EVALUATION OF DIFFERENT METHODS OF LIME APPLICATION AND RATES ON MAIZE PRODUCTION ON ACID SOILS OF NORTH KAKAMEGA AND UGENYA DISTRICTS, KENYA

BY:

JOEL K. KIPLAGAT

AGR/PGS/06/09

(BSc. HORTICULTURAL SCIENCE AND MANAGEMENT)

SUPERVISORS:

PROF. J. R. OKALEBO

DR. C. K. SERREM

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SEPT, 2013

DECLARATION

Declaration by the candidate:

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Joel Kigen Kiplagat (AGR/PGS/06/09)

Signature: .... Date: ....

Declaration by Supervisors:

We declare that the work in this thesis was done by the candidate under our supervision:

Prof. John R. Okalebo

Department of Soil Science, University of Eldoret, Kenya

Signature: .... Date: ....

Dr. Cornelius K. Serrem

Department of Soil Science, University of Eldoret, Kenya

Signature: .... Date: ....

DEDICATION

I dedicate this work to my entire family for their continued support and sacrifices they have made for me to pursue my studies.

ABSTRACT

Western Kenya is experiencing declining food production as a result of infertile soils and soil acidity among other factors in smallholder farms. To counteract this, KARI Kakamega and Moi University have demonstrated the potential of using agricultural lime, inorganic fertilizers and Minjingu rock phosphate to address the food security problem. Despite this, the use of lime is still low due to: unawareness on lime effectiveness, and importance and mode of application by smallholder farmers. The study aimed at comparing methods of applying lime (spot, band and broadcast methods) to acid soils at 4 different rates of application (0, 2, 4 and 6 t/ha) in terms of maize performance in the two target districts of Western Kenya. On farm experiment was conducted in two sites in Ugenya district and two sites in North Kakamega district for three seasons (2010 LR, 2010 SR and 2011 LR). It was laid out in a 3x4 factorial in a randomized complete block design (RCBD) with 4 replications and a parallel experiment was laid out in RCBD with three replications for lime affordability study. Lime was applied once for three cropping seasons at planting time of 2010LR using the three methods, but with phosphorus as TSP and nitrogen as CAN applied as blankets at the rate of 26 kg/ha P and 75 kg/ha N. All the cultural practices were observed equally on all the treatments. Soil sampling was done before applying lime and fertilizers for initial site characterization and repeated thereafter to monitor changes in soil chemical properties. Analysis of the data was done using Statistical Analysis Software (SAS) version 9.1, a computer statistical package and separation of means by orthogonal contrast. Initial soil analysis suggested that the sites needed to be limed to correct soil acidity and to improve the yields. After lime was applied using the different treatments, soil pH was raised from less than 5 in all the sites to 5.85 in Ugenya district and 5.02 in North Kakamega district. The changes in pH were different with band at 6 t/ha of lime in North Kakamega district giving highest increase in pH at the end of three seasons, whereas in Ugenya district the best results were obtained from application of 6 t/ha by broadcast method. This was then reflected in availability of phosphorus for the tested crop and its yield. On average, the yields were increased from 1.50 t/ha to 3.53 t/ha and from 1.78 t/ha to 4.57 t/ha in North Kakamega and Ugenya districts, respectively. The differences between the two sites could possibly be attributed to high buffering capacity of soils in North Kakamega district due to high organic carbon and clay contents compared to those soils of Ugenya, hence lower residual effects of lime. However, economic analysis indicated that, application of 2 t/ha of lime by band or broadcast methods were economically viable in Ugenya district; while in North Kakamega district, similar quantity of lime applied by spot method or banding 4 t/ha of lime were economically viable. Thus application of large quantities of lime e.g. 6 t/ha increases the gross field benefits but reduces the net benefits due to increased cost of purchasing and transporting lime. On the minimum input experiment, it was found that a farmer can apply lime up to 0.5 t/ha in Ugenya district and still realize improved productivity, but this was not possible in North Kakamega district. Therefore there are differences in terms of lime applications depending on the sites due to soil types and climatic conditions. Thus it is recommended in this study that application of lime be done via band method in North Kakamega and broadcast in Ugenya districts.

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LIST OF ACRONYMS

ANOVA	-	Analysis of Variance
$CaCO_3$	-	Calcium Carbonate
CAN	-	Calcium Ammonium Nitrates
CaO	-	Calcium Oxide
CIMMYT	-	Centro Internacional de Mejoramiento de Maiz y Trigo
Cmol	-	centimol
CV	-	Coefficient of Variation
DF	-	Degrees of Freedom
ECEC	-	Effective Cation Exchange Capacity
FAO	-	Food and Agricultural Organization of the United Nations
FSSA	-	Fertilizer Society of South Africa
FURP	-	Fertilizer Use and Recommendation Programme
Ha	-	Hectare(s)
KARI	-	Kenya Agricultural Research Institute
kg	-	Kilogramme(s)
LR	-	Long rains
mg	-	milligramme(s)
MSS	-	Mean Sum of Squares
MT	-	metric tonnes
Pers.	-	Personal
RCBD	-	Randomized Complete Block Design
SED	-	Standard Error of Differences
SR	-	Short rains
SS	-	Sum of Squares
t	-	Tonnes
TSP	-	Triple Superphosphate

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CHAPTER ONE:

1.0. INTRODUCTION

Low soil fertility is one of the yield limiting factors which is caused by soil acidity among other factors. Globally, soil acidity is known to reduce crop yields on nearly 40% of the arable land. In Kenya, acid soils cover about 13% of total land area and are distributed widely in the croplands of central and western Kenya regions, covering over one million hectares under maize, legume, tea and coffee crops, grown by over 5 million smallholder farmers (Kanyanjua *et al.*, 2002; Gudu *et al.*, 2001; Gudu *et al.*, 2005; Gudu *et al.*, 2007; Ligeyo, 2007).

The types of acidic soils in Kenya are Acrisols, Andosols, Arenosols, Cambisols, Ferralsols, Gleysols, Luvisols, Nitisols, Vertisols, Fluvisols, and Regosols. These soils have pH- H_2O ranging from 4.5-6.9 (www.kari.org/../feedview.php; 2011; Okalebo *et al.*, 2009). Soil acidity is mainly caused by pollution that leads to formation of acid rains, soil organic matter during decomposition, leaching of soluble basic cations (e.g. sodium, potasium, calcium and magnessium (Havlin *et al.*, 2005), continuous application of acid forming fertilizers such as Di-ammonium Phosphate to acid soils over years (Nekesa, 2007, Kanyanjua *et al.*, 2002) and inherent acidity from the parent material containing little or no limestone (Skousen and McDonald, 2005).

These soils are characterized by low mineral base saturation, plant mineral nutrient deficiencies, and, for most of the cases, mineral toxicities especially aluminium, manganese and iron (Mamo, 2009). In these soils, phosphorus (P), nitrogen (N), calcium (Ca), potasium (K) and magnessium (Mg) deficiencies are also common. For instance, P levels in some acid soils range from 2- 5 mg/kg soil, which is far below the optimum level of 10 to 15 mg/kg soil, required for optimum production. Moreover, only about 20% of P fertilizer applied to the soil is available to the plant, the rest is fixed in clay minerals of those acidic soils (Clark *et al*., 1988; Kanyanjua *et al.*, 2002; Kochian, 1995; Ligeyo and Gudu, 2005; Maclean, 1971).

In western Kenya, it is estimated that about 57,670 hectares (ha) of land are acidic, with pH less than 5.5 (Kanyanjua *et al.*, 2002). Farming (crop and animal production) is the main economic activity in the region; crop production involves both cash crops (mainly sugar cane, coffee and tea) and subsistence crops (e.g. maize, pearl millet, sorghum, beans, cowpeas and cassava) (en.wikipedia.org/wiki/Western province, 2011). As a result of widespread soil acidity in the region, the average seasonal subsistence maize, beans and cow peas yields, for example, hardly exceed one tonne per ha (Sanchez *et al*, 1997; Nekesa *et al*, 1999; Ayaga, 2003; Okalebo *et al*, 2005), compared to 5-6 t/ha of maize per season obtained from research studies (Okalebo et al., 2009) and research stations in the region e.g. KARI Kakamega (Oluoch- Kosura, 1999).

To solve this, adequate liming and fertilization, as indicated by soil tests and combined with other good management practices, like timeliness in planting, tillage, nutrient application, pest control, and harvesting; proper variety selection, plant population and spacing and crop rotation, can rapidly increase productivity in acid soils (Terman *et al*., 1976 and Mortvedt *et al*., 1999). The other options available to farmers in reducing soil acidity include the use of locally available rock P, Mavuno fertilizers, and organic sources of fertilizers, such as *Tithonia diversifolia,* as P sources for crops, planting of acid tolerant crops (Buresh *et al*., 1997; Smithson *et al*. 2001; Mutuo *et al*. 1999).

1.1. Maize production in Kenya

Botanically, maize (*Zea mays*) belongs to the grass family (Gramineae) and is a tall annual plant with an extensive fibrous root system. It is a cross pollinating species, with the female (ear) and male (tassel) flowers in separate places on the plant. The grain develops in the ears, or cobs, often one on each stalk; each ear has about 300 to 1000 kernels, weighing between 190 and 300 g per I000 kernels, in a variable number of rows (12 to 16). Weight depends on genetic, environmental and cultural practices. Grain makes up about 42 percent of the dry weight of the plant. The kernels are often white or yellow in colour, although black, red and a mixture of colours are also found (FAO, 1992).

The crop (maize) originated from the tropics of Central America. It was domesticated from the wild maize Teosinte, Zea mexicana. Maize was later introduced in Africa by Portuguese explorers in the beginning of the 16th century (Export Processing Zones Authority-Kenya, 2005). Maize is Kenya's staple food, with area under cultivation estimated at 1.6 million hectares. Growing of the crop is concentrated in the Rift Valley (Trans Nzoia, Uasin Gishu and Nakuru districts), a region often referred to as the 'Granary of Kenya'. The production relies on the small-scale farmers who contribute about 75% of the overall production, with the remaining 25% being contributed by the large-scale farmers (Guantai *et al*., 2007).

Maize has two growth stages, vegetative (emergence, first leaf, second leaf, third leaf to n^{th} leaf and tasseling) and reproductive (silking, blister, milk, dough, dent and physiological maturity) stage (Guantai *et al*., 2007). In the first or the vegetative stage, different tissues develop and differentiate until the flower structures appear. The vegetative stage is made up of two cycles. In the first cycle, the first leaves are formed and development is upward. Dry matter production in this cycle is slow. It ends with the tissue differentiation of the reproductive organs. In the second cycle, the leaves and reproductive organs develop. This cycle ends with the emission of the stigmas. The second stage, also known as the reproductive stage, begins with the fertilization of the female structures, which will develop into ears and grains. The initial phase of this stage is characterized by an increase in the weight of leaves and other flower parts. During the second phase, the weight of the kernels rapidly increases (Tanaka and Yamaguchi, 1972).

At early stage, the crop needs proper fertilization for early plant establishment since initiation of other plant parts occurs at early stage as growth begins. At later stage of growth, the plant requires larger amounts of nutrients with uptake accelerated just before the silking stage (Guantai *et al*., 2007). Maize requires nutrients for its growth (both micro and macro-elements) and large quantities of these nutrients are removed from the soil in the harvested crop (Table 1.1), and are contained in the maize stover, which are often removed from the field after crop harvest through burning or use as livestock feeds, or as fuel.

Table 1.1: **Nutrient removal Kg/ha from the soil during harvest from a maize crop**

Nutrient	3 t/ha yield	6 t/ha yield
N	72	120
P	16	22
K	45	100
Ca	-	24
Mg	-	25
S	5	15

(Source: FAO, 2000)

Thus there is need to supplement soils with addition of fertilizers since high crop yields are impossible with low levels of fertility. But the key factors in obtaining the most efficient use of inputs are weather and the management skills of the farmer (Terman *et al.*, 1976 and Mortvedt *et al.*, 1999). Also, the farmer has to consider the cost of the nutrient, cost of transportation and storage and labour used in its application. This is why, the study was conducted in different locations, different levels of nutrients and mode of application to assess the economics of the different treatments. The essential nutrients that were supplied in the experiment either as a factor or as blanket are briefly discussed below:

1.2. Nitrogen and its effect on crop growth

More money and efforts have been, and are being, spent on the management of nitrogen (N) than on any other mineral element (Brady and Weil, 2004). It is estimated that there are 77187 tonnes of N over every hectare on earth. However, this quantity of N_2 in the atmosphere is non- reactive and is not useful for plants (Hodges, 2005).

Nitrogen is an intergral component of many essential plant components. It is a major part of all amino acids, which are the building blocks of all proteins, including the enzymes, which control virtually all the biological processes. Other critical nitrogenous plant components include the nucleic acids, in which hereditary control is vested, and chlorophyll, which is at the heart of photosynthesis. Nitrogen is also essential for carbohydrate used within plants. A good supply of nitrogen stimulates root growth and development, as well as the uptake of other nutrients (Brady and Weil, 2004; Hodges, 2005). For instance N promotes P uptake by plants by: increasing top and root growth, altering plant metabolism and increasing P solubility and availability (Havlin *et al.*, 2005). The plant absorbs nitrogen as nitrate anion

(NO_3^-) and as ammonium cation (NH_4^+). The nitrate occurs mainly as ions in the soil solution, while ammonium cations occur mainly as exchangeable cation held by the soil colloids (Ahn, 1993).

Plants deficient in N tend to have pale yellowish green colour (Chlorosis), have stunted appearance, and develop thin, spindly stems. Nitrogen is quite mobile (easily translocated) within the plant and when plant uptake is inadequate, supplies are transferred to the newest foliage, causing the older leaves to show pronounced chlorosis first (Brady and Weil, 2004).

1.3. Phosphorus and its effect on crop growth

Among the nutrient elements, phosphorus is second only to N in its importance for the productivity and health of both terrestrial and aquatic ecosystems. The total quantity of phosphorus in native soils is low, with most of it present in forms quite unavailable to plants. As a result, this often leads to major social and environmental problems in agricultural systems. Plants absorb P as either di-hydrogen or monohydrogen orthophosphate anions $H_2PO_4^-$ or HPO_4^{-2} depending on soil pH; monohydrogen ion, HPO_4^{-2} is the more important, particularly in acid soils.

Phosphorus is an essential component of adenosine triphosphate (ATP) which is energy currency that drives most biochemical processes, including the uptake of nutrients and their transport within the plant. It is also an essential component of deoxyribonucleic acid (DNA), and ribonucleic acid (RNA) that contain the genetic code of plant to produce proteins and other compounds essential for plant structure, seed yield and genetic transfer. Phospholipids, which may play critical roles in cellular membranes, are another class of universally important phosphorus containing compounds. Adequate P is associated with increased root growth, enhanced crop maturity, particularly in grain crops, and reduces the time required for grain ripening (Brady and Weil, 2004; Havlin *et al*., 2005).

Because P is immobile within plants, deficiency symptoms are first expressed on lower leaves. Deficiency of P results in purple leaf colouration, stunted growth and arrested physiological development. Availability of P is greatly affected by soil pH, becoming fairly insoluble at both low (<4) and high (>8) pH levels. In addition, phosphates are sorbed onto and within clay particles, especially sesquioxides (Sanginga and Woomer, 2009).

1.4. Calcium and its effect on crop growth

Calcium (Ca) is an essential element for all higher plants and is found in relatively large quantities in plant leaves, but plants differ widely in the amounts of calcium they need. Calcium is absorbed by plants as the divalent cation Ca^{2+} and its entry and assimilation is impeded by excess soluble aluminium. It is normally the dominant exchangeable cation in most soils but the amounts become progressively less in more acid soils, under water shortage and excess magnessium (Sanginga and Woomer, 2009).

Deficiencies of Ca result in the terminal buds and root tips becoming stunted and failing to develop normally.

1.5. Problem statement and justification

Total maize production and maize yield per unit area in Kenya has been affected by many different factors. Among the most important are total planted area and productivity. There is limited scope for expanding cultivated land under maize production since unused land is diminishing or is of marginal quality or just unsuitable for maize production (Kenya Soil Survey, 1987, Muchena *et al.,* 1988). To meet the fast growing population in the country, there is need to improve the productivity of the cultivated land through proper fertilizer application, weed control, proper tillage operations, insect and disease control and liming acidic soils.

Due to soil acidity common in most soils in Western Kenya, P deficiencies and Al toxicities are widespread in the region (Opala, 2009) and thus the result is low crop yield. To solve this, Kenya Agricultural Research Institute (KARI) Kakamega and Moi University have demonstrated the potential of using lime in combination with organic manure, inorganic fertilizers and rock phosphates to address the problem of soil acidity and enhancing soil fertility. Despite this, the use of lime is still low because of its "unavailability", lack of awareness of its importance and mode of application by farmers as well as weak extension services reaching the farmers.

Previous researches have shown that returns from lime use are always high, however its use is still neglected in the soil fertility program because, responses to lime are often not as visual as those obtained from N, P and K fertilizers, unless the soil is particularly acidic and secondly liming effects last for several years and the returns are not all realized in the first year (Mortvedt *et al*., 1999 and Terman *et al*., 1976). Earlier, it was felt that liming was not effective on low activity soils with variable charges in the tropics (Russel, 1971)

The agro dealers have not invested on lime in the region and thus it becomes expensive for farmers to acquire the resource from the nearby source, that is Homa Lime Company in Koru, Kisumu which is about 200 Km away from the farmers of the target districts. Application of lime is required in large quantities (about 2 t/ha and above), and for farmers to maximize profits from their farm produce, the management practice, i.e., the mode of application, should be the most appropriate. Currently farmers are aware of only one method of applying lime, that is by broadcasting.

However, the method might be labour costly and a lot of lime is wasted at the time of application in case it is windy. Also most researchers have recommended lime applications at rates of >2 t/ha and most small scale farmers in the region own lands which are less than one hectare and they may not afford this quantity per season. Thus this study looked at a method of lime application that is cheap to employ and where lower rates of lime can be used, which a small scale farmer can afford. This would also assist the fertilizer manufacturing companies in case they want to blend their products with a liming material.

1.6. Objectives

1.6.1. Overall objective

The study aimed at assessing effects and economics of three methods of lime application (spot, band and broadcast) on acid soils at different rates of application for improved maize performance "targeting small scale farmers", in North Kakamega and Ugenya districts of Western Kenya.

1.6.2. Specific objectives

- To determine effectiveness of application of lime using three different methods of application, namely spot, band and broadcast on soil pH and maize grain yield under different locations.
- To determine the residual effect of lime in each of the three methods of application and different rates on maize production and soil properties (i.e. pH and available P).
- To determine minimum lime application rates through spot application method that is effective and economical for small scale farmers.

1.7. Hypotheses

1.7.1. Overall hypothesis

Use of spot, band and broadcast methods of lime application at different rates will have similar effect on maize performance and hence on the yields in the two target districts.

1.7.2. Working hypotheses

Ho: The three methods of lime application at different levels will raise soil pH to similar levels.

Ho: Use of any of the methods of lime application in different locations will give the same results in terms of maize grain yields

Ho: The different rates of lime applied by the three methods will have the same residual effects on soil properties and maize yields.

Ho: Any of the minimum lime application rates will have significant effect in terms of increasing grain yields for a small scale farmer.

CHAPTER TWO:

2.0. LITERATURE REVIEW

2.1. Soil acidity, its causes and effects on plant growth

Soil pH is an indicator of the acidity or alkalinity of soil and is measured in pH units. The pH scale goes from 0 to 14 with pH 7 as the neutral point. Soil pH affects the solubility of minerals or nutrients essential for plant growth (Hollier and Reid, 2005; Uchida and Hue, 2000).

Descriptive terms commonly associated with certain ranges in soil pH in water are:

Extremely acid: less than 4.5; lemon = 2.5

Very strongly acid: 4.5 – 5.0; beer = 4.5 – 5.0

Strongly acid: 5.1 – 5.5

Moderately acid: 5.6 – 6.0

Slightly acid: 6.1 – 6.5; cow's milk = 6.5

Neutral: 6.6 – 7.3; saliva = 6.6 – 7.3

Slightly alkaline: 7.4 – 7.8; eggs = 7.6–7.8

Moderately alkaline: 7.9 – 8.4; sea water = 8.2

(Hue *et al.*, 1998**;** Uchida and Hue, 2000)

The optimum pH range for most plants is between 6.0-6.5 (Mclean, 1998). Extremely and strongly acidic soils (pH 4.0-5.0) can have high concentrations of soluble aluminium, iron and manganese, which may be toxic to the growth of some plants, leading to poor soil structure and nitrogen fixation by legumes, poor plant root system development, herbicide ineffectiveness and inefficient soil-nutrient utilization by plants (Thomas, 2005).

Acidity is a major constraint to production of maize and other crops on tropical soils. At low pH (<5), toxic Al^{3+} ions hinder plant root growth, thus affecting the development of the entire plant (Kidd and Proctor, 2000; Kochian 1995). Al toxicity causes short, thick and underdeveloped roots, thus reducing nutrient uptake and increasing susceptibility to drought (Sasaki *et al*., 1996)

Soils tend to become acidic as a result of:

(i) Rainwater leaching away basic ions particularly (calcium, magnesium, potassium and sodium)

(ii) Carbon dioxide from decomposing organic matter and rain water forming weak organic acids

(iii) Continuous use of fertilizers containing ammonium, urea or sulfur (Brett *et al.,* 2005)

(iv) Acidic soil parent material

If the soil pH is below 5.4, then there is need to apply lime to such a soil (Mclean, 1998).

2.2. Effects of lime application on soil pH

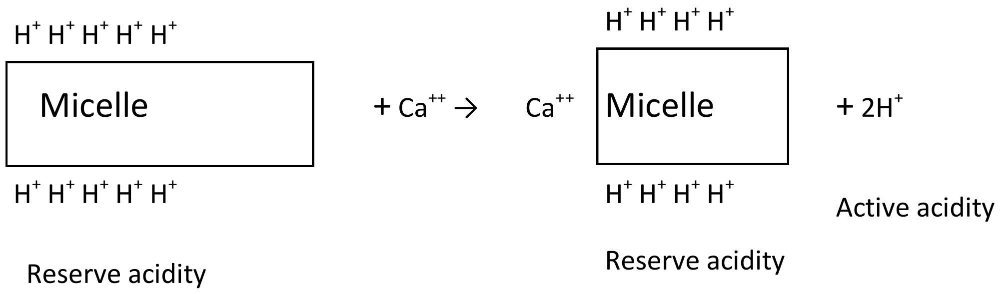
When lime is applied to extremely acid soils, it raises the pH enough to make Al, Fe and Mn less soluble and so prevents their being toxic to plants. In addition, Ca and Mg are supplied as nutrients; phosphorus (P) and molybdenum (Mo) availability are increased. Abundance of Ca and lowered acidity favour soil organism activity that hastens general soil formation processes, resulting in improved conditions for plants as the direct results (Mclean, 1971; Cook and Ellis, 1987).

The term lime refers to all compounds of calcium (Ca) and magnesium (Mg) capable of neutralizing acidity (Plaster, 2003). It neutralizes the soil in two ways; first Ca replaces hydrogen and aluminium ions on the exchange sites by mass action, raising the percent base saturation. Secondly, lime converts hydrogen ions to water (Plaster, 2003). Below are equations illustrating how lime works to correct soil acidity:

2.2.1. Using limestone

$CaCO_3 \rightarrow Ca^{++} + CO_3^{-}$

$2H^{+} + CO_3^{--} \rightarrow H_2CO_3 \rightarrow H_2O + CO_2$



2.2.2. Using burnt lime

$CaO + H_2O \leftrightarrow Ca(OH)_2$

Burnt lime Slaked lime

$Soil^{--} (2H^{+}) + Ca(OH)_2 \leftrightarrow soil^{--} (Ca^{++}) + 2H_2O$

Source (Kolay, 2000; McLaren and Cameron, 1994; Brady and Weil, 2004)

2.3. Importance of correct lime application

Lime raises the soil pH making aluminium, iron and manganese less soluble and so prevents them from being toxic to plants (Cook and Ellis, 1987); it also results to healthy root development by plants because they are exposed to reduced toxicity of Al and Mn; this may improve nutrient uptake and enhance drought tolerance by the plants. Lime is an economical source of essential Ca (as well as beneficial Mg if dolomite limestone is used); furthermore, these nutrients are released slowly over a period of three to four years and may be better protected from leaching than those supplied by more soluble fertilizers. Liming also enhances nodulation of legumes, which improves nitrogen fixation. In addition, it improves efficacy of herbicides such as Triazine, atrazine and simazine that work better in higher pH environment as well as some nematicides (Barber, 1984; Crozier and Hardy, 2003; Crozier *et al*., 1999;

Lippert, 2000; Fertilizer Society of South Africa (FSSA), 2000; Osmond *et al*., 2002). Lime improves crop response to fertilizers by improving nutrient uptake, especially phosphorus, and reducing Al toxicity (Plaster, 2003). Structure of fine textured soils may be improved by liming, as a result of increased soil organic matter content and enhanced flocculation of Ca-saturated clays (Adams ,1984).

