng and Timmer, 1994). The generally low plant tissue Ca and Mg content could be attributed to the low soil Mg and Ca levels in the study sites. Based on the high plant tissue nutrient uptake and removal in this study, incorporation of stovers in the soil would be recommendable practice, as it would ensure nutrient recycling by the stover.

5.3 Effects of treatments on nutrient uptake

The nutrient uptake pattern generally followed that of the dry matter yield at both sites. Nutrient uptake was in the order K > P> N > Ca > Mg at Bototo and P > K> N > Ca > Mg at Kabondo.

The relative differences in nutrient (N, P, K Ca, and Mg) uptake between the sites were related to differences in dry matter yield production at the sites and partly due to the *Striga* parasitism, which masked the crop response to fertilizers and manure. The higher nutrient uptake with combined N and P than the sole P application at the sites could be attributed to the synergistic N enhancement of P uptake (Teng and Timmer, 1994). The Ca and Mg uptake value fall below the uptake range reported by FAO/ IFA (2000) of 24 to 25 kg/ha Ca and Mg. This could be attributed to the low soil Mg and Ca levels in the study sites.

5.4 Effects of treatments on nutrient use efficiency

The mean Agronomic P Efficiencies (APE) for Bototo and Kabondo were 32 and 29 kg grain /kg P respectively. The mean P utilization efficiencies for Bototo and Kabondo were 36 and 42 kg grain / kg P respectively. Kabondo with a lower P uptake (35.73 kg/ha) compared to Bototo (47kg/ha) resulted into a higher PPUE (42 kg grain / kg P) than Bototo 36 kg grain/ kg P (Table 4.4). This could imply a higher internal crop P requirement at Kabondo than Bototo. Fixation of P by manganese and iron given the acidic nature of soil at the sites (Table 4.5) could be a possible explanation for the reduced P use efficiencies. Yang and Jacobsen (1990) proposed that the decreased efficiency in P uptake following P application was a result of conversion of fertilizer P to relatively insoluble forms. Lack of significant differences in plant tissue P between control and lime treatments show that fixed P was not available to the crop even though this soil was limed. This would suggest that lime was ineffective in raising the pH of the soil and consequently release fixed P (Anjos and Rowell, 1987). Interactions involving manure and NP fertilizers led to high % P in plant tissues probably due to the P obtained from both inorganic and organic sources and also the fact that acidity of the soil could have been buffered effectively by the manure applied. This is also similar to findings by Xie et al, (1995). Jungk and Barber (1974) also observed that maize utilization of applied P was greater at low P application rate, indicating that P efficiency decreases as application rate increases. Eghball et al, (1990) and Hikwa et al, (1990) also noted the significant returns to applied phosphorus in a subsequent season to that of application. This could be due to its relative unavailability initially, when applied to phosphorus deficient soils. Therefore, it might be necessary to quantify the cumulative benefits of phosphorus application on the same sites on a long-term basis.

5.5 Effects of treatments on soil nutrient contents after harvest

Initial soil analysis indicated that the soils at the sites were low in fertility, acidic, with low amounts of total N, organic carbon, total and extractable phosphorus and exchangeable bases (Table 4.5a). This could be attributed to the continuous cropping of land with little or no nutrient returns, thus resulting into nutrient depletion and decline in soil fertility (Smalling et al, 1997; Sanchez et al, 1997). The crop response to fertilizers and manure application in these soils was therefore expected.

The significant increase in extractable soil P with application of fertilizers and manure in both the sites (Table 4.5b) could be due to the added fertilizer and manure P, which could have resulted in the saturation of soil P absorption sites and consequently, increased P availability in soil solution. The results conform to those of Evans (1985) that P fertilization affects soil solution P concentration by influencing competition for the sorption sites between the organic and inorganic P compounds. The solution P after crop harvest (Table 4.5b) were below the critical P level for maize of 10 mg / kg reported by Okalebo et al (1977) in both sites. This implies that P input would be necessary to the following crop to enhance maize crop responses at these sites.

The reduction in total soil P content with application of fertilizers and manures (Table 4.5b) could be attributed to the increased dry matter production and hence higher nutrient P removal by the crop following N application (Table 4.5b). This may be due to N effect in promoting dry matter production. It could also be attributed to the synergistic interaction between N and P (Brady, 1984), whereby the availability and P uptake was increased hence the reduction of P in the soil that was observed in this study.

The lack of significant change in total soil N with application of fertilizers and manure in Kabondo could be attributed to the blanket application of the recommended rate of N.

The reduction in total soil K, Mg and Ca contents with fertilizers and manure applications (Table 4.5b) could be attributed to the increased crop nutrient removal following fertilizer N and P application at the sites. The results agree with Janssen (1977) that increased fertilizer N and P application could result in deficiency of other nutrients (such as K, Ca, Mg and Zn) due to rapid crop removal.

The low Ca and Mg uptake (Table 4.5b) could be related to their relatively low levels in these soils: 0.003 and 0.03% at Bototo and 0.002 and 0.02% at Kabondo respectively. The gradual net depletion of soil cations if not compensated by fertilizer and manure inputs, would eventually affect crop yields. The study period (4 months) was too short to produce significant changes in soil chemical properties due to fertilizer and manure application hence long-term assessments of the fertilizer and manure effects could give more conclusive information upon which to make fertilizer and manure recommendations.

5.6 Effects of treatments on Striga infestation.

The mean *Striga* counts were 15 and 19 plants /m ^{2} for Bototo and Kabondo respectively. The variations in *Striga* infestation between the study sites could be due to variations in rainfall and soil conditions. The higher *Striga* density at Kabondo as compared to Bototo could partly be due to differences in rainfall amounts and distribution (Appendix 3). Bototo received 12mm/day for 163 days and Kabondo received 12mm/day for 85 days. Soils with higher soil moisture retention have been shown to suppress *Striga* development (Ogborn, 1972; Kroschel, 1998). Soil textural differences between the sites (clay soil for Bototo and sandy clay loam for Kabondo) could partly explain the differences in *Striga* infestation. This could be based on the fact that *Striga* prefers lighter sandy soils due to their low moisture retention, than heavy clay soils (Dogget, 1965).

The decline in *Striga* infestation with fertilizer and manure application observed in both the sites could be related to the suppressive N effect on *Striga* growth and development. The results are in agreement with the reports by Mumera and Below (1993) and Esilaba et al, (2000) that *Striga* infestation declines with increasing N availability. The inconsistent *Striga* infestation response to fertilizer and manure application at Bototo and Kabondo could partly be due to the interactive effects of other environmental factors, which influence the growth and development of *Striga* plants.

The insignificant MRP and TSP (P fertilizer effects) and inconsistent trend in *Striga* emergence and response to fertilizers and manure could be an indication that P has no direct effect on *Striga* growth and development as suggested by Gacheru and Rao (2001). These workers attributed the insignificant effect of P on *Striga* emergence to its inability to interfere with the production of or the activity of the *Striga* seed germination stimulant from the host plants. This is in contrast to reports that P had a slight reduction effect on *Striga* infestation. Since *Striga* infestation results in stunted crop growth and yield reduction (Esilaba et al, 1997), the difference in *Striga* infestation at the sites could partly explain the variations in maize yield at the sites.

5.7 Farmyard manure nutrient content of samples from farmers' fields in Bototo and Kabondo.

Nutrient analysis of the manures (Table 4.6) show that for example 5 t ha $^{-1}$ cattle manure can supply approximately 58 kg N,11 kg P, 39 kg K, 44 kg Ca, and 13 kg Mg ha $^{-1}$ but these potential, particularly for N, K, Ca and Mg varies across farms. Crop responses to decomposed or non- decomposed manure application may be due to increases in soil pH, N, P, Cations such as Ca and Mg or to physical effects of addition soil organic matter on water filtration and retention. However the responses to cattle manure application are highly variable due to differences in the chemical composition of the manures. The chemical composition of cattle manures differs because of variation in animal diet and manure storage. Poor storage conditions may result in ammonia losses through volatilization and leaching of nitrates. A survey in Kabondo, Rachuonyo district to determine how livestock and manure management practices (stocking rate, feeding, collection, composition and storage) affect the quality of the manure for crop production indicated that collecting boma manure and just heaping it on the soil surface resulted in very low quality manure (Wanjekeche et al.,1999). The organic carbon ranged between 39 and 56 g kg $^{-1}$, while phosphorus ranged between 0.02 and 3.1 g kg $^{-1}$, which were lower than that from smallholder farms in Bototo in Kisii central district. Nitrogen concentration followed similar ranges as those of organic carbon. The differences in organic C and N between the sites could be due to differences in cattle diets, method of collection and storage, degree of decomposition and handling conditions of the manure.

5.8 CONCLUSION AND RECOMMENDATIONS

The study showed that soil P was deficient in these sites. Plants that received fertilizers and manure were more vigorous than those in the control plots in these sites, thus farmers should use phosphate fertilizers and manure when planting. Soils in the sites were low in fertility, acidic, with low amounts of total N, organic carbon, and total and extractable phosphorus and exchangeable bases. The soils require phosphate fertilizers and farmyard manure. The application of lime two weeks before planting would highly be recommended, especially when the soils are wet, because lime when applied to soils is relatively immobile and a thorough mixing to the required depth is therefore important. Where deep mixing is necessary, split applications can be given, one half ploughed under, the other top dressed after ploughing. Split applications also allow the use of both pure and dolomite limestone.

Phosphate fertilizers and manure application significantly increased maize grain and dry matter yields. Highest yields were obtained after 5 t ha $^{-1}$ FYM + 30 kg ha $^{-1}$ $P_2 0_5$ application because N and P nutrients were readily available from the fertilizers used and manure might have effectively regulated the soil acidity and exchangeable Al in these acidic soil to avail favorable conditions for maize growth. From the study, to realize the projected potential maize yield in Kisii and Rachuonyo districts, farmers should apply 5 t ha $^{-1}$ FYM + 30 kg ha $^{-1}$ $P_2 0_5$ because this makes N and P available to the maize crop and regulates the soil acidity. As a follow up, investigations should be done on the effectiveness of manure to binding Fe and Al ions in acidic soils. The study indicated that fertilizers and manure (integrated nutrient management strategies) are essential to improve maize yields, nutrient uptake; nutrients use efficiency and soil nutrient contents of the study soils. The results indicated that the fertilizers and manure applications used reduced *Striga* infestation in low fertility soils. Further work using higher fertilizer and manure rates and different sources for a longer study period is recommended to provide more insight. The results show that under *Striga* infestation, both nutrient uptake and use efficiencies, and hence crop yields are depressed. *Striga* management should therefore be prioritized to enable accurate fertilizer recommendations for both areas

Based on the high crop nutrient (N, P and K) removal in this study, it is suggested that stover removal and disposal practices in the region should aim at nutrient recycling to replenish the nutrient removal by the crop.

