WHEAT RESPONSE TO PHOSPHORUS FERTILIZERS AND AGRICULTURAL LIME IN UASIN GISHU COUNTY, KENYA

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN SOIL SCIENCE OF THE UNIVERSITY OF ELDORET, KENYA

2016

DECLARATION BY THE CANDIDATE

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DEDICATION

This work is dedicated to my husband Sammy Kosgei, my children Dickson, Nahashon, Solomon and Timothy, my parents Mr. and Mrs. Abraham Simatwo and the entire family members.

ABSTRACT

When water is not limiting, soil acidity, deficiencies of phosphorus (P) and nitrogen (N) amongst others are considered to be the major causes of low wheat yields in Uasin-Gishu County, Kenya. In this County, average annual wheat grain yields have always been low with an average of 2.34 t ha^{-1} but small scale farmers get much lower yields of as low as 0.7 t ha^{-1}. The study aimed at investigating response of wheat growth pattern, grain and straw yields, and soil chemical properties as influenced by liming at 2 t ha^{-1} (main plots), P sources 23:23:0 (NPK), (DAP) 18:46:0, and 0:20:0 (SSP) - (sub-plots) and, P rates (sub sub-plots) P0; 0 kg P ha^{-1}, P1; 8.8 kg P ha^{-1}, P2; 17.6 kg P ha^{-1} and P3; 26.4 kg P ha^{-1}. A split-split plot arrangement laid out in a RCBD experiment was set up in two sites; Chepkoilel and Kipsangui in 4 m^2 plots, replicated 3 times. Data collected on soil (pH, available P, SOC, and exchangeable K, Ca, Mg, Na), plant height, grain, straw yields and plant total P and N were subjected to ANOVA using SAS 9.1 for Windows 2012 statistical package. Lime application increased the soil pH thus likely making P more available in the acidic soils in the two sites and generally increased exchangeable cations K, Mg, Na and Ca thus improving soil fertility. Phosphorus rich fertilizer application resulted in a significant ($p \leq 0.05$) increase in P and soil nutrients content during plant growth, heading and maturity stages. ANOVA showed lime application had a significant ($p \leq 0.05$) rise in the wheat grain yield in both sites. Fertilizer application and liming significantly ($p \leq 0.001$) improved grain yield in both sites. Rates of applied P also significantly ($p \leq 0.001$) influenced wheat grain yields in the two sites. Use of compound fertilizers with balanced ratios of nutrients resulted into increased wheat grain yields. Phosphorus application plus lime at 2 t ha^{-1} had a significant ($p \leq 0.001$) influence on the straw yield in Chepkoilel and Kipsangui. Lime at 2 t ha^{-1} significantly ($p \leq 0.05$) influenced straw yields in Kipsangui and Chepkoilel sites. NPK (23:23:0) fertilizer recorded higher wheat straw means in Kipsangui and Chepkoilel, with DAP giving the lowest yields. Grains' total N in Kipsangui was higher under SSP (1.80 %). There was no significant difference ($p \leq 0.05$) in the level of total N in grain using DAP and 23:23:0 in Kipsangui and Chepkoilel respectively. P uptake was high under P3 application rate plus liming. P uptake was high in both sites. The study recommends 23:23:0 fertilizers at a rate of 26.4 kg P ha^{-1} for Chepkoilel and Kipsangui plus lime at 2 t ha^{-1} as most productive and economical. The study also recommends further research on fertilizer use to further increase wheat grain yields from 5.39 t ha^{-1} to the optimum of 7.2 t ha^{-1}, as the study only managed a 43.0 % wheat grain increase.

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ABBREVIATIONS AND ACRONYMS

AE - Agronomic Efficiency

AGRA - Alliance for Green Revolution in Africa

ANOVA- Analysis of Variance

BBS - Broad Based Survey

BW - Bread Wheat

CAN- Calcium Ammonium Nitrate

DAP- Diammonium phosphate

DNA - Deoxy- Ribo Nucleic acid

ERA - Economic Review of Agriculture

FAO- Food and Agriculture Organization of the United Nations

FURP- Fertilizer Use Recommendation Project

GFB - Gross Financial Benefit

GoK- Government of Kenya

ha - Hectare

IFDC – International Centre for Soil Fertility and Agricultural Development

KARI - Kenya Agricultural Research Institute

KES - Kenya Shilling

Kg- Kilograms

KNBS - Kenya National Bureau of Statistics

KS - Kenya Seed Company

LH3 - Lower Highland three zone

LR - Long-Rains

Mg – Magnesium

MOA - Ministry of Agriculture

MRR - Marginal Rate of Return

NALEP - National Agriculture and National Extension Programme

NEMA - National Environment Management Authority

NFP - Net Financial Benefit

NPK - Nitrogen Phosphorus Potassium

PUE - Phosphorus use efficiency

RNA – Ribo Nucleic Acid

RSA – Republic of South Africa

SSA – sub-Saharan Africa

SOM – Soil Organic Matter

SMH - Smallholder Farmer

SSP- Single Super Phosphate

t - tons

T1 – First tillers

T2 – Second tillers

TVC - Total Value Cost

UNEP- United Nations Environmental Programme

UNESCO- United Nations Educational, Social and Cultural Organization

USDA- United States Department of Agriculture

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisors, Professor J.R. Okalebo, Professor C.O. Othieno and Dr. S. Kebeney for their tireless efforts in making the writing of this thesis a success. Special thanks to laboratory and field technicians Johnson Wambua, Patrick Oluko, Anne and Scholastica for their help during the laboratory and field work. A lot of appreciation to the farmer Mr Joseph Keter and School of Agriculture, University of Eldoret who allowed the research to be conducted on their farms. I also wish to give thanks to my colleagues, Margaret Akinyi and Joel Kiplagat for their encouragement and moral support during the study period.

To God be the glory for forever and ever. Amen

CHAPTER ONE

INTRODUCTION

1.0 Background information

Wheat *(Triticum aestivum* L.) originated from the Near East but now is cultivated worldwide. It is one of the important staple food and a widely cultivated leading cereal crop both in acreage and in production among the grain crops of the world. More than one-third of the world population feed on wheat (Manzoor *et al.,* 2013). However, in developing economies, wheat ranks second, for example in sub Saharan Africa (SSA), its consumption is increasing rapidly, faster than any other major food grain (Mason *et al*, 2012). In 2011, world production of wheat was 695 million tons, making it the second most produced cereal after maize (784 million tons) and rice (464 million tons) (USDA, 2012). Globally, wheat is the leading source of cereal protein in human food, and with higher protein content than either maize (corn) or rice. Its total production tonnage used for food is currently second to rice as the main human food crop, and ahead of maize, after allowing for maize's more extensive use in animal feeds (FAO, 2004). Wheat contains calories, minerals and vitamins which are very essential in a human body as shown in Table 1.1.

Table 1.1: Nutritional value of wheat germ per 100 g

Nutrient	**Quantity**
Energy	1,506 kj (360 kcal)
Dietary fiber	13.2 g
Fat	9.72 g
Protein	23.15 g
Thiamine (Vit. B_1)	1.882 mg
Riboflavin (Vit. B_2)	0.499 mg
Niacin (Vit. B_3)	6.813 mg
Pantothenic acid (B_5)	0.05 mg
Vitamin B_6	1.3 mg
Folate (Vit. B_9)	281 mg
Calcium	39 mg
Iron	6.26 mg
Magnesium	239 mg
Phosphorus	842 mg
Manganese	13.301mg
Zinc	12.29 mg
Potassium	892 mg

Source: Stan Ness, 2010

In Kenya, wheat is the second most important cereal crop after maize and is becoming an important source of food for humans and livestock (Mahagayu *et al.*, 2007; Stan, 2010; FAO, 2011). It is grown mainly in Uasin Gishu, Nakuru, Trans Nzoia and Narok counties of the former Rift Valley Province. Other counties where wheat is grown are Nyeri, Nyandarua, Kiambu and Meru (Nyikal, 2000; Njau *et al.*, 2006). The current national wheat production is approximately 350,000 tons per annum with annual average yields of less than one t ha^{-1} to 2.3 t ha^{-1} from estimated area of about 100,000 to 120,000 ha. This meets only about 49% of the national annual demand that is increasing at 7% (Muasya and Mwakha, 1996; Onsongo, 2003; Njau *et al*, 2006; FAO, 2004). Kenya has large suitable areas for wheat production (Muasya and Mwakha, 1996) which, if well utilized, the country can meet its consumption requirement of approximately 720,000 tons annually (Mahagayu *et al.*, 2007). This deficit in consumption is met through importation, which costs the country about ksh.5.85 billion per year (Mahagayu *et.al*, 2007). Over the years, production of wheat in Kenya has not only been low but also fluctuating while consumption has been on a steady increase leading to importation to meet the deficit as shown in table 1.2.

Table 1.2: Trends in wheat production, consumption and imports in Kenya (2010-2014)

Year	**2010**	**2011**	**2012**	**2013**	**2014**
Production(ton)	511,994	268,482	441,944	449,641	328,637
Consumption (ton)	927,956	942,803.3	957,888	973,214	988,785
Imports (tons)	848,100	1,002,710	1,044,844	1,033,054	1,225,690

Source: Economic Review of Agriculture (ERA), 2015.

Wheat crop is a heavy feeder and thus requires adequate amounts of nutrients, particularly nitrogen (N) and phosphorus (P) hence fertilizer application in optimum quantities is essential to boost its yield. However, the availability and crop response to these nutrients are influenced by properties such as pH of the soil, its organic matter, soil fertility status and cropping patterns (Beegle and Durst, 2012).

Fertilizer recommendation for wheat in Kenya is 46 kg N/ha and 17.6 kg P/ha according to FURP (1994). In areas with acid soils, acid tolerant varieties and liming are recommended (FAO, 2004; Koenig R., 2013).

In Kenya, low production of wheat is partly due to depleted soil nutrients, high cost of inputs, especially to small scale farmers, leading to minimal input use; use of low yield potential varieties, unpredictable weather patterns, especially rainfall and reduced farm sizes (Mahagayu *et al.,* 2007; Mukisira *et al.*, 2012). This scenario is applicable to Uasin Gishu County where wheat yields have been low and fluctuating over the years due to continuous cropping without or with minimal nutrient replenishment, depleted soil nutrients particularly P and N, use of acidifying fertilizers mainly DAP and acidic soils among others.

Table 1.3 presents production trends in Uasin Gishu County

Table 1.3: Wheat production trends in Uasin Gishu for the last 10 years

Year	Achieved Ha	Production (bags)	Bags/ha	t/ha
2006	37,080	1,180,560	32	2.88
2007	31,593	726,639	23	2.07
2008	37,108	1,075,385	29	2.61
2009	26,459	349,472	13	1.17
2010	24,766	619,150	25	2.25
2011	31,290	1,024,755	32	2.88
2012	28,045	711,305	25	2.25
2013	21,385	641,550	30	2.70
2014	18,829	488,395	26	2.34
2015	16,680	417,000	25	2.25
Average			**26**	**2.34**

Source: Ministry of Agriculture (MOA), Uasin Gishu annual reports (from the year 2006 - 2015).

Soils in Uasin Gishu County are Ferralsols and thus are acidic Jaetzold *et al.*, 2011). An acidic soil have a negative effect on crop yields through reduced P availability from P fixation and inhibits root elongation and overall plant development due to Al toxicity (Ligeyo and Gudu, 2005). Agricultural lime was therefore applied as it is widely known as the most effective way of correct soil acidity, increase soil pH and thereby reduce Al, H, Mn, and Fe ions toxicities and increase availabilities of P, Mg, Ca and Mo ions in soils (Kamprath 1984a; Kanyanjua *et al.,* 2002).

After nitrogen, phosphorus is the most important essential plant nutrient affecting growth and quality of wheat, and is invariably supplied in the form of commercial fertilizers (Stewart *et al.*, 2003). It is crucial in metabolism of plants, playing a role in cellular energy transfer, respiration and photosynthesis (Manzoor *et al.*, 2013). The amounts and forms of P in soils are related to soil forming factors including climatic conditions. Soil P forms are categorized as either inorganic or organic (Busman *et al.,* 2009). Although the relative importance of each form is dependent on the environment, desirable variation exists in the plant species and available P within both categories (Giller *et al.*, 2002). Only a small fraction of the total soil P is available to plants depending on the status of the soil, although a large fraction of the soil P is not in active form (Busman *et al.*, 2009). Therefore, the amount and source of P fertilizers used in crop production assume important role in plants. Plants display an array of physiological responses to phosphorus availability, including morphological and architectural responses of root systems that may affect phosphorus acquisition (Giller *et al.,* 2002). Plants further differ in their P use efficiencies. This can be due to their differences in root architecture (that is root length, radius, surface area, hair density, and rate of shoot growth) (Fohse *et al.*, 1991). Although genetic variation in P uptake efficiency has been widely reported in many crops, such as wheat, white lupin and maize (Amanullah *et al*., 2010), the mechanism of P uptake efficiency in wheat and other crop species is not clearly understood. Plant species, as well as genotypes within the species are known to differ in their ability to grow well in soils low in P (Fohse *et al*., 1991). Phosphorus efficiency may arise from differential P uptake efficiency (the ability of plants to acquire P from the soil) or from P use efficiency (the ability of plants to utilize P in shoot for dry matter production) or from a combination of these attributes (Bekele and Hofner, 2004; Beegle and Durst, 2012).

Phosphorous deficiency is invariably a common crop growth and yield limiting factor in unfertilized soils (Amanullah *et al.*, 2010). In West Africa, P-deficiency is a major constraint to crop production on the highly weathered, low activity clay soils in the humid zone (Bell and Edwards, 1991; Diekmann and Fishbeck, 2005).

Decline in *per capita* food production of 7% was observed between 1988 and 1995 in Africa compared to 25% increase in Asia over the same period due to decline in soil fertility, mainly caused by continuous cropping without adequately replenishing the removed soil nutrients. The magnitude of this nutrient depletion problem is particularly felt in developing countries with high population growth rates, e.g. Kenya where 57% of Kenyan rural population is living below poverty line and over 10 million people face food insecurity problem (Giller *et al*., 2002). Most smallholder farmers in Africa, Kenya included, appreciate the value of fertilizers but fertilizer recommendations are normally formulated to cover broad areas with diverse soils. This situation leaves the farmers with no specific package for specific areas and soil types. Farmers also lack information about the best fertilizer and rate to use for their particular fields and cropping practices, making crop response to fertilizers more erratic and less profitable (Cooke *et al.*, 1999).