2.4. Liming materials

The common liming materials include; calcitic limestone ($CaCO_3$), dolomitic limestone (mixture of $CaCO_3$ and $MgCO_3$), burned lime or quick lime (CaO) and hydrated lime or slaked lime ($Ca(OH)_2$). Other materials include Marl, slag, wood ash, carbide, water softener, chalk, oyster shells and paper mill refuse (Plaster, 2003; Foth and Boyd, 1988). In Western Kenya farmers can obtain lime from Koru, Kisumu and Athi River mining company, Nairobi which are the main sources of the material in the region and country.

2.5. Lime application and its residual effect

Lime can be applied at any time between the harvest of one crop and the planting of the next (Foth and Boyd, 1988). The reaction of applied lime with soil is distributed over a period of many years. The rate of reaction is more rapid during the first year, or two then gradually declines. Usually it takes two years to reach the maximum pH that will result from liming (Troeh and Louis, 1993; FSSA, 2000). However this may vary depending on the material and its fineness.

Lime can be applied every year to some soils, but this is rarely done because the cost of application might exceed the cost of lime. Under monoculture system, the year of application is determined in the system by the time when soil pH drops below a certain chosen value. But under a rotation system, there is an advantage of applying lime about a year ahead of the crop that needs it most.

The recommended time for applying lime into the soil is at least 6 weeks before planting and applying fertilizers (Guantai *et al*, 2007). However good response to lime has been found when lime is applied on the same day as the crop needing it is planted (Troeh and Louis, 1993), although there is a risk of low germination percentage especially when there is low moisture content in soil.

The residual effects of liming soils with coarse materials is greater than it is with fine materials because larger particles react slowly with acidity and remain in the soil longer (Neil, 1991). Fine particles have large surface area than coarse materials and thus more particles of lime will come in contact with more acidic soil particles haster reaction. On the other hand, coarse materials have low surface area hence the rate of reaction is slow and high residual effect. Thus it has been recommended that lime be applied after every five years for Western Kenya soils (Nekesa, 2007). A more specific recommendation carried out in parts of Western province, Kenya (Bumala and Sega) recommended that the residual effect varies with the rate of lime applied, reapplication of 2, 4 and 6 t/ha need to be done after 2, 3 and 4 years respectively (Kisinyo, 2011). While in another research by Foth and Boyd (1988), conducted in Illinois, it was suggested that, when rotation system includes a legume crop, liming of acid soils is required every three to five years to maintain a satisfactory soil pH. Farmers therefore capitalize on lime’s residual effects when they plant a sequence of crops progressively more tolerant to acidic soils. For instance, one might plant an acid sensitive crop such as beans after liming followed by maize, a moderately sensitive crop. The last crop in the sequence might be cassava, or some other acid tolerant crop (Neil, 1991).

2.6. Methods of lime application

Lime applications in accordance with soil and plant requirements are essential for maximum returns from fertilizer. The returns from liming are quite high when it is applied where needed, though it may vary with lime rate, lime cost, yield response to liming, and crop price (Mortvedt *et al.*, 1999 and Terman *et al.*, 1976). Best results are obtained from liming when there is close contact between the grains of lime and soil (Plaster, 2003). Broadcasting has been the most desirable method of lime application since all soil particles come in contact with lime particles, as much as is possible (Troeh and Louis, 1993; Cook and Ellis., 1987; Guantai *et al.*, 2007). This is advisable because lime does not move far in a horizontal direction (Cook and Ellis, 1987). However, too much wind during application may make it impossible to achieve a uniform application of finely ground lime (Troeh and Louis, 1993). On the other hand, row application of lime at the time of seeding legumes has been tried experimentally and with good results. The method is, however, difficult to manage, because the farmer should also apply fertilizer. Thus to apply both materials, it is necessary to go over the land twice (Cook and Ellis., 1987) . Thus this method (row application) has been used where it is desirable to keep the soil less acidic for a single lime-loving crop in rotation.

Liming, in essence, reverses some of the natural processes that make soil acid. The rate of neutralization is importantly related to fineness, uniformity of distribution in the soil, and the rate of diffusion of calcium from the lime particles to the sites of neutralization. A reasonable diffusion rate for Ca^{2+} is 0.35 cm in 100 days or 0.78 cm in 500 days (Cook and Ellis., 1987).

In another experiment done in Inland Pacific North-West from 2002 to 2005 on spring barley (*Hordeum vulgare*), spring wheat (*Triticum aestivum*) and Winter wheat rotation, to test the alternative liming strategies to evaluate their effects on soil pH, Al toxicity and crop yield, it was found that one time surface broadcasting of lime at 7 t/ha significantly increased soil pH, and reduced Al toxicity in the surface 15 cm. However, banding lime with the fertilizer in small quantities of 224 kg/ha annually, did not result in any measurable effects on soil pH or Al toxicity (Brown *et al.*, 2008).

2.7. Overliming effects on acid soils

Overliming can be defined as liming at rates higher than necessary to neutralize exchangeable Al or eliminate Mn toxicity (Sanchez, 1976). The consequences of overliming are yield reduction, soil structure deterioration, and decreased availability of P, Zn, B, and Mn (Sanchez, 1976; Foth and Boyd, 1988; Troeh and Louis, 1993). These effects occur in sandy soils with low ECEC and also in certain low lying wet soils that are already rich in lime. Phosphorus deficiency occurs because of formation of insoluble calcium phosphates. Overliming soils high in oxide coatings greatly increases the adsorption of boron by clays and reduces the availability of boron (Sanchez, 1976).

Adverse physical effects on acid soils of overliming are mainly a consequence of dispersed aggregates resulting from the dispersing action of the Ca^{2+} ion compared to Fe^{3+} or Al^{3+} ions or of the peptizing effect of OH^- overshadowing the flocculating effect of Ca^{2+} in soils predominantly positively charged (Mclean, 1971).

2.8. Lime requirements in acid soils

Lime requirement of a soil is the amount of lime needed to attain a desired pH for a target crop for maximum yields or maximum economic returns from the crop rotation one wishes to follow (Russel, 1973). Crops seem to have lower pH preference ranges when grown on organic soils than when grown on mineral soils (Cook and Ellis., 1987). This is because of organic chelates, which bind Al and Mn and high levels of exchangeable Ca, which tend to alleviate the toxic effects of Al and Mn (Foster, 1969). Also 2:1 clay minerals such as montmorillonite (a smectite), hydrous mica (Illite) and vermiculite hold Ca against release to plants much more strongly than do the 1:1 clays such as kaolinite. Therefore, 2:1 clays must be 70-90 % saturated with Ca to be sure of sufficiently easy release to plants whereas with 1:1 clays, 40-50 % saturation is sufficient. Also the exchange capacity of 2:1 clays is much higher than that of 1:1 clays (Cook and Ellis, 1987). Thus the soils high in 2:1 clay require much more lime at a given pH than do those high in 1:1 clays, like the tropical soils.

Lime requirement can be determined by titrating a soil with a base (i.e. $Ca(OH)_2$); adding a base to acid soil will increase soil pH. After equilibrium, a pH is determined and the pH values are plotted against milli-equivalents of base added. Thus from the data it is simple to determine the amount of lime to be added (Havlin *et al.*, 2005).

For highly weathered tropical soils, exchangeable Al has been used to serve as a criterion for determining lime requirements. Kamprath (1970) suggested that lime recommendations be based on the amount of exchangeable Al in the top soil and that lime rates also be calculated by multiplying the milliequivalents of Al by 1.5; the reason for 1.5 as a factor is the need to neutralize the hydrogen ions released by organic matter or Fe and Al hydroxides as the pH increases. In soils with higher organic matter, the factor has to be raised to 2 to 3 because of the presence of exchangeable hydrogen (Sanchez, 1976; Guantai *et al.*, 2007). Thus the following method has been proposed:

LR= 1.5[initial exch. Al – (residual per cent Al x CEC)/100] , where LR is the lime requirements.

Where the soil analysis is carried out by leaching the soil with 1M KCl, the equation can be written as:

LR (Ca Cmol/kg)= 1.5[initial exch. Al – (Residual percent Al{exch. Al+Ca+Mg})/100] (Cochrane *et al*., 1980; Cook and Ellis, 1987).

The results are the milliequivalents of Ca needed to be applied as lime. A lime rate calculated by the above method neutralizes 85 to 90 % of exchangeable Al in soil (Cook and Ellis, 1987).

Most maize germplasm grown in Kenya would not tolerate >20% of Al saturation (Ligeyo, 2007) and therefore residual percent Al of 20% should be used in the calculation. The lime requirements (tonnes $CaCO_3$/ha) is calculated by multiplying the Ca (cmol/kg) by the soil specific gravities (Cochrane *et. al*, 1980). To get the equivalent amounts of CaO required, you divide the calculated $CaCO_3$ (tons/ha) by 179 % since CaO has a neutralizing value of 179 %, compared to pure $CaCO_3$. From the previous studies lime requirements of 8.43 t/ha as CaO was found for Sega which is found within Ugenya district (Kisinyo, 2011). Thus this rate is quite expensive for a smallholder farmer in terms of purchasing and transporting to the farm and application.

2.9. Lime and fertilizer use

Liming and fertilization usually go together as complementary practices, at least in humid regions. When applied alone without fertilizers, lime acts as a stimulant producing good crops immediately, followed by a gradual impoverishment of fertility. It is implied that “lime and lime without manure will make both farm and farmer poor” (Troeh and Louis, 1993). This means that if a farmer only applies lime without fertilizer, he/she will get low yields at the same time incurring expenditure in buying lime and application.

Many researchers especially in the western Kenya region have demonstrated liming as a management practice for acid soils in Kenya successfully. Provisional results for demonstrations indicated that application of lime combined with Minjingu phosphate rock (MPR) led to a rise in soil pH on farmers fields and increased maize yields from 0.2 MT/ha (control) to 3.0 MT/ha following application of lime and calcium ammonium nitrate (CAN) (Mbakaya *et al*., 2006). In another Programme of Moi University, the application of lime (from Koru) combined with phosphorus (TSP) and nitrogen (CAN) raised maize yields from 0.5MT/ha to 4-6MT/ha (Obura *et al*., 2003).

Hunter *et al*. (1997) reported change in pH from 5 to 6 and doubled the yield in Western Samoa with lime application in Ferralsols (oxisols). Opala (2009) also reported in his pot experiment carried out with Bukura soils (Acrisols) that application of lime or farmyard manure (FYM) resulted in a significant increase in soil pH. However, besides all the other soil amendments he used, lime was more effective in increasing the soil pH; it increased pH from 4.67 (in control) to 5.49 (in the treatment) (Opala, 2009).

In a study carried out by Meiwes (1995), it was concluded that lime and wood ash are appropriate substances to decrease soil acidity. Kerley (2000), also did an experiment on the effects of liming soil on shoot development, root growth and cluster root activity of white lupin. He found out that soil analysis of the bulk soil at the harvest had a small pH increase on limed soils as compared to unlimed soils, pH remained below 6.9 in the neutral soils and above 7.6 in the limed soil.

2.10. Nutrient Use Efficiency

Nutrient use efficiency (NUE) may be defined as yield per unit input. The nutrients most commonly limiting plant growth are N, P, K and S. NUE is a function of the genotype, environmental differences, types, methods and time of application of the nutrient and soil factors.

Calculation of efficiencies are commonly done using four forms, these are:

Agronomic efficiency (yield increase per unit of nutrient applied) answers a more direct question: "How much productivity improvement was gained by the use of this nutrient?".

This can be calculated as follows: AE = $(Y_T-Y_O)/T$, where

Y_T = crop yield (kg/ha) at a certain level of nutrient applied,

Y_O = crop yield (kg/ha) in the control treatment,

T = the rate of nutrient applied (kg/ha)

Partial factor productivity (crop yield per unit of nutrient applied) answers the question: "How productive is this cropping system in comparison to its nutrient input?"

PFP = (Yo/F) + AE.

Where F = amount of (fertilizer) nutrient applied (kg/ha);

Yo = crop yield (kg/ha) in a control treatment (Dobermann, 2007).

Physiological efficiency (PE): it is a measure of incremental yield above the control per unit nutrient absorbed by the plant. It is calculated as follows:

PE = $(Y_T - Y_0) / U_f - U_0)$

Where U_f = total nutrient uptake at a certain level of fertilization and U_0 = total nutrient uptake in the control plots.

It represents the ability of the plant to transform the acquired nutrient from the fertilizer into economic yield (grain or stover). It depends on plant genotype, environmental factors, management practices, particularly during reproductive growth (Dobermann, 2005).

Recovery efficiency (increase in above-ground crop uptake per unit of nutrient applied) answers the question: "How much of the nutrient applied did the plant take up?". This can be calculated as follows:

% RE =$(N_T - N_O) / T \times 100$, where:

N_T = nutrient uptake in treated plots (Kg/ha), N_O = nutrient uptake in control plots (Kg/ha) and T= rate of the nutrient applied (Kg/ha) (IPNI, 2007)

2.11. Economic analysis

Production process involves combination of various production inputs for maximization of yield. By doing cost analysis, one can be able to determine the most profitable enterprise. This is important when recommending a new technology to the targeted farmers since for a farmer to achieve optimum productivity, efficient and cost effective use of those inputs that will ensure adequate returns on investment is imperative.

To evaluate projects that last several years and have different future costs and benefits, use of discounting approach is the most appropriate (Gittinger, 1995). There are three main discounting methods recommended for evaluation of farm projects: gross field benefits, net benefits and marginal rate of returns. The gross benefits and net benefits analysis uses partial budget approach which takes into consideration only the costs that vary from the control (Table 2.1). Marginal rates of return uses the marginal analysis approach (CIMMYT, 1988).

In partial budgeting, net benefits (NFB) are first calculated followed by dominance analysis in which treatments are listed in order of increasing total cost that vary (TCV). Treatments with NFB less than or equal to treatment with lower TCV are regarded as dominated treatments and are not considered for recommendations to farmers. Marginal analysis is carried out only on undominated treatments in a stepwise manner, starting from one treatment with the lowest TCV to the next (CIMMYT, 1988).

The following formulas are used when calculating NFB and marginal rate of return (MRR)

NFB = (Y x P) – TCV ; where (Y x P) = Gross field benefit, Y = yield per ha, P = field price per unit of grain

MRR (between treatment a and b) = [change in NFB (NFBb – NFBa)]/ [Change in TCV (TCVa – TCVb)] X 100.

Table 2.1: Summary table for partial budgeting and marginal analysis

Income	**Yield (bags/ha (Mt/ha) @ sh. 2,520/ bag**
	VARIABLE COSTS
	Lime applied
	Cost of applying lime
	Cost of transporting lime to farm
	Fertilizer for planting
	Fertilizer for top dressing
	Transporting fertilizer to farm
	Cost of applying fertilizers
	Sub total
	Harvesting
	Shelling
	Sub total
	Gunny sacks and twine
	Input/ produce (transport @ Ksh. 80/ bag
	Sub total
	Total variable cost
	Interest foregone on capital @ 10% per season
	Total expenses (TCV)
	Gross Margin

Source (Guantai *et al.*, 2007)

CHAPTER THREE:

3.0. MATERIALS AND METHODS

3.1. Study sites

On-farm experiment was conducted in four sites within Ugenya district (Sihay and North East Ugenya locations), formerly Siaya district and at Kabras (Chimoroni and Chemuche locations) in North Kakamega district during 2010 LR and SR seasons and 2011 LR season to achieve the first two objectives. While a separate experiment was carried out in two sites within the two districts to achieve the third objective during 2011 LR.

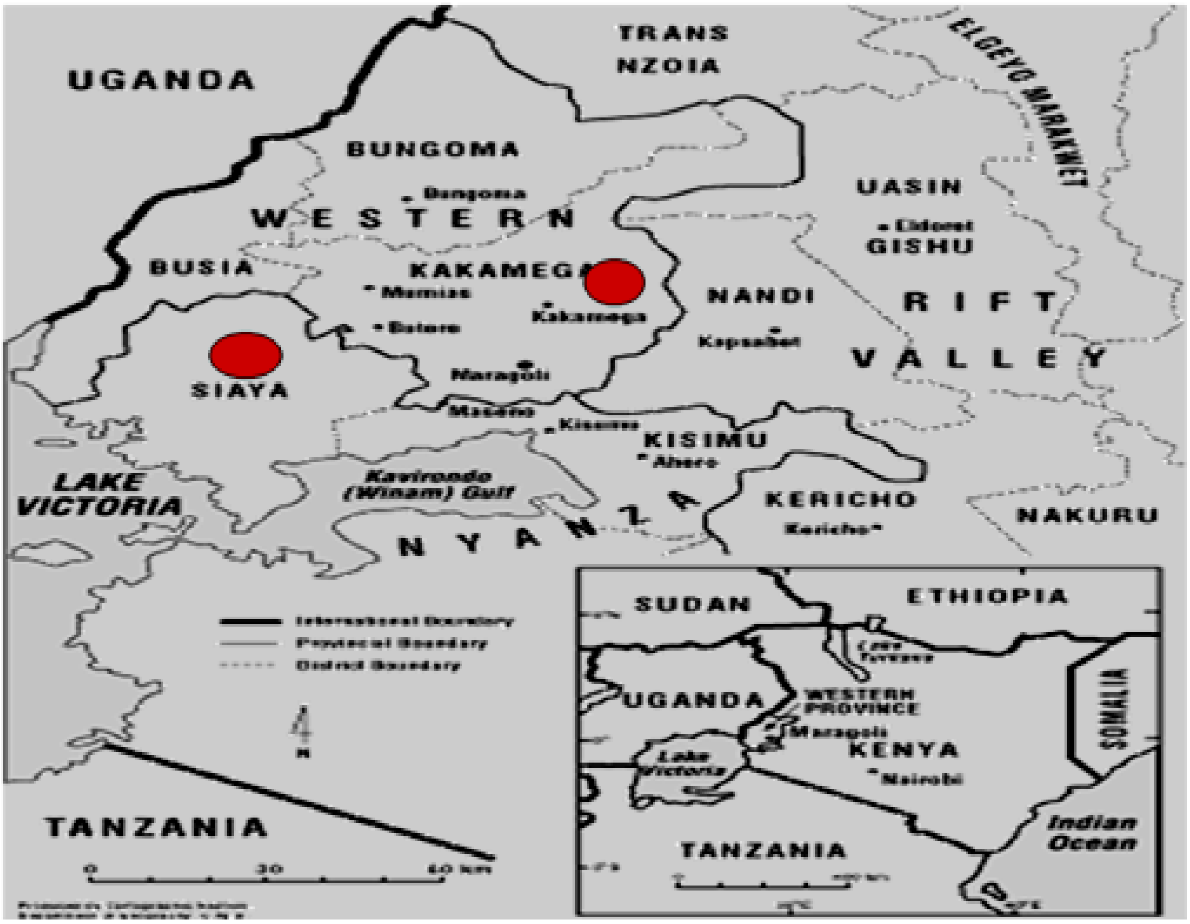


Fig 3.1: A map showing part of Western Kenya where the study was conducted (Source: Jaetzold and Schmidt, 2005)

3.1.1. Ugenya district

The district lies between latitude 0° 03' N and longitude 34° 25' E. The altitude varies from 1140 to 1400 metres above sea level. The area receives a bimodal rainfall pattern with long rains starting from March to June with a peak in April/May, and the short rains starting from August to November with a peak in October. The average annual rainfall ranges from 800 to 2000 mm. The mean maximum temperatures vary from 27°C to 30°C while the annual minimum temperatures range from 15° to 17° C. The soils are developed from the volcanic rock; mainly the basalt, are well developed, deep and friable but in some places shallow over petroferric (with murram). The predominant soil types in the district are mainly the dystric nitisols, orthic ferralsols (FAO, 1996) and acrisols (Republic of Kenya, 1994).

3.1.2. North Kakamega District

The economic activity of the local inhabitants in the district is mainly farming and fishing (http//*en.wikipedia.org.wiki/kakamega-22/07/2012*). It is located in longitudes of between 34° 52' and 15°E and latitudes of 00° 26' and 00° 52' N. The altitude of the area is between 1300 to 1900 m above sea level. The site receives bimodal rainfall of about 2000 mm per annum and a mean minimum and maximum temperature of 8 and 25°C respectively (Jaetzold and Schmidt, 2005; Republic of Kenya, 2007). The soils are highly weathered clay loams classified as Ferralsols and Acrisols (FAO, 1996).

3.1.3. Rainfall distribution in the study sites during the cropping seasons

Most maize production in Kenya is dependant on weather since it is produced under rainfed conditions. Therefore, there was need to have a record of the rainfall data in the study sites since moisture from rainfall determines the rate of lime reaction with the soil and also the growth of the crop. The monthly rainfall for the study sites are shown in Figs 3.2 and 3.3 for the periods when the study was carried out. From the two districts, it is clear that the amount of rainfall and its distributions varies, however the two districts are similar in that they have bimodal rainfall. During 2010 the long rains started in January in both sites and the peak was in May in both sites. The short rainfall seasons started in August; rains dropped in North Kakamega towards October and there was very little rainfall between November and February 2011. While in Ugenya short rainfall season started in August and increased until October in which it dropped.

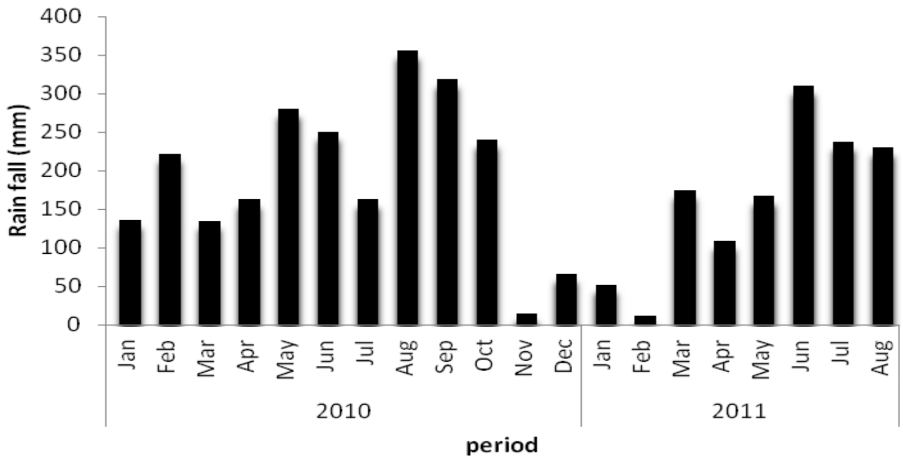


Fig 3.2 : Rainfall distribution in North Kakamega district for 2010 and 2011

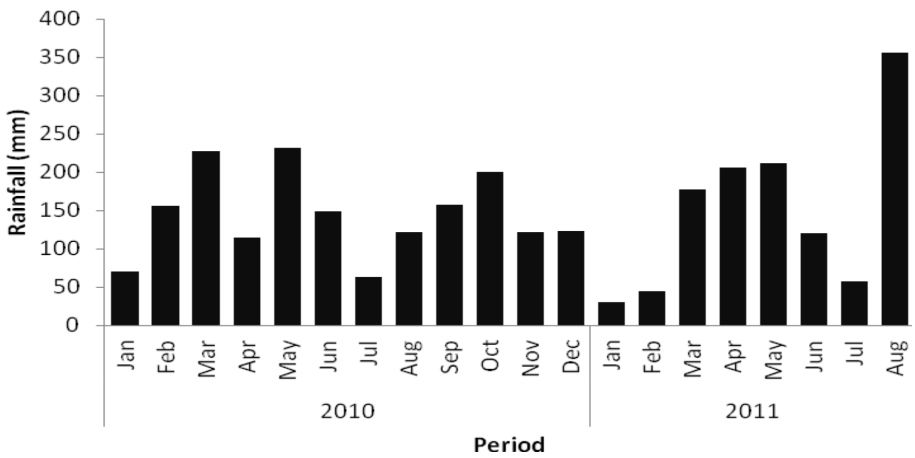


Fig 3.3: Rainfall distribution for Ugenya district during 2010 and 2011

Source: Provincial Director of Meteorological Services, Malava and Siaya stations, Western Province, Kenya, 2012).

3.1.4. Site Characterization

To characterize the soils of the four study sites, profile pits measuring 1m by 1m by 1m were dug in each site. The descriptions done in the field included soil colour, structure, drainage, reaction with hydrogen peroxide and pH determination using the pH colour chart (shown in Plates 3.1 and 3.2). Soil samples were collected from each horizon, air dried, passed through 2 mm sieve and analyzed for Ca, Mg, K, exchangeable acidity and available micronutrients (following standard laboratory procedures stated in Section 3.8).