The soil solution P at crop harvest were below the critical P level for maize (10 mg / kg) in both sites. This implies that P input would be necessary to the following crop to enhance maize crop responses at these sites. Further long-term studies in these soils to investigate the effects of fertilizer use, integrated nutrient management, nutrient balance, as a basis for fertilizer formulations and recommendation is necessary.

In Summary it can be concluded from this study that:

1. The soils at the study sites are deficient in N, P, K, Ca and Mg. Phosphate fertilizers and manure should be used when planting. Phosphate fertilizers and manure significantly increased growth vigour, grain and dry matter yields and the harvest index. Highest yields were obtained after 5 t ha $^{-1}$ FYM + 30 kg ha $^{-1}$ $P_2 0_5$.
2. DAP combined with FYM essential to improve nutrient uptake, phosphorus use efficiency and soil nutrient contents of the study soils.
3. Stover removal and disposal practices in the region should aim at nutrient recycling to replenish the nutrient removal by the crop.
4. The soil solutions P at crop harvest were below the critical P level for maize (10 mg / kg) in both sites. This implies that P input would be necessary to the following crop to enhance maize crop responses.
5. The fertilizers and manure applications used influenced *Striga* infestation in low fertility soils.

Way forward

Areas for further research should therefore include:

1. Investigations on the effectiveness of manure to binding Fe^{3+} and A^{3+} ions in acidic soils.
2. Evaluaton of a wide range of fertilizers and manure rates and types.
3. *Striga* management studies to determine whether nutrient uptake and use efficiencies, and hence crop yields are depressed under *Striga* infestation. *Striga* management should therefore be prioritized to enable accurate fertilizer recommendations for both areas.
4. Evaluation of soil acidity incidence in the neighboring districts with different soil and climatic conditions.
5. Evaluation of alternative sources of plant nutrients which are appropriate, acceptable and adoptable and do not enhance soil acid.

REFERENCES

Adams, F. (1984). Crop response to lime in Southern United States. In: Soil acidity and liming. F. Adams (Ed) pp. 211-265 ASA-CSSA-SSSA. Madison, WI, USA.

Alexander, M. (1977). Introduction to soil microbiology. John Wiley and Sons, NewYork. p, 181.

Allison, L.E. (1964). Salinity in relation to irrigation. Adv. Agron .16:139-180.

Amarasiri, S.L. and Olsen, S.R. (1973). Liming as related to Solubility of P and plant growth in an acid tropical soil. Plant and Soil, 103:75-82.

Anderson, G., William, E.G and Moir, J.O. (1974). A comparison of the sorption of inorganic orthophosphate and inisitol hexaphosphate by six acid soils. J. Soil Sci. 25: 51-62.

Anderson, J.M. and Ingram. J.S.L. (1993). A Handbook of Methods Tropical Soil Biology and Fertility: pp. 57-92. CAB International Waltington, UK.

Anderson, J.P.E, and Domsch, K.H. (1980). Quantities of plant nutrients in the microbial biomass of selected soils. J. Soil Sci. 130: 211-216.

Anjos, J.T. and Rowell, D.L. (1987). The effect of lime on phosphorus adsorption and barbley growth in three acid soils. Plant and Soil 103:75-82.

Bationo, A and Mokwunye, U. (1991). Role of manures and crop residues in alleviating soil fertility constraints to crop production. Fert. Res. 29:117-125.

Baretto, H. J. and Raun, W.R (1995). Regional maize grain yield response to applied phosphorous in Central America. Agron. J. 87: 208-213.

Barneix, A.J. (1981). Kinetics of phosphate absorption by wheat pretreated with ammonia or nitrate. Phyton Argentine, 41:45-51.

Bekunda, M. A. (1990). The effects of fertilizer phosphorus in soils of varying sorption capacities. E. Afri. Agric. For. J. 55:219-226.

Binford,G.D., Blackmer, A. M. and Cerrato, M. E.(1992). Relationship between corn yields and soil nitrates in late spring. Agronomy Journal.84:219-223.

Bonde, T. and Rosswall, T. (1988). Seasonal variation of potentially mineralizable nitrogen in four cropping systems. Soil Science Society of America Journal. 51:1508 – 1514.

Bouyoucos, **A.F. (1962).** Hydrometer method improved for making particle size analysis of soils. Agronomy Journal. 54:464-465.

Brady, N.C. (1984). Nature and properties of soils. (9th edition). Macmillan, USA.

Bulman, P. and Smith, D.L. (1993). Accumulation and redistribution of dry matter and nitrogen by spring barley. Agron. J.85: 1114 –1121.

Buresh, R.J., Smithson, P.C, and Hellums, D.T. (1997). Building soil phosphorus capital in Africa. In: Replenishing soil fertility in Africa (Buresh, R.J., Sanchez, P.A., and Calhoun, F. (eds.) SSSA Special Publication Number 51, American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, pp111-149.

Cochran, W.G. and Cox, G. (1957). Experimental Designs. John Wiley, New York.

Cooke, G.W. (1982). Fertilizing for maximum yields 3rd ed. ELBS, London pp. 342.

Corbett, J.D., Muchungu, E. I., Bush, B.R., Collis, S.N., and Jeske, R.Q., (2001). Kenya ACT Database 3.0 BREC Report Number 01 - 14. Texas A and M University System, Texas Agricultural Experiment station, Blackland Research and Extension Centre, Temple Texas.

Dadi, L. and Gedeno, G. (1990). On–farm economic and agronomic evaluation of selected NP fertilizer rates on maize around Bako, Western Ethiopia pp. 428 –435. Institute of Agric. Research Addis Ababa. Ethiopia.

Dalal, R.C. (1977). Soil organic phosphorus. Biogeochemistry. 4: 41-60.

Doggett, H. (1991)...Coordination of Striga research. In: S. K. Kim (ed) combating *Striga* in Africa. Proceedings of the Internatioal Workshop organised by IITA, ICRISAT, and IDRC, 22nd-24th August 1988. IITA, Ibadan .

Doggett, H. (1965). *Striga hermonthica* on sorghum in East Africa..J. Agric. Sci. 65: 183-194.

Eghball, B., and Sander; D.H. and Skopp, J. (1990). Diffusion, adsorption and predicted longevity of banded phosphorus fertilizer in three soils. Soil Sci. Soc. Am J 54: 1161-11165.

Elliot, G.C. and Luchli, A. (1985). Phosphorus efficiency and phosphate – iron interaction in maize. Agron. J. 77, 399-403.

Esilaba, A. O., Reda, F., Ransom, J. K., Bayu, W., Woldewahid, G and Zemichael, B. (2000). Integrated nutrient management strategies for soil fertility improvement and *Striga* control in Northern Ethiopia. African Crop Science Journal, Vol.8 (4): 403-410.

Esilaba, A.O. and Ransom, J.K. (1997). *Striga* in the eastern and central African countries: A literature review. The Africa Highlands Initiative, Technical Report Series No. 1. pp.29.

Evans, A.J. (1985). The adsorption of inorganic phosphate by a sandy soil as influenced by dissolved organic compounds. Soil Sci. Am. J. 58:249-255.

Fageria, N.K. and Baligar, V.C (1989). Response of legumes and cereals to phosphorous in solution culture. J. of plant nutri. 12: 1005-1019.

Fan, M.X. and Mackenzie, A.F. (1994). Corn yield and phosphorus uptake with banded urea and phosphate mixtures. Soil Sci. Soc. Am. J.58:249-255.

FAO (1988). Nature and management of tropical peat soils. FAO Soils Bulletin No. 59.

FAO-IFA. (2000). Fertilizers and their use: A pocket guide for extension officers (4th edition) FAO/IFA, Rome. pp. 21-26.

FAO-UNESCO. (1990). FAO – UNESCO soil map of the world, revised legend , with corrections. Technical Paper No. 20. International Soil Research Centre (ISRC), Wagenigen.

Ferrar, P. (1995). Foreword. In: An Atlas of resistance genes, In: McIntosh, R.A, Wellings, C.R. and Park R.F. (eds) Commonwealth Scientific and Industrial Research Organisation (CSIRO) Publishers. E Melbourne, Australia.

Fertiliser Use Recommendation Project (FURP). (1994). Fertiliser Use Recommendations, Volumes 1 – 22. Kenya Agricultural Research Institute, Nairobi, Kenya.

Fox, R.L. and Kamprath, E.J. (1970). Phosphate sorption isotherm for evaluating the phosphate requirements of soils. Soil Sci. Soc. Amer. Proc., 34: 902-907.

Freitas, L.M and Van Ray, B., (1974). Residual effects of liming a clay loam latsosol. Soil management and organic management process. Trop . Am . P. 304-311.

Gacheru, E.. and Rao, M. R.., (2001). Managing S*triga* infestation on maize using organic and inorganic nutrient sources in Western Kenya. International Journal of Pest Management Vol.4 (3):233-239.

Gahoonia, J.S., Claasen , N. and Jungk, A. (1992). Mobilization of phosphate in different soils by the grass supplied with ammonium or nitrate. Plant and Soil J. 14: 241 –248.

Gonzaletez- Prieto, S.J , Villa, M.C., Carballas, M. and Carballlus, T. (1992). Nitrogen mineralization and its controlling factors in various kinds of temperate humid – zone soils. Agron, J. 84,220-224.

Guindo, D., Norman R.J. and Wells, B.R. (1994). Cultivation and rate influence on nitrogen uptake and partitioning in rice. Soil Sci. Soc. Am. J. 58:840-845.