Most growers are aware of the importance of nitrogen in producing high yielding wheat but few recognize the crucial role phosphorus plays in increasing yields and in improving efficiency of other nutrients like nitrogen and potassium. Table 1.1 further reinforces the high nutritional value of wheat.

1.1 Statement of the Problem

Soil fertility depletion activities over the years have transformed the once fertile lands into infertile ones, thus reducing maize yields to as low as < 1.0 t ha^{-1} due to low P content in Kenyan soils (Sanchez *et al.,* 1997). Continuous cropping without nutrient replenishment has led to subsequently low yields in maize due to low P content in the Kenyan soils (Okalebo, 2009). This scenario is typical of wheat growing soils of Uasin Gishu County where smallholder farmers continuously grow wheat without or with minimal nutrient replenishment due to high costs of fertilizers and lack of enough capital to purchase required quantities of fertilizers (MOA, 2009).

In addition to the above constraints, the wheat crop in this county is mainly grown on ferralsols which are characterized by low pH (soil acidity) and low nutrient levels particularly P and base elements. Inadequate use of inorganic N and P fertilizers to replenish the losses through crop harvests in Kenya is a common practice especially among the small scale farmers and thus has contributed to their deficiencies (Okalebo, 2009).

The national wheat production attained mainly by small scale farmers in Kenya on average ranges from < 1 – 2.3 t ha^{-1} (Muasya and Mwakha, 1996) while in Uasin Gishu county, average wheat yields rages from < 1 – 2.34 t ha^{-1}. These by any standards are quite low given that yields of upto 7.2 t ha^{-1} can be attained in Kenya (Nafuma *et al.*, 2008; Gitau *et al.,* 2010) if water is not limiting and proper soil management practices are employed.

Uasin Gishu County accounts for 40% of the total wheat production area in Kenya (Nanfuma *et al.*, 2008). Unfortunately, there has been a reduction in wheat grain yield to as low as 0.7 t ha^{-1} as mentioned above due to unpredictable weather, continuous use of acidifying fertilizer (DAP), acidic soils, declining soil fertility, poor seed quality, high cost of inputs, low level of technology adoption by wheat farmers and low use of fertilizers particularly P and N, (Nyikal, 2000, Onsongo, 2003; MOA, 2009). About 60% of the wheat farmers in Uasin Gishu are small scale, resource poor farmers who lack adequate capital to purchase recommended rates of fertilizers, (MOA, 2009). N recommendation as per FURP (1994) is 46 kg ha^{-1} of which is being practiced mainly by large scale farmers but small scale farmers apply even low rates not beyond 26 kg N ha^{-1} (MOA, 2009).

Phosphorus application recommendation in the county is a blanket rate of 17.6 kg P ha^{-1} (FURP, 1994). But small scale farmers still apply even lower rates of 8.8 kg P ha^{-1} because of high fertilizer costs beyond their reach, and there is not a more economic package in place for these farmers to increase wheat yields (Mahagayu *et al.,* 2007; MOA, 2009). This, together with the already depleted soil nutrients, has led to declining wheat yields in the County.

There is need for soil P replenishment for increased crop yields (Okalebo, 2009) and so the study therefore, intended to find out the most practical and economic package that would improve the soil nutrient status and increase wheat yields for smallhold farmers.

1.2 Justification

In Kenya, 57% of the rural population is living below poverty line and 35-40% faces food insecurity problem (Giller *et al*., 2002; GoK, 2009). Use of fertilizers and lime on acid and infertile soils is known to improve soil fertility and increase crop yields (Okalebo, 2009; Sanchez *et al.*, 1997). Research work in Kenya has been geared towards high production by high application of fertilizers and targeting large scale farms but not small scale farms (Nziguheba, 2007). Most smallholder farms in Africa, Kenya included, appreciate the value of fertilizers but fertilizer recommendations are normally formulated to cover broad areas with diverse soils and Agro Ecological Zones. Farmers also lack adequate information about the alternative sources of P fertilizers to the famous acidifying DAP fertilizers, to use for their particular fields and cropping practices, making crop response to fertilizers more erratic and less profitable (Nziguheba, 2007). With the extent of nutrient depletion and high level of acidity in Uasin Gishu soils which has led to declining wheat yields, urgent measures need to be taken to restore soil fertility through soil amendments, particularly P fertilizer application and lime to correct acidity and make P more available to plants thereby increasing the yields. This therefore, was the entry point to this research.

It was therefore necessary to find out the most practical and economic package for the farmers and against this background, a study was carried out to achieve the following objectives.

1.3 Research objectives

1.3.1. Overall objective

To evaluate response of wheat yields to different sources, rates of phosphatic fertilizers and agricultural lime for food security and increased incomes to smallholder farmers in Uasin Gishu County, Kenya.

1.3.2. Specific Objectives

1. To determine the effects of inputs on chemical and physical characteristics of soils at the experimental sites.
2. To determine the effect of different P sources, rates and lime on wheat crop performance.
3. To evaluate the effects of inputs on economics of the wheat crop.

1.3.3 Working Hypotheses

1. Different sources and rates of phosphatic fertilizers and agricultural lime have significant effect on soil properties in Uasin Gishu County (**Ha**).
2. Different sources and rates of phosphatic fertilizers and agricultural lime have significant effect on yield and performance of wheat crop (**Ha**).
3. Different sources and rates of phosphatic fertilizers and agricultural lime have significant effect on the economics of wheat (**Ha**).

CHAPTER TWO

LITERATURE REVIEW

2.1 Botany and ecological requirements

Wheat is essentially a temperate climate crop. It grows well in temperatures between 10 and 24^{o}C but high temperature above 35^{o}C stops photosynthesis and growth and at 40^{o}C the crop dies off. For a wheat crop to thrive, it requires minimum amount of water of about 250 mm in the top 1.5 m of soil. For good performance, rainfall of 700 mm to 1000 mm, which is well distributed during the growing season, is necessary (Mahdi *et al.*, 1998 ; MOA, 2009).

Wheat is propagated by seed and because the seeds are small, they require a fine seed-bed that is free of weeds. Land preparation should start at least within two to three months before planting. This is to control weeds and conserve moisture for the crop. Early land preparation allows any weeds to germinate with the first rains, which are destroyed during harrowing, and this greatly reduces the amount of weeds in the wheat crop (Shewry, 2009).

Sowing depth varies from 2 to 12 cm, with deeper planting required in dry conditions. Seed rate varies from 100-150 kg ha^{-1}, resulting in 250-300 plants/m^{2}, depending on variety. Wheat grows in fertile and well drained soils with pH range of 5.5 to 6.5. Like any other crop, wheat does not tolerate weed infestation which effectively competes with it for nutrients, water and light, which leads to yield reduction. To curb this, weeds should be controlled adequately using herbicides. Insects and diseases are controlled using insecticides and fungicides respectively. At maturity, wheat is harvested and dried to a moisture content of about 13% for general commercial purposes (Bibliography of Wheat, 1971 ; Acland, 1972).

2.2 Phosphorus nutrition and crop response to its application

Phosphorus plays an important role in plants. It is crucial in metabolism of plants, playing a role in cellular energy transfer, respiration and photosynthesis. It is also a structural component of the nucleic acids of genes and chromosomes of many coenzymes, phosphoproteins and phospholipids. Phosphorus is just as important as nitrogen for wheat production (Manzoor *et al.,* 2013). Early season phosphorus nutrition is especially critical. Without an adequate phosphorus supply early in its development, wheat experiences growth restrictions from which it may never recover, even if phosphorus supplies become adequate later (Terry, 1998; Phosphate and Potash Institute (PPI), 1999; Bertrand *et al.,* 2003). A growing plant may experience different stages in mineral nutrition, based on balance among internal and external nutrient supplies and crops' demand for nutrients. Plants will initially utilize their seed reserves with external nutrient supply having little effect on plant growth. During the second stage, plant growth rate will be determined by nutrient supply through a dynamic balance between internal plant factors and external (soil) supply (Grant *et al.,* 2001).

Among different factors that affect plant growth, the role of nutrients is well recognised in crop production. Inadequate supply of the essential plant nutrients in soil is a growth limiting factor towards its production. Among all the elements required by a plant, phosphorus (P) is one of the most important nutrients for crop production and emphasis is being given on the sufficient use of P fertilizer for sustainable crop production (Ryan *et al.,* 2002). P is an expensive nutrient as compared to nitrogen (Nisar, 1996). It must therefore be properly managed so as to achieve its maximum use efficiency.

Phosphorus helps roots and seedlings develop more rapidly, promotes early and uniform heading, and hastens crop maturity. It is vital for seed formation and quality and increases water use efficiency (Terry, 1998; White *et al*., 2006).

Wheat produces two kinds of stems: the main stem, and a variable number of tillers. The kinds and numbers of tillers developed by the wheat crop are determined early in the growing season. Phosphorus or nitrogen deficiency can create stresses that reduce the initiation of tillers. Of all the tillers formed, grain from the T1 and T2 tillers (originating from the bases of the first and second leaves, respectively) account for about half of the final yield. The other half comes from the main stem. On nutrient deficient soils, phosphorus fertilization increases phosphorus uptake. Early in the season, when the number of tillers initiated and thus potential yield is being determined, available phosphorus either from soil or fertilizer may account for more than 50 percent of the total phosphorus in the plant. If phosphorus supplies in the plant become deficient, the initiation of T1 and T2 tillers can be significantly inhibited, approximately half of the final yield (White *et al*., 2006).

Researchers in Montana, USA found that phosphorus is responsible for about 75 percent of adventitious root development (Terry, 1998). Adventitious roots grow from the crown as a complement to each new tiller added and dominate the root mass of mature wheat plants. Wheat plant lacking phosphorus is stunted, has poor root growth, and has few tillers. Phosphorus deficiency hampers most physiological processes in the plant including cell division, photosynthesis, and retarded plant growth and reduced root hydraulic conductance and nutrient and moisture uptake (Sharma *et al*., 2002). The production of cereals throughout the world relies on the use of fertilizers to correct natural deficiencies of plant essential elements in the soil and to replace elements which are removed in the products harvested (Sahawarat, 2000; Paulo and Koziowski, 2013). The amount and quality of food produced using phosphate reserves can be increased by improving P fertilizer use efficiency (Van Straaten, 2007).

Wheat has a high demand for phosphorus and hence takes up phosphorus throughout the growing season (Stewart *et al.*, 2003). An average crop removes about 0.101 kg of P for every 27 kg of harvested grains. But when yields are pushed to high levels, phosphate removal can exceed 0.14 kg P per every 27 kg of harvested grains. About 60 to 70 percent of the phosphorus uptake by wheat occurs prior to flowering, so it is important to have a good supply available early in the growing season (Stewart *et al.*, 2003).

A large proportion of soil resource found in the humid and sub-humid tropical areas is acidic and inherently deficient in plant available phosphorus (P). Soil acidity common in these areas is attributed to the abundance of hydrogen (H^+) and aluminum (Al^{3+}) cations in soils including Fe and Mn at levels that interfere with the normal plant growth. Soil acidity negatively affects crop yields mainly by locking up P thus making it unavailable (Okalebo, 2009). Excess Al^{3+} ions tend to accumulate in plant roots and thereby prevent P translocation to the tops from the roots as evidenced by inhibition of root elongation and overall retarded crop development (Kochian, 1995; Kanyanjua *et al.*, 2002; Ligeyo and Gudu, 2005). Cropping soils without fertilizer use under a continuous intensified farming system facilitates nutrient depletion and if not corrected, leads to soil degradation (Okalebo, 2009; Kanyanjua *et al.*, 2002; Van Straaten, 2007).

2.3 Importance of nitrogen nutrition of plants

Nitrogen (N) is the most commonly used mineral nutrient in plants. It is important for protein production. It plays a vital role in many critical functions, such as photosynthesis, in the plant and is a major component of amino acids, the critical element constituent component of proteins. These amino acids are then used in forming protoplasm, the site of cell division and plant growth. Nitrogen is necessary for enzymatic reactions in plants since all plant enzymes are proteins. It is a necessary component of several vitamins, e.g., biotin, thiamine, niacin and riboflavin. N is part of the nucleic acids (DNA and RNA). Nitrogen availability and internal distribution plays a vital role in the regulation of various growth related and morphogenic aspects of plant development that are attributed to hormonal factors, (McIntyre, 2001; Hikosaka, 2004).

The amount of nitrogen applied to plants is expected to ensure that it will be available throughout the growing season, and vegetative and reproductive development will not be restricted (Fritshi and Ray, 2007; Houles *et al*., 2007). Regulation of metabolic and development processes also often depend on N supply. This suggests that sugar and N signaling pathways interact (Paul and Dricoll, 1997; Wingler *et al.,* 2006).

Environmental and weather conditions are factors in the alterations of the performance of natural aging in wheat plants. However, the suitably designed fertilization regime not only affects the balance between growth and development processes, optimal yield formation, but also delays natural senescence in wheat, prolonging the period of intense photosynthesis, completing the source – sink transport, thereby inducing metabolite accumulation and the rise in grain mass, (Salvagiotti and Miralles, 2007; Hikosaka, 2004).

Nitrogen deficient plants tend to be stunted, grow slowly, and produce fewer tillers than normal. Certain N-deficient crops may reach maturity earlier than plants with adequate N. It is therefore necessary to incorporate nitrogen fertilizers during wheat planting (Hikosaka, 2004), towards N sufficiency.

2.4 Soil fertility depletion and global land degradation

Recent studies show that as the world's population continues to increase into the next millennium, it is likely that food security will be a major global challenge (Scherr and Yadav, 1995). Declining soil fertility and land degradation are increasing in severity and extent in many parts of the world with more than 20 % of cultivated areas, 30 % of forests and 10 % of grasslands undergoing degradation, where 22 % of degrading land is in dry sub-humid areas; while 78 % of it is in humid regions, caused mainly by to poor land management. An estimated 1.5 billion people, almost one quarter of the world's population directly depend on the land that is being degraded (Nkonya *et al.,* 2011). Consequently, this has led to reduced productivity, food insecurity, migration, and damage to basic resources and ecosystems. Land degradation also has important implications for climate change mitigation and adaptation, as the loss of biomass and soil organic matter releases carbon into the atmosphere and affects the quality of soil and its ability to hold water and nutrients, (Nkonya *et al.*, 2011; FAO, 2004).