Plate 3.1: Carrying out soil classification in the field (Source: Author, 2010)

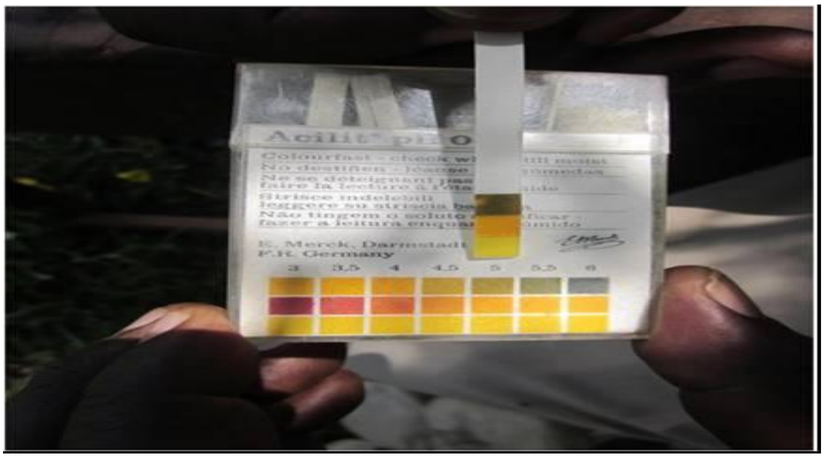


Plate 3.2: Colour chart used to determine pH. (Source: Author, 2010)

3.2. Seed source

The test crop used was maize (*Zea mays*), H 513 variety from Kenya Seed Company; this was planted in both districts. The variety is tolerant to high temperatures of low land areas and also matures within 4-5 months. It yields up to 4.4 t/ha per season (Guantai *et al.*, 2007). It can yield two cobs and has strong stalk (Kiiya *et al.*, 2005).

3.3. Treatments:

To achieve the first two objectives, the treatments applied were: lime application methods at three modes (Spot, Broadcast and Band application); and lime rates at four levels (0, 2, 4 and 6 tonnes per hectare of Koru lime). The lime was obtained from Homa Lime Company in Kisumu (21% CaO material). In addition, there was a blanket application of N, as Calcium Ammonium Nitrate (CAN)-26%N at the rate of 75 kg/ha N to all treatments except controls and P as Triple Super phosphate (TSP) at the rate of 26 kg/ha P as recommended (FURP, 1994). Nitrogen was applied in splits where 30 kg/ha and 45 kg/ha were applied at planting and as top dress respectively.
While for the third objective, the treatments applied were five rates of lime (0, 0.5, 1, 1.5 and 2 t/ha) all applied via spot method targetting affordability of lime to poor farmers. The source was as above and both P and N were applied as above inclusive of control (no lime) to quantify the effect of lime only.

3.4. Experimental Design and field layout

To achieve objectives one and two, the experimental design used was a 3 x 4 factorial arranged in a Randomized Complete Block design with three levels of lime application methods, Broadcasting, Band and Spot; and four levels of lime rates, (0, 2, 4 and 6 t/ha) with four replicates. This gave twelve treatment combinations and forty eight experimental units per site (the layout for one block used in one of the study sites is shown in the Appendix vi), whereby:

M_1L_0, M_1L_1, M_1L_2, M_1L_3, M_2L_0, M_2L_1, M_2L_2, M_2L_3, M_3L_0, M_3L_1, M_3L_2 and M_3L_3, where M is the method and L is the lime rate.

M_1= broadcast, M_2=band and M_3=spot, while L_0=no lime, L_1=2 t/ha, L_2=4 t/ha and L_3=6 t/ha

Each plot was of 4.8 m by 4.5 m (21.6 m^2) and a space of 1 m was left between blocks and 0.5 m between plots.

To achieve the 3rd objective, a separate experiment was laid out in a RCBD with 3 replicates. The treatments were 0, 0.5, 1, 1.5 and 2 t/ha lime from Homa Lime Company (21% CaO).

3.5. Statistical models

3.5.1. A model for experiment on rates and methods of lime application

$$\mathbf{Y_{ij} = \mu + M_i + L_j + (ML)_{ij} + R_k + E_{ij}}$$

Where:

Y_{ij} = means of the $(ij)^{th}$ treatment combination (plot observation)

M = common component to all factors at all levels

M_i = mode of application effect at i^{th} level

L_j = lime rate effect at j^{th} level

$(ML)_{ij}$ = interaction of method and lime rate effect

R_k = block (replication) effect

E_{ij} = error term

3.5.2. A model for minimum lime input experiment

$$\mathbf{X_{jk} = \mu + L_j + B_k + E_{jk}}$$

Where:

X_{jk} – p lot observation

μ – overall mean

L_j – lime effect

B_k – block effect

E_{jk} – error effect

3.6. Installation of field trials

3.6.1. Lime application

3.6.1.1. Broadcasting- lime at different rates was spread evenly on the plot or seedbed then incorporated into the soil before making seed hills (as shown in Plate 3.3). Time taken for carrying out the activity per plot was recorded.

3.6.1.2. Banding- seed hills were dug, then beside each row (about 20 cm below the row) a band was made for placing lime then lime was placed evenly and mixed thoroughly with soil (as shown in Plate 3.4). Again time spent per plot was recorded. At the end of the first season, metal rods were placed at the ends of each row for easy identification of the previous areas applied with lime in the following seasons.

3.6.1.3. Spot application- seed hills were dug using a hoe and then in each hill lime was placed at equal rates following calibrations made for different lime rates applied per hectare, and then thorough mixing with soil was done before placing seeds in the hole (as shown in Plate 3.5). Time spent was also recorded and the metal rods were put at the end of each row for ease of identification in the following seasons.

Calibrations of lime rates used were done as shown in Appendix.

Plate 3.3: Lime being applied by broadcasting method (Source: Author, 2010)

Plate 3.4: Lime being banded (Source: Author, 2010)

Plate 3.5: Application of lime by spot method (Source: Author, 2010)

3.6.2. Planting, fertilizer application and thinning

Seeds were planted at a spacing of 75 cm between rows and 30 cm within rows (recomendation by Kiiya *et al.,* 2005). Two seeds were placed per hill and later thinned to one seedling per hill at 3-4 leaf stage. Thinning was done early before weeding and when the soil was wet. In the case of missing hills, gapping was done.

Phosphorus was applied at planting time in form of triple super phosphate (with negligible liming effect) at the rate of 26 kg/ha P by spot application method. Nitrogenous fertilizer (CAN) was applied in splits during planting (30 kg/ha) and top-dressing (45 kg/ha) by broadcast. Top-dressing was done when the crops were knee high ensuring that each individual plant received at least the same amount of nitrogen. The rates were selected basing on recommendations by FURP, 1994.

3.6.3. Pest control

Hand weeding was done twice per cropping season using a hoe giving same treatment to all the experimental units i.e., weeding was done on the same day for each site. Some of the important insect pests were termites and stalk borer in Ugunja district and they were controlled by use of Gladiator and bulldock respectively, while in North Kakamega, there were blue beetles and stalk borers. The stalk borer was controlled as above while dimethoate was used to control the blue beetle.

3.6.4. Harvesting

Harvesting was done at physiological maturity of the crop i.e. indicated by the formation of a black layer at the tip of the grain. The weights of the ears and maize stalks from an effective area were taken after removing the guard rows. The size of the effective plot harvested was 4.2 m by 3 m (12.6 m^2) size. Ten ear/cob samples per plot were taken and transferred to the green house at Chepkoilel Campus for air drying and later threshed; the sample dry weights and threshed weights were taken to calculate the grain yield per plot. Weight of 1000 seeds was also taken and the thousand seeds were ground, sieved through 60 mesh (<0.25mm) sieve for analysis of N and P. Grain yield in tonnes per hectare was calculated as below:

Weight per plot (Kg) = (Fresh weight (kg) of cobs and grains in an effective area x Weight of shelled grain (g) from the samples)/Dry weight of sampled ears (g).

Grain Yield (t/ha) = (10 x weight/ plot)/ effective area

3.7. Data collection

To achieve the research objectives, data was collected on: date of planting (PD), germination percentage (GP), stand count at thinning (SAT), crop height (HC), ear height (EHT), stand count at harvest (SAH), total number of ears harvested (EH), weight of useable ears (WUE), Dry weight of grains from useable ears and weight of 1000 seeds. Soil samples were collected to assess changes in both selected physical and chemical properties. Grain and plant tissue analysis were done to determine the nutrient uptake and use efficiencies.

Germination percentage was done two weeks after planting to determine if any of the methods might have had an effect on the seed germination in terms of lime reaction. **SAT** was done by counting to know the number of plants that remained per plot for further data collection. **HC** measurement of crop height was done at an interval of two weeks to assess the rate of height increase to nutrient accumulation. Plant height up to flag leaf was also done at physiological maturity. This was to help in establishing whether there was climatic effect on the variety height. **EHT** was measured from the ground to point of insertion of uppermost ear. It was done at black layer stage (physiological maturity). This helped to know whether there was abnormality in the ear placement since the length of ear position to that from ear to the flag leaf should almost be equal.

3.8. Soil and plant tissue analysis

Soil samples were collected from each experimental plot before applying lime and thereafter throughout the crop growing seasons at intervals of 1 ½ months. The soil samples were collected from twelve spots in each plot from within the plant rows, then mixed thoroughly and a composite sample of about 1 kg was put in a labelled polyethene bag for laboratory analysis. Soil samples collected in the field were first air dried for at least two weeks in the green house and subsequently the aggregates were broken by carefully pounding with a pestle and mortar. The samples were then passed through a 2 mm sieve to obtain fine earth [for analysis for pH- 1:2.5 soil: water, available P (Olsen method), paticle size (hydrometer method)]. Exchangeable bases (Ca, Mg and K) were extracted by 1.0 M ammonium acetate (NH_4OAc) at pH 7. Exchangeable Ca and Mg in the extracts were determined using the atomic absorption spectrophotometry and exchangeable K by flame photometry; exchangeable acidity (H and Al) by 1.0 M potassium chloride (KCl). Further, the samples were passed through <0.25 mm or 60 mesh (for analysis of organic carbon- Walkley-Black method, total nitrogen- Kjeldahl method) (Okalebo *et al.*, 2002).

3.9. Data analysis

ANOVA was used to determine if there were significant differences between treatments. The differences were then subjected to orthogonal contrast to separate treatment means. The following are ANOVA tables that were used for the experiment.

Table 3.1: ANOVA table for the factorial arrangement

Source of variation	DF	SS	MSS	F calculated	F tabulated
Block	3				
Method of application	2				
Rate of lime application	3				
Interaction (Method* rates)	6				
Error	33				
Total	47				

Table 3.2: ANOVA table for RCBD

Source of variation	DF	SS	MSS	F calculated	F tabulated
Block	2				
Treatment	4				
Error	9				
Total	14				

3.10. Economic analysis of the different treatments used

In determination of the most economically accepted treatment, partial budget analysis was carried out to estimate gross value using the adjusted maize grain yield (CIMMYT, 1988; Asumadu *et al.*, 2004) at market prices for the grains and inputs during the cropping seasons. The prices of lime, bags for storing maize grains, transport and maize grain yield were determined through market surveys during the research period. Labour wage rates for applying lime, harvesting and shelling the grain were determined through survey to estimate the cost of labour that vary. The data from the harvested grain yield was adjusted down by 10% due to the findings that researchers could get 10% higher yields than the farmers practice using the same technology (Kisinyo *et al*., 2011). This is because of the small plot size, application of the treatment and management could differ (CIMMYT, 1988). Also an opportunity cost on capital of 10% per season was added to the costs that vary.

The values that were used to calculate the net benefits during the cropping seasons are given in Table 3.3:

The accruing net benefit and the costs that vary were then compared across the treatments indominance analysis based on the criterion that any treatment that had net benefit equal to or lower than that of another treatment with lower cost is dominated and as such would not be considered for investment by the farmer (CIMMYT, 1988).

Then marginal analysis was carried out on the undominated treatments in a stepwise manner (using the formula in Section 2.11), starting from one treatment with the lowest cost that vary to the next. This is to show how the net benefit from a decision to change from one combination of treatment to another increased with cost.

Table 3.3: Values used for Costs and benefit analysis during the three cropping seasons (2010 LR, 2010 SR and 2011 LR

Parameters	Quantity/cost (Ksh.)
TSP kg/ha applied	129.48 kg
CAN kg/ha applied	288.46 kg
Price of TSP per kg	77
Price of CAN per kg	48
Transporting 50 kg of CAN/TSP to the farm	80
Cost of 50 kg bag of lime at the factory	230
Transporting 50 kg bag of lime to the farm	80
Cost of sacks for storing grain/bag	35
Labour costs	
Lime application by broadcast per ha	6790.12
Lime application by band per ha	4706.64
Lime application by spot per ha	5652.01
Application of TSP/CAN fertilizer per 50 kg bag	100
Cost of harvesting 1 bag of maize cobs	30
Cost of shelling one bag of maize grain	40
Price of maize grain per kg	28
Opportunity cost on capital (%)	10% per season

N/B: 2.5 bags of maize cobs = 1 bag of 90 kg grain

CHAPTER FOUR:

4.0. RESULTS

4.1. Soil Analysis

4.1.1. Soil characterization of the study sites

The data in Table 4.1 below indicates that the initial pH for the four study sites was below the minimum pH required for growing maize for optimum production, i.e., pH of 5.5-6.5 (Guantai *et al*., 2007). The pH was 4.95, 4.98, 4.85 and 4.44 in East Ugenya, Sihay, Chimoroni and Tumbeni sites, respectively. Similarly available P was also below the minimum amount required for growing maize, i.e., not less than 10 ppm P (Okalebo et al., 2009); the two sites in North Kakamega district had high Al (>2 Cmol/kg soil), and Al saturation in all the four sites was very high (>20%); the basic cations according to ratings by Tekalign *et al*., (1991) showed that Ca and K contents were very low in all the four sites, Mg was low in Sihay, Chimoroni and Tumbeni but medium in East Ugenya. The above characteristics justify the need to ammend these soils by use of lime.

The measured organic carbon content was low in East Ugenya and Sihay while in Chimoroni it was moderate and high in Tumbeni. Levels of organic carbon determine the availability of nitrogen in the soil, when there is high carbon content in the soil and low total nitrogen then the C:N ratios are high hence immobilization of nitrogen takes place.

Table 4.1: Initial pH, available P, organic C, total N, cations (Ca, Mg, K, Zn, Cu and Fe, Al^+, H^+ and the soil texture of the four study sites of soils sampled from 0-15 cm depth.

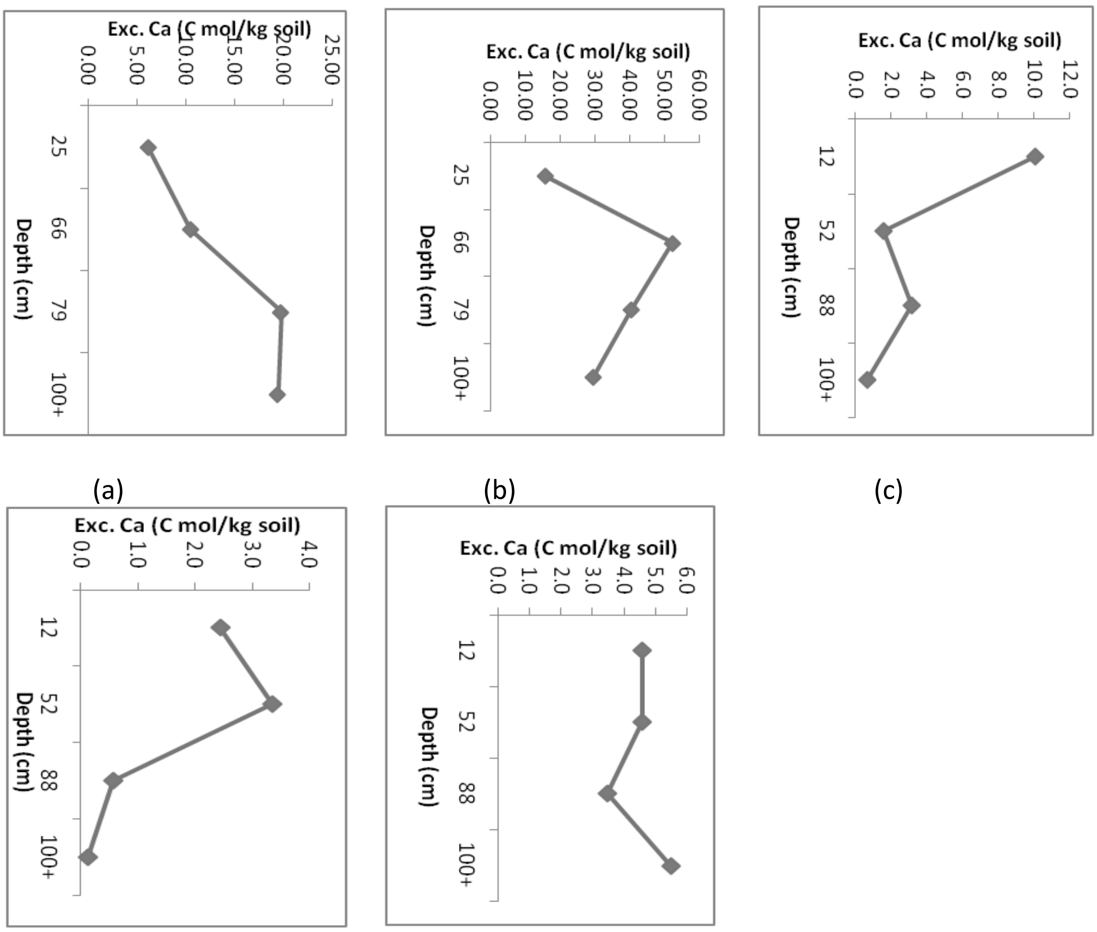
	Ugenya district		North Kakamega district	
	East Ugenya (Isaac)	**Sihay (Owoko)**	**Chimoroni (Atsangu)**	**Tumbeni (Indombela)**
pH (H_2O)	4.95	4.98	4.85	4.44
Available P (ppm)	1.36	4.64	6.87	3.54
Al (Cmol/kg)	Trace	Trace	2.8	2.8
H (Cmol/kg)	3.5	2.5	7.1	5.7
% Al saturation	trace	trace	23.61	27.18
Organic C (%)	1.3	1.4	2.4	3.4
Total N (%)	0.14	0.13	0.27	0.23
C:N ratio	9:1	11:1	9:1	15:1
Ext. Ca (C mol/kg of soil)	1.46	1.59	0.34	0.42
Mg (C mol/kg of soil)	0.98	0.74	0.67	0.54
K (C mol/kg of soil)	0.81	1.02	0.95	0.84
Zn (C mol/kg of soil)	0.31	0.25	0.01	0.28
Cu (C mol/kg of soil)	0.10	0.06	0.10	0.06
Fe (C mol/kg of soil)	3.08	2.10	3.03	2.78
Textural class				
Sand (%)	55	67	65	65
Clay (%)	23	16	20	20
Silt (%)	22	17	15	15
Textural class	Sandy clay loam	Sandy loam	Sandy clay loam	Sandy clay loam

4.1.2. Soil profile descriptions

The variations in the quantities of Ca, Mg and K down the profile are shown in Figures 4.1, 4.2 and 4.3 below. It was found that soils of Ugenya district were shallower compared to those of North Kakamega district. At a depth of 1m, the C horizon was reached in Ugenya while in North Kakamega, B horizon was continuous beyond 1m depth.

Analyzing the chemical properties (basic cations) for each horizon from the profile pits, there was an indication that Ca, Mg and K were higher in the sub surface horizon than in the surface horizons in Ugenya district. In North Kakamega district, higher basic cations in the surface horizon was found and decreased down the profile.

In Tumbeni, it was found that there were two different soil types distinguished by the colour and topography of the land and thus two profile pits were dug during soil characterization.



(d) **(e)**

Fig. 4.1: Available Ca in different soil horizons in (a) East Ugenya (b) Sihay (c) Chimoroni (d) Tumbeni 1 (e) Tumbeni 2

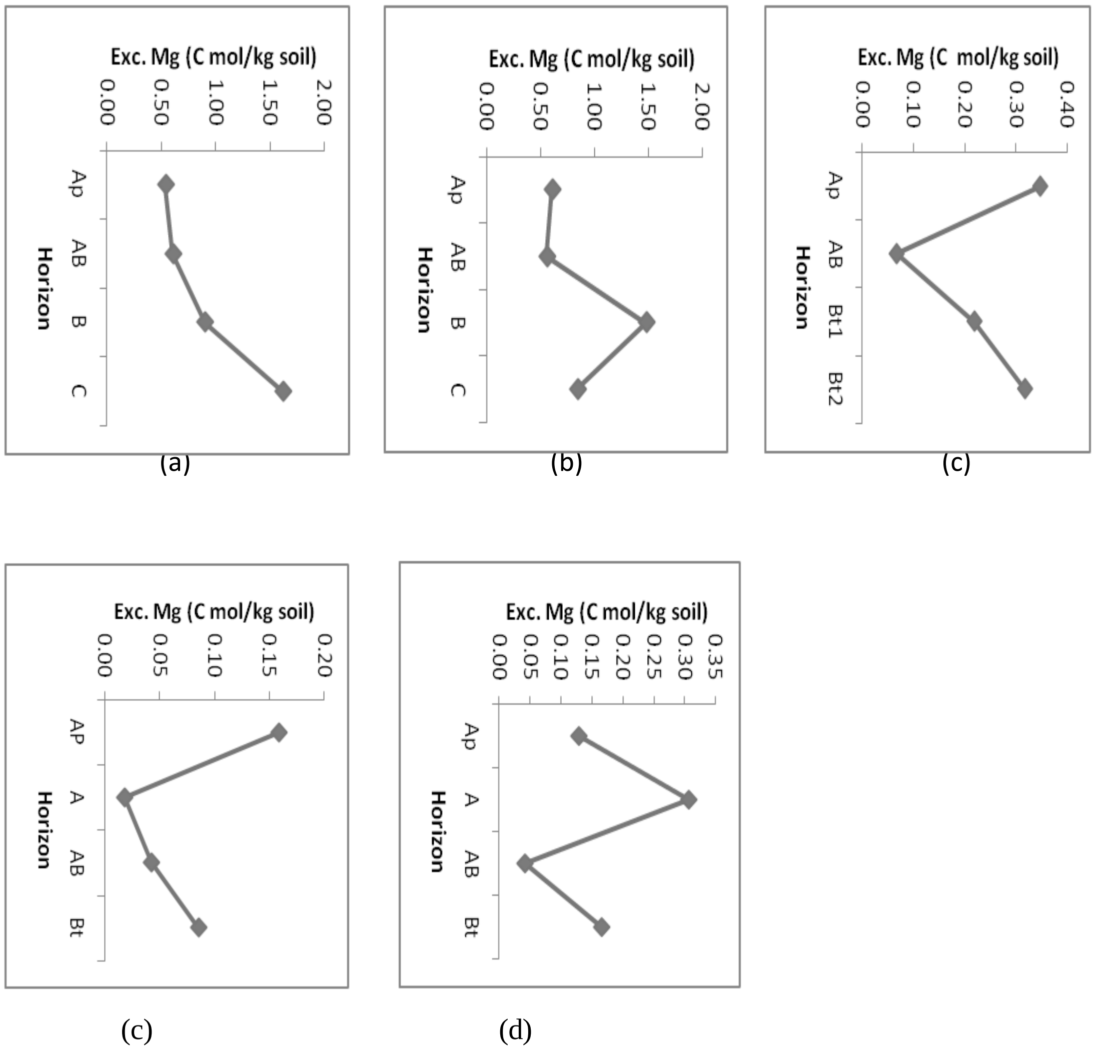


Fig. 4.2: Available Mg in different soil horizons in (a) East Ugenya (b) Sihay (c) Tumbeni 1 (d) Tumbeni 2 and (e) Chimoroni sites

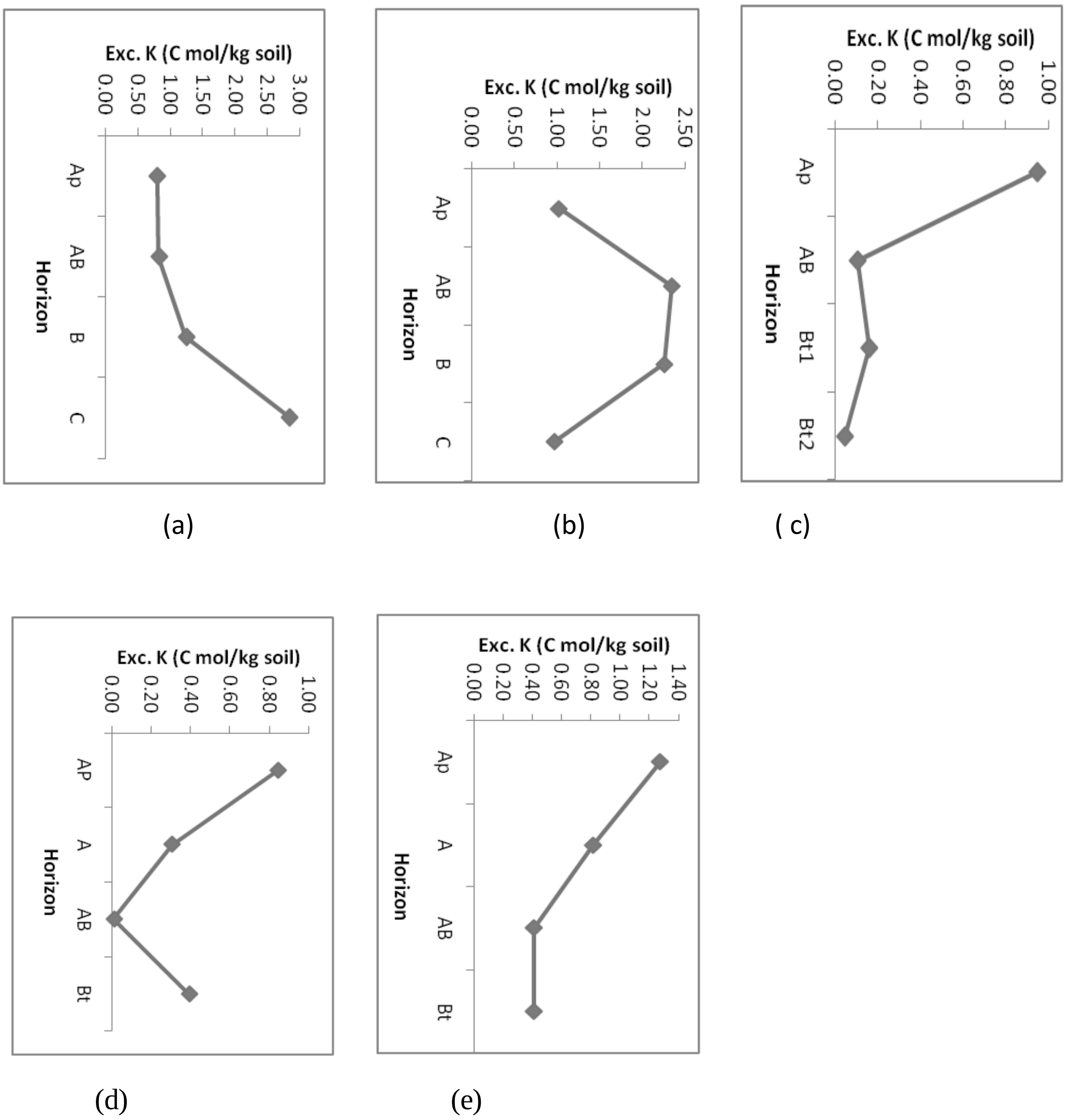


Fig 4.3: Available K in different soil horizons in (a) East Ugenya (b) Sihay (c) Chimoroni (d) Tumbeni 1 and (e) Tumbeni 2

Plate 4.1: Kavirondian shells in North Kakamega (Source: Author, 2010)

Plate 4.2:Reaction of soils in Tumbeni to Hydrogen Peroxide (Source: Author, 2010)

4.2. Effects of different lime rates and methods of lime applications on soil pH

The results reported in Fig 4.4, 4.5, 4.6 and 4.7 below show the effects of applying lime using three different methods on soil pH on soil samples collected at intervals of 1-2 months throughout the three cropping seasons. There is an indication that with application of lime, there was a significant rise in soil pH ($p< 0.05$) (as shown in Appendix ii); there was rise on average from 5.13 to 5.71, 5.69 to 6.16, 4.52 to 5.07 and 4.53 to 4.89 in East Ugenya, Sihay, Chimoroni and Tumbeni sites, respectively.