Guindo, D., Norman R.J. and Wells, B.R. (1995). Accumulation of fertilizer N^{-15} by rice at different stages of development. Soil Sci. Amer. J. 58:840-845.

Hamid, A. (1972). Efficiency of N. uptake by wheat as affected by time and rate of application, using N^{15} labelled ammonium sulphate and sodium nitrate. Plant and Soil. 37:389-394.

Haynes, R.J (1984). Lime and phosphate in the soil- plant system. Adv. Agron. 37: 249-315.

Hikwa, D., Mataruka, D.F. and Natarayan, M. (1990). Response of maize to nitrogen and phosphorus application on small scale in Zimbabwe. pp. 467-476 Agron. Inst. Dept. of Research and Specialist Services.

Hue, N.V (1989). Effects of organic acids on P Sorption and phytoavailability in soil with different mineralogies. *Agronomy Abstract.* p. 242.

Hue, N.V., Gaddock, G.R. and Adams , F. (1986). Effect of organic acids on aluminium toxicity in sub soils. Soil Sci**.** Soc. Am. J. 50,28-34.

Jaetzold, R. and Schmidt, H. (1983). Farm management handbook of Kenya- natural conditions and farm management information. Volume II/A western Kenya Ministry of Agriculture, Nairobi.

Janssen, B.H. (1977). Interim report on soil fertility studies in Kisii and South Nyanza in Kenya. A paper presented to the Third Annual General Meeting of the Soil Science Society of East Africa, 2nd –4th November, 1977, Nairobi Kenya.

Jones, M.J. (1973). Time of application of nitrogen fertilizer to maize at Samaru, Nigeria. Exptal. Agric. 13-120 .

Jungk, A., and Barber, S.A. (1974). Phosphorus uptake rate of corn root exposed to phosphate. Agronomy J.66:554-557.

Juric, I., Zugec, I. and Bulvan, V. (1986). The effects of liming and phosphorus on the chemical properties of soil and yields of maize. *Zemljiste –Biljka* 35,165-177.

Kamprath, E. J. (1993 b). Phosphorus. pp.138-161. In: P. A. Sanchez (ed). A Review of Soils Research in Tropical Latin America. North Carolina Agri. Exp. Sta. Bull.219.

Kanyanjua, S.M. and Schnier, H. F. (1994). Response of cabbage, (*Brassicae Oleraceae L.)* to phosphorus, nitrogen, and manure application in Kenya. In: Focus on agricultural research for intensifying rural and industrial development. P.O. Fungo et. . al., (Eds) pp. 205-217, Proceedings of the 4th KARI Scientific Conference. Nairobi, Kenya.

KARI-KISII (1979). Annual Report, 1992. Kenya Agricultural Research Institute, KARI Nairobi.

KARI, (1993). Annual Report, 1992. Kenya Agricultural Research Institute, KARI Nairobi.

KARI. (1991). Kenya agricultural research priorities to the year (2000). Kenya Agricultural Research Institute, Nairobi Kenya.

Keulen, Van H. (1983). Nutrient supply and crop response. Crop production as determined by nutrient availability In: modelling of agricultural production; Weather,soils and crops. Agricultural University. Wagenigen, The Netherlands. Pp. 486.

Kroschel, J. (1998). *Striga*- How will it affect African agriculture in the future? An ecological perspective. SPLITS 16 (2) :137 – 157 Margraf Verlag, Weikersheim, Germany.

Kunishi, H.M. (1982). Combined effects of lime, phosphate fertilizer and aluminium on plant yield from an acid soil of the south Eastern United States. Soil Sci. 134:233-238.

Lemcoff, J.H. and Loomis, R.S. (1986). Nitrogen influences on yield determination in maize. Crop Sci. 26: 1017-1022.

Leonce, F.S., and Miller. M. H. (1966). A physiological effect of nitrogen on phosphorous absorption by corn. Agron. J. 58:245-249.

Marschner, H. (1995). Mineral nutrition of higher plants. Academic Press, London, pp. 674.

Marthers, A.C., Thomas , J.D Stewart, B.A and Hewing, J.E. (1980). Manure and inorganic fertilizer effects on sorghum and sunflower growth on iron- deficient soil. Agron J.(6) 72: 1025-1029.

Mehlich, A. (1942). The significance of percentage base saturation and pH in relation to soil differences. Proceedings of the Soil Science Society of America (SSSA) 7:167-174.

Miller, M.H., (1971). Effects of nitrogen on phosphorus absorption by plants. pp. 643-668.

Miranda, L.N. De; and Rowell, D. L. (1987). The effects of lime and phosphorus on the function of wheat roots in acid tropical soils and subsoils. Plant and Soil 104: 253-262.

Mokwunye, U and Bationo, A. (2002). Meeting the phosphorus needs of the soil and crops in West Africa. CAB, Publishing, Wallingford, UK.pp. 209-224..

Muchdar, S.N; and Dahlan, M. (1988). The response of maize to fertilization with N, P, K. and S on young volcanic soils. Penelitia- Palawija (Indonesia) 3: 33-41.

Mumera, L.M. and Below, F.E. (1993). Role of nitrogen in resistance to *Striga* parasitism of maize. Crop Science Journal 33:758-763.

Njenga, M., Kimani, S. T., Romney, D., Karanja, N. (2007). *Nutrient recovery from solid waste and likage to urban and peri-urban agriculture in Nairobi, Kenya.*

Njui, A.N. and Musandu, A.A.O (1999). Response to phosphorus fertilization at selected sites in western Kenya. African Crop Science Journal, Vol 7 (4), pp. 397-409.

Norman, R. J., Guindo D., Wells, B. R. and Wilson C.E. (1992) Seasonal accumulation and participation of N ^{15} in rice. Soil Soc. Am. J.56:1552-1557.

Nurlaeny, N., Marschner, H. and George, E.(1996).Effects of liming and mycorrhizal colonization on soil phosphate depletion and phosphate uptake by maize (*Zea mays L)* and soybean (*glycine, max L.*) growth in two tropical acid soils. *Plant and Soil.* 181: 275-285.

Nyandat, N.N. (1981). The primary minerals of some Kenya's top soils and their significance to inherent soil fertility. E. Afric Agric. and For. Journal. 46: 71-76.

Odhiambo, J.O. (1989). The effect of nitrogen fertilization in maize (*Zea mays L* Katumani composite B.) performance and nitrogen mineralization in Kabete Nitisols. MSc Thesis, University of Nairobi, Nairobi, Kenya.

Odongo, O. M. (1995). Witchweed (*Striga Hermonthica* (del.)) management strategies in maize farming system in Western Kenya: Report of 1991 and current research by RRC Kakamega. A paper presented at the East and Central African *Striga* Research Working Group on 12-14 June,1995 in Mombasa (Kenya) and Tanga (Tanzania).

Ogborn, J. E. A., (1972). The significance of seasonal pattern of emergence of *Striga* hermonthica Benth. Pp. 562-571. In: Ganga Paradasa Rao, N., and House,L. R (eds.). Sorghum in the seventies. Proceedings of an IBH Publishing Co., New Delhi, India.

Ogborn, J. E. A., (1987). *Striga* control under peasant farming conditions In: L. J. *Musselman* (eds.) Parasitic Weeds in Agriculture. Vol.1 pp. 145-158. CRC Press Inc. Boca Raton, Florida**.**

Okalebo, J. R.; Gathua, K. W. and Woomer, P.L. (1993). Laboratory methods of soil and plant analysis: A Working Manual. UNESCO, Nairobi, Kenya.

Okalebo, J.R. (1977). Maize response to three high analysis phosphate fertilizers in some soils of East Africa. Part 1. Effects on growth. E. Afr. Agric. and For. Journal, 43:75-83.

Okalebo, J.R. (1979). The uptake and removal of potasium by maize as influenced by nitrogen and phosphorous fertilizer application in some East African soils. A paper presented to the Potasium - Workshop, organised by the International Potash Institute, November 16th, Nairobi, Kenya.

Okalebo, J.R. and Woomer, P.L. (1994). Use of rock and fertilizer phosphorus in Eastern and Sourthern Africa: A data summary. Presented at the 14th Conference of the Soil Science Society of East Africa, Mbarara, Uganda. November, 1994.

Okalebo, J.R., Schnier, F. and Lekasi, J.K. (1993). Maize response to fertilizer and rock P in a high P- fixing soil of Malava, Kakamega. National Agricultural Research Centre, Record of Research, KARI Annual Report, Muguga, Kenya.

Olsen, D.N. and Sommers, L.E. (1982). Methods of soil analysis, part 2, chemical and microbiological properties. In: Page A.L., Miller, R.H. and Keeney, D.R.(Eds.). Agronomy monograph No. (2nd edition). ASA, Madison, Wisconsin.

Olsen, R. A., Dreier, A.F., Hoover, C.A. and Rhoads, H.F., (1962). Factors responsible for poor response of corn and grain sorghum to phosphorus fertilization: Soil phosphorus level and climate factors, Soil Sci Soc. Am Proc. Pp. 571- 574.

Power, J. F. (1983). Recovery of nitrogen and phosphorus after 17 years from various fertilizer materials applied to crested wheat grass. Agron. J. 75:249-254.

Raju, P. S., Osman, M. A., Soman, P and Peacock, J. M., (1990) Effect of N, P and K on the incidence of *Striga* asiatica (L) *Kuntze* seed germination and infestation on sorghum. Weed Research 30: 139-144.

Raju, A., S., Kamath, M. B. and Goswami, N. N. (1982). Influence of split application and seed coating with phosphate on phosphorus utilization by maize (*Zea mays L.*,). Nuclear Agric Biol., 11:43-46.

Ransom, J. K. and Odhiambo G . D. (1994). Long term effects of fertility and hand weeding on *Striga* in maize. In : Pieterse A.H.,Verkleij, J. A. C. and Terborg, S. J. (Eds.). Biology and management of *Orobanche*. Proceedings of the 3rd International Workshop on Orobanche and related *Striga* research. The Royal Tropical Institute, Amsterdam, The Netherlands, pp. 513-519.

Reeve, N.G., and Summer , M.E., (1970). Effects of aluminium toxicity and phophorus fixation on crop growth , on Oxisol of Natal. Soil sci Am. Proc. 34: 263-267.