2.4.1 Soil fertility depletion and land degradation in Africa

In Africa, over 180 million people are food insecure, where this food insecurity is related to insufficient food production. Soil nutrient depletion and likely degradation have been considered as serious threats to agricultural productivity and identified as possible major causes of decreased crop yields and *per capita* food production alongside other concomitant problems of weeds, pests and diseases, in SSA (Henao and Baanante, 2006; Sanchez *et al*., 1997). In the tropics, the major soil fertility factors limiting crop production are soil acidity, P and N deficiencies and inherent low soil organic matter (Gudu *et al.,* 2007; Opalla *et al.,* 2010). Over the years, small scale farmers have removed larger quantities of nutrients from their soils without using sufficient quantities of manure or fertilizer to replenish the soil. This has resulted in a very high level of depletion rate of 22 kg of N, 2.5 kg of P and 15 kg of potassium (K) per hectare of cultivated land over the last 50 years (Sanchez, 2002). Over 77% of Africa is affected by soil erosion. Serious soil eroded areas in Africa can be found in RSA, Sierra Leone, Guinea, Ghana, Liberia, Kenya, Nigeria, Zaire, Central African Republic, Ethiopia, Senegal, Mauritania, Niger, Sudan & Somalia (Cooke *et al.,* 1999).

Soils in Africa typically vary in fertility and in how they respond to inputs, (Hossner and Juo, 1999: AGRA, 2007). Most soil resources in Africa have low nutrient levels and are likely to lose nutrients faster due to their fragile nature, (Lal *et al.,* 1993; Juo and Wilding, 1994). According to the World Bank report of 2006, the rate of cereal yield increase in Africa is estimated at 0.7% while in the developing regions of the world, the rate is 1.2 - 2.3% (AGRA, 2007). Owing to these poor trends in productivity, African nations and more so in SSA have to tirelessly work to improve their soil fertility status and increase productivity.

Some studies on land degradation in Africa have provided substantial evidence on nutrient depletion. The International Centre for Soil Fertility and Agricultural Development (IFDC) estimated that Africa loses 8 million metric tons of soil nutrients per year and over 95 million ha of land have been degraded to the point of greatly reduced productivity (Henao and Baanante, 2006). It is also estimated that 65 per cent of SSA's agricultural land is degraded mainly because of soil erosion and chemical and physical degradation (Olderman *et al*., 1991; Scherr and Yadav, 1995). Effective soil fertility restoration interventions have been identified in sub-Saharan Africa (Sanchez *et al.*, 1997; Okalebo *et al.*, 2005), yet the adoption of the technologies remains negligible among small-scale farmers (Woomer *et al.,* 2003). In as much as over-application of inorganic and organic fertilizers has led to environmental contamination in a number of areas in the developed world, insufficient application of nutrients and poor soil management, along with harsh climatic conditions and other factors, have contributed to the degradation of soils in sub-Saharan Africa (SSA) (Batiano *et al.*, 2006). The average intensity of fertilizer use in SSA, excluding South Africa, is about 9 kg N/ha, (FAO, 1998). However, the status of African soils has been a constant challenge for both farmers and agriculturalists and all other stakeholders in the continent. Owing to conflicting interests of various stakeholders in exploitation of soil resources, mismanagement and soil degradation has set in (Omotayo and Chukwuka, 2009). In SSA, soil productivity maintenance remains a major environmental issue (Oyetunji *et al.*, 2009). Poor cultivation practices have resulted in decrease in soil fertility, reduction of soil organic matter (SOM) and increase in occurrence of acidified soils (Aihou *et al.*, 1998). Poor soil conservation methods in SSA are likely to cause long term decline in soil productivity unless soil management practices are instigated.

Phosphorus deficiency is widespread in East Africa and particularly the soils in Western Kenya, 80% of the land held by small scale owners that is used for maize is extremely deficient in phosphorus. In Kenya, the western part is characterized by low agricultural productivity, food insecurity and increasing poverty (Okalebo, 2009). The ongoing increase in population has created pressure on the land, thus the remaining option is to increase production per unit area rather than expansion (Scherr and Yadav, 1995; Sanchez *et al*., 1997).

Wheat growing areas in Kenya are deficient in nitrogen and phosphorus (Rashid *et al.*, 1991). The average loss in soil nutrients is about 112 kg N ha^{-1}, 3 kg P/ha and 70 kg K ha^{-1} per year which is among the largest in Africa (Smaling *et al.*, 1993). The extent of such losses is of sufficient importance that action, such as recapitalization of soil fertility, increased use of inorganic fertilizer, and more efficient recycling of biomass within the farming system are being taken.

2.5 Soil acidity and liming

Soil acidity is known to be a widespread limitation of crop production in many parts of the world including sub-Saharan Africa (SSA) (Sanchez *et al*., 1997). Acid soils occupy about 40% (4 billion ha) of the world soils (von Uexkull and Mutert, 1995) and 29 % of the total land area in SSA (Sanchez *et al*., 1997). In Kenya, acid soils occupy about 13 % (7.5 million ha) of the land area (Kanyanjua *et al.*, 2002). Soil acidity is common in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the surface of soil, (Oluwatoyinbo *et al.*, 2005; Oyetunji *et al.*, 2009), such as soils in western Kenya, (Kanyanjua *et al.*, 2002).

Liming is an ancient agricultural practice for rehabilitating acid soils and it continues to be accepted as an essential step to effective agricultural production in several areas of the humid tropics. Liming and phosphorus applications are common practices for improving crop production in acid soils of tropical as well as temperate regions, (Fageria *et al.*, 2008).

Apart from the general causes of low yields of maize and wheat such as unpredictable weather, poor economies (FAO, 1998), the low wheat yields are due to the widespread nitrogen (N) and phosphorus (P) deficiencies in soils, mainly the acrisols (ultisols) and ferralsols (oxisols). These highly weathered and leached nutrient depleted soils are further made unproductive through their soil acidity (H^{+} $+Al^{3+}$) constraint. Globally, soil acidity is known to limit maize yields in nearly 40% of the arable land (Gudu *et al.,* 2007). This condition is quite applicable to wheat which is also grown in the highlands, and more so in the maize-wheat growing zones in Kenya. Soil acidity has a negative effect on crop yields through reduced P availability from P fixation in soils whereby the iron (Fe) and aluminium (Al) soil components (sesquioxides) fix sizeable quantities of P. Al toxicity on the other hand (mainly in acid soils) inhibits root elongation and overall plant development (Kochian, 1995; Kanyanjua *et al.,* 2002; Ligeyo and Gudu, 2005). Although effective soil fertility restoration interventions have been identified in sub-Saharan Africa (Sanchez *et al;* 1997; Woomer *et al.,* 1998), the adoption of the technologies remains negligible among small-scale farmers (Woomer *et al.,* 2003).

In the Kenyan highlands, particularly west of the Rift Valley, where maize and wheat are mainly grown, parent materials of acidic origin and continuous application of acidifying chemical fertilizers such as diammonium phosphate (DAP) or sulphate of ammonia account for soil acidity (Jaetzold *et al*., 2006; Kanyanjua *et al.,* 2002). High acidity is associated with aluminium (Al), hydrogen (H), iron (Fe) and manganese (Mn) toxicities and corresponding phosphorus (P), molybdenum (Mo) and calcium (Ca), magnesium (Mg) and potassium (K) deficiencies in the soil (Giller *et al.,* 2002). Phosphorus deficiency in SSA soils is due to inherent low soil P, high P fixation by Al and Fe oxides (Buresh *et al.,* 1997), and also due to insufficient fertilizers used to replace P removed in harvested plant products or correct inherent low P (Opalla *et al.,* 2010). High P fixation in acid soils also makes it difficult for plants to utilize the added P fertilizer with high efficiency. Soil acidity constraints reduce grain yield by about 10% of the maize growing areas in tropical developing countries (Scherr and Yadav, 1995). In acid soils of the western Kenya region, Al toxicity and P deficiency (normally below the critical level of 10 mg kg^{-1} soil Olsen P) reduce maize grain yield by about 16% and 28%, respectively (Ligeyo, 2007).

In acid soils and P deficient tropical soils where the plant capacity to utilize the available or use added P with high efficiency is critical, correcting soil acidity and P fertilizer addition is important. Agricultural lime is widely known as the most effective way of correcting soil acidity, increase soil pH and thereby reducing Al, H, Mn, and Fe ions toxicities and increase availabilities of P, Mg, Ca and Mo ions in soils (Kamprath 1984a; Kanyanjua *et al.,* 2002; Moody *et al.,* 1998). Reduction in soil exchangeable Al and Fe results in less P fixation thus making the native and applied P fertilizers available for plant uptake. Therefore, in P fixing acid soils, combined lime and P application is necessary for increased availability of the applied P for plant uptake. Although not permanent, the effect of lime lasts longer than the other soil amendments such as organic and inorganic materials. Lime residual effect depends on how Ca^{2+} and Mg^{2+} ions are being displaced by residual acidity (Al^{3+} and H^{+} ions) (Sanchez *et al*., 1997). Large lime rates normally have longer term residual effect than lower ones, but may also lead to negative effects just like soil acidity (Abruna *et al.,* 1964). Excess lime in the soil increases the pH to high levels such that it ties up other elements like boron, manganese, copper and zinc. Use of high amounts of CaO will increase the levels of calcium in the soil and as a result, other elements including K and Mg will be tied up and made unavailable to plants, causing deficiencies and reduced yields. Plant growth in acid soils with high Al and low P can be improved by the use of plant germplasm tolerant to Al toxicity (Viterello *et al.,* 2005) and/or soil amendment through the use of inorganic fertilizers, manures and lime (Baligar *et al.*, 1997).

The overall effects of lime on soils include among others, increases soil pH, calcium and magnesium saturation, neutralization of toxic concentrations of mainly aluminum. Liming also permits improved water penetration for acidic soils and improves the uptake of major plant nutrients like nitrogen, phosphorus and potassium (Bell and Jeff, 1999; Sarker *et al.,* 2014). Uasin Gishu soils are well known to be acidic and thus require liming to increase the pH levels and improve the nutrient availability and uptake, (Nekesa, 2007).

2.5 Efforts to manage soil fertility

Most of Africa's soils are derived from granite parent rocks through millennia of weathering and contain inherently low levels of plant nutrients (Bationo *et al.*, 2006). Soil fertility is highly variable and so is the response of these soils to inputs. Soil fertility is highly heterogeneous with large on-farm variation within and from field to field and nearly as much variation on a local level across Africa (Zingore *et al.*, 2007). To reverse nutrient depletion and restore soil fertility, scientists in Africa have for so long sought linear solutions in rate-response trials, largely geared at studying the yield increasing effect of mineral fertilizers. Low inherent soil fertility in the highly weathered and leached soils largely accounts for low and unsustained crop yields in most African countries where major nutrients, N and P are commonly deficient in these soils (Okalebo *et al.,* 2007). This scenario of nutrient depletion has caused continuous food insecurity over the years making the affected countries to continuously rely on food aid and more so in sub-Saharan Africa, Kenya included. To curb this problem, a lot of efforts have been made through fertilizer application in Africa to replenish the fertility of degraded soils with an aim of raising crop yields for self-sufficiency and export (Okalebo *et al.*, 2007). As a result, positive crop responses have been obtained in the East African region where maize yields have been raised in one growing season from below 0.5 t/ha without nutrient inputs, to 3–5 t/ha from various nutrient amendments at the smallhold farm level (Scherr and Yadav, 1995). Inorganic resources or fertilizers often give immediate crop responses, but their use is rather restricted to large-scale farmers who can afford to buy these materials (Okalebo *et al.*, 2007).

Long term experiments have played a key role in understanding the changes in soil fertility resulting from changes in land management practices, (Scherr and Yadav, 1995; Sanchez *et al*., 1997). Results from these experiments indicate that there are positive crop yield responses following application of mineral fertilizers on impoverished soils. This potential is recognized by large-scale farmers in Kenya, Zambia, and Zimbabwe who have been able to sustain relatively high yields of cereals such as maize for periods of up to 30 years on the same piece of land (Batiano *et al.*, 2006).

In Kenya, a review of soil fertility research showed nearly one thousand field trials were conducted between 1966-1986 primarily on mineral fertilizers (FURP, 1994), from which blanket recommendations were formulated. Although there is evidence that such recommendations can raise crop yields in the short term (FURP, 1994), recent studies suggest that recommendations based on limiting nutrients result in much higher nutrient use efficiencies than those of blanket fertilizer recommendations (FURP, 1994). To overcome the constraint of low nutrient recovery and optimize fertilizer use, there is need to replace such general and over-simplistic fertilizer recommendations with those that are rationally differentiated according to agro-ecological zones (soils and climate), crop types, nutrient uptake requirement and socioeconomic circumstances of farmers (FURP, 1994).

A 12-year field trial carried out between 1990-2001, to evaluate effects of fertilization on soil fertility under continuous wheat (*Triticum aestivum* L). corn (Zea mays L.) double cropping system in the North China Plain showed that there was a significant increase in total soil nitrogen of top soil (0-20 cm) over time in the treatments with N application, such as NPK, NP and NK treatments and in those of subsoil (20-60 cm) there was no significant difference in all treatments. The changes of available soil N were very similar under each treatment, which increased yearly up to the seventh year when irregular decreases in available soil N were reported. This suggests that N had been utilized by plants within the top 20 cm where there is concentration of the roots causing imbalance in N: P: K ratio. Also, both total soil P and available soil P of topsoil (0-20 cm) increased markedly with time in the treatments with P application such as NPK, NP and PK, while those in subsoil (20-60 cm) remained relatively stable in all the treatments. The changes of total soil K fluctuated very much under each treatment. However, available soil K of topsoil (0-20 cm) increased significantly with time in treatments with K application such as NPK, NK and PK, while levels of K decreased slightly in K-omitted treatments; those in subsoil (20-60 cm) decreased slightly in all treatments showing that plants utilize nutrients within 60 cm in the soil and therefore there is need to replenish the soil with fertilizers so as to restore back the harvested nutrients. With time, soil organic matter in topsoil (0-20 cm) remained relatively stable and soil organic matter in 20-60 cm depth decreased slightly in all treatments. This shows that balanced use of N, P and K is required to maintain soil fertility. Application of P-fertilizers to a wheat crop resulted in increase in plant height, leaf area, grain weight, and grains per ear, straw yields, shelling percentage and harvest index of wheat (Amanullah *et al.*, 2009b). The levels of P applied and its timings of application determine the availability of P to the plants, consequently affecting plant growth and yield (Amanullah *et al,* 2010). In order to achieve sustainable crop production, further research on economical P levels, sources and timing of P management is indispensable.