The pH readings started to stabilize 272 days since lime was applied in Ugenya district, while in North Kakamega it took about 365 days for the pH to stabilize, i.e., the point where there was no further increase in soil pH. Higher pH change at the end of the cropping season was attained with application of 6 t/ha lime by broadcast method in East Ugenya, 6 t/ha by spot application in Sihay and broadcast of 6 t/ha in both Chimoroni and Tumbeni sites.

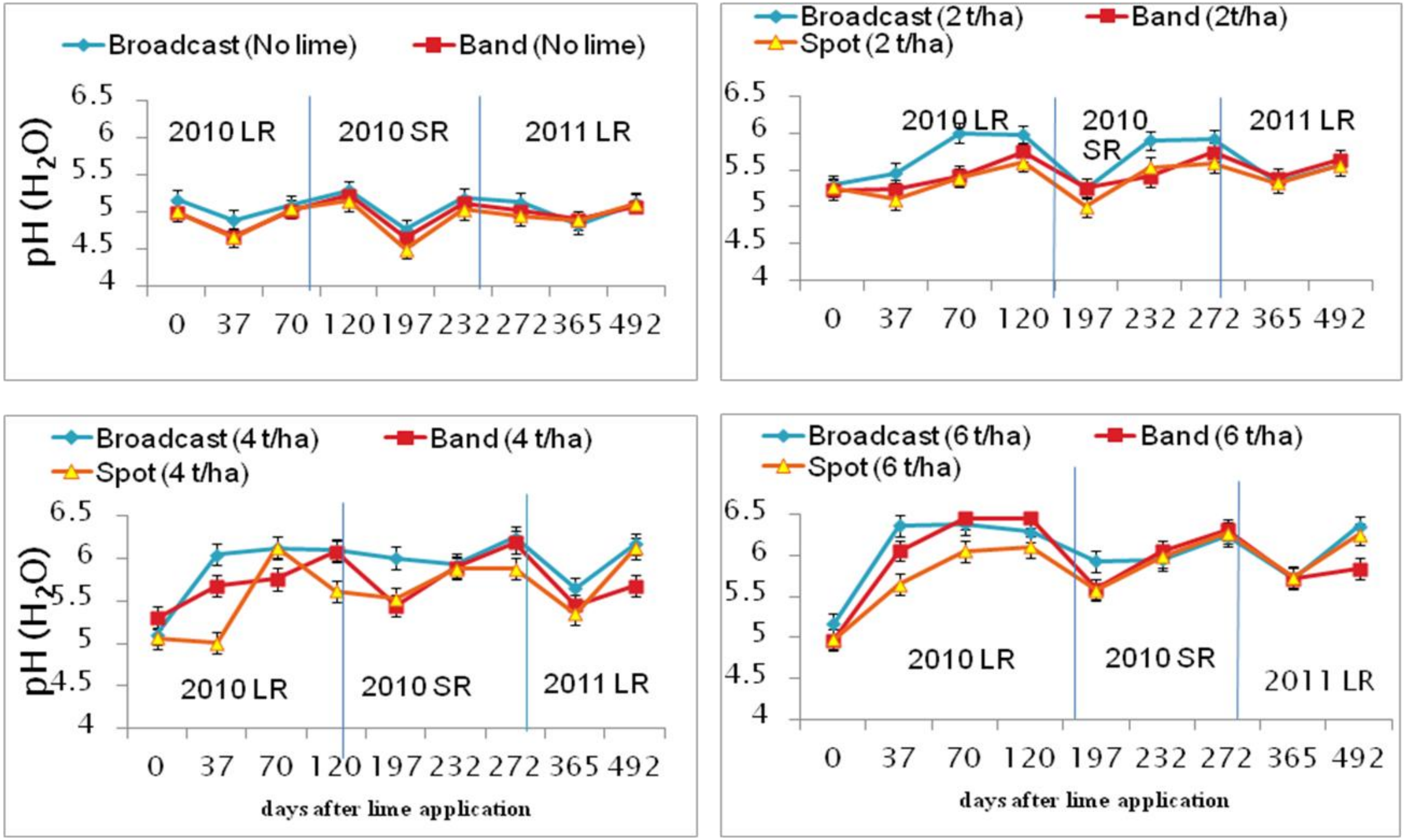


Fig 4.4: Effects of lime and lime placement on soil pH after three cropping seasons in East Ugenya site

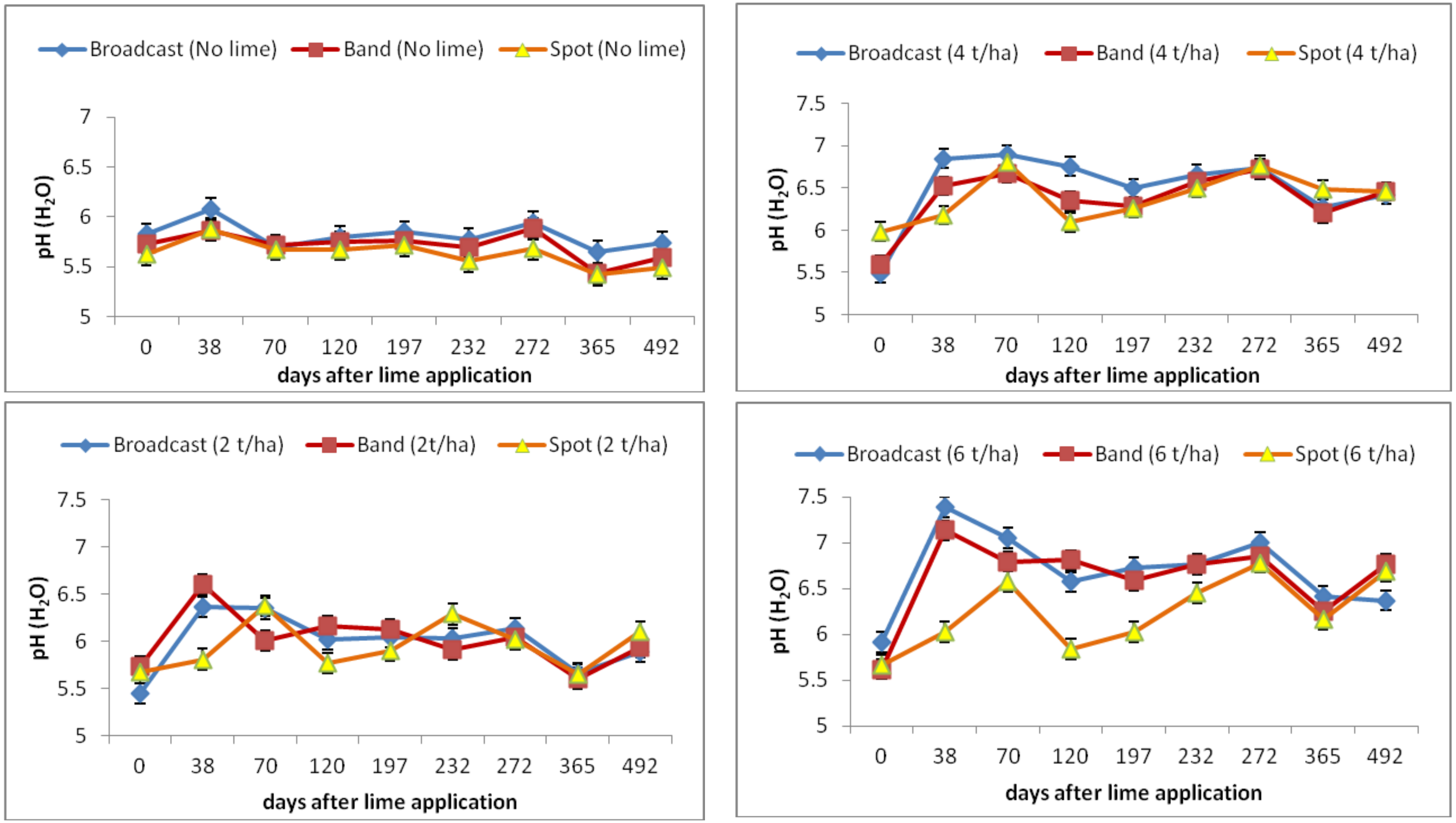


Fig 4.5: Effects of lime and lime placement on soil pH after three cropping seasons in Sihay site

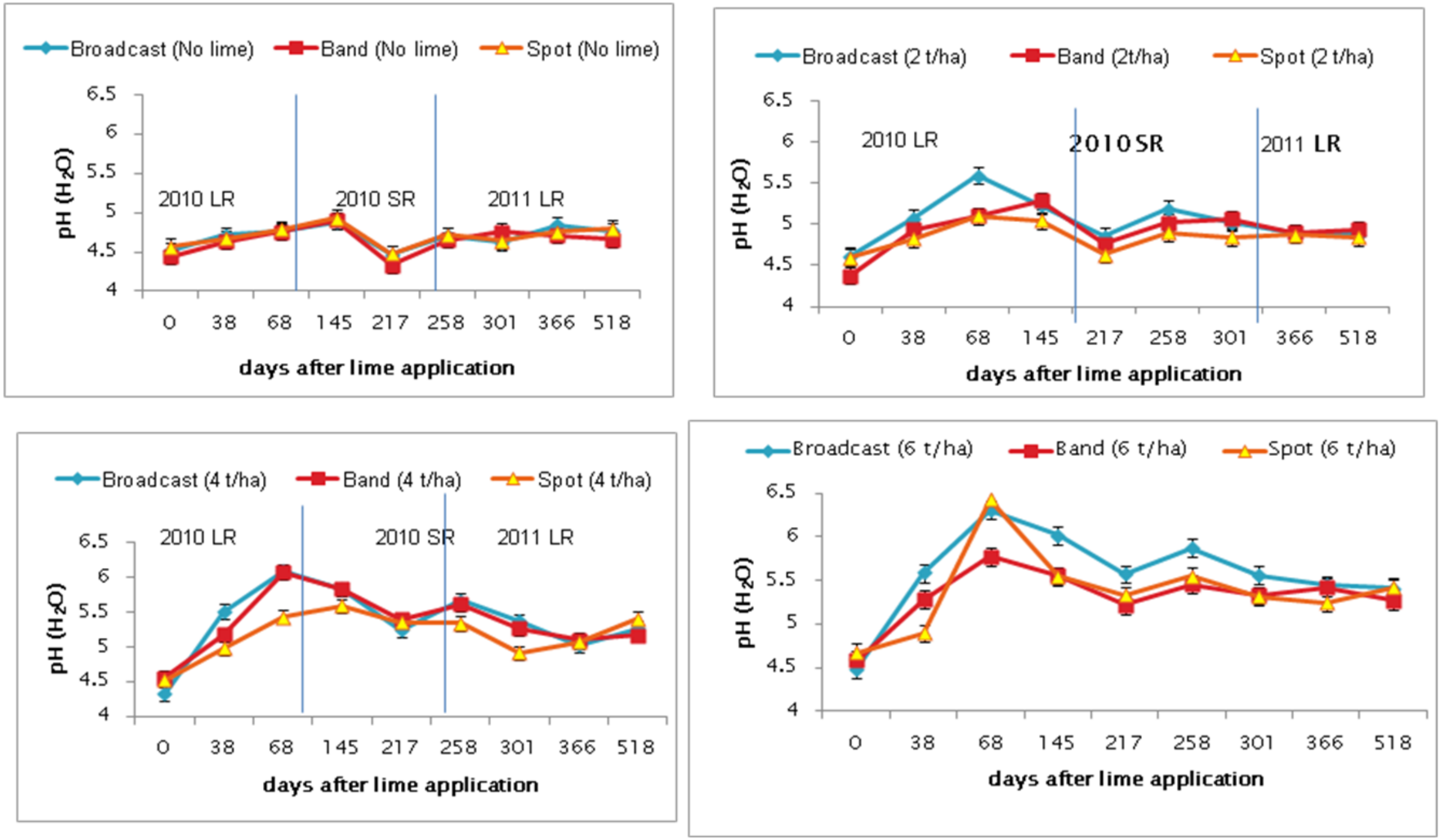


Fig 4.6: Effects of lime and lime placement on soil pH after three cropping seasons in Chimoroni site

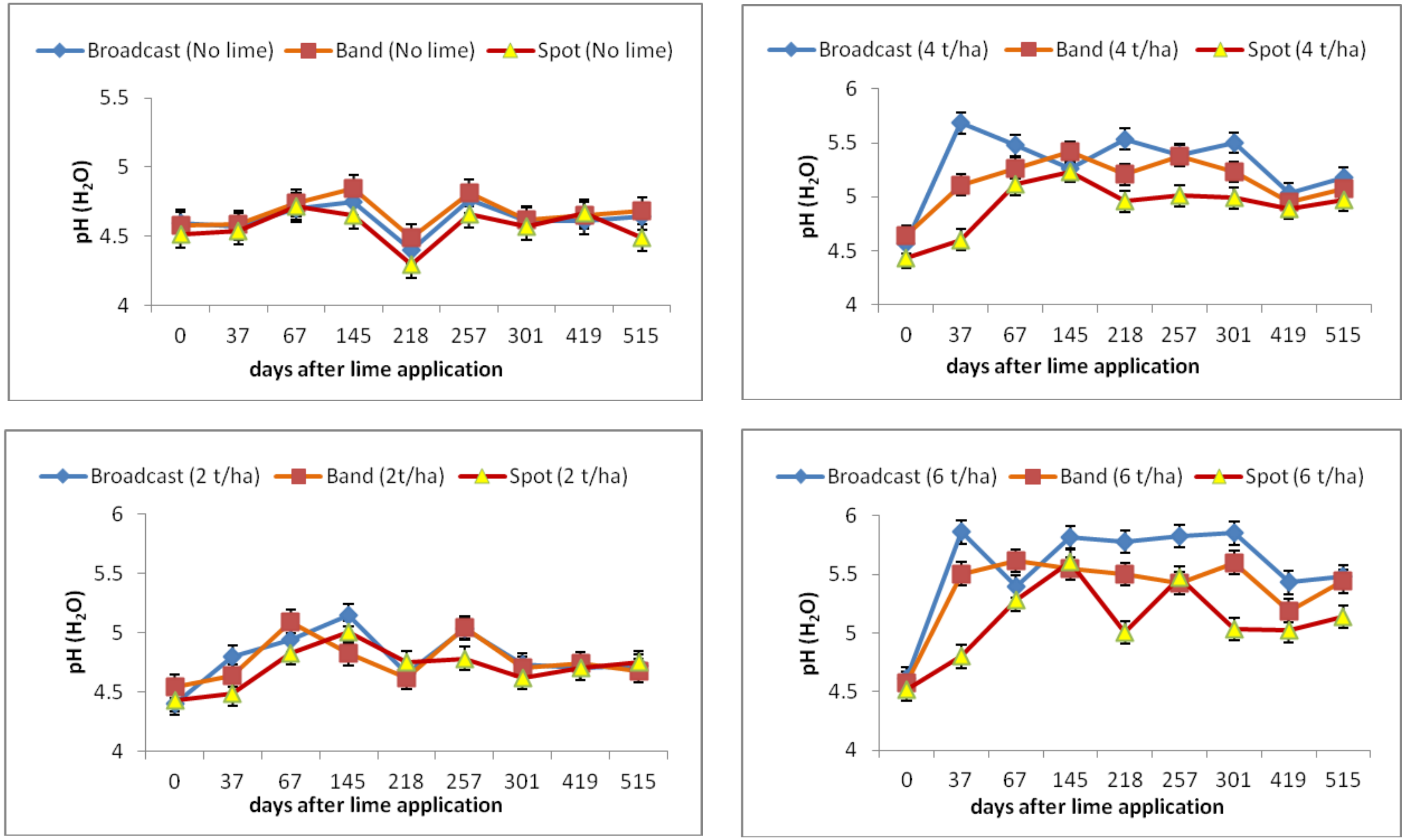


Fig 4.7: Effects of lime and lime placement on soil pH after three cropping seasons in Tumbeni site

4.3. Maize grain yield in relation to lime rates and lime placement

The effects of applying lime to acid soils and their impact on the crop yield is shown in Figures 4.8(a, b, c), 4.9(a, b, c), 4.10(a, b, c) and 4.11(a, b, c) below. Generally, there was a significant ($p<0.05$) increase in maize grain yield beyond the control in all the sites throughout the growing seasons. In East Ugenya, higher grain yield on average (5.54 t/ha) was obtained from application of 6 t/ha lime via broadcast application for the three seasons (2010 LR, SR and 2011 LR). But in Sihay, lime broadcast at 4 t/ha gave higher grain yield (4.60 t/ha) on average for the three cropping seasons. In Chimoroni, the higher grain yield was obtained with band addition of 6 t/ha of lime (3.52 t/ha) on average while in Tumbeni similar results were obtained from band and broadcast lime at 6 t/ha (3.55 t/ha of grain yield) on average.

Statistical analysis indicated that the interaction effects of methods of lime applications and lime rates were not significant ($p=0.05$) for 2010 LR, 2010 SR and 2011 LR in East Ugenya. In Sihay the effect was significant during 2010 LR and 2011 LR (Appendix iii). There were no significant interaction effects of the rates of lime and the methods of application in Chimoroni and Tumbeni for the three cropping seasons.

Plate 4.3 shows the quantity of maize harvested in the field from a plot receiving lime and where lime was not applied. It is clear that the quantity in terms of size and the number of cobs produced are different. In plots with lime some individual plants could bear two cobs or ears, while in control plots some could have none.

(a) (b)

Plate 4.3: Maize cobs harvested from (a) A plot with 6 t/ha of lime by broadcast method and (b) A plot with No lime in Ugenya district (Source: Author, 2010)

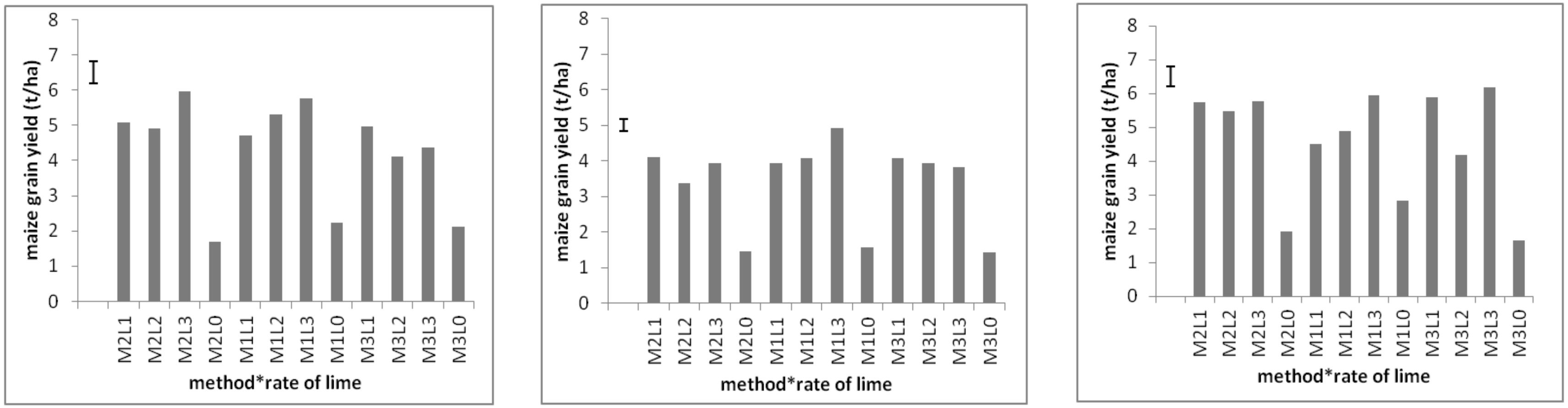


Fig 4.8 (a) 4.8 (b) 4.8 (c)

Where: M2L1 = band (2 t/ha), M2L2 = band (4 t/ha), M2L3 = band (6 t/ha), M2L0 = band (No lime), M1L1 = broadcast (2 t/ha), M1L2 = broadcast (4 t/ha) , M1L3 = broadcast (6 t/ha), M1L0 = broadcast (No lime), M3L1 = spot (2 t/ha), M3L2 = spot (4 t/ha), M3L3 = spot (6t/ha) and M3L0 = spot (No lime). The bar in the graph represents SED. This applies to all the tables of yield below.