Riley, M.M Adcock K.G and Bolland, M.D.A (1993). A small increase in the concentration of phosphorus in the sown seed increase the early growth of wheat. J. plant nutrition 16: 815-864.

Rong, F. Z., Zin, P. C., Fu,S. Z., Hailin, Z.,Jackie, S., and Volker, R.,(2005). *Fertilization and nitrogen balance in a wheat- maize rotation system in North China.*

Russell, E.W. (1988). Soil conditions and plant growth. (11th edition). Longman Press, London.

Sanchez, P. A. Gavidia G.E, Ramirez, R., Vergara R, and Muinguillo (1973). Performance of sulphur – coated urea under intermittently flooded rice culture in Peru. Soil Sci. Soc. Amer. Pro.37:789-79.

Sanchez, P.A., Shepherd, K.D., Soule, M.J., Place, F.M., Buresh, R.J., Izac, A.M.N., Kwesiga, F.R., Mokwunye, A.U. Nderitu, C.G. and Woomer, P.L.. (1997). Soil fertility replenishment in Africa: An investment in natural resources capital. pp. 1-47. In: Buresh R.J.,Sanchez,P.A. and Calhoun F.(eds.) Replenishing Soil Fertility in Africa. SSSA. Special Publication No.51, Soil Science Society of America, Madison,Wisconsin, USA.

Sayre, J.D (1955). Mineral accumulation in corn and corn improvement. Am. Soc. Agron 5: 259 -314.

Schlegel, A.J. and Havlin, J. L. (1995). Corn response to long–term N and P fertilization. J. of Prod. Agric. 8:181-185.

Schrader, L.E., Doinska, D. Jr. Jung, P.E. and Peterson, L.A. (1972). Uptake and assimilation of ammonium N and nitrate N and their influence on the growth of corn (*Zea mays)*L. Agron. J. 64, 690-695.

Seeling , B and Zasoski, R. J (1993). Microbial effects in maintaining organic and inorganic solution phosphorus concentration in a grassland topsoil. Plant and Soil 148: 277-284.

Shepherd, K.D., Ohlsson, E., Okalebo, J.R., and Ndufa, N.K. (1996). Potential impact of agroforestry on soil nutrient balance at the farm scale in the East African highlands. Fertilizer Research. 44: 87 – 99.

Sigunga, D.O., Janssen, B. H., and Oenema, O. (2002). Effects of improved drainage and nitrogen source on yields, nutrient uptake, and utilization efficiencies by maize *(Zea mays L.)* on vertisols in the sub-humid environments. Nutrient Cycling in Agroecosystems, 62:263-275.

Silberbush, M. and Barber, S.A. (1983). Sensitivity of simulated phosphorus uptake to parameters used by a mechanistic – mathematical model. Plant and Soil. 74: 93-100.

Simard, R.R., Evans, L.J. and Bates, T. E. (1988). The effect of additions of $CaCO_3$ and P in the soil solutions chemistry of a podzolic soil. Can J. Soil Sci. 68: 44-52.

Smalling, E.M.A., Nandwa, S.M. and Janssen, B.H. (1997). Soil fertility in Africa is at stake. In: Buresh, R.J, Sanchez, P.A and Calhoun, F. (eds.), In: Replenishing Soil Fertility in Africa. pp. 47-61. SSSA Spec. Publ. 51, A, Madison, WI.

Smith, C.J Tuomi, S.S., and People, M.B. (1994). Effect of surface application of lime, gypsum and phosphogypsum on alleviating of surface and subsurface acidity in a soil under pasture. Aust. J. of Soil Res. 32, 995-1008.

Smyth, T.J. and Sanchez , P.A. (1980). Effects of lime, silicate application to an Oxisol on phosphorus sorption and ion retention. Soil Sci. Soc. Am. J. 44: 500-505.

Stevenson, F. J. (1986). Cycles of soil. John Wiley and Sons. New York, USA pp. 350.

Stoorvogel, J.J., Smalling, E.M.A., and Janssen, B.H. (1993). Calculating soil nutrient balance at different scales: I. Supra-national scale. Fertiliser Research. 35:227-235.

Ta, C.T and Weiland, R.T. (1992). Nitrogen partitioning in maize during ear development. Crop Sci. 32:443-451.

Tekalign, T.,Haque, I., and Aduayi, E. A. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis manual. Plant Science Division Working Document 13,ILCA, Addis Ababa, Ethiopia.

Teng, Y. and V.R Timmer. (1994). Nitrogen and phosphorus interaction in an intensively managed nursery soil-plant system. Soil Sci Soc of America R. J 8.2-23 58 (1): 232-238.

Tisdale, SL., Nelson, W. L. and Beaton, J.D. (1990). Soil fertility and fertilizers. (6th edition). Macmillan, New York.

Wanjekeche, E. T., Mwangi, T. Powon, P and Khaemba, J., (1999). Survey of management practices of manure and its nutrients in west Pokot district of Kenya. p 355-399.

Wapakala, W.W.W. (1976). Changes in some chemical properties of a red clay soil: results of long-term fertilizer and rotational trials in central Kenya. E. Afric Agric. and For. Journal, 27: 365 – 386.

Warren, R.G. (1962). Comparisons between methods of measuring soluble phosphorus and potassium in soils used for fertilizer experiments on sugar beet. Journal of Agricultural Science Vol. 59. pp. 269-274.

Welch, R.M., Allaway, W. H., House, W. A and Kubota, J. (1991). Geographical distribution of trace elements problems. In: J.J.Mortvedt, F.R.Cox, L.M Shuman and R.M. Welch (Eds.), Micronutrients in Agriculture, (2nd edition). pp. 31-57 Soil Science Society of America (SSSA) Book Series No.4, Madison,WI,USA.

Xie, X. H., Makenzie A.F., Xie R.J. Fyles, J.W. and O' Halloran, 1. (1995). Effects of ammonium sulphate and diammonium phosphate on soil organic carbon, soil phosphorus fractions and phosphorus uptake by corn. Canadian Journal of Soil Science. 75: 233-238.

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

Yang, J.E. and Jacobsen, (1990). Soil inorganic phosphorus fractions and their uptake relationship in calcareous soils . Soil Science Soc. Am. 54:1666-1669.

APPENDICES

Appendix 1: Plant interpretative data

The interpretative data contained in these tables came from various reference books, research papers, and from the accumulated data from actual assays conducted by the authors, mainly Dr. Benjamin Wolf, who has had over 40 years of consulting experience in the use of plant analysis for diagnosing plants for their elemental status.

When using the interpretative data given in these tables, it is important that the user understand the importance of the relationship that exists between the plant part sampled and the time it is sampled versus its elemental content. If the data given in these tables are applied to a plant analysis results for tissue not in conformity to the given (i.e., different plant part and/or time of sampling), then the interpretative data given may not be a reliable indicator of elemental status.

Table of interpretative values 1

Crop	*Maize*		
Plant part	Whole top		
Time	Less than 12" tall		
Element	Low	Sufficient	High
	%		
N	<3.5	3.50 – 5.00	>5.0
P	< 0.3	0.30 – 0.50	>0.5
K	< 2.5	2.50 – 4.00	>4.0
Ca	< 0.3	0.30 – 0.70	>0.7
Mg	< 0.15	0.15 - 0.45	>0.45
S	< 0.15	0.15 - 0.50	>0.5
ppm			
B	< 5.0	5 – 25	> 25
Cu	<5.0	5 –20	> 20
Fe	<50	50 – 250	> 250
Mn	<20	20 – 300	> 300
Mo	<0.1	0.1 – 10	> 10
Zn	< 20	20 – 60	> 60

Table of interpretative values 2

Crop	**Maize**		
Plant Part	Leaf Below Whorl		
Time	Prior To Tasseling		
Element	Low	Sufficient	High
	%		
N	< 3.0	3.00 – 3.50	>3.5
P	< 0.25	0.25 – 0.45	>0.45
K	< 2.00	2.00 – 2.50	>2.5
Ca	< 0.25	0.25 - 0.50	>0.5
Mg	< 0.13	0.13 – 0.30	>0.3
S	< 0.15	0.15 - 0.50	>0.5
	ppm		
B	< 4	4 – 25	> 25
Cu	< 3	3 - 15	> 15
Fe	< 10	10 - 20	> 20
Mn	< 15	15 - 300	> 300
Mo	< 0.1	0.1 – 3.0	> 3.0
Zn	< 15	15 - 60	> 60

Table of interpretative values 3

Crop	**Maize**		
Plant Part	Ear Leaf		
Time	Initial Silk.		
Element	Low	Sufficient	High
	%		
N	2.00 – 2.60	2.7 –4.0	> 4.0
P	0.15 – 0.24	0.25 – 0.5	0.51 – 0.8
K	1.00 – 1.60	1.70 – 3.0	3.1 – 5.0
Ca	0.10 – 0.20	0.21 – 1.0	> 1.0
Mg	0.10 – 0.19	0.20 – 1.0	> 1.0
S	0.10 – 0.20	0.21 – 0.5	0.51 – 0.8
	ppm		
B	2.4	5 – 25	26 – 60
Cu	2.5	6 –20	21 – 70
Fe	10 – 20	21 –250	251 – 350
Mn	10 – 19	20 – 200	201 300
Mo	0.1 – 0.2	> 0.2	-
Zn	15 - 24	25 - 100	101 - 150

Table of interpretative values 4 Soil pH

pH	Rating
Below 4.5	Extremely acid
4.5 – 4.9	Strongly acid
5.0 – 5.9	Moderately acid
6.0 – 6.4	Slightly acid
6.5 – 6.9	Near neutral
7.0 – 7.4	Slightly alkaline
7.5 – 8.4	Moderately alkaline
8.5 - 8.9	Strongly alkaline
Above 9.0	Extremely alkaline

Table of interpretative values 5. General guidelines on the interpretation of soil N and C test results (Tekaligh, 1991).