As reported by Bekele and Hofner (2004), planted barley and rape using various P sources showed marked response in yield, P uptake by both crops as well as available soil P. In another experiment, Sepehr *et al.*, (2009), found that when different maize genotypes were planted using variable rates of P, maize showed significant differences in chlorophyll meter reading, number of tillers, and P concentration and content in plant materials. Sanchez, (2002) worked on optimal P rates for wheat and rice cropping system when various rates of P were applied and reported that grain yield and P accumulation by wheat were highest for larger levels of P rates. Also Zia *et al.,* (2000) concluded during his study that wheat grain yield increased with increasing levels of P over control. Similarly, Hussein (2009) in his study found out that direct application of P increased the yield of wheat by 11.4% to 35%, which was confirmed by Khan *et al.,* (2007) when their study revealed that grain yield of wheat was significantly increased by P fertilization compared with control treatment. According to Ashiono *et al., (*2005), positive responses were recorded in sorghum to P application when yields increased between 12.7% to 175.1%, where maximum yields were achieved with rates between 50-70 kg P/ha while crop response to N application was observed when N was applied ranged from 15.5% -112.4%.

In summary, low soil fertility, soil acidity, high capital costs, continuous use of acidifying fertilizers and inappropriate production technologies, characterize wheat production in Kenya (Mahagayu *et al.*, 2007). These constraints make wheat production a high cost crop thus making Kenya a destination for imported wheat. However, future production increases must come largely from vertical expansion (i.e. greater production per unit area) (Onsongo, 2003; Njau *et al.*, 2006).

2.6 Nutrients Use Efficiency in plants

Nutrient use efficiency (NUE) is a measure to determine crop response to inputs or fertilizers. Various indices are used in agronomic research to assess the efficiency of the applied N and P fertilizers (Hussein, 2009). It is the function of the crop genotype, environmental differences, types, method and time of application of the nutrient and soil factors. The indices are calculated based on differences in crop yield and total nutrient uptake within the above ground mass between fertilized and control plots (Doberman, 2005).

2.6.1 Agronomic efficiency (AE)

Agronomic efficiency is the amount of harvestable product per kg of applied nutrient. It is a measure of grain yield increment per unit kg of the applied nutrient. AE is a product of the efficiency of recovery of the applied fertilizer and the efficiency with which the plant uses each additional unit of the acquired fertilizer. It can be increased with fertilizer additions or soil amendment practices that affect recovery efficiency (Dobermann, 2005)

2.6.2 Physiological efficiency (PE)

The physiological efficiency (PE) is the efficiency with which plant uses each unit of the acquired nutrient from the applied fertilizer to produce grain or stover yield.

The physiological index represents the ability of a plant to transform the nutrient taken up to yield above the control per unit uptake of P or N in the grain (Bowen and Zapata, 1991). It is determined by the following formula:-

$PE = (Y_T - Y_O)/(Uf - U_O)$--2.2

Where

Uf = total nutrient uptake at a certain level of fertilization and

U_O = 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 or straw). It depends on the plant genotype, environmental factors, management practices, particularly during reproductive growth. Low PE is an indication of sub-optimal growth conditions (nutrient deficiencies, drought stress, mineral toxicities, pests and diseases) (Dobermann, 2005)

2.6.3 Phosphorus Use Efficiency (PUE)

Phosphorus use efficiency is the product of P uptake efficiency and P utilization efficiency. It measures the amount of grain produced (mg/plant) per unit of available P in the soil (mg/plant).

2.7 Factors affecting nutrient use efficiency in plants

Inorganic fertilizers are normally applied to the soil so as to provide the crops with the necessary nutrients for good development and grain yield as long as other factors are not limiting (Barber, 1995). However, plant interaction with environmental factors such as solar radiation, temperature, rainfall, deficiency of other nutrients and soil acidity have a greater influence on nutrient use efficiency by plants (Giller *et al*., 2002). Soil amendments may interact to alter the efficiency to capture and use of another resource by plants (Baligar *et al*., 2001). The ways are, short term nutrient interactions, for example, efficient utilization of P it requires N also. Secondly, amelioration of adverse soil conditions such as acidity through use of lime or organic materials and thirdly alteration of soil physical conditions through use of organic matter to increase water capture and storage.

2.8 Economic analysis

For every undertaken agricultural intervention, it is necessary to carry out economic evaluation access performance under farmers' environmental, economic and managerial conditions with the aim of either implementing or revising the proposed technology and make it more consistent with farmers' conditions with the aim of facilitating adoption (Onsongo, 2003). Cost and return analysis are the most commonly used methods for economic analysis of treatment combinations, which are used to determine the impact of a new technology (Nekesa *et al*., 1999; Kisinyo e*t al*., 2009). Parameters used in economic analysis include gross margin analysis (GM), returns to land, labour, capital and value of cost ratios. Gross Margin is used to determine profitability of enterprises produced under alternative technologies or treatments while return to land, labour and capital productivities, are used as measures of performance of technologies. Value to cost ratio refers to the ratio of the total revenue and total variable costs and is usually used as a measure of performance of technologies particularly when capital is a constraint. Net change in income is a technique used in evaluation of costs and benefits that varied from control. The average gross returns and variable costs per unit of land are usually determined on the basis of average market prices, while overland inputs such as land and sunken capital are ignored (Onsongo, 2003). Moreover, the benefit cost analysis remains partial because it ignores the system context in which the technologies relating to the farm extremes should actually be evaluated. However, since the farming system is a superstructure that rests on a function comprising basic resources of land, family labour, fixed capital and animal power, those farming activities can be varied to the limits of these resources without affecting the cost of these basic resources (Ndungu *et al*., 2006).

CHAPTER THREE

MATERIALS AND METHODS

3.1The study area

Field trials were conducted in Kipsangui area, Soy Sub County and in Crop, Seed and Horticultural Science Department Field, University of Eldoret in Moiben sub County. These sub counties have been identified as having acidic soils with N and P deficiencies mainly due to continuous cropping over the years with the use of acidifying fertilizers mainly DAP (Lwayo *et al.,* 2001; Nekesa, 2007). These sites are located in Lower highlands (LH3) agro-ecological zone with favourable climatic conditions for wheat crop production with nearly unimodal rainfall distribution. The soils in the two divisions have been classified as ferralsols which have developed from various parent materials, mixed igneous and metamorphic rocks (FURP, 1994; Jaetzold *et al.,* 2011).

3.2 Uasin Gishu County

Uasin Gishu County is one of the counties in the former Rift Valley province of Kenya. It lies between longitudes 34^0 50’ and 35^0 37 East and latitudes 0.03^o and 0.55’ North. It neighbours, Trans Nzoia to the North, Marakwet and Keiyo to the East, Koibatek to the South East, Kericho to the South, North and South Nandi to the west and Kakamega and Lugari to the North West. The county covers a total area of 3327.8 km^2. There are about 894,179 people, 209,273 households (KNBS, 2010).

Uasin Gishu county has an annual rainfall of between 900 - 1200 mm which occurs in one long season (unimodal) March to September with two peaks in April and August. Humidity is moderate, averaging 56%. The dry spell normally starts in November and ends in February. The temperature ranges from 18^oC during the wet season and 26^oC

during the dry season and normally February and July are the hottest and coolest months respectively**.** Uasin Gishu County is a highland plateau with an altitude varying between 1500 m at Kipkaren to the West to 2100 m, at Timboroa to the East. The County has agro-ecological zones identified as LH_3 – Low highland which occupies the largest part of it and covers Moiben, Kesses, Soy and Kapsaret. Maize and wheat are the major crops. UH_4 – Upper highland covering Turbo (Tapsangoi and Sugoi areas) and is a maize zone. UH_2 – Upper highland covering Timboroa. Wheat and pyrethrum are the main crops. LH_4 – Lower highland covering Moiben, Soy, Kesses, and Kapsaret. Cattle, sheep are reared, and crops grown include wheat and barley (GoK, 2006).

3.2.1 Specific study site description

3.2.1.1 Chepkoilel

The experimental site was in The University of Eldoret farm in Kimumu sub-location, Kimumu location, Moiben sub County, Uasin Gishu County. The area receives a bimodal rainfall distribution pattern with the long rains (LR) starting from March to August while the short rains occur from September to November. The soils from study site are Rhodic ferralsols which are of igneous origin, acidic with pH range of 4.9 - 5.2, are low in fertility and are underlain with murram (FURP, 1994; KARI, 1994). The soils of the area have developed from various parent materials, mixed igneous and metamorphic rocks**.**

3.2.1.2 Kipsangui

The study was also carried out on small hold maize-wheat cropping systems farm, in Kong’asis sub-location, Kipsangui location, Soy sub County of Uasin Gishu County. The area receives a bimodal rainfall distribution pattern with the long rains (LR) starting from March to August while the short rains occur from September to

November. The average annual rainfall received in the area for the last ten years is 1171mm. According to National Agricultural and Livestock Extension Programme Broad Based Survey (NALEP-BBS) report of 2011, the soils are sandy loam. They are classified as Rhodic Ferralsols according to the FAO/UNESCO classification and as Oxisols according to the USDA classification (Jaetzold and Schmidt, 2006, KARI 1994).

3.2.3. Wheat seed, fertilizers and lime used

In the two sites, one certified wheat variety, (Njoro BW2), which is a high yielding variety and fairly resistant to soil acidity and rust, obtained from Kenya Seed Company was planted. Seed rate was 125 kg ha^{-1}, (KARI, 1992). Nitrogen was applied at the rate of 46 kg ha^{-1} in all the treatments except the control. For DAP and 23:23:0, the N supplied in them during planting were subtracted from the recommended 46 kg N ha^{-1} as CAN for topdressing (KARI, 1992).

3.2.4 Determination of lime requirement

Agricultural lime CaO 21% from Koru, Kisumu was applied at the rate of 2 tons ha^{-1}. According to the findings in Kisinyo *et al.*, (2013) in which lime requirement was determined and this rate of application was recommended for areas around Kuinet in Uasin Gishu County.

3.3 The treatments

The experiment recognized the need to improve soil fertility status i.e. nutrient availability of Uasin Gishu County soils for wheat production; hence it evaluated the response of various sources and rates of phosphatic fertilizers and agricultural lime (21% CaO) from Koru Kisumu. Phosphorus was applied at the rates of 0, 8.8, 17.6 and 26.4 kg ha^{-1} from different P fertilizers. These were selected with an aim of addressing the affordability and subsequent adaptation by most small scale farmers while lime was applied at a blanket rate of 2 t ha^{-1} from previous experience in Uasin Gishu (Nekesa, 2007; Kisinyo *et al.*, 2013).

Individual components tested:

1) Control
2) Agricultural lime (CaO 21%)
3) Single Super phosphate 20% P_2O_5 (SSP)
4) Di ammonium phosphate 46% P_2O_5 (DAP)
5) 23:23:0 23% P_2O_5 and 23% N which is sold in the market as NPK

Table 3.1: Treatment combinations as applied at two study sites in Uasin Gishu County

	Lime	**No lime**
SSP	0.0 kg P ha^{-1} + 2 t ha^{-1} CaO	0.0 kg P ha^{-1}
	8.8 kg P ha^{-1}+ 2 t ha^{-1} CaO + 46 kg N ha^{-1}	8.8 kg P ha^{-1}+ 46 kg N ha^{-1}
	17.6 kg P ha^{-1}+ 2 t ha^{-1} CaO + 46 kg N ha^{-1}	17.6 kg P ha^{-1}+ 46 kg N ha^{-1}
	26.4 kg P ha^{-1}+ 2 t ha CaO + 46 kg N ha^{-1}	26.4 kg P ha^{-1}+ 46 kg N ha^{-1}
DAP	0.0 kg P ha^{-1} + 2 t ha^{-1} CaO	0.0 kg P ha^{-1}
	8.8 kg P ha^{-1} + 2 t ha^{-1} CaO + 46 kg N ha^{-1}	8.6 kg P ha^{-1}+ 46 kg N ha^{-1}
	17.6 kg P ha^{-1}+ 2 t ha^{-1} CaO + 46 kg N ha^{-1}	17.6 kg P ha^{-1}+ 46 kg N ha^{-1}
	26.4 kg P ha^{-1} + 2 t ha^{-1} CaO + 46 kg N ha^{-1}	26.4 kg P ha^{-1} + 46 kg N ha^{-1}
NPK (23:23:0)	0.0 kg P ha^{-1} + 2 t ha^{-1} CaO	0.0 kg P ha^{-1}
	8.6 kg P ha^{-1} + 2 t ha^{-1} CaO + 46 kg N ha^{-1}	8.8 kg P ha^{-1} + 46 kg N ha^{-1}
	17.6 kg P ha^{-1} + 2 t ha^{-1} CaO + 46 kg N ha^{-1}	17.6 kg P ha^{-1} + 46 kg N ha^{-1}
	26.4 kg P ha^{-1}+ 2 t ha^{-1} CaO + 46 kg N ha^{-1}	26.4 kg P ha^{-1} + 46 kg N ha^{-1}

Where:

- CaO = Calcium oxide

- Phosphorus supplied as kg P ha^{-1}

3.3.1 Experimental design and layout

A split-split plot arrangement laid out in a Randomized Complete Block Design was used, where; liming and no lime were the main plots, the 3 different P sources (commonly used) were the sub-plots and P rates were the sub-sub plots. The treatments were randomly assigned to plots and replicated three times. There were 24 plots in total per site each measuring 4 m x 4 m, which gave a total area of 16 m^2. Paths between each plot were l m wide while the paths separating each P source and different P levels were 0.5 m. This gave an experimental area of 66 m by 120 m. The field layout and treatment allocations for one replicate are given in table 3.2.