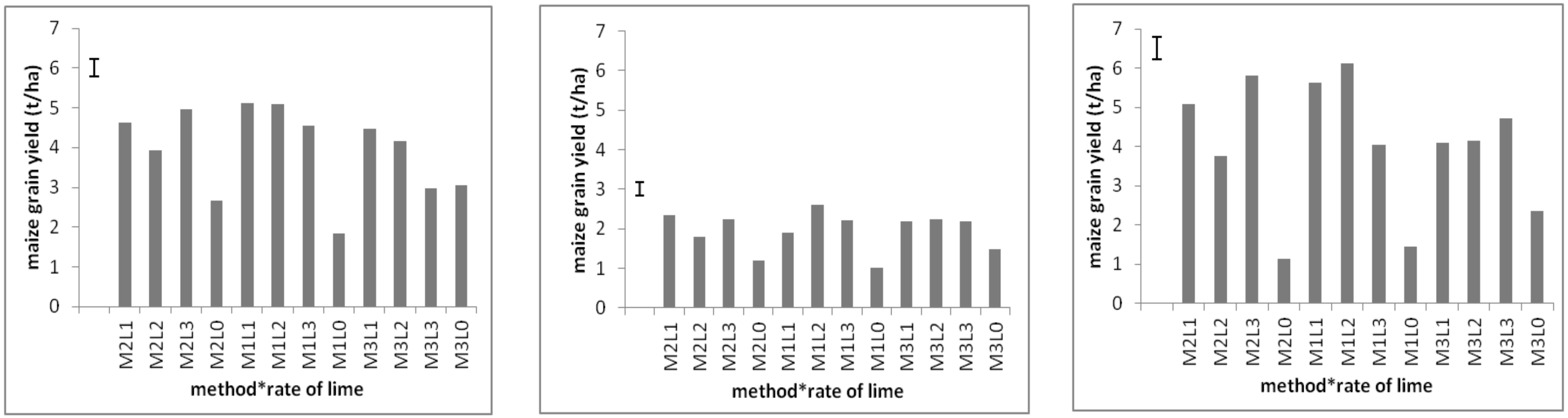


Fig 4.9 (a) 4.9 (b) 4.9 (c)

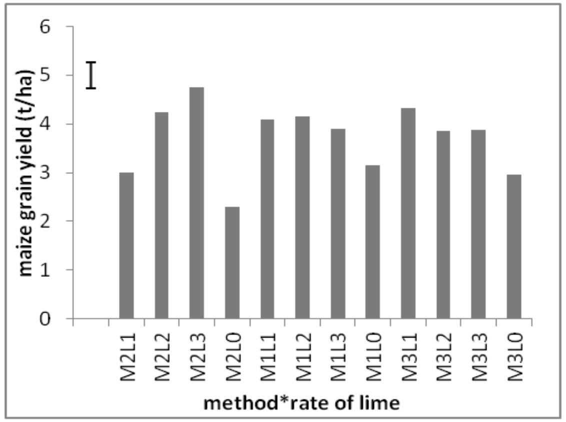
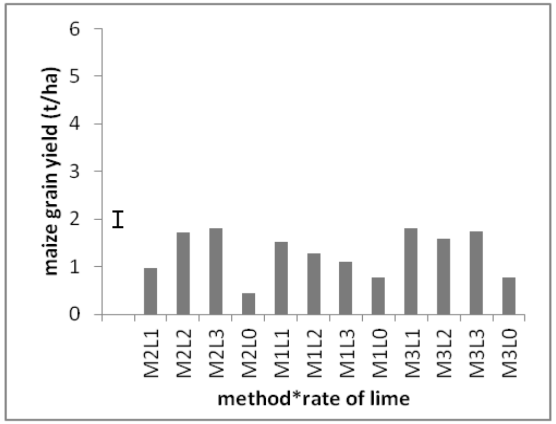
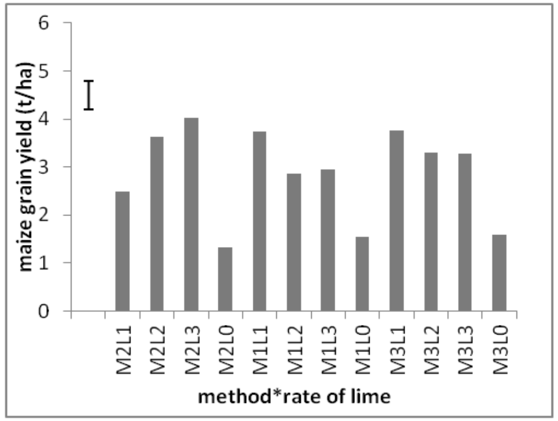


Fig 4.10 (a)



4.10 (b)



4.10 (c)

Where: M2L1= band (2 t/ha), M2L2 = band (4 t/ha), M2L3 = band (6 t/ha), M2L0 = band (No lime), M1L1= broadcast (2 t/ha), M1L2 = broadcast (4 t/ha) , M1L3 = broadcast (6 t/ha), M1L0 = broadcast (No lime), M3L1= spot (2 t/ha), M3L2 = spot (4 t/ha), M3L3 = spot (6t/ha) and M3L0 = spot (No lime). The bar in the graph represents SED.

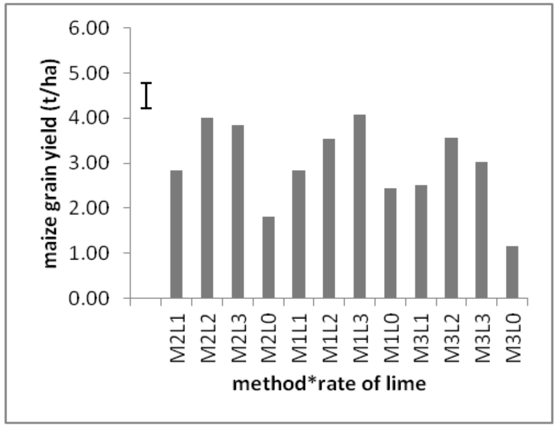
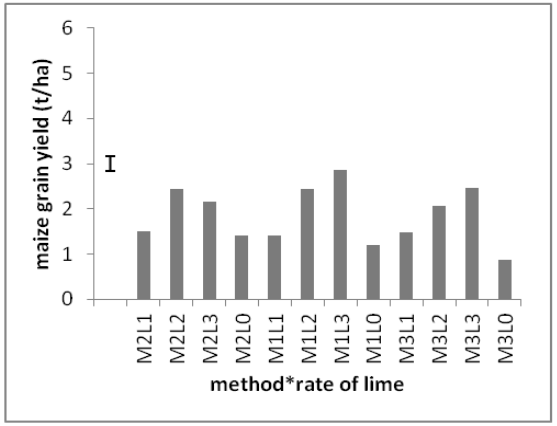
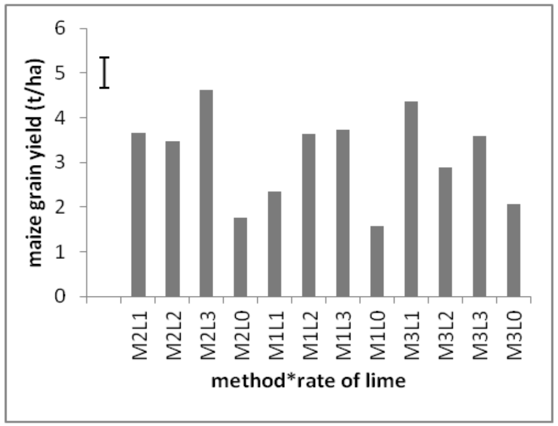


Fig 4.11 (a)



4.11 (b)



4.11 (c)

Fig 4.8, 4.9, 4.10 and 4.11: Effects of lime rates and liming methods on maize grain yield in East Ugenya, Sihay, Chimoroni and Tumbeni, respectively, for (a) 2010 LR (b) 2010 SR and (c) 2011 LR

4.4. Nutrient Use Efficiency

The agronomic and physiological use efficiencies of the nine treatment combinations are shown in Tables 4.2 and 4.3 and 4.4 and 4.5, Tables 4.2 and 4.3 show the agronomic P and N use efficiencies due to the treatment combinations. The results indicate that in Sihay and East Ugenya , broadcast method gave higher efficiencies compared to the other methods while in Chimoroni and Tumbeni, band method was better in terms of the efficiencies compared to the other methods.

Table 4.4 shows the physiological P use efficiencies as a result of the different treatment combinations. It indicates that use of band method with 2 t/ha and 4 t/ha gave higher maize grain yield per unit of added P in Chimoroni and Tumbeni sites, respectively. However in East Ugenya, band (4 t/ha) was the best in terms of P use and spot (6 t/ha) was the best in Sihay site. On average, spot method gave highest efficiency in Chimoroni and East Ugenya sites with 438.2 and 494.3 kg of grain per kg of P uptake, respectively. While in Tumbeni, best results were obtained from use of band method (529.7 kg of grain per kg of P uptake) and in Sihay broadcast method (481.2 kg of grain per kg of P uptake) was the best.

Table 4.2: Agronomic nutrient use efficiency (Kg of grains/kg of nutrients) and Partial factor productivity (PFP) for N and P averaged for three cropping seasons (2010 LR, SR and 2011 LR) in Ugenya district

	Sihay site				East Ugenya			
Treatment	**AE (N)**	**AE (P)**	**PFP (N)**	**PFP (P)**	**AE (N)**	**AE (P)**	**PFP (N)**	**PFP (P)**
Broadcast (2 t/ha)	37.22	107.35	56.32	162.47	28.93	83.46	58.48	168.69
Broadcast (4 t/ha)	42.27	121.92	61.38	177.05	33.83	97.59	63.38	182.83
Broadcast (6 t/ha)	28.94	83.48	48.05	138.60	44.34	127.90	73.89	213.13
Mean	**36.14**	**104.25**	**55.25**	**159.37**	**35.70**	**102.98**	**65.25**	**188.22**
Band (2 t/ha)	31.33	90.39	53.59	154.60	44.56	128.54	67.14	193.67
Band (4 t/ha)	19.87	57.31	42.13	121.53	38.60	111.34	61.18	176.47
Band (6 t/ha)	35.52	102.47	57.78	166.69	47.07	135.77	69.65	200.90
Mean	**28.91**	**83.39**	**51.17**	**147.60**	**43.41**	**125.22**	**65.99**	**190.35**
Spot (2 t/ha)	17.28	49.84	47.79	137.84	43.16	124.50	66.24	191.09
Spot (4 t/ha)	16.31	47.04	46.81	135.04	31.09	89.69	54.18	156.28
Spot (6 t/ha)	13.37	38.56	43.88	126.56	40.82	117.76	63.91	184.35
Mean	**15.65**	**45.15**	**46.16**	**133.15**	**38.36**	**110.65**	**61.44**	**177.24**

AE (N)= Agronomic use efficiency for nitrogen AE (P) = Agronomic use efficiency for phosphorus and PFP (N)= Partial factor productivity for N and PFP (P) = Partial factor producivity for P.

Table 4.3: Agronomic nutrient use efficiency (Kg of grains/kg of nutrients) and Partial factor productivity (PFP) for N and P averaged for three cropping seasons (2010 LR, SR and 2011 LR) in North Kakamega district

	Chimoroni				Tumbeni			
Treatment	**AE (N)**	**AE (P)**	**PFP (N)**	**PFP (P)**	**AE (N)**	**AE (P)**	**PFP (N)**	**PFP (P)**
Broadcast (2 t/ha)	17.15	49.48	41.51	119.74	6.21	17.92	29.40	84.81
Broadcast (4 t/ha)	12.55	36.19	36.90	106.45	19.57	56.45	42.76	123.34
Broadcast (6 t/ha)	11.03	31.81	35.38	102.07	24.13	69.61	47.32	136.50
Mean	**13.58**	**39.16**	**37.93**	**109.42**	**16.64**	**47.99**	**39.83**	**114.88**
Band (2 t/ha)	10.80	31.16	28.86	83.26	13.47	38.86	35.59	102.66
Band (4 t/ha)	24.66	71.14	42.72	89.20	21.87	63.08	43.99	126.88
Band (6 t/ha)	28.94	83.47	47.00	135.57	25.15	72.55	47.27	136.35
Mean	**21.47**	**61.92**	**39.53**	**102.68**	**20.16**	**58.17**	**42.28**	**121.97**
Spot (2 t/ha)	20.40	58.84	44.11	127.23	21.73	62.67	37.03	106.82
Spot (4 t/ha)	15.17	43.77	38.88	112.16	22.57	65.10	37.87	109.24
Spot (6 t/ha)	15.87	45.77	39.57	114.16	25.07	72.31	40.37	116.45
Mean	**17.15**	**49.46**	**40.86**	**117.85**	**23.12**	**66.69**	**38.42**	**110.84**

AE (N) = Agronomic use efficiency for nitrogen AE (P) = Agronomic use efficiency for phosphorus and PFP (N) = Partial factor productivity for N and PFP (P) = Partial factor producivity for P.

Table 4.4: Effects of lime and its placement on a three season mean physiological P use efficiency by the grain for 2010 LR, SR and 2011 LR at the four study sites

	Chimoroni	Tumbeni	East Ugenya	Sihay
Broadcast (2 t/ha)	443.3	409.8	461.2	491.3
Broadcast (4 t/ha)	430.0	442.9	450.3	488.3
Broadcast (6 t/ha)	405.2	462.4	478.7	463.9
Mean	**426.2**	**438.4**	**463.4**	**481.2**
Band (2 t/ha)	471.2	535.0	487.7	436.1
Band (4 t/ha)	453.2	556.1	513.6	444.2
Band (6 t/ha)	285.4	498.0	476.5	505.3
Mean	**403.3**	**529.7**	**492.6**	**461.9**
Spot (2 t/ha)	465.2	478.4	491.3	467.9
Spot (4 t/ha)	423.7	520.4	487.9	454.5
Spot (6 t/ha)	425.7	534.1	503.7	516.8
Mean	**438.2**	**511.0**	**494.3**	**479.7**

Table 4.5: Effects of lime and its placement on a three season mean recovery P use efficiency by the grain for 2010 LR, SR and 2011 LR at the four study sites

	Chimoroni	Tumbeni	East Ugenya	Sihay
Broadcast (2 t/ha)	11.2	4.4	18.1	19.4
Broadcast (4 t/ha)	8.4	12.7	21.7	22.5
Broadcast (6 t/ha)	7.9	15.1	26.7	22.8
Mean	**9.1**	**10.7**	**22.2**	**21.6**
Band (2 t/ha)	6.6	7.3	25.8	24.8
Band (4 t/ha)	15.7	11.3	21.7	19.0
Band (6 t/ha)	18.3	14.6	28.5	23.6
Mean	**13.5**	**11.1**	**25.3**	**22.5**
Spot (2 t/ha)	12.6	13.1	25.4	18.6
Spot (4 t/ha)	10.3	12.5	18.4	15.0
Spot (6 t/ha)	10.8	13.5	23.4	15.1
Mean	**11.2**	**13.0**	**22.4**	**16.3**

4.5. Effects of lime rates and lime placement on available phosphorus in soils

The available P in soils at the end of every cropping season (2010 LR, 2010 SR and 2011 LR) are shown in Tables 4.6 and 4.7. Detailed trends of available P during cropping seasons are shown in Appendix v (a-d). In Table 4.6, it was found that highest increase of available P at the end of the third season was due to application of 6 t/ha of lime by band method in both sites (East Ugenya and Sihay sites). There were increases of available P by 6.79 mg/kg and 10.57 mg/kg in East Ugenya and Sihay, respectively. While in Table 4.7 there was higher inrease of available P at the end of the third season from 6 t/ha of lime applied by band method in Tumbeni by 1.21 mg/kg, while in Chimoroni there was a decline in available P at the end of the third season.

Table 4.6: Effects of rates of lime and lime placement method on available P (mg P/kg) in the soil in Ugenya district

	East Ugenya			Sihay		
P (Mg/kg)/ Treatment combination	**Season 1**	**Season 2**	**Season 3**	**Season 1**	**Season 2**	**Season 3**
Band 2 t/ha	3.77	4.01	5.30	7.73	5.89	11.15
Band 4 t/ha	3.04	4.36	4.17	8.55	5.67	9.47
Band 6 t/ha	3.81	3.89	5.52	6.89	4.80	11.55
Band no lime	2.35	3.02	1.90	5.59	4.33	3.91
Spot 2 t/ha	3.97	2.71	3.47	6.07	7.20	13.23
Spot 4 t/ha	3.93	2.80	3.69	6.85	4.08	13.53
Spot 6 t/ha	4.17	3.21	3.11	6.48	5.89	11.48
Spot no lime	2.22	1.40	0.77	3.00	3.33	2.56
Broadcast 2 t/ha	3.68	3.12	2.19	4.29	5.86	6.43
Broadcast 4 t/ha	4.01	3.92	3.73	7.21	5.30	8.37
Broadcast 6 t/ha	4.17	5.26	8.15	9.60	11.21	15.21
Broadcast no lime	2.92	2.80	1.90	6.36	4.14	4.06
SED (method)	0.053	0.064	0.076	0.11	0.098	0.18
SED (rate)	0.062	0.074	0.088	0.13	0.11	0.21
SED (method*rate)	0.107	0.128	0.152	0.22	0.20	0.36
CV (%)	4.31	5.42	5.89	4.79	4.93	5.64

Table 4.7: Effects of rates of lime and lime placement on available P (mg P/kg) in the soil in North Kakamega district

	Chimoroni			Tumbeni		
P (Mg/kg)/ Treatment combination	**Season 1**	**Season 2**	**Season 3**	**Season 1**	**Season 2**	**Season 3**
Band 2 t/ha	4.71	5.81	2.47	4.04	5.10	3.47
Band 4 t/ha	3.18	7.81	3.47	10.19	6.95	3.97
Band 6 t/ha	5.47	4.60	4.84	5.91	5.35	4.75
Band no lime	3.65	4.45	1.64	8.10	5.20	3.75
Spot 2 t/ha	4.34	7.43	2.33	5.37	3.78	4.43
Spot 4 t/ha	4.46	4.46	4.06	8.08	6.17	2.51
Spot 6 t/ha	5.22	5.27	3.24	8.26	8.88	4.20
Spot no lime	5.91	4.13	2.19	4.49	4.63	3.38
Broadcast 2 t/ha	7.76	4.24	3.79	6.37	9.94	3.88
Broadcast 4 t/ha	3.05	5.24	3.24	7.26	6.73	2.51
Broadcast 6 t/ha	5.47	4.67	6.39	7.53	5.45	3.01
Broadcast no lime	8.44	5.53	3.15	4.58	4.88	2.69
SED (method)	0.16	0.064	0.073	0.16	0.11	0.07
SED (rate)	0.19	0.074	0.084	0.18	0.13	0.081
SED (method*rate)	0.32	0.13	0.15	0.32	0.23	0.14
CV (%)	8.76	3.48	6.25	6.74	5.49	5.68

4.6. Correlations of pH (H_2O), available P, plant height and maize grain yields as influenced by lime applications

The data in the table below show correlations between pH, available P, maize grain yield and the ratio between total plant heights and the ear heights. It was found that there was a significant correlation between grain yield and the maize heights. Also soil pH was correlated positively with the maize grain yield.

Table 4.8: Correlations of pH, P, plant height and maize grain yields as influenced by lime applications in East Ugenya

a) Season 1 (2010 LR)

Pearson Correlation Coefficients, N = 48
Prob > |r| under H0: Rho = 0

	pH (H_2O)	Available P	yield	Height
pH (H_2O)				
Available P	0.21 n.s			-
Yield	0.62**	0.29*		
Height	0.42**	0.12 n.s	0.75**	

b) Season 2 (2010 SR)

Pearson Correlation Coefficients, N = 48
Prob > |r| under H0: Rho = 0

	pH (H_2O)	Available P	Yield	Height
pH (H_2O)				
Available P	0.25 n.s			
Yield	0.63**	0.16 n.s		
Height	0.52**	0.10n.s	0.73**	

c) Season 3 (2011 LR)

Pearson Correlation Coefficients, N = 48
Prob > |r| under H0: Rho = 0

	pH (H_2O)	Available P	yield	Height
pH (H_2O)				
Available P	0.36*			
Yield	0.47**	0.49**		
Height	0.52**	0.20 n.s	0.66**	

n.s = not significant, * = significant at 95% confidence level, ** = significant at 99% confidence level.

Table 4.9: Correlations of pH, P, plant height and maize grain yields as influenced by lime applications in Sihay site

a) Season 1 (2010 LR)

Pearson Correlation Coefficients, N = 48 Prob > |r| under H0: Rho = 0				
	pH (H_2O)	**Available P**	**yield**	**Height**
pH (H_2O)				
Available P	0.27n.s			
Yield	0.41**	0.14 n.s		
Height	0.26 n.s	0.29*	0.08 n.s	

b) Season 2 (2010 SR)

Pearson Correlation Coefficients, N = 48 Prob > |r| under H0: Rho = 0				
	pH (H_2O)	**Available P**	**yield**	**Height**
pH (H_2O)				
Available P	0.41**			
Yield	0.38**	0.36**		
Height	0.04 n.s	0.04 n.s	0.2 n.s	

c) Season 3 (2011 LR)

Pearson Correlation Coefficients, N = 47 Prob > |r| under H0: Rho = 0				
	pH (H_2O)	**Available P**	**yield**	**Height**
pH (H_2O)				
Available P	0.30*			
Yield	0.51**	0.26 n.s		
Height	0.16 n.s	0.12 n.s	0.39**	

n.s = not significant, * = significant at 95% confidence level, ** = significant at 99% confidence level.

Table 4.10: Correlations of pH, P, plant height and maize grain yields as influenced by lime applications in Chimoroni site

a) Season 1 (2010 LR)

Pearson Correlation Coefficients, N = 48 Prob > |r| under H0: Rho = 0				
	pH (H_2O)	**Available P**	**yield**	**Height**
pH (H_2O)				
Available P	0.05 n.s			
Yield	0.28*	0.06 n.s		
Height	0.041 **	0.04 n.s	0.74**	

b) Season 2 (2010 SR)

Pearson Correlation Coefficients, N = 48 Prob > |r| under H0: Rho = 0				
	pH (H_2O)	**Available P**	**yield**	**Height**
pH (H_2O)				
Available P	0.09 n.s			
Yield	0.43**	0.19 n.s		
Height	0.57**	0.03 n.s	0.34*	

c) Season 3 (2011 LR)

Pearson Correlation Coefficients, N = 48 Prob > |r| under H0: Rho = 0				
	pH (H_2O)	**Available P**	**yield**	**Height**
pH (H_2O)				
Available P	0.20 n.s			
Yield	0.29*	0.15 n.s		
Height	0.46**	0.25 n.s	0.69**	

n.s = not significant, * = significant at 95% confidence level, ** = significant at 99% confidence level.

Table 4.11: Correlations of pH, P, plant height and maize grain yields as influenced by lime applications in Tumbeni site

a) Season 1 (2010 LR)

Pearson Correlation Coefficients, N = 48
Prob > |r| under H0: Rho = 0

	pH (H_2O)	Available P	yield	Height
pH (H_2O)				
Available P	0.34*			
Yield	0.58**	0.18 n.s		
Height	0.48**	0.22 n.s	0.73**	

n.s = not significant, * = significant at 95% confidence level, ** = significant at 99% confidence level.

b) Season 2 (2010 SR)

Pearson Correlation Coefficients, N = 48
Prob > |r| under H0: Rho = 0

	pH(H_2O)	Available P	yield	Height
pH (H_2O)				
Available P	0.02 n.s			
Yield	0.74**	0.16 n.s		
Height	0.49**	0.18 n.s	0.46**	

n.s = not significant, * = significant at 95% confidence level, ** = significant at 99% confidence level.

c) Season 3 (2011 LR)

Pearson Correlation Coefficients, N = 47
Prob > |r| under H0: Rho = 0

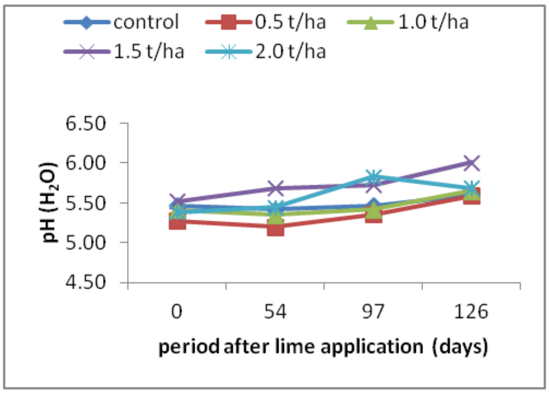
	pH (H_2O)	Available P	yield	Height
	0.04 n.s			
	0.50**	0.16 n.s		
	0.39**	0.09 n.s	0.43**	

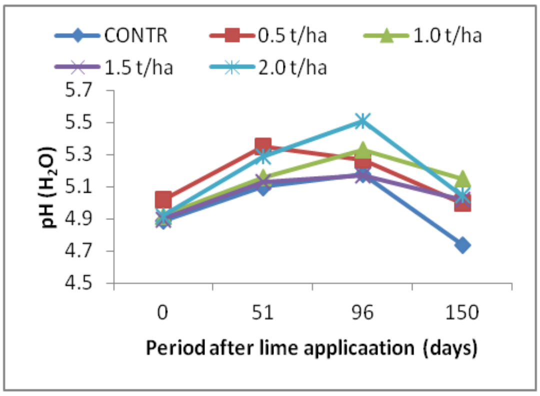
n.s = not significant, * = significant at 95% confidence level, ** = significant at 99% confidence level.

4.7. Minimum rate of lime application by spot method

4.7.1: Effects of applying low or reduced lime rates on soil pH

From Figure 4.12, there is an indication that application of low rates of lime by spot method can increase soil pH significantly within a short period of time. In Ugenya there was an increase in soil pH with application of low rates in which 1.5 t/ha of lime increased pH slightly above the control, but the change was not significant. In North Kakamega there was an increase in pH within the first three months after application and then the values decreased to their initial pH values.