Organic carbon ratings

Organic carbon (%)	Rating
Below 0.5	Very low
0.5 –1.5	Low
1.5 – 3.0	Moderate
Above 3.0	High

Table of interpretative values 6. Total nitrogen (%)

Total nitrogen (%)	Rating
< 0.05	Very low
0.05 – 0.12	Low
0.12 – 0.25	Moderate
> 0.25	High

Table of interpretative values 7. .Evaluation of exchangeable cation levels in soils

Rating	K	Mg	Ca
	mg kg^{-1}		
Very High	> 300	>180	>2400
High	175-300	80-180	1600-2400
Medium	100-175	40-80	1000-1600
Low	50-100	20-40	500-1000
Very Low	<50	<20	< 500

Table of interpretative values 8. Available nutrient classification

Nutrient %	Deficiency level	Adequate	Excess level
Sodium %	-	0.0 –2.0	>2.0
Manganese ppm	< 0.11	0.11- 2.0	> 2.0
Phosphorus ppm	< 20	20-80	>80

Extractable phosphorus by Mehlich extraction method .

Appendix 2: How soil pH affects availability of plants nutrients

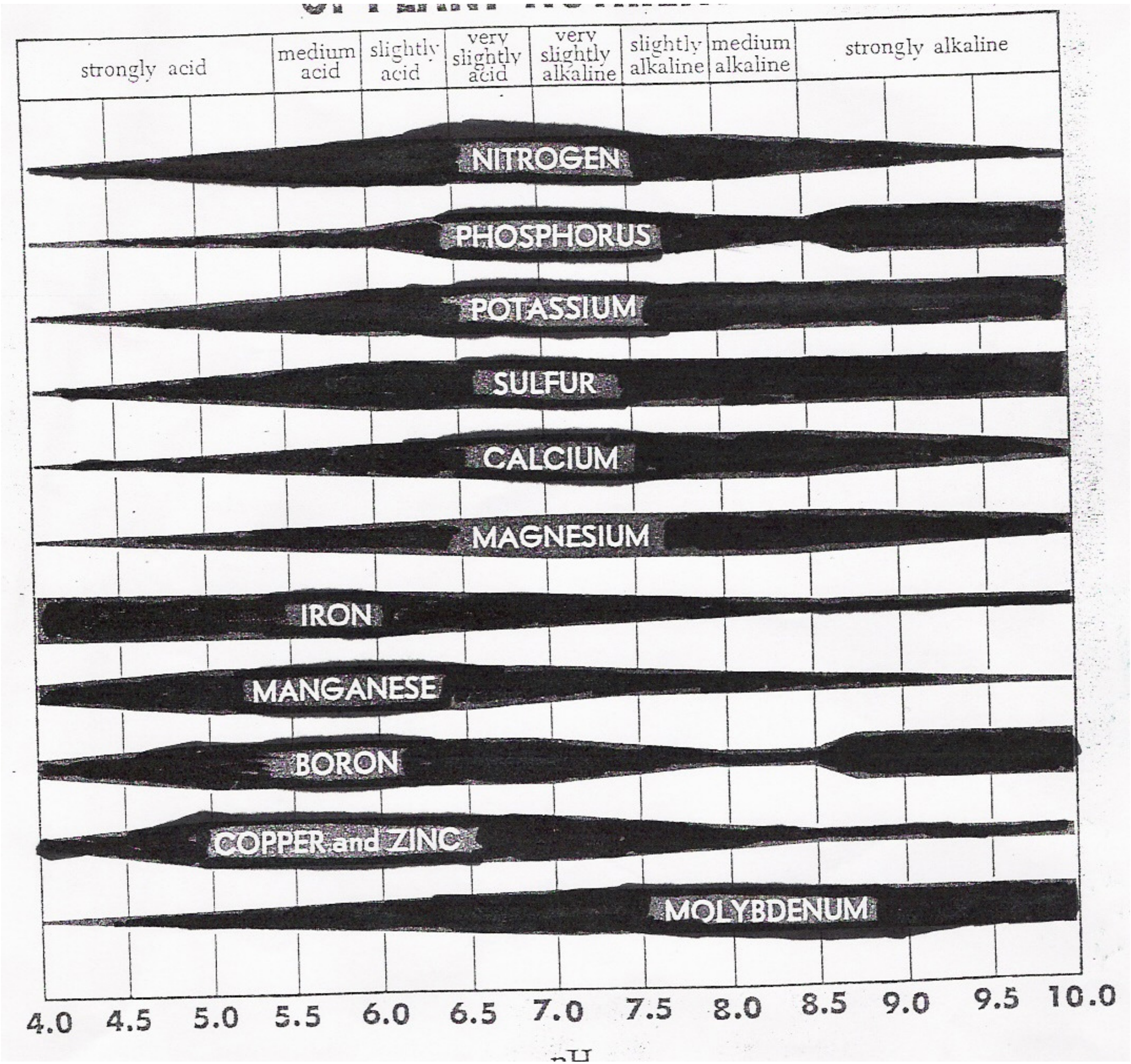

Figure 2: Effects of soil reaction on availability to plants of soil nutrients (after Truog). The width of the bar determines the relative availability of each element with a change in soil reaction.

Soil Reaction

Soil reaction exerts tremendous influence on the availability of plant nutrients either already present in the soil or added as commercial fertilizer. It should be remembered that pH 7.0 is neutral, while values less than 7.0 express increasing acidity and values greater than 7.0 express increasing alkalinity. A change of one pH in unit expresses a 10-fold change in reaction. In other words, pH 5.0 is expressing acidity 10 times as intense as pH 6.0 (see figure 2).

In diagramming the effect of reaction on the availability of each nutrient, the wider the band is, the more favourable is the influence of the soil reaction. For example, the favourable reaction – range for maintaining an adequate supply of nitrogen is pH 6.0 to pH 8.0 A soil within this range does not necessarily mean there is an adequate supply of nitrogen, it merely means that as far as soil reaction is concerned, conditions are favourable for a satisfactory supply of available nitrogen. Also the narrow band for nitrogen at pH 5.0 does not necessarily mean there is a deficiency, but it means that the conditions are not favourable for an abundant supply of available nitrogen.

Soil reaction also affects the availability of the other plant-food nutrients .The pH range of 6.5 to 7.5 is most favourable for phosphorus availability: below pH 5.5 the phosphates may be tied up in insoluble iron and aluminium compounds and above pH 7.5 phosphorus may also be tied up in an insoluble calcium compound.

It will be noted that the most favorable pH range for most of the plant nutrients is about pH 6.8 with the exception of certain minor elements. The availability of iron, manganese, boron, copper, and zinc is greatly reduced when the pH goes above 7.5. At about pH 8.0 boron becomes available again. The availability of molybdenum is affected differently by soil reaction from most elements. At the lower pH values molybdenum is tied up to a considerable degree, but beyond the neutral point its availability increases.

Thus, it can be seen that most minor element deficiencies are likely to occur on over limed or alkaline soils. Experience has demonstrated this to be the case. The most important point to remember is that pH 6.5 is a very desirable reaction when the availability of all plant – food nutrients is considered. This is why for general farming; it is usually recommended that acid soils be limed to pH 6.5.

Appendix 3: Rainfall distribution at the study sites during the crop growth period in 2007.

Month/season	**Bototo**		**Kabondo**	
Long Rains	**Rainy days**	**Rainfall (mm)**	**Rainy days**	**Rainfall (mm)**
March	14	179.6	7	109.8
April	17	232.0	15	224.9
May	21	319.7	10	137.3
June	16	267.7	7	111.9
July	11	107.3	6	84.9
Total	79	1106.3	45	668.9
Short Rains				
August	13	257.2	7	93.2
Sept	14	165..0	7	66.9
October	20	199.6	7	75.4
November	22	154.6	8	74.4
December	15	112.6	11	63.9
Total	84	889	40	373.8

Source: Kisii meteorological site

Data collected on site.

1. Crop growth period covered the months of March to July.
2. Crop growth period covered the months of August to December
3. Days with at least 2 mm of rainfall