Table 3.2: Experimental Treatment Layout

	Main plot with lime (L1)								Main plot without lime (L0)						
Sub plot 1	L1 A P1		L1 A P0		L1 A P3		L1 A P2		L0 A P3		L0 A P1		L0 A P2		L0 A P0
Sub plot 2	L1 B P0		L1 B P2		L1 B P3		L1 B P1		L0 B P2		L0 B P3		L0 B P0		L0 B P1
Sub plot 3	L1 C P3		L1 C P2		L1 C P1		L1 C P0		L0 C P2		L0 C P1		L0 C P0		L0 C P3

Key:
L0 = No lime; L1 = lime (2 t ha^{-1})
A = SSP
B = DAP
C = NPK
P0 = 0 kg P ha^{-1}
P1 = 8.8 kg P ha^{-1}
P2 = 17.6 kg P ha^{-1}
P3 = 26.4 kg P ha^{-1}

Treatment combinations

L0AP0 L1AP0
L0AP1 LIAP1 SSP source for sub plot 1
L0AP2 L1AP2
L0AP3 L1AP3

L0BP0 L1BP0
L0BP1 L1BP1 DAP source for sub plot 2
L0BP2 L1BP2
L0BP3 L1BP3

L0CP0 L1CP0
L0CP1 L1CP1 NPK source for sub plot 3
L0CP2 L1CP2
L0CP3 L1CP3

This is for Rep 1 hence only a representation.

3.3.2 Installation and management of the experiment

3.3.2.1 Application of treatments

The treatments were applied randomly as given in section 3.3. The three phosphatic fertilizer sources were applied and compared, each at the rates of 0, 8.8, 17.6 and 26.4 kg P ha^{-1}, considered economical to smallholders. Lime was applied in all the treatments in one application in one split plot at the rate of 2 t ha^{-1} (Kisinyo *et al.*, 2013) and the other split plot was without lime.

3.3.2.2 Planting of wheat

Planting was done manually with a row spacing of 20 cm by drill. Prior to planting, measurements for the particular rows were done considering the recommended spacing and pegged accordingly. Using pointed sticks, the rows measuring 2.5 – 3 cm deep were made, then fertilizers were incorporated with the soil and mixed thoroughly. The seeds were then sowed, covered with top soil and slightly compressed to ensure close seed-soil contact for rapid and even germination (Acland, 1971). This gave 19 rows of wheat per plot.

3.3.2.3 Management of the experiment

Hand weeding as well as an herbicide, puma komplete was used to control weeds while pesticides, metasystocks and fungicides, Folicur were used to control pests and diseases respectively.

3.4 Plant heights measurements.

Plant height measurements were taken at the 6th, 8th and10th weeks after planting (i.e. at 2 week intervals). Twenty eight wheat plants were randomly selected and tagged from the central rows in every plot for all the sites for height measurements. This gave a total of 672 tagged plants per block. The height measurements were taken from the ground level to the tip of the longest leaf when the plant and its leaves were held vertically. These data were used to construct the growth curves of wheat for the various treatments and sites, to assess responses.

3.5 Crop harvesting procedures

Physiological maturity of wheat is attained when the flag leaf and spikes turn yellow Zečević *et al*., (2007). At maturity, the wheat was harvested at above the ground level. This was done only on the central rows of each plot leaving out guard rows at the end of each plot, as well as 15 cm from the end of each row. This was done manually on the effective area of 3.5 m x 3.4 m using sickles after which, fresh weights of the straws plus grains for every plot were taken before threshing. Threshing was then done by hand and fresh weights of both grains and straws were taken after which sub-samples of grains and chopped straws were dried in the green house for two weeks and their weights taken and used to compute the yields of straw and grains per plot. The yield was calculated using the relationships:

Yield/plot = (total dry weight* yield/ha)*effective area…………………equation 3.1.

Total fresh weight

3.6 Yield components sampling and chemical analysis

The plants from the harvested area in each plot were separated into wheat grain and straws. Component yields per hectare were determined from the experimental plot yield. The straws were chopped into small pieces (2-5 cm length), weighed, sub-sampled and dried in the green house to attain approximately 13% moisture content for dry matter determination. The dried plant tissues were prepared for chemical analysis to determine N and P contents, and their use efficiencies. The plant samples were ground and 0.3 g of the ground tissues were digested in a mixture of Selenium (Se), Lithium Sulphate ($LiSO_4$), Hydrogen Peroxide (H_20_2) and concentrated Sulphuric acid. The concentrations of N, P in the digest were determined. Total P and N were determined using a colorimetric method using a spectrophotometer. The procedure used for determination of N content was similar to that of soils (Okalebo *et al*, 2002).

3.7 Soil sampling and preparation

3.7.1 Initial soil sampling

Soil samples from each site were taken to determine (characterize) some physical and chemical properties prior to the start of the experiment (Okalebo *et al*., 2002). Ten soil samples were taken from the top 0-20 cm depth randomly from each experimental site using a soil auger and bulked to get a representative or composite sample. These were obtained by thoroughly mixing equal proportions of soil samples from each sampling point of the respective site on a polythene sheet. The soil samples were labeled and taken to the laboratory for analyses, after air drying and sieving.

3.7.2 Subsequent soil samplings

Soil sampling was done at two other crop growth stages, vegetative stage and at harvesting stage to evaluate the effect of various treatments on soil properties as affected by the wheat crop. Sampling was done in each plot and soils placed (about 50 g) in well labeled paper bags after which, the samples were air-dried in the green house before analysis. The air-dried soils were then crushed using a pestle and mortar and passed through 2 mm sieve. The sub-samples from these were further passed through a 60 mm mesh for total N and organic carbon analyses.

3.8 Laboratory analyses

3.8.1 Soil pH Determination

The pH of the soil was determined as outlined in Okalebo *et al.* (2002). Thus, the pH was measured using a pH meter on a glass electrode (1:2:5 soil to water ratio).

3.8.2 Total Organic Carbon (C) Determination

Organic carbon is determined by the sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture. After complete oxidation from the heat of solution and external heating, the unused or residual $K_2Cr_2O_7$ (in oxidation) was then titrated against ferrous ammonium sulphate. The used $K_2Cr_2O_7$, the difference between added and residual $K_2Cr_2O_7$, gives a measure of organic C content of soil. The chemical reaction takes place as:

$$2Cr_2O_7^{2} + 3 C + 16 H^+ = Cr^{3+} + 3 CO_2 + 8 H_20$$

0.5 g of ground (60 mesh) for each soil sample was weighed into a block digester tube. 5 ml potassium dichromate solution and 7.5 ml conc. H_2SO_4 was added. The tubes were placed in a pre-heated block at 145-155°C for exactly 30 minutes. They were then removed and allowed to cool. The digests were quantitatively transferred into 100 ml cornical flasks and 0.3 ml of the indicator solution was added. Using a magnetic stirrer, the digest was titrated with ferrous ammonium sulphate solution; the endpoint was obtained when the colour changed from greenish to brown. The titre was recorded and corrected for the mean of 2 reagent blanks (T).

3.8.3 Available soil phosphorus (P), Olsen et al. (1954) Method

Available P was determined by extraction of soils using 0.5 M sodium bicarbonate ($NaHCO_3$) solution buffered to pH 8.5 (the Olsen extractant). This extractant decreases the concentration of Ca in solution as $CaCO_3$ in calcareous, alkaline and neutral soils containing calcium phosphates. As a result, P concentration will increase in the solution but in acid soils containing Al and Fe phosphates, P concentration in the solution increases as pH rises. Concentrations of Ca, Al and Fe in the extractant solution remain at low levels due to reduced precipitation reactions in acid and calcareous soils. P was then measured by ascorbic acid-based colorimetry using spetrophotometer after a blue colored phosphomolibdate complex was developed as outlined below:

3.8.3.1 Colorimetric measurement of P

The available P was determined by adding sample filtrate, reagent blanks and 10 ml of each P standard solution (0, 0.5, 1, 2.5, 5.0, 10, and 12.5 ppm P) into 50 ml volumetric flasks. Five ml of 0.8 M boric acid was added into each flask to suppress the interference of fluorides and sulphates. Ten ml of ascorbic acid reducing agent was added and the flasks were topped using distilled water to 50 ml mark and shaken well. After one hour, the absorbance was read at 880 nm (Murphy and Riley, 1962). Concentration of ppm P in soil = concentration of P in solution x 100.

3.8.4 Total N and P in plants and soils

Digestion of plant and soil materials is done by oxidation of the organic material into N and P components (NH_4 and phosphates) in H_2SO_4, Hydrogen peroxide, Se and $LiSO_4$ digestion mixture. 0.3 g of dry ground plant material (20 mesh) or soil was weighed into a dry digestion tube and 4.4 ml of digestion mixture including two reagent blanks for each batch of samples. Using a block digester, the mixture was then slowly digested upto a 360^{o} C temperature for three hours until the solution was clear and allowed to cool. The solution was then quantitatively transferred into 50 ml volumetric flasks and topped to mark with distilled water then transferred into 75 ml storage bottles and the mixtures were used to determine both total N and P.

Total N was determined by colorimetric method. Standard solution of 0, 5, 10, 15, 20 and 25 ml was added into 50 ml volumetric flasks. 0.2 ml of the sample was pipetted into labeled test tubes. 5 ml of the reagents N1 (made by dissolving 34 g of sodium salicylate, 25 g of sodium nitrate and 25 g of sodium citrate in about 750 ml of distilled water). 0.12 g of sodium nitroprusside was then added and shaken well and topped to make 1000 ml with distilled water and allowed to stand for fifteen minutes. Five ml of reagent nitrogen was added and well shaken. Absorbance was then read at 655 nm after standing for one hour for colour development.

3.8.5 Soil particle size analysis by Hydrometer method

The soil particle size analysis estimates the percentage sand, silt and clay of the soil. Based on the proportions of different particle sizes, textural classes were assigned to the soil samples. The analysis was performed on air-dry bulk samples from each of the sites mentioned above.

3.8.6 Exchangeable bases

The principle is that a soil sample is extracted with an excess of 1 M NH_4OAc (ammonium acetate) solution such that the maximum exchange occurs between the NH_4 and the cations originally occupying exchange sites on the soil surface. The amounts of exchangeable sodium, potassium, calcium and magnesium in the extract are determined by flame photometry (Na and K) and by atomic absorption spectrophotometry (Ca and Mg). Lanthanum or strontium is added as a releasing agent to prevent formation of refractory compounds, which may interfere with the determinations (e.g. phosphate).

Exchangeable bases were determined by extraction of the soil samples with excess 1M NH_4OAc solution (pH 7.0). The amounts of sodium, potassium calcium and magnesium present in the extracts were then determined by flame photometry (Na and K) and by atomic absorption spectrophotometry (Ca and Mg). Standard curves for K^+, Ca^2 and Mg^{2+} were constructed from which the readings were made from the standard calibration curves.

3.9 Phosphorus use efficiency (PUE)

Calculation and determination of Physiological efficiency as described in chapter 2 section 2.6.2, followed the procedures outlined in Dobermann (2005); where the difference in nutrient uptake at between control and the treatment are divided by the difference in yield between the control and the treatment.

PUE was calculated using the formulae as described by Fageria *et al.* (1997).

$$\text{PUE \%} = \frac{\text{Total P uptake kg/ha - Total P uptake kg/ha in fertilized and control plot}}{\text{P dose applied kg/ ha}} \times 100\%$$

3.10 Agronomic efficiency (AE)

Agronomic efficiency was calculated and determined as described in chapter 2 section 2.6.1 by dividing the amount of P applied by the difference in grain yield (fertilizer) and grain yield (control) as outlined in Dobermann (2005).

AE was calculated using the following equation;

$$AE = \frac{\text{crop yield (kg ha}^{-1}\text{) at a certain level of fertilizer- Crop yield in the control treatment}}{\text{T = the rate of fertilizer applied (kg ha}^{-1}\text{).}}$$

3.11 Data analysis

All the generated wheat data were subjected to analysis of variance (ANOVA) with the split- split plot layout arrangement using SAS 9.1 for windows 2012 statistical package to detect the treatment differences on yields, returns to investment and nutrient uptake and interaction effects on the variables determined for wheat. Correlation analysis was done for the grain yields versus the soil total N, organic carbon, pH and available phosphorus. The standard errors of difference between means (SED) were used to compare the treatment means at statistical significance level of $p \leq 0.05$.

The statistical model equation used for data analysis was:-

Yijkl = μ + Ai + Lj + αij + Pk + APik + βijk + Rl + ARil + RPkl + LRPijkl + λijkl ……equation 3.2 (The University of Pennsylvania State, 2016)

Where:

Yijkl = plot observation

μ= Mean of the plot observation

Ai = main plot effect of lime

Lj= effect of replicate

αij = Main plot error

Pk = effect of P Source

APik = Lime * effect of P source

βijk = Split plot error

Rl= Effect of P-Rate

ARil = P-Rate * Lime interaction

RPkl = P source * P-Rate interaction

LRPijkl = replicate * lime * P source * P-Rate interaction

λijkl = Split split plot error

Table 3.3: Data presentation and skeletal ANOVA

Source of Variation	df
Replicate	2
Lime	1
Error (a)	2
Fertilizer (P source)	2
Lime * Fertilizer (P source)	3
Error (b)	12
P Rates	3
Lime * P Rates	3
P Rates * Fertilizer (P source)	3
Lime* Fertilizer (P source)* P Rates	3
Replicate* Lime* Fertilizer (P source)* P Rates	12
Error (c)	24
Total	71

3.12 Economic analysis for grain yields

Several economic indicators were estimated and used to compare the benefits of producing wheat under the different P application rates at each site. Input data consisted of: labour requirements for land preparation, planting, weed control, application of herbicides and pesticides, harvesting and threshing of wheat grains, same procedure as in (Chikowo *et al.*, 2004; CIMMYT, 1988). Labour was valued using the prevailing wage rate for each site and calculated for each activity per plot and then converted to a unit hectare basis. Prices of inputs such as wheat seeds, DAP, CAN, NPK and SSP were obtained from nearby markets locally. Opportunity cost of capital was estimated as 10% per person, which is the commonly used rate for studies involving resource-poor smallholder farmers (Jama *et al.,* 1998).

The production cost was the product of the prevailing prices of wheat in that particular season. The most economically acceptable treatments were determined by partial budgeting analysis to estimate the gross value of grain by using the adjusted yield at the market value of grain inputs during the cropping year. Here, only costs that vary from the control were referred to as total costs that vary (TCV).