(a) Ugenya **(b) North Kakamega**

Fig 4.12: one season pH changes due to application of low rates of lime by spot method

4.7.2: Effects of applying minimum lime rates on available P

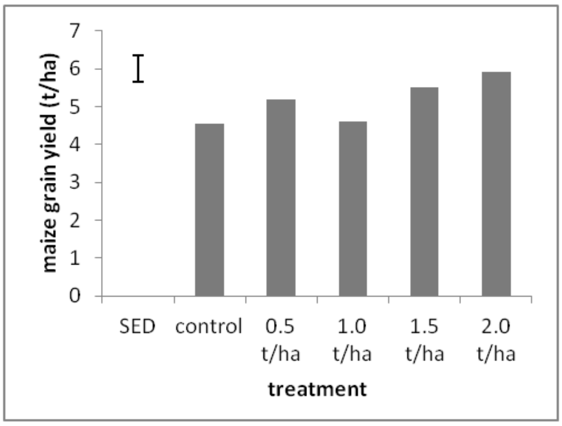
Table 4.12 shows that application of lime at low rates from 2 t/ha to 0.5 t/ha could increase availability of P in the soil significantly in Ugenya while in North Kakamega the rates had no significant effect on soil P.

Table 4.12: Effects of application of low rates of lime via spot method on available P (mg P/kg) in soil

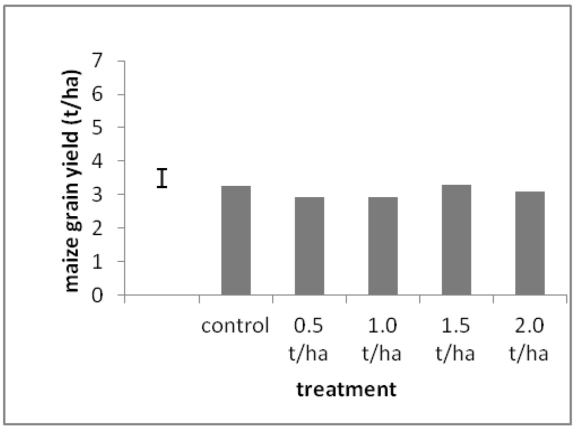
	Ugenya		**North Kakamega**	
Treatment/time	**Before lime application**	**Final**	**Before lime application**	**Final**
0.5 t/ha	3.23	5.54	3.90	2.13
1.0 t/ha	3.19	4.41	2.74	1.83
1.5 t/ha	4.47	4.68	2.66	2.74
2.0 t/ha	4.51	4.14	3.20	2.50
Control	2.51	2.63	3.28	2.26
Grand mean	3.58	5.28	3.16	2.29
SED	1.321	1.336	1.199	0.690
CV (%)	29.6	16	27.1	21.2

4.7.3: Effects of applying low lime rates on maize grain yield

Figure 4.13 shows that application of lime at low rates up to 1.5 t/ha could increase maize grain yield in Ugenya district significantly but there was no effect with applications of such rates in North Kakamega district.



a) Ugenya



b) North Kakamega

Fig 4.13: Effects of spot application of low rates of lime on maize grain yield

N/B: The bars in the graphs represent the SED

4.8: Economic analysis

The gross field benefits (GFB), total cost that vary (TCV), net field benefits (NFB) and marginal rates of return (MRR) are shown in Table 4.13 from investments with different treatments. It is clear that broadcast of 6 t/ha of lime gave highest gross benefits (KES. 357437) cumulated for three seasons but the investment was not economically viable because it involves higher costs hence reducing the net benefits. The only treatments that were economically viable in East Ugenya were, application of 2 t/ha of lime by band and broadcast method. The other treatments were dominated and were not considered for future recommendations to farmers.

Table 4.14 indicated that 4 t/ha of lime applied by broadcast method gives highest GFB (296,919) but the investment is not economically viable because the MRR is less than the minimum rate of return (50%). However 2 t/ha of lime applied by band, spot or broadcast method were economically viable in Sihay.

Table 4.15 shows that band (6 t/ha) of lime produces highest gross field benefits but with higher cost incurred (KES. 156,897), resulting to low net benefit hence the treatment is not worth for investment by farmers. The only treatment that was economically viable for investment in Chimoroni was application of 2 t/ha of lime by spot. Broadcasting 2 t/ha of lime was not economically viable since the returns was less than the minimum rates. Table 4.16 indicates that investments on 2 t/ha of lime by either band method or spot application are economically viable investments.

Table 4.13: Gross field benefits, total cost that vary, net field benefits and marginal rate of return for different treatment combination in East Ugenya

2010LR					2010LR & SR					2010LR, SR & 2011LR				
Trt	**GFB**	**TCV**	**NFB**	**MRR (%)**	**Trt**	**GFB**	**TCV**	**NFB**	**MRR (%)**	**Trt**	**GFB**	**TCV**	**NFB**	**MRR (%)**
No lime	26816	7490	19326		No lime	45340	11301	34039		No lime	71281	16782	54499	
M2L1	108826	59747	49079	57	M2L1	197088	98169	98919	75	M1L1	282911	138552	144359	74
M3L1	106587	60487	46100	D	M3L1	193828	98807	95020	D	M2L1	324804	141236	183568	461
M1L1	101120	61118	40002	D	M1L1	185941	99121	86821	D	M3L1	320468	141767	178701	D
M3L2	88039	71935	16104	D	M2L2	177912	109516	68396	D	M3L2	262090	148445	113645	D
M2L2	105615	72990	32625	D	M3L2	172216	109874	62342	D	M2L2	295952	151428	144524	D
M1L2	113913	76262	37651	D	M1L2	201476	114652	86823	D	M1L2	306615	155012	151604	D
M3L3	94046	86288	7758	D	M3L3	176288	124034	52253	D	M3L3	309164	167692	141472	D
M2L3	128049	89324	38725	D	M2L3	212870	127327	85544	D	M2L3	336931	169992	166940	D
M1L3	123775	91075	32700	D	M1L3	229506	131620	97886	D	M1L3	357437	174708	182729	D

GFB = gross field benefits, TCV = total cost that vary, NFB = net field benefit, MRR = marginal rates of return, M1L1 = broadcast (2 t/ha), M1L2 = Broadcast (4 t/ha), M1L3 = Broadcast (6 t/ha), M2L1 = Band (2 t/ha), M2L2 = Band (4 t/ha), M2L3 = Band (6 t/ha), M3L1 = Spot (2 t/ha), M3L2 = Spot (4 t/ha) and M3L3 = Spot (6 t/ha), D = Dominated treatments, The underlined treatments means economically viable investments.

Table 4.14: Gross field benefits, total cost that vary, net field benefits and marginal rate of return for different treatment combination in Sihay

2010LR					**2010 LR & SR**					**2010 LR, SR & 2011 LR**				
Trt	**GFB**	**TCV**	**NFB**	**MRR (%)**	**Trt**	**GFB**	**TCV**	**NFB**	**MRR (%)**	**Trt**	**GFB**	**TCV**	**NFB**	**MRR (%)**
No lime	32333	8741	23591		No lime	43689	11890	31800		No lime	55904	16144	39760	
M2L1	99414	58618	40796	34	M2L1	149834	92544	57290	32	M3L1	231177	131114	100063	52
M3L1	96043	59246	36797	D	M3L1	143023	92752	50271	D	M2L1	259274	133408	125866	94
M1L1	110311	62186	48125	205	M1L1	151217	94973	56244	D	M1L1	272483	137283	135200	241
M2L2	84585	70475	14110	D	M2L2	123179	102993	20186	D	M2L2	203808	140452	63356	D
M3L2	89561	72125	17436	D	M3L2	137455	105723	31732	D	M3L2	226469	144170	82299	D
M1L2	109108	75707	33401	D	M1L2	165333	110325	55008	D	M1L2	296919	153855	143065	47
M3L3	64117	82734	-18617	D	M3L3	111204	116251	-5047	D	M3L3	212259	156127	56132	D
M2L3	106623	86731	19893	D	M2L3	154839	120399	34441	D	M1L3	232448	159772	72676	D
M1L3	98013	88012	10001	D	M1L3	145584	121616	23968	D	M2L3	279545	163128	116417	D

Table 4.15: Gross field benefits, total cost that vary, net field benefits and marginal rate of return for different treatment combination in Chimoroni

2010 LR					2010 LR & SR					2010 LR, SR & 2011 LR				
Trt	**GFB**	**TCV**	**NFB**	**MRR (%)**	**Trt**	**GFB**	**TCV**	**NFB**	**MRR (%)**	**Trt**	**GFB**	**TCV**	**NFB**	**MRR (%)**
No lime	28317	9498	18818		No lime	41263	11214	30050		No lime	53300	15043	38257	
M2L1	64699	54472	10228	D	M2L1	85878	84911	967	D	M2L1	139630	119157	20473	D
M3L1	93081	58912	34169	31	M1L1	120396	91330	29067	D	M1L1	200810	128729	72081	30
M1L1	87715	59515	28200	D	M3L1	132321	91495	40826	13	M3L1	213380	128997	84383	459
M2L2	91230	71290	19940	D	M3L2	117370	103340	14030	D	M3L2	188108	139622	48486	D
M3L2	83022	71321	11701	D	M2L2	128427	103631	24796	D	M1L2	178519	139728	38791	D
M1L2	89182	73301	15881	D	M1L2	116811	104536	12275	D	M2L2	206690	140777	65913	D
M3L3	83406	85037	-1631	D	M1L3	107528	117060	-9532	D	M1L3	171171	152483	18688	D
M2L3	102228	86216	16011	D	M3L3	120925	117410	3515	D	M3L3	191448	153633	37815	D
M1L3	83931	86342	-2411	D	M2L3	140930	118746	22184	D	M2L3	227364	156897	70466	D

Table 4.16: Gross field benefits, total cost that vary, net field benefits and marginal rate of return for different treatment combination in Tumbeni

2010 LR					2010 LR & SR					2010 LR, SR & 2011 LR				
Trt	**GFB**	**TCV**	**NFB**	**MRR (%)**	**Trt**	**GFB**	**TCV**	**NFB**	**MRR (%)**	**Trt**	**GFB**	**TCV**	**NFB**	**MRR (%)**
No lime	15735	6930	8805		No lime	26955	9904	17051		No lime	44404	13978	30426	
M2L1	61120	54039	7081	D	M2L1	93694	85843	7851	D	M1L1	142231	121746	20484	D
M3L1	54060	54222	-162	D	M3L1	85827	85946	-119	D	M2L1	172173	123011	49162	17
M1L1	61065	56325	4740	D	M1L1	91488	87877	3612	D	M3L1	179142	124898	54244	269
M3L2	76781	70584	6196	D	M3L2	121073	103785	17288	0.3	M3L2	183211	139020	44191	D
M2L2	86209	70675	15534	11	M2L2	138402	104816	33587	582	M2L2	212796	141500	71296	103
M1L2	76333	71792	4541	D	M1L2	128580	105938	22642	D	M1L2	206844	143085	63759	D
M3L3	65113	82833	-17720	D	M3L3	118328	117114	1214	D	M3L3	195302	154093	41208	D
M2L3	82736	83892	-1156	D	M2L3	129125	117340	11784	D	M2L3	228674	157066	71608	2
M1L3	87664	86790	874	D	M1L3	149156	122010	27147	D	M1L3	228925	159383	69542	D

CHAPTER FIVE

5.0. DISCUSSION

5.1. Initial soil characterization

The pH values indicate whether or not the soil is acidic or alkaline and to what degree or extent. pH values obtained from the four sites indicated that the soils were acidic. This is also supported in Plate 4.2 in which the soil reacted vigorously with hydrogen peroxide indicating presence of manganese. It has been suggested that, if the soil pH is below 5.4, then there is need to apply lime to such a soil (Mclean, 1998) and basing on this the results in Table 4.1 show that there was need to apply lime to the soils to correct the low pH. Those soils of East Ugenya, Sihay and Chimoroni are rated as strongly acidic while those of Tumbeni are extremely acidic (Kanyanjua *et al*., 2002). The reason for the low pH values could be due to leaching of basic cations, acidic parent material (Plate 4.1) and continuous use of nitrogenous fertilizers containing ammonium ions. The low pH affected the P availability to plants, by making it fairly insoluble hence the low values of P. When soils are acidic, their capacity to adsorb cations is reduced so that nutrient cations, especially Ca^{2+} and Mg^{2+}, pass into solution and are leached in the drainage water (Wild, 1993). This is evident from the analysis for basic cations (refer to Section 5.2) where the cations increased with depth. Carbon to nitrogen ratios affect the immobilization and mineralization of nitrogen in the soil. The higher the C:N ratio, the higher the rate of immobilization and vice versa. From the results, the C:N ratio was higher in Tumbeni compared to the other sites. This is because the site was previously planted with sugarcane and the trash contributed to high organic matter content. Also, the site has low phosphorus content and high acidity resulting to high C:N ratio (Breimer *et al*., 1986). Organic matter and clay contents determine the buffering capacity of the soil; soils with high organic matter and clay content have high buffering capacity and vice versa (Havlin *et al*., 2005). Therefore higher rates of lime are needed to be applied to soils of Chimoroni and Tumbeni because of high amounts of carbon content than in Sihay and East Ugenya sites.

5.2. Soil profile description

According to profile description and Jaetzold and Schimdt (2005), soils of Ugenya district are Acrisols while those of North Kakamega are Ferralo-humic Acrisols (Jaetzold and Schimdt, 2006). Acrisols are fully formed soils while Ferralo-humic acrisols have ferralic phase and are inter-mediary soils that are still undergoing the soil formation process. Both of these soils are poorly drained and contain 2:1 type of clays, they seem to hold potassium more strongly than Ca. Ferralic soils are vulnerable to removal of plant nutrients by leaching while Acrisols have high Al toxicity that impair root development and reduces the nutrient and water uptake by plants (Poss and Saragoni, 1992). Addition of bases (such as lime) to these soils causes more hydroxide groups to deprotonate and produce additional negative charges. From the graphs (Figs 4.1, 4.2 and 4.3) it is clear that basic cations are low in the top soil and increased in the subsoils in East Ugenya and Sihay sites. This could be attributed to leaching of the cations into sub-soil layers together with nitrates (Poss and Saragoni, 1992) along with ferrolysis which is a common feature to Acrisols (Somasiri, 1985) and possibly due to continuous cropping with addition of little or low supplemental nutrients to the soil. Ferrolysis is a mineral destruction process that contributes to textural differentiation in profiles. It starts with the reduction of Fe^{3+} to Fe^{2+} that displaces bases from the exchange complex and subsequently removes the bases from top soil by leaching. When the soils dry, the oxidation of Fe^{3+} produces H^+ that intensifies the weathering of clay and primary minerals. However in Tumbeni, the basic cations decreased down the profile due to the fact that the site is found at the valley of Nandi escarpment and thus there is a possibility that these elements might have been brought via erosion. Also for the element K, the site is a sugarcane growing zone (Jaetzold and Schimdt, 2005) and farmers normally supply K for sugarcane in their farms. While in Chimoroni, the availability of the basic cations was distributed almost equally down the profile; this site differs from Tumbeni because of its location since they are both separated by a stream hence it does not benefit from the erosion deposits.

5.3. Effects of rates of lime and lime placement on soil pH

When lime was applied and mixed thoroughly with soil, the soil pH was raised within a few weeks after liming (Fig 4.4-4.5 and tabulated data shown in appendix ii) . This was because calcium (from lime) very likely replaced Al^{+++} , Mn^{++} and H^{+} ions on the exchange sites by mass action hence likely raising the percentage base saturation (Plaster, 2003). Lime reduces soil acidity (i.e., increases pH) by changing some of the hydrogen ions into water and carbon dioxide (CO_2). The Ca^{++} ions from the lime replace two H^{+} ions on the cation exchange complex. The carbonate (CO_3^{-}) reacted with water to form bicarbonate (HCO_3^{-}). These then reacted with H^{+} to form H_2O and CO_2 (refer to equation in Section 2.2). The pH increased because of the reduced concentration of H^{+} ion.

The pH continued to increase very slowly until another tillage operation redistributed the lime particles, bringing them into contact with more acid soil, as a result pH dropped and then increased. This can be observed in Figs 4.4, 4.5, 4.6 and 4.7 between 120 and 197 days after lime applications in Ugenya district and 145 and 218 days in North Kakamega district after lime application in which land preparation was carried out for 2010 SR cropping season and 272 and 365 days in Ugenya district and

301 and 366 days in North Kakamega. Another factor that contributed to the trends of pH value changes observed is the rainfall patterns. In North Kakamega district (Chimoroni and Tumbeni) the amount of rainfall in the first season (Fig 3.2) likely aided in the reaction of lime with the soil and hence raising the soil pH. When the soil was ploughed for the second season, there was redistribution of lime. However, there was low rainfall thereafter (months of Nov to Feb) hence the pH values taken between 217 and 366 days were the same.

At the end of the three cropping seasons (2010 LR, SR and 2011 LR) increased pH changes were attained from application of 6 t/ha of lime by band method because there was high lime to soil contact in all the study sites and also the residual effect was high.

Results of increased soil pH as a result of addition of lime have been reported by Hunter *et al*, (1997) (soil pH increased from 5 to 6) in Western Samoa with lime application in Ferralsols (oxisols), Opala (2009) (increased pH from 4.67 (in control) to 5.49 (in the treatment). Also the increased residual effect with increased rate of lime was reported by Kisinyo (2011).

5.4. The effects of lime rates and lime placement on available phosphorus in soils

From the results, it is clear that lime increased the available P in the soil at the end of the three cropping seasons. Highest increase was achieved from application of 6 t/ha of lime by broadcast method in both sites in Ugenya district (East Ugenya and Sihay). While in North Kakamega, there was an increase in available P on only one site (Chimoroni) from band of 6 t/ha. This was due to increased soil pH thus making Al, Fe and Mn less soluble and hence they were possibly replaced by basic elements like Ca and Mg on the exchange sites hence solubilizing fixed P (Cook and Ellis, 1987).

The highest available P is attributed to the higher rise in pH explained in Section 5.3, hence increasing the solubility of fixed phosphorus.

The trends of changing P with time (Appendix v) shows that in Ugenya district, P increased from date of application and it reached the maximum after 70 days, then it dropped until harvesting of the crops. This is because the plant (maize) requires larger amounts of nutrients with uptake accelerated just before the silking stage (Guantai *et al*., 2007), while in North Kakamega district available P started increasing after 38 days from the time of lime application. This could be due to pH changes and also uptake of P by the plant at this growing period.

5.5. Effects of lime rates and lime placement on maize grain yield

There is a clear evidence that with application of lime to acidic soils, there is a significant rise in maize grain yield in all the study sites. This could be attributed to factors such as increased soil pH (shown in Figs 4.4, 4.5, 4.6 and 4.7), increased availability of P for plant uptake, efficient use of N and P (Tables 4.4 and 4.5) and most likely the addition of the Ca nutrient from the added lime.

In all the sites, there was insufficient rainfall during the second cropping season (2010 SR) and this is why the yields were low compared to 2010 LR and 2011 LR. When there was insufficient moisture in the soil, most of the plant nutrients became insoluble and hence sparingly available.

In Ugenya district the average grain yields for the three cropping seasons indicated that the two sites (Sihay and East Ugenya) were significantly different in characteristics ($p<0.05$) (Appendix iii). This could be attributed to the differences in the soil texture in which east Ugenya had more clay content than Sihay hence east Ugenya had higher cation exchange capacity. It was also found that there was no significant interaction effects between the method of applying lime and the lime rate. This indicates that the effects due to the levels of the method (i.e., broadcasting, band and spot) do not depend on the level of the lime rates, therefore the tests for individual effects were valid (SAS/STAT(R) Users Quide, 2008)

The methods were significantly different from each other ($p<0.05$) with averages of 3 seasons and 2 sites; highest grain yield was obtained from the use of broadcast method (4.52 t/ha). Band and spot method yielded 4.38 and 4.03 t/ha respectively. Liming by spot method had the lowest yield specifically during the first season because there were visual overliming effects shown by low germination rates particularly with application of 4 and 6 t/ha of lime as recorded. The result of low yields due to overliming has also been reported elsewhere (Sanchez, 1976; Foth and Ellis, 1988; Troeh and Louis, 1993). The overliming effect was because large quantities of lime were concentrated in small area or small soil volume from spot application. From the rates, application of 6 t/ha of lime gave the highest grain yield (4.46 t/ha) on average for the three seasons because of the residual effects also reported by Kisinyo (2011).

Similarly in North Kakamega district, there was no significant interaction effects between the rates of lime and its method of application. The methods of lime application were not significantly different since in these sites the lime requirement was higher than in Ugenya district and hence there was no overliming effect. However the rates were significantly different ($p<0.05$) on 2 t/ha band and 4 and 6 t/ha band, 6 t/ha broadcast; 2 t/ha broadcast and 6 t/ha band; 4 t/ha spot and 6 t/ha band lime (Appendix iv). Highest grain yield was obtained from application of 6 t/ha of lime (3.21 t/ha of maize grains) and band method gave highest yields compared to the other methods. This could be attributed to the fact that the soils require large quantities of Ca to neutralize the acidity and also the soil to lime contact within the crop rooting zone which increased availability of P and uptake of nitrogen and phosphorus.

5.6. Effects of rates of lime and lime placement on N and P use efficiencies

From the results, agronomic, physiological and recovery P and N use efficiencies were all positive because lime likely relieved the plants from Al and possibly Mn toxicity which created a conducive environment for good root development which enhanced P and N uptake necessary for high grain yield (Kisinyo, 2011).

The agronomic, physiological and recovery efficiencies of N and P fertilizers increased with increasing rates of lime by broadcast and band methods but decreased with increased lime rates by spot method. The increase could be attributed to conducive environment created by lime within the root zone of the crop hence good root growth which enhanced efficient nutrient uptake and utilization by plants (He *et al.*, 1996; Kochian, 1995 and Ligeyo *et al*., 2006). Similar findings were reported by Kisinyo (2011). However, the decrease in yield from spot method could be attributed to overliming effect which possibly resulted in decreased availability of P, Zn, B, and Mn (Sanchez, 1976; Foth and Ellis, 1988; Troeh and Louis, 1993).

5.7. Correlations between laboratory data and field data

The significant and positive strong correlations between maize grain yield and the ratio of total height to ear height could be attributed to the fact that maize is a self pollinated as well as cross pollinated plant in which high percentage is self pollinated. Therefore the nearer the tassel to the ear, the more the pollen grains that fall on the ear and hence the more grains are formed after fertilization resulting to high grain yield

(Guantai *et al*., 2005). In addition, there will be more leaves below the ear which feed the roots hence increased nutrient uptake.

Soil pH was significantly correlated with maize grain yield because high soil pH makes aluminium, iron and manganese less soluble and so prevents them from being toxic to plants (Cook *et al*, 1987); it also results to healthy root development by plants because they are exposed to reduced toxicity of Al and Mn. This may improve nutrient uptake and enhance drought tolerance by the plants particularly under dry spells. Soil pH possibly affected the solubility of minerals or nutrients essential for plant growth (Uchida and Hue, 2000).

During the 2010 SR seasons maize grain yields were either not correlated to height as was observed in 2010 and 2011 LR or weakly correlated ($p<0.05$). This is because there was little rainfall during the season (Fig 3.2 and 3.3) hence there was poor root development resulting to low nutrient uptake.

5.8. Minimum lime applications towards affordability

This study was done after an observation discussed in the previous sections. From the result it was clear that lime applications could raise the soil pH in both sites but within a short time compared to application of higher rates more than 2 t/ha. The increase in soil pH was also reflected on availability of P as a result of probably increased solubility of fixed P. The results of significant increase of maize grain yield in Ugenya and not in North Kakamega, confirm the findings noted earlier that soils of North Kakamega have higher buffering capacity compared to those of Ugenya due to high carbon and clay content (Table 4.1).

5.9. Economic analysis

From the economic analysis results, banding 2 t/ha of lime was found to be economically viable in East Ugenya site. This could be attributed to the fact that band method introduces lime within the rooting zone of the crop resulting to high yield. This was also due to low cost incurred on buying and labour for applying lime hence increasing the net benefits.

In Sihay, use of broadcast, band or spot method to apply 2 t/ha of lime was economically viable. The differences from the results of East Ugenya could be likely due to slightly higher pH in Sihay compared to East Ugenya and the level of exchangeable acidity is higher in East Ugenya than in Sihay hence affecting lime requirements. Application of low quantities of lime changed the soil pH hence improving availability of nutrients, e.g., Ca, P and B which was translated to yield. As lime rates were increased, there was increased cost for purchase of lime and transportation costs and this reduced the net benefits.

In Chimoroni and Tumbeni, the soils are more acidic compared to the two sites in Ugenya district (see Table 4.1). Therefore, it was more economical to reduce the acidity within the rooting zones of the crop rather than the entire field hence application of 2 t/ha was found to be economically viable.

CHAPTER SIX

6.0. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

From the field and laboratory findings of the soil and plant analysis as well as grain yield, the following are concluded:

- Application of lime at different rates and methods could affect the soil pH differently. Generally soil pH was raised from less than 5 to pH values more than 5.5 in Ugenya district and more than 5.4 in North Kakamega district from application of 6 t/ha of lime via broadcast method and band method in Ugenya and North Kakamega districts.