Appendix 4: Analysis of variance (ANOVA) table of treatments effects On growth vigour, maize grain yield, dry matter yield, harvest index, Nutrient uptake, phosphorus use efficiency, plant tissue nutrient content, soil nutrient ontent and Striga count in Bototo .

```
                         BY SITES
------------------------- Site=Bototo ----------------------

                     The GLM Procedure
Dependent Variable: growth vigour

                       Sum of
Source      DF         Squares    Mean Square F Value Pr > F

Model      25     511.6714286      20.4668571 34.28    <.0001

Error     114      68.0714286       0.5971178
Corrected
Total     139     579.7428571
R-Square     Coeff Var      Root MSE    growth Mean
0.882583      20.56706      0.772734       3.757143
Source      DF     Type III SS  Mean Square  F Value    Pr > F

Farmer     19      10.0285714    0.5278195      0.88    0.6031
Treatment   6     501.6428571    3.6071429    140.02    <.0001

Dependent Variable: grain yield
                  Sum of
Source     DF     Squares     Mean Square    F Value    Pr > F

 Model    25     736214740.1   29448589.6      18.01    <.0001
 Error    114     186392712.6   1635023.8
 Corrected
 Total    139     922607452.7
 R-Square  Coeff Var  Root MSE  gyield Mean
```

```
 0.797972  32.51796   1278.680   3932.229

Source   DF   Type III SS     Mean Square    F Value    Pr > F
Farmer  19   470253592.1      24750189.1      15.14     <.0001
Treatment 6  265961148.0      44326858.0      27.11     <.0001

Dependent Variable: dmyield

                  Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F

Model    25     3093.111146  123.724446     19.01      <.0001

Error   114      742.144011    6.510035
Corrected
Total   139     3835.255157

 R-Square     Coeff Var      Root MSE    dmyield Mean

 0.806494      22.24063      2.551477        11.47214
Source  DF     Type III SS    Mean Square    F Value    Pr > F

 Farmer   19    1859.645129    97.876059      15.03    <.0001
Treatment 6     1233.466017   205.577670      31.58    <.0001
Dependent Variable: hindex
                  Sum of
Source    DF      Squares     Mean Square    F Value    Pr > F

Model      25      0.43777357   0.01751094      14.54    <.0001
Error     114      0.13726857   0.00120411
Corrected
 Total              139      0.57504214
R-Square     Coeff Var      Root MSE    hindex Mean
0.761290      10.79805      0.034700       0.321357
```

```
Source  DF     Type III SS     Mean Square   F Value    Pr > F
Farmer  19       0.27235643    0.01433455      11.90    <.0001
Treatment 6      0.16541714    0.02756952      22.90    <.0001


Dependent Variable: NUptake
                                           Sum of
Source     DF      Squares     Mean Square    F Value    Pr > F
Model      25  36503.23243     1460.12930       99.61    <.0001
Error     114   1671.06157       14.65843
Corrected
 Total    139  38174.29400
R-Square     Coeff Var      Root MSE       NUptake Mean
0.956225      7.683391      3.828634        49.83000
Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer  19      3527.12543      185.63818      12.66    <.0001
Treatment6     32976.10700     5496.01783     374.94    <.0001

Dependent Variable: PUptake
                   Sum of
Source   DF         Squares     Mean Square    F Value   Pr > F

Model    25    31807.96921     1272.31877      44.06    <.0001

Error   114     3292.19729       28.87892
Corrected
 Total  139    35100.16650
R-Square     Coeff Var      Root MSE    PUptake Mean

0.906206      11.35054      5.373911      47.34500
Source   DF    Type III SS     Mean Square    F Value   Pr > F

Farmer   19    2609.89221       137.36275       4.76    <.0001
Treatment 6     29198.07700    4866.34617     168.51    <.0001

Dependent Variable: KUptake
```

```
               Sum of
Source   DF    Squares    Mean Square    F Value    Pr > F

Model    25   45753.92679      1830.15707   39.09    <.0001

Error   114    5337.59114        46.82097
Corrected
 Total             139     51091.51793
R-Square     Coeff Var      Root MSE    KUptake Mean
0.895529      8.855505      6.842585        77.26929
Source     DF  Type III SS   Mean Square    F Value    Pr > F
Farmer     19    2682.24936      141.17102       3.02    0.0001
Treatment   6   43071.67743     7178.61290    153.32    <.0001

Dependent Variable: CaUptake

                  Sum of
Source     DF     Squares     Mean Square    F Value    Pr > F

Model      25     622.5263621   24.9010545    106.81    <.0001

Error     114      26.5783314    0.2331433
Corrected
Total     139     649.1046936
R-Square     Coeff Var      Root MSE    CaUptake Mean
0.959054      8.355546      0.482849         5.778786
Source     DF   Type III SS   Mean Square    F Value    Pr > F
Farmer     19      15.1832936   0.7991207       3.43    <.0001
Treatment   6     607.3430686  01.2238448     434.17    <.0001

Dependent Variable: MgUptake
                  Sum of
Source     DF     Squares     Mean Square    F Value    Pr > F
Model     25     92.5787850    3.7031514      21.36    <.0001
Error    114     19.7679143    0.1734028
```

```
Corrected
 Total   139     112.3466993
R-Square     Coeff Var      Root MSE    MgUptake Mean
0.824045      12.89244      0.416417         3.229929

Source      DF Type III SS     Mean Square    F Value    Pr > F
Farmer      19     21.02507071   1.10658267      6.38    <.0001
Treatment    6     71.55371429  11.92561905     68.77    <.0001


Dependent Variable: PPUE

                  Sum of
Source    DF      Squares     Mean Square    F Value    Pr > F
Model      25     4613.535714   184.541429      40.36    <.0001
Error     114      521.285714     4.572682

Corrected
 Total   139     5134.821429
R-Square     Coeff Var      Root MSE     PPUE Mean
0.898480      6.017560      2.138383      35.53571
Source       DF    Type III SS    Mean Square   F Value  Pr > F
Farmer       19     1533.964286     80.734962   17.66    <.0001
Treatment     6     3079.571429    513.261905  112.25    <.0001


Dependent Variable: ExtP
                  Sum of
Source       DF   Squares     Mean Square    F Value    Pr > F
Model         25     305.8507143 12.2340286     65.77    <.0001
Error        114      21.2047143  0.1860063
Corrected
 Total              139     327.0554286
R-Square     Coeff Var      Root MSE     ExtP Mean
0.935165      7.936359      0.431284      5.434286
Source   DF     Type III SS   Mean Square    F Value    Pr > F
```

```
Farmer   19      8.3782857      0.4409624       2.37    0.0027
Treatment 6     97.4724286    49.5787381     266.54    <.0001

Dependent Variable: Ppercent
                                               Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F
Model    25      4.46564286    0.17862571       8.76    <.0001
Error   114      2.32428571      0.02038847
Corrected
 Total  139      6.78992857

R-Square     Coeff Var      Root MSE       Ppercent Mean
0.657686      6.429832      0.142788         2.220714
Source   DF     Type III SS     Mean Square  F Value    Pr > F
Farmer  19      1.68421429      0.08864286      4.35    <.0001
Treatment6      2.78142857      0.46357143     22.74    <.0001

Dependent Variable: kpercent
                  Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F
Model   25      7101.03282      284.04131       1.00    0.4749
Error  114     32421.29474      284.39732
Corrected
Total  139     39522.32755
R-Square     Coeff Var      Root MSE    kpercent Mean
0.179671      412.3824      16.86408         4.089429

Source DF     Type III SS     Mean Square    F Value    Pr > F

Farmer 19     5286.645754      278.244513       0.98    0.4913
Treatment 6   1814.387064      302.397844       1.06    0.3888

Dependent Variable: capercent
                                           Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F
Model    25    0.00001488      0.00000060      25.24    <.0001
```

```
Error   114    0.00000269      0.00000002
Corrected
Total   139    0.00001757
R-Square     Coeff Var      Root MSE    capercent Mean
0.846964      6.181192      0.000154          0.002484

Source    DF   Type III SS     Mean Square    F Value    Pr > F
Farmer    19    0.00000244      0.00000013       5.44    <.0001
Treatment 6     0.00001244      0.00000207      87.93    <.0001


Dependent Variable: scount
               Sum of
Source    DF   Squares          Mean Square    F Value    Pr > F
Model     25   3284.671429      131.386857      29.64    <.0001
Error   114     505.328571        4.432707
Corrected
 Total  139   3790.000000