Table 3.4: Values used for costs and benefits analysis (Ksh) during the year 2010

Parameters	Chepkoilel	Kipsangui
DAP Kg/ha applied	132.29	132.29
CAN Kg/ha	143.21	141.78
NPK Kg/ha applied	135.62	135.62
SSP Kg/ha applied	131.55	131.55
Price CAN/ha	89.15	89.15
Transporting 50 kg of fertilizer to the experimental farm	23.00	24.00
Cost of sacks for grain storage	25.00	21.77
Labour costs		
Planting and application of P or CAN fertilizer/ha	150.00	100.00
Cost of harvesting 1 bag of maize cobs or beans	30.00	20.00
Cost of shelling one bag of maize or beans grains	45.00	35.00
Price of maize grain/ kg	40.00	30.00
Opportunity cost of Capital (%)	10.00	10.00

Yield data were adjusted downward by 10% since research has found out that farmers using the same technologies would obtain 10% yield lower than those obtained by researchers (Kipkoech *et al.*, 2006) The discounted rate of capital was determined at the rate of 10 and 20% per season and year, respectively and was applied to cash costs only. The discounted rate reflects the farmer’s preference to receive benefits as early as possible and to postpone costs. All costs and benefits were converted to monetary values in Kenya Shilling (Ksh) and reported on a per hectare basis (CIMMYT, 1988). The net accrued net financial benefits (NFBs) and TCV were then compared across the treatments dominance analysis the formula:

$$\mathbf{NFBs} = (\mathbf{Y} * \mathbf{P}) - \mathbf{TCV}$$

Where;

(Y$*$ P) = Gross Field Benefit (GFB),

Y=Yield per ha and

P=Field price per unit of the crop.

Treatment with less than or equal to treatment with lower TCV are dominated (CIMMYT, 1988). Treatments with higher NFB than the treatments and lower TCV are undominated. Since the control treatments (conventional tillage and continuous maize-bean intercropping without N fertilizer application) had no input of fertilizers, TCV of the treatments were compared to the TCV of the control. This was done to determine the most economical treatment.

CHAPTER FOUR

RESULTS

4.1 Soil characteristics of the study sites prior to treatment applications

The initial chemical and physical characterization of the top 0-20 cm soils from the two sites showed that Chepkoilel site had strongly acidic sandy clay loam soil with pH of 4.62 and Kipsangui site had a moderately acidic (pH 5.02) sandy loam soil (Table 4.1).

Table 4.1: Physical and chemical characteristics of surface soils (0-20 cm depth) taken before planting (2010 LR) at two experiment sites in Uasin Gishu County, Kenya

Soil property	Chepkoilel	Kipsangui
% sand	74	66
% Clay	22	12
% silt	4	22
Textural class	Sandy Clay Loam	Sandy Loam
pH (1:2:5 H_20)	4.62	5.02
% SOC	1.02	1.27
% total N	0.105	0.124
cmol P kg soil	4.16	2.96
cmol K kg of soil	1.87	4.04
cmol Ca kg of soil	3.72	5.24
cmol Na kg of soil	2.09	2.06
cmol Mg kg of soil	16.9	18.54

The levels of exchangeable cations and Phosphorus levels in both Chepkoilel and Kipsangui sites were low except for K according to (Okalebo *et al.,* 2002), indicating P nutrient depleted soils, with moderate % N and % SOC levels (Table 4.1) (Kanyanjua *et al.,* 2002).

4.2 Effects of Lime, fertilizer and P rates on soil parameters (0 – 20 cm depth)

4.2.1 Effects of Lime, fertilizer and P rates on soil pH (1:2:5)

The results indicate that there was an increase in soil pH in response to P sources, rates and lime application across the study sites.

Results show that fertilizer and P rates in combination with lime application had no significant effect on soil pH in Chepkoilel site both at vegetative and at harvesting stages. However, lime application improved the soil pH.

Table 4.2 presents the results on the effects treatments on soil during vegetative stage in Kipsangui site.

Table 4.2: Soil pH (1:2:5) at vegetative stage in Kipsangui site

	L0				**L1(2 t/ha)**				**P-Rate Overall Mean**
Treatments	**DAP**	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	4.92	4.92	4.92	**4.92**	5.67	5.67	5.67	**5.67**	**5.30**
8.8	5.46	5.60	5.58	**5.55**	5.87	6.03	6.04	**5.98**	**5.77**
17.6	5.45	5.55	5.57	**5.52**	5.12	6.07	5.89	**5.69**	**5.61**
26.4	5.41	5.54	5.58	**5.51**	5.66	6.09	5.88	**5.88**	**5.69**
mean	**5.31**	**5.40**	**5.41**		**5.58**	**5.97**	**5.87**		
Lime mean				**5.38**				**5.81**	
Overall fertilizer mean					**5.45**	**5.68**	**5.64**		
	SE	**$LSD_{(0.001)}$**							
Lime	0.037	*							
Fertilizer	0.058	***							
P-Rate	0.038	ns							
Lime*Fert	0.080	ns							
Lime*PRate	0.059	ns							
Fert*PRate	0.079	ns							
Lime*Fert*PRate	0.110	ns							
%CV		12.3							

**significant at p≤0.05, ***significant at p≤0.001, ns; not significant (DAP- Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0 – no lime, L1-Lime application at 2t/ha)*

Lime application at 2 t ha^{-1} in Kipsangui site had a significant influence ($p \leq 0.05$) on soil pH at vegetative stage, resulting to a soil pH of 5.81. This was high as compared to no-lime with a soil pH of 5.38. Fertilizer application significantly affected ($p \leq 0.001$) the pH levels of Kipsangui soils at vegetative stage (Table 4.4).

Among the fertilizers, NPK (23:23:0) gave the highest mean soil pH of 5.97 in combination with liming at 2 t ha^{-1}.

Results on effects of treatments on soil pH at harvesting stage in Kipsangui are presented in Table 4.3.

Table 4.3: Soil pH at harvesting stage in Kipsangui site

Treatments	L0				L1 (2 t/ha)				P-Rate Overall Mean
	DAP	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	5.27	5.27	5.27	**5.27**	5.54	5.54	5.54	**5.54**	**5.41**
8.8	5.49	5.49	5.52	**5.50**	5.57	5.56	5.63	**5.59**	**5.54**
17.6	5.39	5.50	5.53	**5.47**	5.63	5.72	5.90	**5.75**	**5.61**
26.4	5.39	5.44	5.57	**5.47**	5.59	5.65	5.72	**5.65**	**5.56**
mean	**5.39**	**5.43**	**5.47**		**5.58**	**5.62**	**5.70**		
Lime mean				**5.43**				**5.63**	
Overall fertilizer mean					**5.48**	**5.52**	**5.59**		
	SE	**$LSD_{(0.05)}$**							
Lime	0.033	*							
Fertilizer	0.029	***							
P-Rate	0.028	ns							
Lime*Fert	0.049	ns							
Lime*PRate	0.048	ns							
Fert*PRate	0.049	ns							
Lime*Fert*PRate	0.074	ns							
%CV		7.8							

**significant at $p \leq 0.05$, ***significant at $p \leq 0.001$, ns; not significant (DAP- Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2t/ha)*

At harvesting, there was a significant effect ($p \leq 0.05$) where liming at 2 t ha^{-1} recorded the highest soil pH mean of 5.63 while no lime had a soil pH of 5.43 in Kipsangui site (Table 4.3). Fertilizer application had a significant effect ($p \leq 0.001$) on soil pH; results show SSP fertilizer at the rate of 17.6 kg P ha^{-1} with lime increased the levels of soil pH in comparison to control although this was not significant.

4.2.2 Effects of Lime, fertilizers and P rates on soil total nitrogen

The data derived showed that fertilizer source, P rate and lime application had no significant effect on % N levels in Chepkoilel soil both at vegetative and at harvesting stage, although lime application at 2 t ha^{-1} gave slightly higher levels of soil total N in both stages.

Table 4.4 presents results on soil total N (%) at vegetative stage in Kipsangui study site.

Table 4.4: Soil's total N (%) at vegetative stage in Kipsangui site

	L0				L1				P-Rate Overall Mean
Treatments	**DAP**	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	0.137	0.137	0.137	**0.137**	0.148	0.148	0.148	**0.148**	**0.143**
8.8	0.148	0.153	0.138	**0.146**	0.158	0.156	0.148	**0.154**	**0.150**
17.6	0.167	0.152	0.147	**0.155**	0.162	0.148	0.151	**0.154**	**0.155**
26.4	0.150	0.153	0.144	**0.149**	0.196	0.151	0.160	**0.169**	**0.159**
mean	**0.151**	**0.149**	**0.142**		**0.166**	**0.151**	**0.152**		
Lime mean				**0.147**				**0.156**	
Overall fertilizer mean					**0.158**	**0.150**	**0.147**		

	SE	**LSD$_{(0.05)}$**
Lime	0.002	ns
Fertilizer	0.004	**
P-Rate	0.003	ns
Lime*Fert	0.005	ns
Lime*PRate	0.004	ns
Fert*PRate	0.006	ns
Lime*Fert*PRate	0.008	ns
%CV		14.2

***significant at p≤0.01, ns; not significant (DAP -Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2t/ha)*

The total N levels in Kipsangui soils improved with liming and P application as opposed to no lime despite there being no significant effect (Table 4.4). Fertilizer application had a significant effect (p≤0.01) on % N. At harvesting, results on effects of lime, fertilizer source and P rates on total N (%) of Kipsangui site showed that there was no significant effect on the levels of total N at this stage.

4.2.3 Effects of lime, fertilizer source and P rates on soil organic carbon (SOC)

Results indicate that fertilizers, P rates and lime application significantly influenced the levels of Soil Organic Carbon (SOC) in Chepkoilel soil at vegetative stage, with both SSP and P application rate at 8.8 kg ha^{-1} together with lime application at 2 t ha^{-1} recording higher means of SOC at vegetative stage of the crop at Chepkoilel site (Table 4.5). A mean of 4.58% C was recorded under this treatment.

Table 4.5: SOC (%) at vegetative stage in Chepkoilel site

	L0				**L1 (2 t/ha)**				**P-Rate Overall Mean**
Treatments	**DAP**	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	1.93	1.93	1.93	**1.93**	3.38	3.38	3.38	**3.38**	**2.56**
8.8	2.38	2.65	2.34	**2.46**	3.41	4.40	4.58	**4.13**	**2.43**
17.6	2.34	2.59	2.55	**2.49**	3.72	4.16	4.17	**3.88**	**2.39**
26.4	2.81	2.52	2.48	**2.60**	3.69	4.04	4.16	**3.96**	**2.33**
mean	**2.37**	**2.42**	**2.33**		**3.55**	**4.00**	**4.07**		
Lime mean				**2.37**				**3.87**	
Overall fertilizer mean					**2.96**	**3.21**	**3.20**		
	SE	**$LSD_{(0.05)}$**							
Lime	0.062	*							
Fertilizer	0.068	***							
P-Rate	0.066	**							
Lime*Fert	0.103	***							
Lime*PRate	0.101	***							
Fert*PRate	0.115	***							
Lime*Fert*PRate	0.167	***							
%CV		12.4							

**significant at p≤0.05, **significant at p≤0.01, ***significant at p≤0.001, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

The results show that liming improved significantly ($p \leq 0.05$) the SOC in Chepkoilel soils at vegetative soil sampling stage. This is evident with a mean of 3.87% as compared to no-lime treatment mean of 2.37% (Table 4.5). Results show that fertilizer application and P rate in combination with lime application at 2 t ha^{-1} significantly ($p \leq 0.001$) increased SOC. Liming with SSP at the rate of 17.6 kg P ha^{-1} significantly ($p \leq 0.001$) increased (+ 2.62% SOC) in comparison to no lime with the same fertilizer and rate (Table 4.10). The results further indicate a decreasing increase of % SOC with increase with P rate (26.4 kg P ha^{-1}) with lime application at vegetative stage (Table 4.10). From the results, interaction of lime, fertilizer and rates of applied P significantly ($p \leq 0.001$) influenced the levels of % SOC at vegetative stage in Chepkoilel site (Table 4.5).

Results on effect of fertilizer source and P rate in combination with lime at 2 t ha^{-1} on % SOC at harvesting stage in Chepkoilel site are presented in table 4.6.

Table 4.6: SOC (%) at harvesting stage in Chepkoilel site

Treatments	L0				L1 (2 t/ha)				P-Rate Overall Mean
	DAP	NPK	SSP	Mean	DAP	NPK	SSP	Mean	
P-Rate (kg P/ha)									
0	1.04	1.04	1.04	**1.04**	1.46	1.46	1.46	**1.46**	**1.40**
8.8	1.61	1.87	1.64	**1.71**	1.56	1.87	1.64	**1.69**	**1.70**
17.6	1.08	1.86	1.74	**1.56**	1.49	1.96	2.04	**1.83**	**1.80**
26.4	1.70	1.71	1.73	**1.71**	1.82	1.91	1.93	**1.89**	**1.87**
mean	**1.36**	**1.62**	**1.54**		**1.58**	**1.80**	**1.77**		
Lime mean				**1.51**				**1.72**	
Overall fertilizer mean					**1.47**	**1.71**	**1.65**		
	SE	**LSD$_{(0.05)}$**							
Lime	0.017	ns							
Fertilizer	0.012	***							
P-Rate	0.034	ns							
Lime*Fert	0.022	***							
Lime*PRate	0.046	ns							
Fert*PRate	0.050	ns							
Lime*Fert*PRate	0.072	**							
%CV		5.8							

***significant at p≤0.01, ***significant at p≤0.001, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2t/ha)*

During harvesting stage, results show that lime application at 2 t ha^{-1} did not significantly influence the levels of SOC of Chepkoilel soils (Table 4.6). P fertilizer source in combination with lime application indicated a significant ($p \leq 0.001$) difference on SOC. Results further indicate a significant ($p \leq 0.01$) influence on SOC with interactions of lime, fertilizer and P rates (Table 4.6).

Table 4.7 presents the results on the levels of SOC (%) during vegetative stage in Kipsangui study site as influenced by lime, fertilizer and rates of P application.