- Maize grain yield was increased with application of lime. Highest increase was obtained from applications of 6 t/ha of lime via band and broadcast methods in North Kakamega and Ugenya districts, respectively. This was correlated to the changes in soil pH, since pH determines availability of nutrients for crop growth and is reflected by the yield. The higher yield could be as a result of high lime to soil contact, hence enhanced lime reaction with soils and the residual effects of higher lime rates.

- However, economic analysis indicated that application of 2 t/ha of lime by band or broadcast methods are economically viable in Ugenya district while in North Kakamega district similar quantity of lime applied by spot method or banding 4 t/ha of lime was economically viable.

- From the low lime application rate, there was a clear evidence that in Ugenya, one could apply low rates of up to 0.5 t/ha by spot method and realise increased yields better than planting with fertilizer P and N alone. However, supplying the required amounts of P and N fertilizers in Ugenya could improve yield up to 3 t/ha compared to planting without lime or fertilizer or with little fertilizer in which the results are less than 1 t/ha of maize grain yield.

- Application\ of lime in North Kakamega by band and spot method is appropriate while in Ugenya application by band and broadcast method is appropriate. The difference is due to the differences in climatic conditions and soil type.

6.2. Recommendations

From the findings the following recommendations are made:

- Determination of lime requirement for the study sites should be carried out.
- To achieve good results from application of lime in North Kakamega district, band or spot method should be used while in Ugenya district, farmers should apply by band or broadcast method to realise good results. When band method is used in North Kakamega, the lime should be higher than when spot method is employed.
- Appropriate rates for North Kakamega is 2 t/ha of Koru lime if spot method is used or 4 t/ha by band method; while in Ugenya district 2 t/ha of lime is appropriate.
- The experiment on the low lime rates applications by spot method be conducted for atleast three years to look at residual effects or carry out an experiment on application of low rates of lime (e.g., 0.5 t/ha) each season.

REFERENCES

Adams, F. (1984) Crop Response to Lime in the Southern United States. P 211-265. In: F . Adams (ed) Soil Acidity and Liming. 2nd ed. Agronomy 12. Am. Soc. Agron; Madison, W. I.

Ahn, P.M. (1993). Manure fertilizer and use. Tropical Soils and Fertilizer use, Intermediate Tropical Agriculture series, Longman group, UK Ltd, England. pp 147-148.

Asumadu, H., P.Y. Sallah, P.B. Boa-Amponsem, J.M. Aduening and Oseibonsus (2004). On-farm Evaluation and Promotion of Quality Protein Maize Hybrids in Ghana. *African Crop Science Proceedings, Vol. 4: 358-364.*

Ayaga, G.O. (2003). Maize Yield Trends in Kenya in the Last 20 Years. A keynote paper, pp 7-3. In: Othieno C. O., Odindo, A. O. and Auma, E. O. (eds). *A Workshop on Declining Maize Yield Trends in Trans Nzoia District Proceedings. 22nd- 23rd May, 2003. Kitale, Kenya.*

Barber, S.A. (1984). "Liming Materials and Practices" Chapter 4 P.171-209) In: F. Adams (ed.) Soil Acidity and Liming. 2nd Edition, agronomy 12. Am. Soc. Madison, W. I.

Bell, L.C. and D.G. Edwards, (1991) Soil Acidity and its Amelioration. In: ASIALAND Workshop on the Establishment of Experiments for the Management of Acid Soils: *Proceedings of the Training Workshop on Site Selection, Characterization and Establishment of Experiments for the Management of Acid Soils in Asia of the ASIALAND Programme* Held at Hat Yai, Thailand: 10-20, June 1990.

Brady N.C., and R.R. Weil (2004). Elements of the Nature and the Properties of Soil (2nd Edition). Macmillan Publishing Company. USA.

Breimer, R.F., Van Kekem A.J., Van Reuler H. (1986). Guidelines for Soil Survey and Land Evaluation in Ecological Research. MAB Technical Notes 17. UNESCO, Paris

Brett, U., G. Fenton and M. Conyers (2005). Soil Acidity and Liming, Agfact Ac. 19, 3rd Edition, NSW department of primary industries

Brown, T.T., Koenig, R.T., Huggins, D.R., Harsh, J.B., Rossi, R.E. (2008). Lime Effects on Soil Acidity, Crop Yield and Aluminium Chemistry in Inland Pacific Northwest Direct-seed Cropping System. *Soil Science Society of America Journal 72:634-640*.

Buresh, R.J., P.C. Smithson and D.T. Hellums (1997). Building Soil Phosphorus Capital in Africa. pp 111-149. In: R.J. Buresh, P.A. Sanchez and F. Calhoun eds. Replenishing Soil Fertility in Africa. SSSA Special Publ. No. 51, ASA, Madison, WI, USA.

CIMMYT (1988). From agronomic data to farmer recommendations: An Economics Training Manual. Completely revised edition. Mexico D.F. pp. 9-38.

Clark, R.B., C.L. Flores, L.M. Gourley (1988). Mineral Element Concentrations in Acid Soil Tolerant and Susceptible Sorghum Genotypes. Comm. Soil Sci. Plant Anal. 18: 1003-1017.

Cook, R.L. and G.E. Boyd (1987). Soil Management, a world view for conservation and Production. *Canada Society of America Journal 72:634-640.*

Crozier, C.R., G.C. Naderman, M.R. Tucker and R.E. Sugg (1999). Nutrition and pH Stratification with Conventional and no-till Management. Commun. Soil Sci. Plant Anal. 30:65-74.

Crozier, C.R. and D.H. Hardy (2003). Soil Facts: Soil Acidity and Liming- Basic Information for Farmers and Gardeners. North Carolina. Cooperative Extension Service, NC, USA

Dobermann, A. (2005). Nitrogen Use Efficacy- state of the art. IFA international workshop on *Enhanced-Efficiency Fertilizers*. Frankfurt, Germany, 28-30 June 2005.

Dobermann A., (2007). Nutrient use efficiency – measurement and management. 22 pp. Proc. of International Fertilizer Industry Association (IFA) Workshop on *Fertilizer Best Management Practices*. Brussels, Belgium. March 7-9, 2007.

Eswaran, H., P. Reich and F. Beinroth (1997). Global Distribution of Soils With Acidity. In: Moniz A.C., Furlani A.M.C., Schaffert R.E., Fageria N.K., Rosolem C.A., Cantarella H., ed. *Plant Soil Interactions at Low pH*. Brazil, 159-164.

Export processing Zones Authority (2005). Grain Production in Kenya, a report prepared by, PKF consulting Ltd and International Research Network.

FAO (1992). Maize in Human Nutrition, food and nutrition series, No. 25, ISBN 92-5- 103013-8: Rome, Italy.

Fertilizer Society of South Africa (2000). Application of Lime, National department of agriculture: Pretoria, South Africa or *www.nda.agric.za/publications,* accessed on 12th Nov 2011

Food and Agricultural Organization (FAO) of the United Nations (1996). Soil Fertility Initiative, FAO, Rome, Italy.

Foth, D.F. and G.E. Boyd (1988). Soil Fertility: John Wiley and Sons, New York.

FURP. (1994). Fertilizer Use Recommendations Project. Fertilizer Recommendations Vol. 1-22. Kenya Agricultural Research Institute (KARI/Ministry of Agriculture, Nairobi, Kenya).

Gittinger, J.P. (1995). Economic Analysis of Agricultural Projects. The John Hopkins University Press, Baltimore, Maryland 21218, USA.

Guantai, S., P. Steward, J.A. Ochieng, E. Njoka, E. Ogwora, S. Collins and S. Walker (2007). Kenya Maize Hand Book; ACDI/ VOCA- Kenya Training Manual: Modern lithographics (K) ltd, Kenya.

Gudu, S., S.M. Maina, A.O. Onkware, G. Ombakho, D.O. Ligeyo (2001). Screening of Kenya Maize Germplasm for Tolerance to Low pH and Aluminium for Use in Acid Soils of Kenya; presented at the 7th Eastern and Southern Africa Regional Maize Conference, 11th -15th Feb 2011. Pp 216-221.

Gudu, S., Okalebo, J.R., Othieno, C.O., Obura, P.A. & Ligeyo, D.O. (2005). New Approach for Improving Phosphorus Acquisition and Aluminium Tolerance of Plants in Marginal Soils. Third Year Progress Report, 1 march 2004-28 February, 2005, McKnight Foundation Project. pp. 107.

Gudu, S.O., J.R. Okalebo, C.O. Othieno, P.O. Kisinyo, P.A. Obura and D.O. Ligeyo (2007). New Approach for Improving Phosphorus Acquisition and Aluminium Tolerance of Plants in Marginal Soils; Soil Research Component (2003-2007). Presented at a Workshop in France, October, 2007.

Havlin, J.L., J.D. Beaton, S.L. Tisdale and W.L. Nelson, (2005). Soil Fertility and Fertilizers; an Introduction to Nutrient Management(7th ed.), Pearson Education: New Jersey

He, Z.I., V.C. Baligar, D.C. Martens, K.D. Ritchey and W.D. Kemper (1996). Factors Affecting Phosphate Rock Dissolution in Acid Soil Ammended With Liming Material and Cellulose. *Soil Sci. Soc. Amer. Journ*. 60: 1596-1601.

Hodges S.C. (2005). Soil Fertility Basics; NC certified Crop Advisor Training, Soil Science Extension: North Carolina State University.

Hollier, C. & R. Michael (2005). Acid Soils. AG1182 ISSN 1329-8062

Hue, N.V., J.A. Silva, G. Uehara, R.T. Hamasaki, R. Uchida, and P. Bunn. (1998). Managing manganese toxicity in former sugarcane soils on Oahu. 7 p. SCM-1. Coll. of Tropical Agr. Human Resources, Univ. Hawaii.

Hunter, D.J., L.G.G. Yapa, N.V. Hue, (1997). Effects of Green Manure and Coral Lime on Corn Growth and Chemical Properties of an Acid Oxisol in Western Samoa: Biol Fertil Soils 24 (3): 266-273. Spring-verlag, Western Samoa.

Jaetzold R. and H. Schmidt (1983). Farm Management Handbook of Kenya Vol.II B, Central Kenya (Rift Valley and Central Provinces). Ministry of Agriculture, Nairobi, Kenya.

Jaetzold, R. and H. Schmidt, (1983). Farm Management Hand Book of Kenya-Natural Conditions and Farm Management Information, Part A Vol. II, West and Western (Nyanza and Western Provinces), Ministry of Agriculture, Nairobi, Kenya.

Kamprath, E.J., (1970). “Exchangeable aluminium as a criterion for liming leached mineral *soils,” Soil Sci. Soc. Amer. J.* 34:252-254.

Kanyanjua, S.M., L. Ireri, S. Wambua, S.M. Nandwa (2002). Acid Soils in Kenya; Constraints and Remedial Options, KARI Technical Note 11, Nairobi Kenya.

Kenya Soil Survey (1987). Soil and land resources surveys and investigations. National Agricultural Research Laboratories, Nairobi, Kenya.

Kerley, S.J. (2000). The Effects of Soil Liming on Shoot Development, Root Growth, and Cluster Root Activity of white Lupin: IACR- Rothamsted, Harpenden, Hertfordshire, Al52JQ, UK.

Kidds, P.S. and J. Proctor (2000). Effects of Aluminium on the Growth and Mineral Composition of *Betula pendula,* Roth J. Expt. Botany 51 (347): 1057-1066.

Kiiya, W., F. Ndung'u, R. Onyango, E. Lunzalu and J. Mulati (2005). Maize Varieties, Soil Fertility Improvement and Appropriate Agronomic Practices. Bulletin supported and funded by the KARI and Rock Feller Foundation.

Kisinyo, P.O. (2011). Constraints of Soil Acidity and Nutrient Depletion on Maize (Zea mays L.) Production in Kenya. D. Phil. Thesis, Moi University, Eldoret, Kenya.

Kochian, L.V. (1995). Cellular Mechanism of Aluminium Toxicity and Resistance in Plants. Annu. Rev. Plant Physiol. Mol. Biol. 46:237-260.

Kolay, A.K. (2000). Basic Concepts of Soil Science. New Age International (P) Limited Publishers. Printo Pack Delhi, India.

Ligeyo, D.O. & S. Gudu (2005). Further Labouratory Screening of More Kenyan Maize Inbred Lines for Tolerance to Aluminium (Experiment 2). In: Third Year Progress Report, 1 March 2004 to 28th Feb 2005. McKnight Foundation USA funded Project. pp 107.

Ligeyo, D.O., S. Gudu, G.A. Ombakho, P.A. Obura, J.R. Okalebo and C.O. Othieno (2006). Differential Phosphorus Uptake and P Use Efficiency by Kenyan Maize Inbreds and Hybrids Populations in Acid Soils of Western Kenya. In: Alves *et al*. (eds). 3rd International Symposium on Phosphorus Dynamics in

Soil-Plant Continuum: Intergrating Marginal Lands into Productive Agricultural Systems by Means of Improving Soil and Fertilizer Phosphorus Efficiency. 14th- 19th May, 2006. Uberlandia, Minas Gerais, Brazil.

Ligeyo, D.O. (2007). Genetic Analysis of Maize (*Zea mays* L.) Tolerance to Aluminium Toxicity and Low Phosphorus Stress and Development of Synthetics for Use in Acid Soils of Western Kenya. Ph.D Thesis. Moi University, Eldoret, Kenya.

Lippert, R. (2000). Soil Acidity and Liming. Extension Internet Inservice Training, part II.

Mamo, M. (2009). Lime Use for Soil Acidity Management. Neb guide, University of Nabraska Lincoln or http://extension.unl.edu/publication.

Mbakaya, D.S., J.O. Odenya, C. Njeru and J. Luteya, (2006). Effects of Liming, Organic and Inorganic Fertilizers on Yield of Maize in Western Kenya In: Proceeding of the 8th KARI Scientific Conference 12th-17th November 2006, KARI Headquarters, Kaptagat Road, Nairobi.

McLaren, R.G. and K.C. Cameron (1994). Soil Science. An Introduction to the Properties and Management of NewZealand Soils. Oxford University Press. New York, pp 167-177.

McLean, E.O. (1971). Potentially beneficial effects from liming: Chemical and Physical. *Proceedings of Soil Crop Science Society of Florida*. Proc 31: 189-196.

Meiwes, K.J. (1995). Application of Lime and Wood Ash to Decrease Acidification of Forest Soils, In: Water, Air and Soil Pollution 85 (1): 143-152, Kluwer Academic Publ. Netherlands.

Mortvedt, J.J., L.S. Murphy, and R.H. Follet (1999). Fertilizer Technology and Application. Meister Publishing Co. Willoughby, OH.

Muchena, F.N., J.P. Mbuvi, and Wokabi, S.M. (1988). Report on Soils and Land Use in Arid and Semi-arid lands of Kenya. Ministry of Natural Resources, National Environment Secretariat, Nairobi, Kenya.

Neil, C. (1991). Ground Works 1: Managing Soil Acidity. In. Proceedings of Tropsoils Workshop on Soil Acidity and Liming. pp 1-23.

Nekesa, A.O. (2007). Effects of Minjingu Phosphate Rock and Agricultural Lime in Relation to Maize, Groundnuts, Soy bean Yields on Acid Soils of Western Kenya. Mphil. Thesis, Moi University, Eldoret. Kenya.

Nekesa, P., Maritim, H.K., Okalebo, J.R. & Woomer, P.L. (1999). Economic analysis of Maize-bean Production Using a Soil Fertility Replenishment Product (PREP-PAC) in Western Kenya. *African Crop Science Journal 7 (4), 423-432.*

Obura, P.A., Okalebo, J.R., Othieno, C.O., Gudu, S., Ligeyo, D.O. & Shulze, D. (2003). Effects of Lime and Phosphorus on the Performance of Five Maize Genotypes in Acid Soils of Western Kenya. Presented at the KARI, Kenya, Headquarters Seminar, December 2003, pp22.

Okalebo, J.R., Othieno, C.O., Karanja, N.K., Semoka, J.R.M., Bekunda, M.A., Mugendi, D.N.,Woomer, P.L., & Bationo, A. (2006). Appropriate Available Technologies to Replenish Soil Fertility in East Africa. Nutrient Cycling in Agroecosystems, Springer, The Netherlands.

Okalebo, J.R. (2009). Recognising the Constraints of Soil Fertility Depletion and Technologies to Reverse it in Kenyan Agriculture. Moi University Inaugural Lecture Series No. 1, Moi University Press, Eldoret, Kenya.

Okalebo, J.R., C.O. Othieno, A.O. Nekesa, K.W. Ndungu-Magiroi and M.N. Kifuko-Koech (2009). Potential for Agricultural Lime on Improved Soil Health and Agricultural Production in Kenya. African Crop Science Conference Proceedings, vol 9. pp. 339-341, Uganda.

Oluoch-Kosura, W. (1999). Intensification: Best Option for Agricultural Growth in Kenya. AgriForum 9:9-11.

Opala, P.A. (2011). *Comparative Effects of Lime and Organic Materials on Selected Soil Chemical Properties and Nutrient Uptake by Maize in an Acid Soil*. Archives of Applied Science Research; 2011, Vol. 3 Issue 1, pp 96.

Osmond, D.L., C.R. Crozier, and D.H. Hardy (1997) Careful Soil Sampling- the Key to Reliable Soil Test Information. North Carolina Cooperative Extension Service, AG-439-30.http://www.soil.ncsu.edu/publications/soilfacts/AG-439-30/. Accessed on 5th November 2011.

Plaster, J.E. (2003). Soil Science and Management, 4th Edition. Delmar Learning, a division of Thompson Learning, INC. pp 319-322, USA.

Sanchez, P.A. (1976). Properties and Management of Soils in the Tropics. John Willey & Sons, Inc. New York. USA.

Sanchez, P.A., Izac, A.M., Valencia, A., Pieri, C., (1996). Soil Fertility Replenishment in Africa. A concept note. In: Breth, S.A. (ed.) Achieving Greater Impacts from Research Investments in Africa. Sasakawa Africa Association.

Sanginga, N. and P.L. Woomer (eds) (2009). *Intergrated Soil Fertility Management in Africa: Principles, practices and development process*. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF- CIAT). Nairobi.

SAS Institute Inc. (2008). SAS/ STAT(R) 9.2 User's Guide. Cary, NC: SAS Institute, Inc., USA.

Sasaki, M., Yamamoto, Y. and Matsumoto, H. (1996). Lignin Deposition Induced by Aluminium in Wheat (*Triticum aestivum*) roots. Physiol. plant. 96: 193-198

Skousen J. S. and L. M. McDonald (2005). Land Reclamation. Extension Service, Western Virginia.

Somasiri, S., (1985)"Wet Alfisols with special reference to Sri Lanka," In S. Banta and C. V.Mendoza (eds.), *Wetland Soils: Characterization, Classification, and Utilization*. International Rice Research Institute, Los Banos, Philippines, 1985, pp. 421-438.

Scientific Staff of the International Plant Nutrition Institute (IPNI) (2007). Effective Nutrient Use Efficiency Improvement. Plant Nutrition Today, Summer, 2007, No. 1, Georgia, USA.

Tegalign T., I. Haque and E.A. Aduayi (1991). Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis Manual. Plant Science Division Working Document 13. ILCA, Addis Ababa, Ethiopia.

Terman, G.L., and O.P. Engelstad, (1976). Agronomic Evaluation of Fertilizers: Principles and Practices. Bull. Y-21. Muscle Shoals, Ala.: Tennessee Valley Authority, National Fertilizer Development Center.

Thomas, R. (2005). Get the Lime Out. Quality Whitetails Magazine. Vol 12, Issue 1.

Troeh, F.R. and Louis M.T.(1993). Soils and Soil Fertility, 5th Edition: Oxford University Press, New York; pp 149-170.

Uchida, R. and Hue N.V. (2000) Soil Acidity and Liming. In: Silva, J.A. and Uchida, R. Eds. Plant Nutrient Management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa.

APPENDICES

Appendix i: Calculations to determine lime to be applied per plot

For 2 t/ha lime: if 2000 kg (2t) = 10,000 m^2 (1 ha)

What amount will a plot of 21.6 m^2 (4.8 mx4.5 m) require?

(21.6/10000) x 2000 kg = 4.32 kg lime per plot

If the plant spacing is 75 cm x 30 cm (used), a plot will have approximately 96 hills;

Then lime applied per hill = 4320 g /96

Thus for 2 t/ha lime, each hill should get at least 45 g.

Lime applied 4 t/ha, each hill should get at least 90 g.

Lime applied 6 t/ha, each hill should get at least 135 g.

Appendix ii: Tables of the effects of lime rates and its applications on soil pH over the three cropping seasons

Table i – iv below gives a summary of the pH changes over time per each rate applied via any of the three methods of applications.

Table i: Effects of lime and lime placement on soil pH after three cropping seasons in East Ugenya site

Method* rate of lime applied /Days after lime application	0	37	70	120	197	232	272	365	492	Mean
Band (2t/ha)	5.23	5.24	5.42	5.74	5.25	5.41	5.74	5.39	5.64	**5.45**
Band (4 t/ha)	5.30	5.68	5.76	6.08	5.45	5.89	6.19	5.45	5.68	**5.72**
Band (6 t/ha)	4.97	6.06	6.46	6.46	5.59	6.06	6.32	5.72	5.84	**5.94**
Band (No lime)	4.99	4.66	5.01	5.22	4.64	5.12	5.00	4.89	5.07	**4.95**
Spot (2 t/ha)	5.26	5.10	5.39	5.60	5.00	5.54	5.59	5.32	5.56	**5.37**
Spot (4 t/ha)	5.06	5.01	6.13	5.62	5.52	5.88	5.87	5.34	6.12	**5.62**
Spot (6 t/ha)	4.98	5.65	6.06	6.11	5.58	5.99	6.28	5.74	6.26	**5.85**
Spot (No lime)	4.99	4.65	5.04	5.14	4.49	5.03	4.94	4.88	5.11	**4.92**
Broadcast (2 t/ha)	5.29	5.46	6.00	5.98	5.25	5.90	5.92	5.33	5.55	**5.63**
Broadcast (4 t/ha)	5.11	6.04	6.12	6.10	6.01	5.93	6.25	5.65	6.17	**5.93**
Broadcast (6 t/ha)	5.17	6.37	6.39	6.30	5.93	5.95	6.24	5.73	6.36	**6.05**
Broadcast (No lime)	5.16	4.89	5.08	5.28	4.76	5.18	5.12	4.83	5.11	**5.04**
Mean	5.13	5.40	5.74	5.80	5.29	5.66	5.79	5.36	5.71	**5.54**
SED 0.05 (Method)	0.10	0.16	0.19	0.09	0.13	0.11	0.14	0.11	0.14	
SED 0.05 (rate)	0.12	0.18	0.22	0.10	0.15	0.13	0.17	0.12	0.16	
SED 0.05 (Method*rate)	0.21	0.31	0.38	0.17	0.26	0.23	0.29	0.21	0.27	
CV (%)	6.0	8.5	9.7	4.4	7.3	5.9	7.0	5.9	7.0	

Table ii: Effects of lime and lime placement on soil pH after three cropping seasons in Sihay site

Method* rate of lime applied /Days after lime application	0	38	70	120	197	232	272	365	492	Mean
Band (2t/ha)	5.73	6.00	6.01	6.16	5.76	5.91	6.04	5.60	5.94	**5.91**
Band (4 t/ha)	5.59	7.04	6.67	6.35	6.30	6.57	6.72	6.20	6.45	**6.43**
Band (6 t/ha)	5.62	7.13	6.79	6.81	6.68	6.76	6.85	6.25	6.76	**6.63**
Band (No lime)	5.73	5.87	5.71	5.74	5.46	5.70	5.88	5.43	5.59	**5.68**
Spot (2 t/ha)	5.67	5.81	6.38	5.77	5.91	6.29	6.02	5.65	6.10	**5.96**
Spot (4 t/ha)	5.98	6.06	6.80	6.09	6.36	6.50	6.77	6.48	6.45	**6.39**
Spot (6 t/ha)	5.66	6.03	6.58	5.84	6.46	6.45	6.77	6.15	6.69	**6.29**
Spot (No lime)	5.62	5.87	5.67	5.67	5.28	5.56	5.68	5.41	5.49	**5.58**
Broadcast (2 t/ha)	5.45	6.37	6.35	6.03	6.02	6.03	6.13	5.66	5.89	**5.99**
Broadcast (4 t/ha)	5.48	6.85	6.89	6.75	6.46	6.66	6.74	6.27	6.42	**6.50**
Broadcast (6 t/ha)	5.91	7.39	7.05	6.57	6.76	6.76	7.00	6.40	6.36	**6.69**
Broadcast (No lime)	5.82	6.07	5.70	5.79	5.54	5.77	5.94	5.64	5.74	**5.78**
Mean	5.69	6.42	6.38	6.13	6.08	6.25	6.38	5.93	6.16	**6.16**
SED 0.05 (Method)	0.11	0.16	0.09	0.09	0.12	0.10	0.11	0.11	0.12	
SED 0.05 (rate)	0.12	0.19	0.10	0.10	0.14	0.12	0.13	0.13	0.14	
SED 0.05 (Method*rate)	0.21	0.33	0.17	0.18	0.25	0.21	0.22	0.22	0.24	
CV (%)	5.3	7.2	3.8	4.2	5.8	4.7	5.00	5.3	5.5	