R-Square     Coeff Var      Root MSE    scount Mean
0.866668      14.03600      2.105399       15.00000
Source    DF   Type III SS     Mean Square    F Value    Pr > F
Farmer    19   2196.571429      115.609023      26.08    <.0001
Treatment 6    1088.100000      181.350000      40.91    <.0001

Dependent Variable: StoN
                  Sum of
Source    DF       Squares      Mean Square    F Value    Pr > F
Model     25     6618.242857    264.729714      32.84    <.0001
Error   114       918.928571      8.060777
Corrected
 Total  139      7537.171429
R-Square     Coeff Var      Root MSE     StoN Mean

0.878080      7.314706      2.839151      38.81429

Source   DF    Type III SS     Mean Square    F Value    Pr > F
```

```
Farmer  19    4233.171429      222.798496       27.64   <.0001
Treatment 6     2385.071429     397.511905     49.31    <.0001

Dependent Variable: StoP

                  Sum of
Source   DF         Squares     Mean Square    F Value    Pr > F

Model    25   152.8071429       6.1122857      33.11    <.0001
Error   114    21.0428571       0.1845865
Corrected
Total   139     173.8500000

R-Square     Coeff Var      Root MSE     StoP Mean
0.878960      9.876673      0.429635      4.350000
Source  DF    Type III SS     Mean Square    F Value    Pr > F

Farmer 19     62.70714286      3.30037594      17.88    <.0001
Treatment 6   90.10000000     15.01666667      81.35    <.0001

Dependent Variable: StoK
                   Sum of
Source   DF         Squares     Mean Square    F Value    Pr > F
Model    25   65873.08571      2634.92343      76.98    <.0001
Error   114    3902.31429       34.23083
Corrected
Total   139     69775.40000

R-Square     Coeff Var      Root MSE     StoK Mean
0.944073      4.654504      5.850712      125.7000
Source  DF    Type III SS     Mean Square    F Value    Pr > F

Farmer  19    30781.68571      1620.08872      47.33    <.0001
Treatment6     35091.40000     5848.56667     170.86    <.0001
```

```
Dependent Variable: StoCa
                Sum of
Source   DF    Squares     Mean Square    F Value    Pr > F

Model    25    0.00220639      0.00008826      15.03    <.0001
Error   114    0.00066930      0.00000587
Corrected
 Total  139    0.00287569

R-Square     Coeff Var      Root MSE    StoCa Mean
0.767256      13.55810      0.002423      0.017871

Source DF     Type III SS     Mean Square    F Value    Pr > F

Farmer 19      0.00110140      0.00005797       9.87    <.0001
Treatment 6    0.00110499      0.00018416      31.37    <.0001

Dependent Variable: StoMg
                  Sum of
Source   DF        Squares     Mean Square    F Value    Pr > F
Model    25    0.00090461      0.00003618       9.85    <.0001
Error   114    0.00041879      0.00000367
Corrected
Total   139    0.00132339


R-Square     Coeff Var      Root MSE    StoMg Mean

0.683551      16.51270      0.001917      0.011607

Source DF     Type III SS     Mean Square    F Value    Pr > F

Farmer 19      0.00035596      0.00001873       5.10    <.0001
Treatment 6    0.00054864      0.00009144      24.89    <.0001
```

```
Dependent Variable: GraN
                  Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F

 Model   25    7618.100000      304.724000     333.80    <.0001
Error   114    104.071429        0.912907
Corrected
 Total  139     7722.171429

R-Square     Coeff Var      Root MSE     GraN Mean
0.986523      1.813512      0.955462      52.68571

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer 19     6963.028571      366.475188     401.44    <.0001
Treatment 6    655.071429      109.178571     119.59    <.0001
Dependent Variable: GraP
                  Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F
Model  25     1472.071429       58.882857     172.56    <.0001
Error 114       38.900000        0.341228
Corrected
 Total 139     1510.971429
R-Square     Coeff Var      Root MSE     GraP Mean
0.974255      4.523265      0.584147      12.91429
Source  DF     Type III SS    Mean Square    F Value    Pr > F
Farmer  19    594.4000000      31.2842105      91.68    <.0001
Treatment6    877.6714286     146.2785714     428.68    <.0001

Dependent Variable: GraK
                                               Sum of
Source   DF     Squares     Mean Square    F Value    Pr > F
Model     25     3447.257143  137.890286      47.72    <.0001
Error   114       329.428571        2.889724
Corrected
 Total  139     3776.685714
```

```
R-Square     Coeff Var      Root MSE     GraK Mean
0.912773      11.94722      1.699919      14.22857

Source  DF   Type III SS     Mean Square    F Value    Pr > F
Farmer 19     1660.971429      87.419549      30.25    <.0001
Treatment 6   1786.285714     297.714286     103.03    <.0001

Dependent Variable: GraCa
Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F

Model   25     0.01178125      0.00047125       1.97    0.0088
Error  114     0.02732089      0.00023966
Corrected
 Total             139      0.03910214

R-Square     Coeff Var      Root MSE    GraCa Mean
0.301294      79.71018      0.015481      0.019421
Source   DF   Type III SS     Mean Square    F Value    Pr > F
Farmer   19    0.00806356      0.00042440       1.77    0.0346
Treatment 6    0.00371769      0.00061961       2.59    0.0219
Dependent Variable: GraMg
                  Sum of
Source     DF      Squares     Mean Square    F Value    Pr > F

Model      25  0.00477283      0.00019091       5.58   <.0001
Error     114  0.00390386      0.00003424

Corrected
 Total   139       0.00867669
R-Square     Coeff Var      Root MSE    GraMg Mean

0.550075      80.95470      0.005852      0.007229

Source DF     Type III SS     Mean Square    F Value    Pr > F
```

```
Farmer   19    0.00200954      0.00010577       3.09    0.0001
Treatment 6    0.00276329      0.00046055      13.45    <.0001

Dependent Variable: CobN
                  Sum of
Source    DF      Squares     Mean Square    F Value    Pr > F

Model      25    6479.750000   259.190000     358.65    <.0001

Error    114       82.385714     0.722682
Corrected
 Total   139     6562.135714
R-Square     Coeff Var      Root MSE     CobN Mean
0.987445      2.717857      0.850107      31.27857
Source DF     Type III SS     Mean Square    F Value    Pr > F
Farmer 19     2431.564286      127.977068     177.09    <.0001
Treatment 6   4048.185714      674.697619     933.60    <.0001


Dependent Variable: CobP
                  Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F

Model   25    322.8357143      12.9134286      26.11    <.0001
Error  114      56.3857143       0.4946115
Corrected
 Total 139     379.2214286

R-Square     Coeff Var      Root MSE     CobP Mean
0.851312      22.22575      0.703286      3.164286

Source  DF    Type III SS     Mean Square    F Value    Pr > F

Farmer 19      80.3642857       4.2296992       8.55    <.0001
Treatment 6   242.4714286      40.4119048      81.70    <.0001
```

```
Dependent Variable: CobK

                   Sum of
Source  DF         Squares     Mean Square    F Value    Pr > F

Model  25     3487.428571      139.497143     205.08    <.0001

Error 114       77.542857        0.680201
Corrected
Total 139     3564.971429
R-Square     Coeff Var      Root MSE     CobK Mean

0.978249      8.177335      0.824743      10.08571


Source  DF    Type III SS     Mean Square    F Value    Pr > F

Farmer  19      899.257143       47.329323      69.58    <.0001
Treatment 6   2588.171429      431.361905     634.17    <.0001
Dependent Variable: CobCa
                   Sum of
Source DF          Squares     Mean Square    F Value    Pr > F

Model  25      0.00150524      0.00006021      39.19    <.0001

Error 114      0.00017516      0.00000154

Corrected
 Total139      0.00168040

R-Square     Coeff Var      Root MSE    CobCa Mean

0.895765      10.50460      0.001240      0.011800

Source DF     Type III SS     Mean Square    F Value    Pr > F
```

```
Farmer 19      0.00076354      0.00004019      26.16    <.0001
Treatment6      0.00074170     0.00012362      80.46    <.0001

Dependent Variable: CobMg
                   Sum of
Source DF         Squares     Mean Square    F Value    Pr > F
Model  25      0.00339016      0.00013561       3.54    <.0001

Error  114      0.00436163      0.00003826
Corrected
 Total 139      0.00775179
R-Square     Coeff Var      Root MSE    CobMg Mean

0.437339      128.6722      0.006185      0.004807
Source DF     Type III SS     Mean Square    F Value    Pr > F
Farmer  19     0.00217322      0.00011438       2.99    0.0002
Treatment  6   0.00121694      0.00020282       5.30    <.0001
```