Table 4.7: SOC (%) at vegetative stage in Kipsangui site

Treatments	L0				L1 (2 t/ha)				P-Rate Overall Mean
	DAP	NPK	SSP	Mean	DAP	NPK	SSP	Mean	
P-Rate (kg P/ha)									
0	2.07	2.07	2.07	**2.07**	2.14	2.14	2.14	**2.14**	**2.11**
8.8	2.42	2.40	2.38	**2.40**	2.44	2.48	2.46	**2.46**	**2.43**
17.6	2.39	2.34	2.15	**2.29**	2.47	2.50	2.50	**2.49**	**2.39**
26.4	2.36	2.49	2.16	**2.34**	2.50	2.76	2.56	**2.61**	**2.47**
mean	**2.31**	**2.33**	**2.19**		**2.39**	**2.47**	**2.42**		
Lime mean				**2.28**				**2.42**	
Overall fertilizer mean					**2.35**	**2.40**	**2.30**		
	SE	**LSD$_{(0.05)}$**							
Lime	0.006	*							
Fertilizer	0.042	*							
P-Rate	0.030	ns							
Lime*Fert	0.052	ns							
Lime*PRate	0.037	ns							
Fert*PRate	0.060	ns							
Lime*Fert*PRate	0.079	ns							
%CV		12.3							

**significant at p≤0.05, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

Results from the data show that application of lime at 2 t ha^{-1} significantly (p≤0.05) influenced SOC (%) in Kipsangui study site at vegetative stage (Table 4.12). Fertilizer source and lime application had a significant (p≤0.05) difference on SOC (%) at vegetative stage in Kipsangui site (Table 4.7).

During harvesting stage, results show that SOC (%) levels were lower in Kipsangui compared to vegetative stage (Table 4.8).

Table 4.8: SOC (%) at harvesting stage in Kipsangui site

Treatments	L0				L1 (2 t/ha)				P-Rate Overall Mean
	DAP	NPK	SSP	Mean	DAP	NPK	SSP	Mean	
P-Rate (kg P/ha)									
0	2.04	2.04	2.04	**2.04**	2.17	2.17	2.17	**2.17**	**2.11**
8.8	2.11	2.27	2.28	**2.22**	2.24	2.18	2.23	**2.22**	**2.22**
17.6	2.12	2.23	2.09	**2.15**	2.29	2.29	2.32	**2.30**	**2.22**
26.4	2.14	2.23	2.10	**2.16**	2.34	2.46	2.37	**2.39**	**2.27**
mean	**2.10**	**2.19**	**2.13**		**2.26**	**2.28**	**2.27**		
Lime mean				**2.14**				**2.27**	
Overall fertilizer mean					**2.18**	**2.23**	**2.20**		
	SE	**$LSD_{(0.05)}$**							
Lime	0.032	ns							
Fertilizer	0.037	***							
P-Rate	0.029	**							
Lime*Fert	0.055	ns							
Lime*PRate	0.048	ns							
Fert*PRate	0.055	ns							
Lime*Fert*PRate	0.08	ns							
%CV		7.8							

significant at p≤0.01,significant at p≤0.001, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

Results indicate that fertilizer application had a significant (p≤0.001) influence on the levels of SOC (%) in Kipsangui at harvesting stage. Also, the rate of P application had a significant effect (p≤0.01) on SOC (%) levels (Table 4.8). NPK (23:23:0) fertilizer with lime and application rate of 26.4 kg P ha^{-1} gave the highest (2.76) levels of SOC (%) at harvesting stage in Kipsangui (Table 4.8).

4.2.4 Effect of Lime, Fertilizer source and P rates on soil available phosphorus

Results on the influence of fertilizer and P rates in combination with lime application on soil available P in Chepkoilel site during vegetative stage are presented in Table 4.9.

Table 4.9: Soil available P (cmol P/kg of soil) at vegetative stage in Chepkoilel site

Treatments	L0				L1 (2 t/ha)				P-Rate Overall Mean
	DAP	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	4.32	4.32	4.32	**4.32**	5.12	5.12	5.12	**5.12**	**4.72**
8.8	5.28	5.72	7.49	**6.16**	7.62	16.95	8.40	**10.99**	**8.58**
17.6	5.41	5.98	7.53	**6.31**	5.88	14.50	10.92	**10.43**	**8.37**
26.4	5.76	5.15	8.64	**6.52**	7.49	19.21	12.08	**12.93**	**9.72**
mean	**5.19**	**5.29**	**7.00**		**6.53**	**13.95**	**9.13**		
Lime mean				**5.83**				**9.87**	
Overall fertilizer mean					**5.86**	**9.62**	**8.06**		
	SE	$LSD_{(0.05)}$							
Lime	0.207	*							
Fertilizer	0.234	***							
P-Rate	0.251	**							
Lime*Fert	0.353	***							
Lime*PRate	0.370	***							
Fert*PRate	0.424	***							
Lime*Fert*PRate	0.613	**							
%CV		10.9							

significant at p≤0.05, **significant at p≤0.01,*significant at p≤0.001, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

Lime application at 2 t ha^{-1} realized a significant ($p \leq 0.05$) influence on the levels of soil available P in Chepkoilel at vegetative stage (Table 4.9)

Results also show that fertilizer application had a significant ($p \leq 0.001$) influence while rates of P applied had a significant ($p \leq 0.01$) influence on the levels of soil available P. The interactions of lime, fertilizer and rates of P application had a significant ($p \leq 0.01$) influence soil available P levels at vegetative stage in Chepkoilel site (Table 4.9). Results also show that NPK (23:23:0) at a rate of 26.4 kg P ha^{-1} gave the highest level, 19.21 of soil available P in Chepkoilel at vegetative stage (Table 4.9)

During harvesting stage, results indicate that lime, fertilizer and rates of P applied influenced the levels of soil available P in Chepkoilel study site (Table 4.10).

Table 4.10: Soil available P (cmol P/kg of soil) at harvesting stage in Chepkoilel site

Treatments	L0				L1				P-Rate Overall Mean
	DAP	NPK	SSP	Mean	DAP	NPK	SSP	Mean	
P-Rate (kg P/ha)									
0	1.63	1.63	1.63	**1.63**	2.35	2.35	2.35	**2.35**	**1.99**
8.8	2.08	4.23	7.67	**4.66**	2.83	10.44	3.19	**5.49**	**5.07**
17.6	1.33	8.53	6.55	**5.47**	3.10	12.57	8.71	**8.13**	**6.80**
26.4	2.60	8.79	8.82	**6.74**	2.67	15.83	13.95	**10.82**	**8.78**
mean	**1.91**	**5.80**	**6.17**		**2.74**	**10.30**	**7.05**		
Lime mean				**4.62**				**6.70**	
Overall fertilizer mean					**2.32**	**8.04**	**6.61**		

	SE	$LSD_{(0.05)}$
Lime	0.063	**
Fertilizer	0.070	***
P-Rate	0.067	***
Lime*Fert	0.106	***
Lime*PRate	0.104	***
Fert*PRate	0.118	***
Lime*Fert*PRate	0.171	***
%CV		6.9

****significant at p≤0.001, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

From the results obtained at harvesting time (Table 4.10), lime application at 2 t ha^{-1} had significant ($p\leq0.01$) influence on the levels of soil available P in Chepkoilel at harvesting stage. Results further show that all the other experimental treatments and their interactions had a highly significant ($p\leq0.001$) effect on available soil phosphorus in the soils of Chepkoilel. There was an increase in soil available P in Chepkoilel soils at harvesting stage concurrent with an increase in P application rates (Tables 4.10).The phosphorus application at a rate of 26.4 kg P ha^{-1} resulted into higher mean levels of available phosphorus in Chepkoilel soils irrespective of the P sources (Table 4.10).

Results on the influence of lime, fertilizer and rates of P application on soil available P during vegetative stage at Kipsangui site are presented in table 4.11.

Table 4.11: Soil available P (cmol P/kg of soil) at vegetative stage in Kipsangui site

Treatments	L0				L1				P-Rate Overall Mean
	DAP	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	3.81	3.81	3.81	**3.81**	4.03	4.03	4.03	**4.03**	**3.92**
8.8	5.08	5.20	5.08	**5.12**	5.62	5.90	5.74	**5.75**	**5.44**
17.6	6.01	4.13	4.20	**4.78**	5.71	6.44	6.41	**6.19**	**5.48**
26.4	6.99	5.05	5.21	**5.75**	5.74	6.92	6.90	**6.52**	**6.14**
mean	**5.47**	**4.55**	**4.58**		**5.28**	**5.82**	**5.77**		
Lime mean				**4.87**				**5.62**	
Overall fertilizer mean					**5.37**	**5.19**	**5.17**		
	SE	$LSD_{(0.05)}$							
Lime	0.032	ns							
Fertilizer	0.037	*							
P-Rate	0.029	ns							
Lime*Fert	0.055	ns							
Lime*PRate	0.048	ns							
Fert*PRate	0.055	**							
Lime*Fert*PRate	0.08	ns							
%CV		7.8							

**significant at p≤0.05, **significant at p≤0.01, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

Results indicate that fertilizer application significantly improved (p≤0.05) the levels of soil available P with NPK (23:23:0) outperforming the other P sources (DAP and SSP). Results also show that interactions of fertilizer and rates of applied P had a significant (p≤0.01) effect on soil available P at vegetative stage in Kipsangui site (Table 4.11).

Results on the influence of lime, fertilizer and rates of P application on soil available P during harvesting stage at Kipsangui site are presented in table 4.12.

Table 4.12: Soil available P (cmol P/kg of soil) at harvesting stage in Kipsangui site

	L0				L1				P-Rate Overall Mean
Treatments	**DAP**	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	3.04	3.04	3.04	**3.04**	3.90	3.90	3.90	**3.90**	**3.47**
8.8	3.16	3.42	3.98	**3.52**	4.94	4.98	4.07	**4.66**	**4.09**
17.6	5.44	4.24	3.26	**4.31**	4.61	5.68	5.94	**5.41**	**4.86**
26.4	6.21	4.92	3.70	**4.94**	5.46	6.72	6.15	**6.11**	**5.53**
mean	**4.46**	**3.91**	**3.50**		**4.73**	**5.32**	**5.02**		
Lime mean				**3.95**				**5.02**	
Overall fertilizer mean					**4.60**	**4.61**	**4.26**		
	SE	$LSD_{(0.05)}$							
Lime	0.229	ns							
Fertilizer	0.337	ns							
P-Rate	0.234	*							
Lime*Fert	0.473	ns							
Lime*PRate	0.368	ns							
Fert*PRate	0.473	ns							
Lime*Fert*PRate	0.666	*							
%CV		12.6							

**significant at $p \le 0.05$, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

From the results presented (Table 4.12), P application rates had a significant ($p \le 0.05$) effect in the levels of available P in the soils of Kipsangui site at harvesting stage. Interactions of lime, fertilizer and rates of P application significantly ($p \le 0.05$) influenced soil available P in Kipsangui at harvesting stage (Table 4.12).

In Kipsangui, application of NPK (23:23:0) fertilizer at a rate of 26.4 kg P ha^{-1} together with liming resulted into increased levels of available soil P in Kipsangui at both vegetative and harvesting stages (Tables 4.11 and 4.12).

4.2.5 Effects of Lime, Fertilizer and P rates on exchangeable cations (K, Na, Ca and Mg) in Chepkoilel and Kipsangui soils

4.2.5.1 Effects of Lime, Fertilizer and P rates on exchangeable cations (K, Na, Ca and Mg) at harvesting stage in Chepkoilel soils

In Chepkoilel, results showed that lime, fertilizer and rates of applied P did not significantly influence the levels of exchangeable potassium and calcium.

Table 4.13 presents the results of the influence of lime, fertilizer and rates of applied P on exchangeable sodium in Chepkoilel soils at harvesting stage.

Table 4.13: Treatment effects on the exchangeable sodium (cmol/kg of soil) levels at harvesting stage in Chepkoilel soils

Treatments	L0				L1 (2 t/ha)				P-Rate Overall Mean
	DAP	NPK	SSP	Mean	DAP	NPK	SSP	Mean	
P-Rate (kg P/ha)									
0	2.09	2.09	2.09	**2.09**	3.05	3.05	3.05	**3.05**	**2.57**
8.8	4.24	3.65	5.49	**4.46**	3.80	4.61	3.87	**4.09**	**4.28**
17.6	3.14	4.09	3.73	**3.65**	3.58	4.02	5.12	**4.24**	**3.95**
26.4	3.21	4.09	4.53	**3.94**	3.87	4.17	5.05	**4.36**	**4.15**
mean	**3.17**	**3.48**	**3.96**		**3.58**	**3.96**	**4.27**		
Lime mean				**3.54**				**3.94**	
Overall fertilizer mean					**3.37**	**3.72**	**4.12**		
	SE	**$LSD_{(0.05)}$**							
Lime	**0.011**	**ns**							
Fertilizer	**0.011**	*****							
P-Rate	**0.094**	**ns**							
Lime*Fert	**0.017**	**ns**							
Lime*PRate	**0.011**	**ns**							
Fert*PRate	**0.011**	*****							
Lime*Fert*PRate	**0.007**	**ns**							
%CV		**13.3**							

**significant at $p\leq0.05$, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

From the results, fertilizer application significantly ($p\leq0.05$) influenced the levels of exchangeable sodium in the soils of Chepkoilel (Table 4.13). Interaction of fertilizer with P rate had a significant effect ($p\leq0.05$) on exchangeable sodium levels in Chepkoilel soils.

Results indicate that P sources, P rates in combination with lime had no significant influence the levels of exchangeable magnesium (cmol/kg of soil) in Chepkoilel soils

4.2.5.2 Effects of lime, fertilizer and P rates on exchangeable cations (K, Na, Ca and Mg) at harvesting stage in Kipsangui soils

Results indicate that P sources, P rates in combination with lime had no significant influence on the levels of exchangeable potassium, calcium magnesium and sodium (cmol/kg of soil) in Kipsangui soils

4.3 Plant measurements

4.3.1 Effects of Lime, P fertilizer sources and rates on wheat growth- plant height

There was a slightly higher mean of plant height in Kipsangui than Chepkoilel site with a mean of 72.39 cm and 72.52 cm respectively at 10th week stage, with controls performing poorly at the two sites. P application rate significantly ($p \leq 0.001$) influenced plant height above the control in both Chepkoilel and Kipsangui sites, with 26.4 kg P ha^{-1} rate performing better than 17.6 and 8.8 kg P ha^{-1}.

Liming gave a slight increase in plant heights in Kipsangui at 6th week stage though it was not significantly different. The mean plant heights under L1 and L0 were 43.07 and 42.27 cm respectively (Figure 4.1).