Table iii: Effects of lime and lime placement on soil pH after three cropping seasons in Chimoroni site

Method* rate of lime applied /Days after lime application	**0**	**38**	**68**	**145**	**217**	**258**	**301**	**366**	**518**	**Mean**
Band (2t/ha)	4.37	4.93	5.10	5.28	4.76	4.83	5.06	4.90	4.94	**4.91**
Band (4 t/ha)	4.56	5.18	6.07	5.83	5.39	5.51	5.27	5.09	5.16	**5.34**
Band (6 t/ha)	4.58	5.28	5.77	5.56	5.22	5.68	5.33	5.41	5.26	**5.34**
Band (No lime)	4.44	4.63	4.75	4.90	4.33	4.79	4.76	4.71	4.65	**4.66**
Spot (2 t/ha)	4.59	4.83	5.10	5.05	4.63	4.94	4.84	4.87	4.85	**4.86**
Spot (4 t/ha)	4.52	4.98	5.43	5.59	5.36	5.42	4.92	5.06	5.40	**5.19**
Spot (6 t/ha)	4.67	4.89	6.43	5.55	5.33	5.81	5.32	5.25	5.42	**5.41**
Spot (No lime)	4.56	4.67	4.79	4.93	4.48	4.85	4.64	4.75	4.80	**4.72**
Broadcast (2 t/ha)	4.61	5.07	5.59	5.23	4.85	4.97	5.02	4.89	4.87	**5.01**
Broadcast (4 t/ha)	4.32	5.51	6.10	5.83	5.24	5.43	5.36	5.03	5.27	**5.34**
Broadcast (6 t/ha)	4.49	5.66	6.31	6.02	5.57	5.58	5.56	5.44	5.40	**5.56**
Broadcast (No lime)	4.52	4.77	4.77	4.88	4.47	4.89	4.62	4.84	4.76	**4.72**
Mean	4.52	5.04	5.52	5.39	4.97	5.23	5.06	5.02	5.07	**5.09**
SED 0.05 (Method)	0.07	0.09	0.15	0.14	0.10	0.10	0.10	0.07	0.11	
SED 0.05 (rate)	0.08	0.10	0.17	0.16	0.11	0.11	0.12	0.08	0.12	
SED 0.05 (Method*rate)	0.14	0.18	0.30	0.27	0.19	0.20	0.20	0.14	0.21	
CV (%)	4.5	5.0	7.7	7.2	5.5	5.4	5.6	3.9	6.1	

Table 4.5: Effects of lime and lime placement on soil pH after three cropping seasons in Tumbeni site

Method* rate of lime applied /Days after lime application	0	37	67	145	218	257	301	366	515	Mean
Band (2t/ha)	4.55	4.64	5.09	4.82	4.62	5.04	4.70	4.73	4.67	**4.76**
Band (4 t/ha)	4.64	5.11	5.26	5.41	5.20	5.38	5.23	4.95	5.08	**5.14**
Band (6 t/ha)	4.57	5.50	5.61	5.55	5.50	5.42	5.60	5.19	5.43	**5.37**
Band (No lime)	4.58	4.58	4.74	4.85	4.49	4.81	4.62	4.65	4.67	**4.67**
Spot (2 t/ha)	4.43	4.48	4.83	5.01	4.75	4.78	4.62	4.69	4.75	**4.70**
Spot (4 t/ha)	4.43	4.60	5.11	5.23	4.96	5.01	4.98	4.89	4.97	**4.91**
Spot (6 t/ha)	4.52	4.80	5.28	5.61	5.00	5.47	5.03	5.02	5.14	**5.10**
Spot (No lime)	4.51	4.54	4.71	4.65	4.30	4.66	4.56	4.67	4.49	**4.57**
Broadcast (2 t/ha)	4.40	4.80	4.94	5.15	4.65	5.03	4.73	4.27	4.71	**4.74**
Broadcast (4 t/ha)	4.57	5.68	5.47	5.26	5.53	5.39	5.50	5.09	5.18	**5.30**
Broadcast (6 t/ha)	4.61	5.86	5.39	5.81	5.78	5.82	5.85	5.43	5.47	**5.56**
Broadcast (No lime)	4.60	4.57	4.70	4.75	4.40	4.77	4.61	4.61	4.64	**4.63**
Mean	4.53	4.92	5.10	5.17	4.92	5.12	4.99	4.88	4.89	**4.95**
SED 0.05 (Method)	0.05	0.11	0.12	0.16	0.09	0.09	0.1	0.10	0.05	
SED 0.05 (rate)	0.06	0.12	0.14	0.18	0.10	0.11	0.11	0.12	0.06	
SED 0.05 (Method*rate)	0.11	0.22	0.24	0.32	0.18	0.19	0.19	0.20	0.10	
CV (%)	3.3	6.2	6.5	8.8	5.3	5.2	5.5	2.8	5.8	

Appendix iii: Statistical analysis of the effects of lime rates and its placements on the average grain yield for the three cropping seasons (2010 LR, 2010 SR and 2011 LR) in Ugenya district

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Site	1	6	6.58	0.0426
Method	2	56	3.45	0.0385
Rate	2	56	1.80	0.1748
method*rate	4	56	1.96	0.1127

Least square means

Effect	site	method	rate	Estimate
Site	Sihay			3.8139
Site	Ugenya			4.8103
Method		Band		4.3829
Method		Broad		4.5187
Method		Spot		4.0346
Rate			2t/ha	4.3592
Rate			4t/ha	4.1129
Rate			6t/ha	4.4642
method*rate		Band	2t/ha	4.4950
method*rate		Band	4t/ha	3.8750
method*rate		Band	6t/ha	4.7788
method*rate		Broad	2t/ha	4.3062
method*rate		Broad	4t/ha	4.6775
method*rate		Broad	6t/ha	4.5725
method*rate		Spot	2t/ha	4.2762
method*rate		Spot	4t/ha	3.7863
method*rate		Spot	6t/ha	4.0412

Differences of Least Squares Means

Effect	site	method	rate	_site	_method	_rate	Standard Error	DF	Pr > |t|
Site	Sihay			Ugenya			0.3884	6	0.0426
Method		Band			Broad		0.1901	56	n.s
Method		Band			Spot		0.1901	56	n.s
Method		Broad			Spot		0.1901	56	0.0136
Rate			2t/ha			4t/ha	0.1901	56	n.s
Rate			2t/ha			6t/ha	0.1901	56	n.s
Rate			4t/ha			6t/ha	0.1901	56	n.s
method*rate		Band	2t/ha		Band	4t/ha	0.3292	56	n.s
method*rate		Band	2t/ha		Band	6t/ha	0.3292	56	n.s
method*rate		Band	2t/ha		Broad	2t/ha	0.3292	56	n.s
method*rate		Band	2t/ha		Broad	4t/ha	0.3292	56	n.s
method*rate		Band	2t/ha		Broad	6t/ha	0.3292	56	n.s
method*rate		Band	2t/ha		Spot	2t/ha	0.3292	56	n.s
method*rate		Band	2t/ha		Spot	4t/ha	0.3292	56	0.0356
method*rate		Band	2t/ha		Spot	6t/ha	0.3292	56	n.s
method*rate		Band	4t/ha		Band	6t/ha	0.3292	56	0.0081
method*rate		Band	4t/ha		Broad	2t/ha	0.3292	56	n.s

method*rate	Band	4t/ha	Broad	4t/ha	0.3292	56	0.0180
method*rate	Band	4t/ha	Broad	6t/ha	0.3292	56	0.0386
method*rate	Band	4t/ha	Spot	2t/ha	0.3292	56	n.s
method*rate	Band	4t/ha	Spot	4t/ha	0.3292	56	n.s
method*rate	Band	4t/ha	Spot	6t/ha	0.3292	56	n.s
method*rate	Band	6t/ha	Broad	2t/ha	0.3292	56	n.s
method*rate	Band	6t/ha	Broad	4t/ha	0.3292	56	n.s
method*rate	Band	6t/ha	Broad	6t/ha	0.3292	56	n.s
method*rate	Band	6t/ha	Spot	2t/ha	0.3292	56	n.s
method*rate	Band	6t/ha	Spot	4t/ha	0.3292	56	0.0039
method*rate	Band	6t/ha	Spot	6t/ha	0.3292	56	0.0291
method*rate	Broad	2t/ha	Broad	4t/ha	0.3292	56	n.s
method*rate	Broad	2t/ha	Broad	6t/ha	0.3292	56	n.s
method*rate	Broad	2t/ha	Spot	2t/ha	0.3292	56	n.s
method*rate	Broad	2t/ha	Spot	4t/ha	0.3292	56	n.s
method*rate	Broad	2t/ha	Spot	6t/ha	0.3292	56	n.s
method*rate	Broad	4t/ha	Broad	6t/ha	0.3292	56	n.s
method*rate	Broad	4t/ha	Spot	2t/ha	0.3292	56	n.s
method*rate	Broad	4t/ha	Spot	4t/ha	0.3292	56	0.0090
method*rate	Broad	4t/ha	Spot	6t/ha	0.3292	56	n.s
method*rate	Broad	6t/ha	Spot	2t/ha	0.3292	56	n.s
method*rate	Broad	6t/ha	Spot	4t/ha	0.3292	56	0.0203
method*rate	Broad	6t/ha	Spot	6t/ha	0.3292	56	n.s
method*rate	Spot	2t/ha	Spot	4t/ha	0.3292	56	n.s
method*rate	Spot	2t/ha	Spot	6t/ha	0.3292	56	n.s
method*rate	Spot	4t/ha	Spot	6t/ha	0.3292	56	n.s

Appendix iv: Statistical analysis of the effects of lime rates and lime placements on the average grain yield for the three cropping seasons (2010 LR, 2010 SR and 2011 LR) in North Kakamega district

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Site	1	6	0.02	0.8877
Method	2	56	0.34	0.7159
Rate	2	56	3.73	0.0301
method*rate	4	56	1.87	0.1279

<u>Least square means</u>

Effect	**site**	**method**	**rate**	**Estimate**
Site	Chimoron			2.9575
Site	Tumbeni			3.0142
Method		Band		3.0688
Method		Broad		2.9154
Method		Spot		2.9733
Rate			2t/ha	2.7050
Rate			4t/ha	3.0404
Rate			6t/ha	3.2121
method*rate		Band	2t/ha	2.4163
method*rate		Band	4t/ha	3.2538
method*rate		Band	6t/ha	3.5363

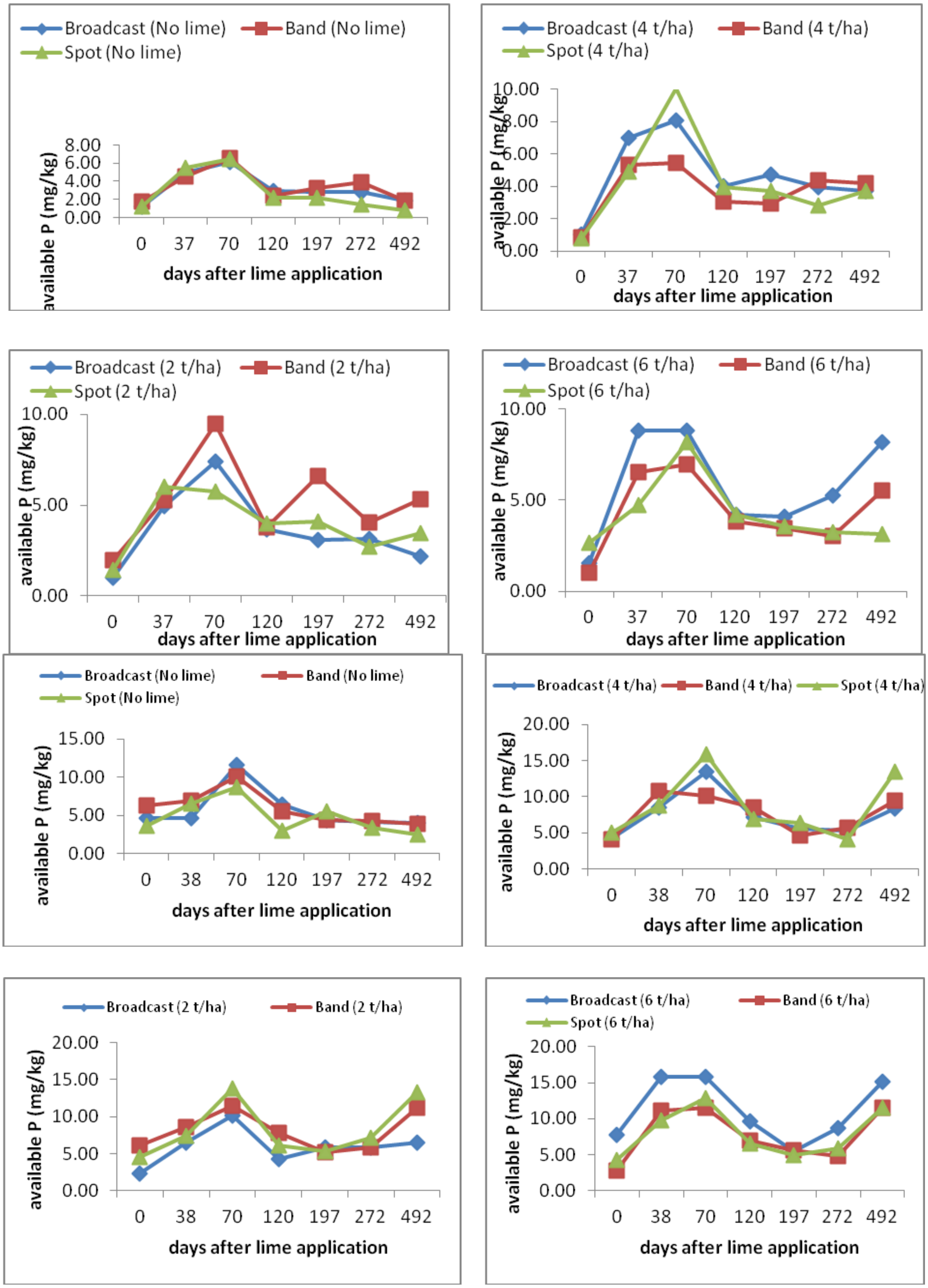
method*rate	Broad	2t/ha	2.6563
method*rate	Broad	4t/ha	2.9875
method*rate	Broad	6t/ha	3.1025
method*rate	Spot	2t/ha	3.0425
method*rate	Spot	4t/ha	2.8800
method*rate	Spot	6t/ha	2.9975

Differences of Least Squares Means

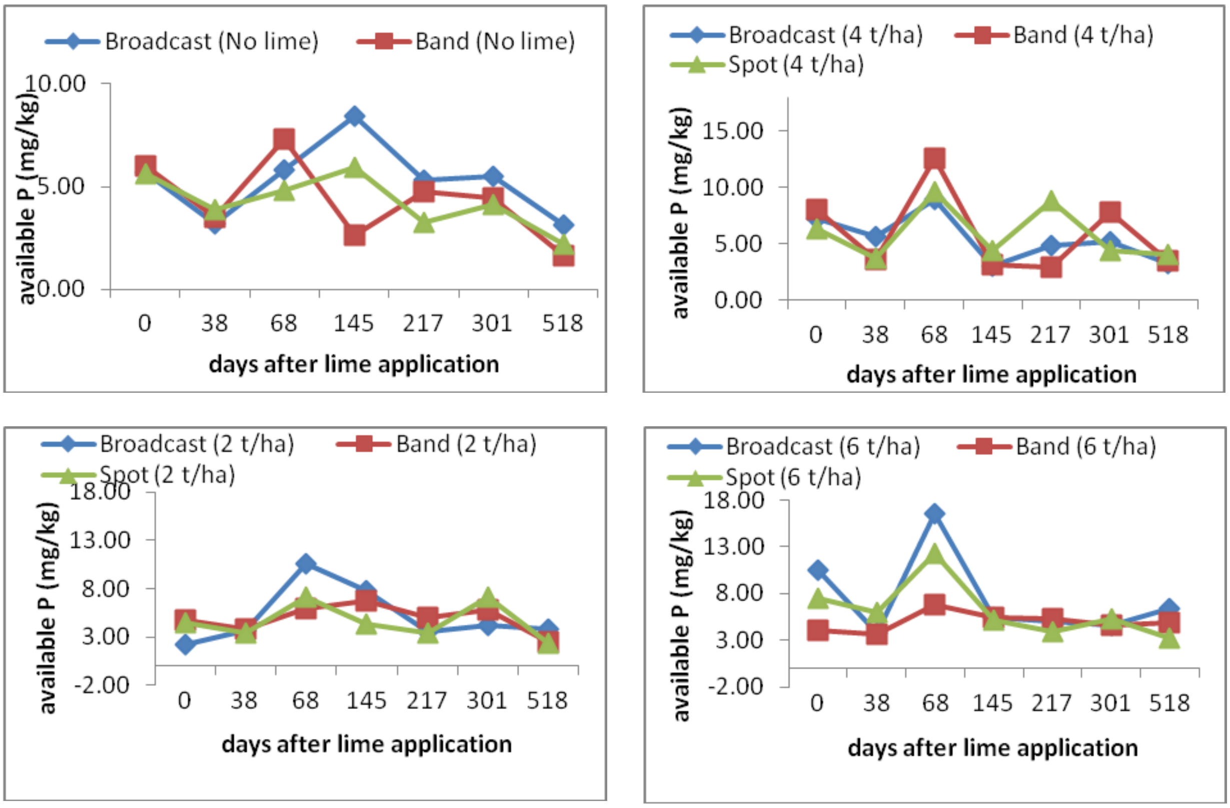
Effect	site	method	rate	_site	_method	_rate	Standard Error	DF	Pr > |t|
Site	Chimoroni			Tumbeni			0.3846	56	n.s
Method		Band			Broad		0.1888	56	n.s
Method		Band			Spot		0.1888	56	n.s
Method		Broad			Spot		0.1888	56	n.s
Rate			2t/ha			4t/ha	0.1888	56	n.s
Rate			2t/ha			6t/ha	0.1888	56	0.0095
Rate			4t/ha			6t/ha	0.1888	56	n.s
method*rate		Band	2t/ha		Band	4t/ha	0.3271	56	0.0132
method*rate		Band	2t/ha		Band	6t/ha	0.3271	56	0.0012
method*rate		Band	2t/ha		Broad	2t/ha	0.3271	56	n.s
method*rate		Band	2t/ha		Broad	4t/ha	0.3271	56	n.s
method*rate		Band	2t/ha		Broad	6t/ha	0.3271	56	0.0404
method*rate		Band	2t/ha		Spot	2t/ha	0.3271	56	n.s
method*rate		Band	2t/ha		Spot	4t/ha	0.3271	56	n.s
method*rate		Band	2t/ha		Spot	6t/ha	0.3271	56	n.s
method*rate		Band	4t/ha		Band	6t/ha	0.3271	56	n.s
method*rate		Band	4t/ha		Broad	2t/ha	0.3271	56	n.s
method*rate		Band	4t/ha		Broad	4t/ha	0.3271	56	n.s
method*rate		Band	4t/ha		Broad	6t/ha	0.3271	56	n.s
method*rate		Band	4t/ha		Spot	2t/ha	0.3271	56	n.s
method*rate		Band	4t/ha		Spot	4t/ha	0.3271	56	n.s
method*rate		Band	4t/ha		Spot	6t/ha	0.3271	56	n.s
method*rate		Band	6t/ha		Broad	2t/ha	0.3271	56	0.0094
method*rate		Band	6t/ha		Broad	4t/ha	0.3271	56	n.s
method*rate		Band	6t/ha		Broad	6t/ha	0.3271	56	n.s
method*rate		Band	6t/ha		Spot	2t/ha	0.3271	56	n.s
method*rate		Band	6t/ha		Spot	4t/ha	0.3271	56	0.0497
method*rate		Band	6t/ha		Spot	6t/ha	0.3271	56	n.s
method*rate		Broad	2t/ha		Broad	4t/ha	0.3271	56	n.s
method*rate		Broad	2t/ha		Broad	6t/ha	0.3271	56	n.s
method*rate		Broad	2t/ha		Spot	2t/ha	0.3271	56	n.s
method*rate		Broad	2t/ha		Spot	4t/ha	0.3271	56	n.s
method*rate		Broad	2t/ha		Spot	6t/ha	0.3271	56	n.s
method*rate		Broad	4t/ha		Broad	6t/ha	0.3271	56	n.s
method*rate		Broad	4t/ha		Spot	2t/ha	0.3271	56	n.s
method*rate		Broad	4t/ha		Spot	4t/ha	0.3271	56	n.s
method*rate		Broad	4t/ha		Spot	6t/ha	0.3271	56	n.s
method*rate		Broad	6t/ha		Spot	2t/ha	0.3271	56	n.s
method*rate		Broad	6t/ha		Spot	4t/ha	0.3271	56	n.s
method*rate		Broad	6t/ha		Spot	6t/ha	0.3271	56	n.s
method*rate		Spot	2t/ha		Spot	4t/ha	0.3271	56	n.s
method*rate		Spot	2t/ha		Spot	6t/ha	0.3271	56	n.s
method*rate		Spot	4t/ha		Spot	6t/ha	0.3271	56	n.s

Appendix v: Effects of lime rates and lime placements on the available P in the four study sites during the cropping seasons

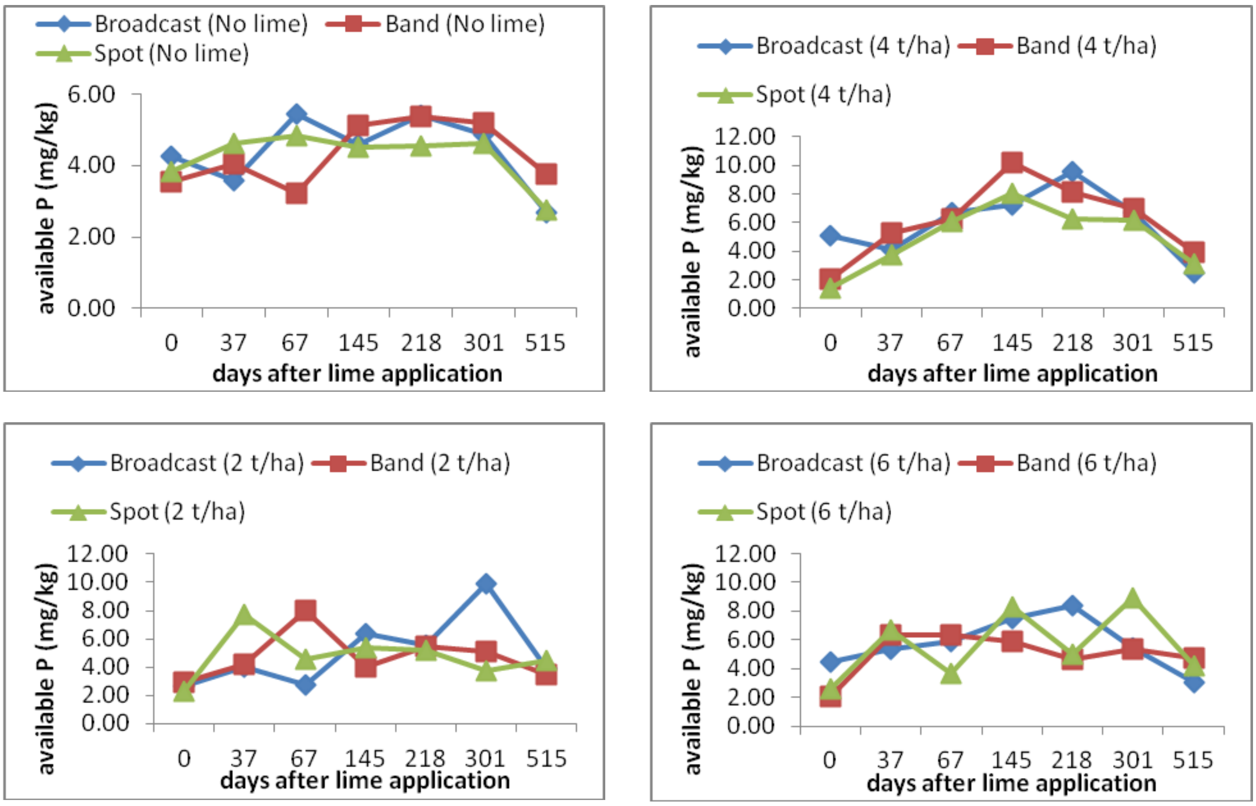
a. **East Ugenya**



c. Chimoroni



d. Tumbeni



Appendix vi: A field layout used in east Ugenya