Appendix 5: Analysis of variance (ANOVA) table of treatments effects on growth vigour, maize grain yield, dry matter yield, harvest index, nutrient uptake, phosphorus use efficiency, plant tissue nutrient content, soil nutrient content and Striga count in Kabondo .

```
                              BY SITES
          -------------- Site=Kabond -------
                         The GLM Procedure

Dependent Variable: growth

                  Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F
Model     25    435.6428571    17.4257143      14.04    <.0001
Error    114    141.5000000     1.2412281
Corrected
 Total   139    577.1428571
R-Square     Coeff Var      Root MSE    growth Mean
0.754827      28.88418      1.114104       3.857143

Source   DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19      4.0000000      0.2105263       0.17    1.0000
Treatment 6    431.6428571     71.9404762      57.96    <.0001

Dependent Variable: grain yield

                   Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F
Model     25    229590672.0     9183626.9      19.09    <.0001
Error    114     54828634.6      480952.9
Corrected
 Total   139    284419306.6
R-Square     Coeff Var      Root MSE    grain yield Mean
0.807226      22.58909      693.5077       3070.100
```

```
Source   DF   Type III SS     Mean Square    F Value    Pr > F

Farmer   19   106021654.0       5580087.1      11.60    <.0001
Treatment 6   123569018.0      20594836.3      42.82    <.0001

Dependent Variable: dmyield

                  Sum of
Source    DF      Squares     Mean Square    F Value    Pr > F
Model      25     967.208951    38.688358      15.67    <.0001
Error    114      281.504946        2.469342
Corrected
 Total   139     1248.713897

R-Square     Coeff Var      Root MSE    dmyield Mean
0.774564      14.62441      1.571414        10.74514

Source   DF   Type III SS     Mean Square    F Value    Pr > F
Farmer   19   583.5409543      30.7126818      12.44    <.0001
Treatment 6   383.6679971      63.9446662      25.90    <.0001

Dependent Variable: hindex

                  Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F
Model   25     0.45111929      0.01804477      11.83    <.0001
Error  114     0.17386571      0.00152514
Corrected
 Total 139      0.62498500

R-Square     Coeff Var      Root MSE    hindex Mean
0.721808      14.12406      0.039053       0.276500

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19    0.22769929      0.01198417       7.86    <.0001
Treatment 6    0.22342000      0.03723667      24.42    <.0001
```

```
Dependent Variable: NUptake
                    Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F
Model    25   8772.745786      350.909831      40.94    <.0001
Error   114    977.044143        8.570563
Corrected
Total   139     9749.789929
R-Square     Coeff Var      Root MSE    NUptake Mean
0.899788      10.39218      2.927552        28.17071

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19      590.001357       31.052703     3.62    <.0001
Treatment 6     8182.744429     1363.790738   159.12    <.0001


Dependent Variable: PUptake
              Sum of
Source   DF   Squares     Mean Square    F Value    Pr > F
Model    25   13474.25971       538.97039     184.29    <.0001
Error   114     333.39429         2.92451
Corrected
 Total  139     13807.65400

R-Square     Coeff Var      Root MSE    PUptake Mean
0.975854      4.786231      1.710120        35.73000

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19      1133.85971       59.67683     20.41   <.0001
Treatment 6     12340.40000     2056.73333    703.27   <.0001

Dependent Variable: KUptake
                  Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F
Model    25   9477.708786      379.108351     100.68    <.0001
Error   114    429.269143        3.765519
```

```
Corrected
 Total  139   9906.977929

R-Square     Coeff Var      Root MSE    KUptake Mean
0.956670      5.990897      1.940494        32.39071

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer  19     427.229357       22.485756       5.97    <.0001
Treatment 6   9050.479429     1508.413238     400.59    <.0001


Dependent Variable: CaUptake

                  Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F
Model   25     241.2185179       9.6487407    558.76    <.0001
Error  114       1.9685757       0.0172682
Corrected
 Total 139     243.1870936

R-Square     Coeff Var      Root MSE    CaUptake Mean
0.991905      2.885699      0.131409         4.553786

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19     23.7195793       1.2483989     72.29    <.0001
Treatment 6    217.4989386      36.2498231   2099.22    <.0001

Dependent Variable: MgUptake
                Sum of
Source   DF    Squares     Mean Square       F Value    Pr > F
Model    25   36.75546500      1.47021860      44.99    <.0001
Error   114    3.72497714      0.03267524
Corrected
 Total  139   40.48044214

R-Square     Coeff Var      Root MSE    MgUptake Mean
```

```
0.907981      10.36697      0.180763         1.743643

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer  19     3.53632786      0.18612252       5.70    <.0001
Treatment6    33.21913714      5.53652286     169.44    <.0001

Dependent Variable: PPUE

                  Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F
Model    25   3612.507143      144.500286     147.19    <.0001
Error   114    111.914286        0.981704
Corrected
 Total  139     3724.421429
R-Square     Coeff Var      Root MSE     PPUE Mean
0.969951      2.383801      0.990810      41.56429

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer  19     1514.135714      79.691353      81.18    <.0001
Treatment6     2098.371429     349.728571     356.25    <.0001


Dependent Variable: ExtP
                  Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F
Model   25     32.70464286     1.30818571      39.61    <.0001
Error  114      3.76528571     0.03302882
Corrected
 Total 139     36.46992857


R-Square     Coeff Var      Root MSE     ExtP Mean
0.896756      8.263516      0.181738      2.199286

Source   DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19     3.38421429      0.17811654       5.39    <.0001
```

```
Treatment 6   29.32042857      4.88673810     147.95    <.0001

Dependent Variable: Ppercent
                                     Sum of
Source  DF   Squares     Mean Square    F Value    Pr > F
Model   25     36.48614286      1.45944571     20.39    <.0001
Error  114      8.15785714      0.07156015
Corrected
 Total 139     44.64400000

R-Square     Coeff Var      Root MSE    Ppercent Mean
0.817269      8.573952      0.267507         3.120000

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer 19     12.38114286      0.65163910       9.11    <.0001
Treatment 6    24.10500000     4.01750000      56.14    <.0001

Dependent Variable: npercent

                  Sum of
Source   DF        Squares     Mean Square    F Value    Pr > F
Model    25    0.00680286      0.00027211       0.82    0.7131
Error   114      0.03795714      0.00033296
Corrected
 Total  139      0.04476000


 R-Square     Coeff Var      Root MSE    npercent Mean
 0.151985      114.0445      0.018247         0.016000

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19    0.00570286      0.00030015       0.90    0.5820
Treatment 6    0.00110000      0.00018333       0.55    0.7686

Dependent Variable: kpercent
```

```
               Sum of
Source  DF    Squares     Mean Square    F Value    Pr > F
Model   25    135.3543571       5.4141743       9.21    <.0001
Error  114      67.0138571       0.5878409
Corrected
 Total 139     202.3682143

R-Square     Coeff Var      Root MSE    kpercent Mean
0.668852      8.860016      0.766708         8.653571

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19   41.21964286      2.16945489       3.69    <.0001
Treatment 6   94.13471429     15.68911905      26.69    <.0001

Dependent Variable: capercent
                                              Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F
Model  25      0.00003057      0.00000122      15.89    <.0001
Error 114      0.00000878      0.00000008
Corrected
 Total 139      0.00003935

R-Square     Coeff Var      Root MSE    capercent Mean
0.776968      17.51236      0.000277          0.001584

Source   DF   Type III SS     Mean Square    F Value    Pr > F
Farmer   19    0.00000084      0.00000004       0.57    0.9177
Treatment 6    0.00002973      0.00000496      64.37    <.0001

Dependent Variable: scount


                                               Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F
Model    25   1874.671429       74.986857      35.72    <.0001
Error   114    239.328571        2.099373
Corrected
```

```
 Total            139     2114.000000

R-Square     Coeff Var      Root MSE    scount Mean
0.886789      7.625902      1.448921       19.00000

Source   DF   Type III SS     Mean Square    F Value    Pr > F
Farmer   19   1396.571429       73.503759      35.01    <.0001
Treatment 6    478.100000       79.683333      37.96    <.0001

Dependent Variable: StoN

                  Sum of
Source  DF         Squares     Mean Square    F Value    Pr > F
Model   25    3870.914286      154.836571      21.34    <.0001
Error  114     826.971429        7.254135
Corrected
 Total139     4697.885714

R-Square     Coeff Var      Root MSE     StoN Mean
0.823969      16.65499      2.693350      16.17143

Source   DF   Type III SS     Mean Square    F Value    Pr > F

Farmer   19    557.028571       29.317293       4.04    <.0001
Treatment 6   3313.885714      552.314286      76.14    <.0001

Dependent Variable: StoP

                 Sum of
Source   DF     Squares     Mean Square    F Value    Pr > F
Model    25   347.4571429     13.8982857      60.67    <.0001
Error   114      26.1142857       0.2290727
Corrected
Total    139     373.5714286

R-Square     Coeff Var      Root MSE     StoP Mean
```

```
0.930096      14.89026      0.478615      3.214286


Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19       91.2857143      4.8045113     20.97    <.0001
Treatment 6     256.1714286     42.6952381    186.38    <.0001

Dependent Variable: StoK
                Sum of
Source   DF     Squares     Mean Square    F Value    Pr > F
Model    25   15532.25000       621.29000     169.95    <.0001
Error   114        416.74286         3.65564
Corrected
 Total  139     15948.99286

R-Square     Coeff Var      Root MSE     StoK Mean
0.973870      3.175657      1.911973      60.20714

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19       5526.70714      290.87932     79.57    <.0001
Treatment 6     10005.54286      1667.59048   456.17    <.0001

Dependent Variable: StoCa
                 Sum of
Source     DF     Squares     Mean Square     F Value     Pr > F

Model  25      0.00460405      0.00018416      13.70    <.0001
Error 114      0.00153289      0.00001345
Corrected
 Total139      0.00613694

R-Square     Coeff Var      Root MSE    StoCa Mean
0.750220      33.27090      0.003667      0.011021

Source  DF   Type III SS     Mean Square     F Value     Pr > F
Farmer   19    0.00135436      0.00007128       5.30    <.0001
```

```
Treatment 6    0.00324969      0.00054161      40.28    <.0001

Dependent Variable: StoMg

                  Sum of
Source    DF     Squares     Mean Square    F Value    Pr > F
Model     25    0.00078761      0.00003150      15.26    <.0001
Error    114    0.00023539      0.00000206
Corrected
 Total   139    0.00102299

R-Square     Coeff Var      Root MSE    StoMg Mean
0.769905      30.52673      0.001437      0.004707

Source    DF   Type III SS     Mean Square    F Value    Pr > F
Farmer    19    0.00022356      0.00001177       5.70    <.0001
Treatment 6     0.00056404      0.00009401      45.53    <.0001

Dependent Variable: GraN
                                                      Sum of
Source   DF        Squares     Mean Square    F Value    Pr > F
Model    25    2033.685714       81.347429     518.49    <.0001
Error   114      17.885714        0.156892
Corrected
 Total 139      2051.571429

R-Square     Coeff Var      Root MSE     GraN Mean
0.991282      2.227047      0.396096      17.78571

Source   DF    Type III SS     Mean Square    F Value    Pr > F
Farmer    19   1408.714286       74.142857     472.57    <.0001
Treatment 6     624.971429      104.161905     663.91    <.0001


Dependent Variable: GraP
```

```
                  Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F
Model   25    1247.392857       49.895714      97.40    <.0001
Error  114      58.400000        0.512281
Corrected
 Total 139     1305.792857

R-Square     Coeff Var      Root MSE     GraP Mean
0.955276      10.85626      0.715738      6.592857

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19   630.6500000      33.1921053      64.79    <.0001
Treatment 6   616.7428571     102.7904762     200.65    <.0001


Dependent Variable: GraK

               Sum of
Source   DF   Squares     Mean Square    F Value    Pr > F
Model    25    895.342857       35.813714      30.62    <.0001
Error   114      133.342857        1.169674
Corrected
 Total            139     1028.685714

R-Square     Coeff Var      Root MSE     GraK Mean
0.870376      13.91655      1.081515      7.771429

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer  19    677.2571429      35.6451128      30.47    <.0001
Treatment 6   218.0857143      36.3476190      31.07    <.0001


Dependent Variable: GraCa

                   Sum of
Source   DF       Squares     Mean Square    F Value    Pr > F
```

```
Model    25     0.02225851      0.00089034       4.51    <.0001
Error   114       0.02251414      0.00019749
Corrected
 Total  139       0.04477265

R-Square     Coeff Var      Root MSE    GraCa Mean
0.497145      80.53411      0.014053      0.017450

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19     0.01707551      0.00089871       4.55    <.0001
Treatment 6     0.00518300      0.00086383       4.37    0.0005

Dependent Variable: GraMg

                  Sum of
Source   DF        Squares     Mean Square    F Value    Pr > F
Model    25     0.00052326      0.00002093      27.87    <.0001
Error   114     0.00008563      0.00000075
Corrected
 Total  139     0.00060889

R-Square     Coeff Var      Root MSE    GraMg Mean
0.859368      24.96598      0.000867      0.003471

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19     0.00011517      0.00000606       8.07    <.0001
Treatment 6     0.00040809      0.00006801      90.55    <.0001

Dependent Variable: CobN
               Sum of
Source  DF      Squares     Mean Square    F Value    Pr > F
Model   25  4268.650000      170.746000     828.80    <.0001
Error  114       23.485714        0.206015
Corrected

 Total            139     4292.135714
```

```
R-Square     Coeff Var      Root MSE     CobN Mean
0.994528      3.010158      0.453889      15.07857

Source   DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19   1271.564286        66.924436     324.85    <.0001
Treatment 6   2997.085714      499.514286    2424.65    <.0001

Dependent Variable: CobP
              Sum of
Source   DF    Squares     Mean Square    F Value    Pr > F
Model    25    223.8285714       8.9531429      40.32    <.0001
Error   114     25.3142857       0.2220551
Corrected
 Total 139     249.1428571

R-Square     Coeff Var      Root MSE     CobP Mean
0.898394      14.99359      0.471227      3.142857

Source   DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19  176.2857143       9.2781955      41.78    <.0001
Treatment 6   47.5428571       7.9238095      35.68    <.0001

Dependent Variable: CobK

                  Sum of
Source   DF         Squares     Mean Square    F Value    Pr > F
Model   25     1610.978571       64.439143      42.26    <.0001
Error 114       173.842857        1.524937
Corrected
 Total 139     1784.821429

R-Square     Coeff Var      Root MSE     CobK Mean
0.902599      18.89439      1.234884      6.535714

Source   DF    Type III SS     Mean Square    F Value    Pr > F
```

```
Farmer 19     805.1071429      42.3740602      27.79    <.0001

Treatment 6   805.8714286     134.3119048      88.08    <.0001

Dependent Variable: CobCa

                                               Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F
Model  25      0.00175339      0.00007014       1.68    0.0345
Error 114      0.00474830      0.00004165
Corrected
 Total139      0.00650169

R-Square     Coeff Var      Root MSE    CobCa Mean
0.269682      49.15856      0.006454      0.013129

Source DF     Type III SS     Mean Square    F Value    Pr > F
Farmer   19    0.00081540      0.00004292       1.03    0.4329
Treatment 6    0.00093799      0.00015633       3.75    0.0019


Dependent Variable: CobMg

                  Sum of
Source  DF        Squares     Mean Square    F Value    Pr > F
Model    25    0.00073291      0.00002932      29.61    <.0001
Error  114     0.00011289      0.00000099
Corrected
 Total 139     0.00084579

R-Square     Coeff Var      Root MSE    CobMg Mean
0.866533      32.17416      0.000995      0.003093

Source  DF    Type III SS     Mean Square    F Value    Pr > F
Farmer   19     0.00014236     0.00000749       7.57    <.0001
Treatment 6     0.00059054     0.00009842      99.40    <.0001
```