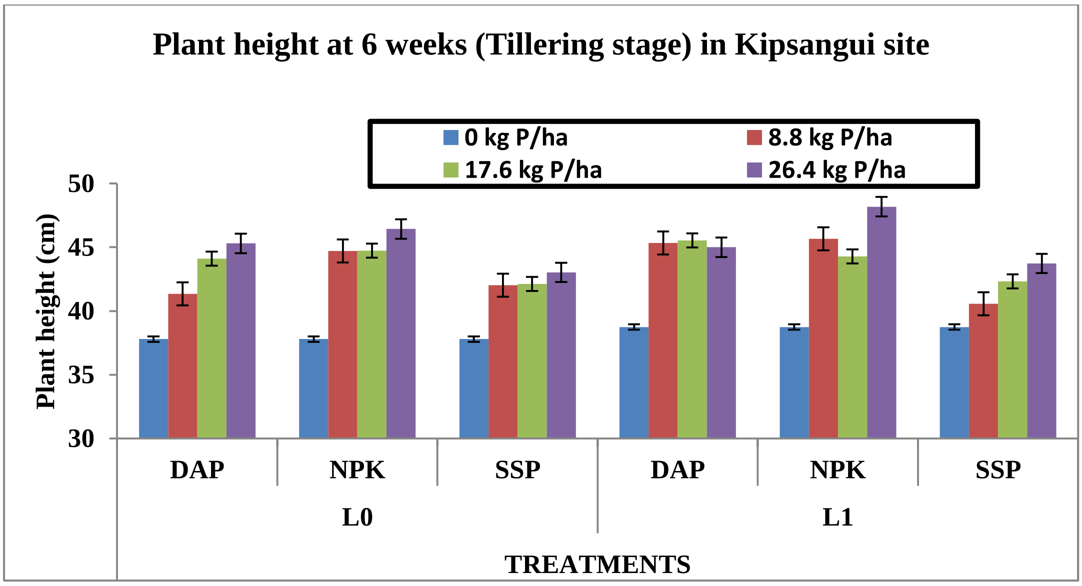


Fig 4.1: Plant height (cm) at 6 weeks tillering stage in Kipsangui site

The results indicate that fertilizer application significantly ($p \leq 0.001$) affected plant heights at 6th week stage in Kipsangui. Results further show that plant heights increased with increasing levels of P applied and this increase was significant ($p \leq 0.001$).The interaction of fertilizer and lime application had a significant influence ($p \leq 0.05$) on plant heights in Kipsangui at the 6th week stage. The fertilizer NPK (23:23:0) at a rate of 26.4 kg P ha^{-1} gave the highest plant height measurements of 48.18 cm. P source and P rate in combination with lime had a significant increase ($p \leq 0.01$) in plant heights in Kipsangui at the 6th week stage.

At 8th week stage, results showed that P source and P rate significantly affected plant heights in Kipsangui site (Fig 4.2).

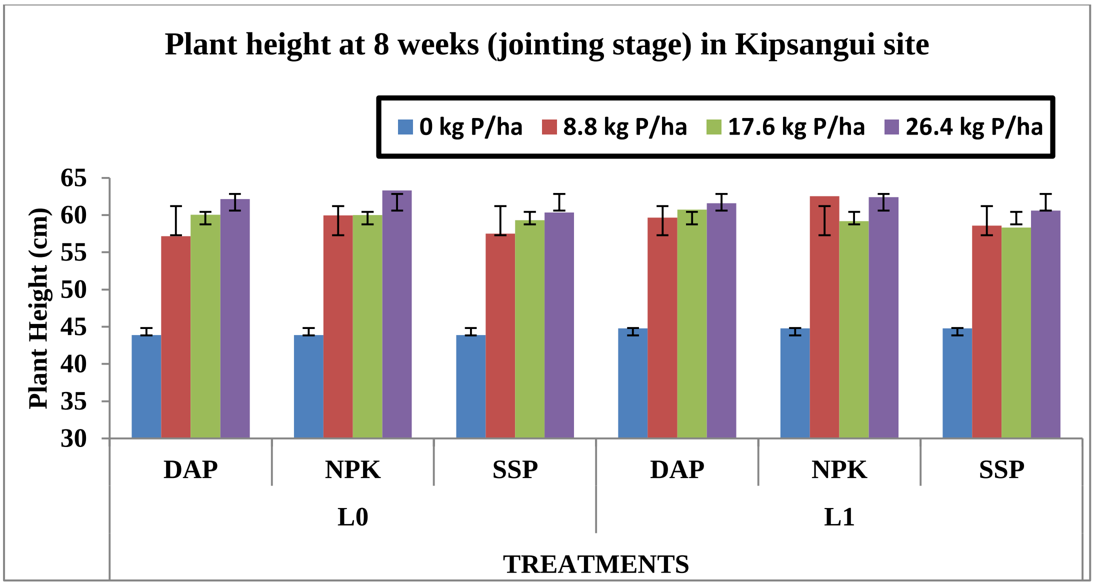


Fig 4.2: Plant height (cm) at 8 weeks stage in Kipsangui site

Lime application had influence on wheat plant heights in Kipsangui at 8th week stage where L0 and L1 recorded plant height means of 55.95cm and 56.50 cm respectively although this was not significantly different (Fig 4.2). Lime application showed no significant difference between SSP and the DAP and NPK (23:23:0) phosphorus sources in terms of their influence on wheat plant height in Kipsangui site at the eighth week stage. Fertilizer application as well as P application rates significantly influenced ($p \leq 0.001$) plant heights at 8th week stage in Kipsangui. NPK (23:23:0) fertilizer gave the highest mean of 57.23 cm, followed by DAP (56.69 cm) and lastly SSP (55.57 cm). Overall, There was no significant difference ($p \leq 0.05$) between P2 (17.6 kg P ha^{-1}) and P1 (8.8 kg P ha^{-1}) rates of P application (Fig 4.2). However, P application at 26.4 kg P ha^{-1} recorded the highest mean of plant height of 62.40 cm at 8 weeks stage.

Results at 10th week stage indicate a significant ($p \leq 0.01$) influence on plant height by P sources and rates of P application in Kipsangui site (Fig 4.3).

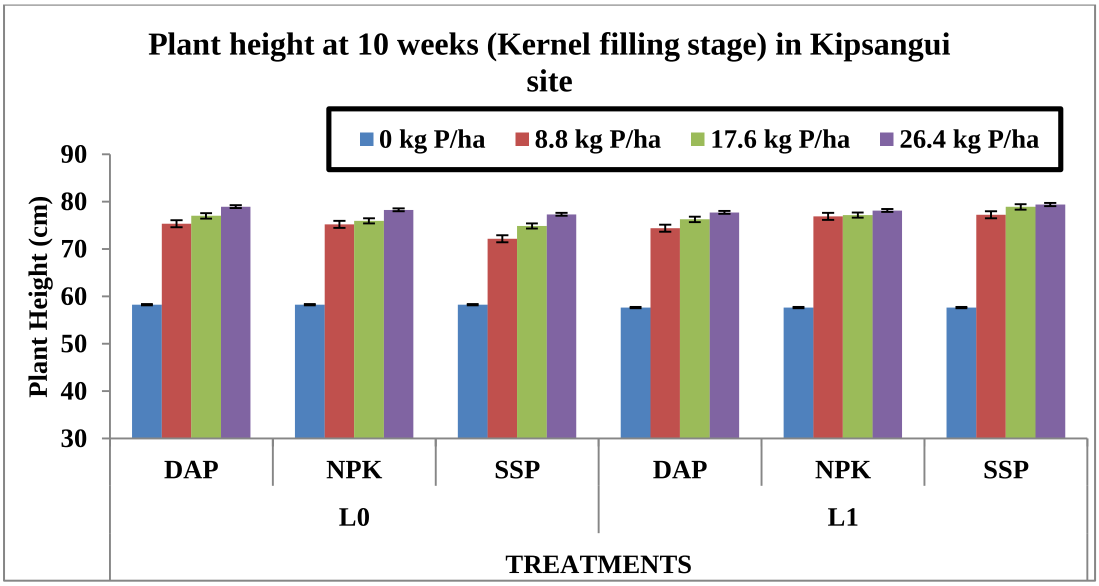


Fig 4.3: Plant height (cm) at 10 weeks stage in Kipsangui site

At ten weeks stage, lime application in Kipsangui site had an effect on the plant height and recorded highest mean of 72.43 cm against no lime which gave 71.62 cm although this was not significant (Figure 4.3). Fertilizer application had a significant influence ($p \leq 0.001$) on plant heights at 10th week in Kipsangui site. SSP recorded the highest mean of plant height at a rate of 26.4 kg P ha^{-1} (79.37 cm). Rates of applied P had a significant effect (p≤0.001) on plant height in Kipsangui. Generally, NPK (23:23:0) out performed SSP and DAP (Fig 4.3).

In Chepkoilel, the highest mean of plant height of 28.73cm was recorded under DAP fertilizer at 6th week stage (Fig 4.4).

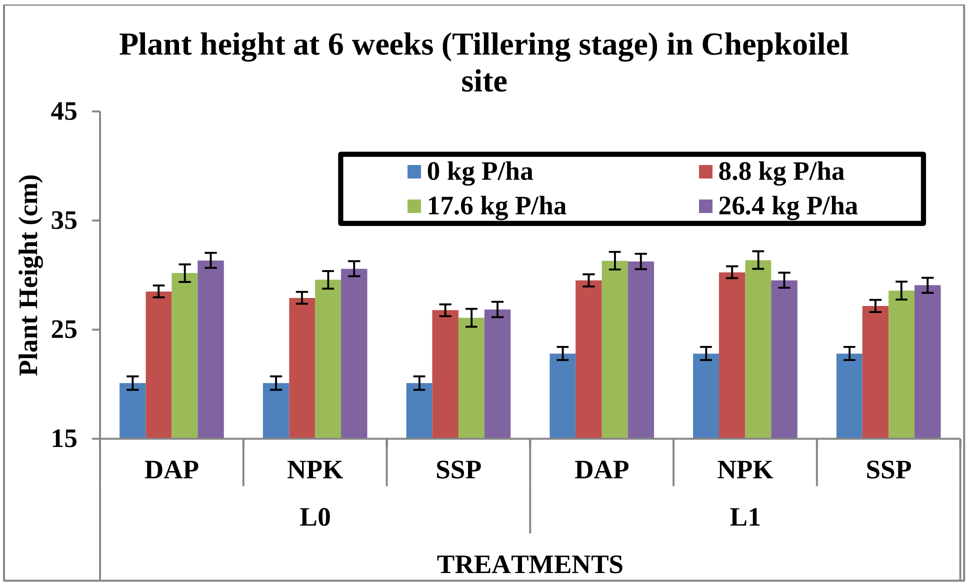


Fig 4.4: Plant height (cm) at 6 weeks stage in Chepkoilel site

Fertilizer application plus lime at 6th week stage had a significant influence (p≤0.05) on plant heights in Chepkoilel site with DAP recording largest mean plant height (28.03 cm), followed by 23:23:0 and SSP (Figure 4.4). Rates of applied P also significantly (p≤0.05) influenced plant heights where NPK (23:23:0) application at 17.6 kg P/ha resulted into higher means of plant height (31.38 cm) at this stage as compared to DAP (31.32 cm) and SSP (28.58 cm) at the same rate. This was in combination with liming at 2 t ha^{-1} (Fig 4.4).

Results on influence of P source and P rate in combination with lime application at 8th week stage in Chepkoilel site are presented in Figure 4.5.

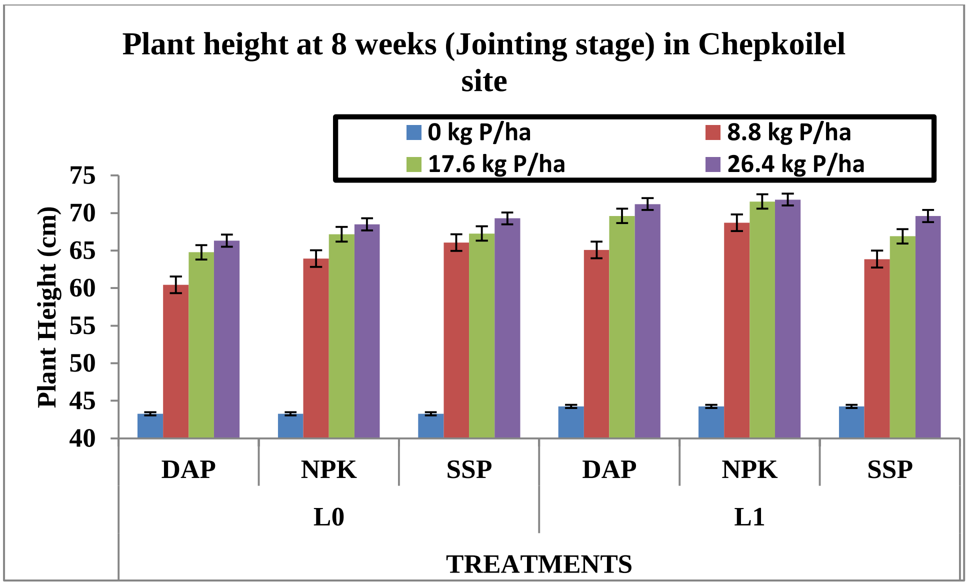


Fig 4.5: Plant height (cm) at 8 weeks stage in Chepkoilel site

From the results, liming at 2 t ha^{-1} had an influence on plant height in Chepkoilel site at 8 weeks stage although this was not significant ($p \leq 0.05$). The overall mean of plant height at 8 weeks sampling stage was 62.59 cm under L1, as compared to 60.30 cm at L0 (Figure 4.5). Fertilizer application with lime at 2 t ha^{-1} significantly ($p \leq 0.05$) influenced plant heights at 8th week stage in Chepkoilel while P application rates had significant ($p \leq 0.001$) influence on plant heights. Also, interaction of fertilizer and P application rates significantly ($p \leq 0.05$) influenced plant heights. NPK (23:23:0) gave the tallest measured plant height means at a rate of 26.4 kg P/ha with a mean of 71.79 cm (Fig 5). This was followed by DAP at 26.4 kg P ha^{-1} with a mean of 71.19 cm. Overall, at 8 weeks, phosphorus application at a rate of 26.4 kg P/ha resulted into a high plant height with a mean of 69.45 cm, as compared to P2 (17.6 kg P ha^{-1}) and P1 (8.8 kg P ha^{-1}), with means of 67.88 cm and 64.68 cm respectively (Fig 4.5).

During the 10th week stage, P source and P rate had a significant ($p \leq 0.001$) influence on plant heights in Chepkoilel site (Fig 4.6).

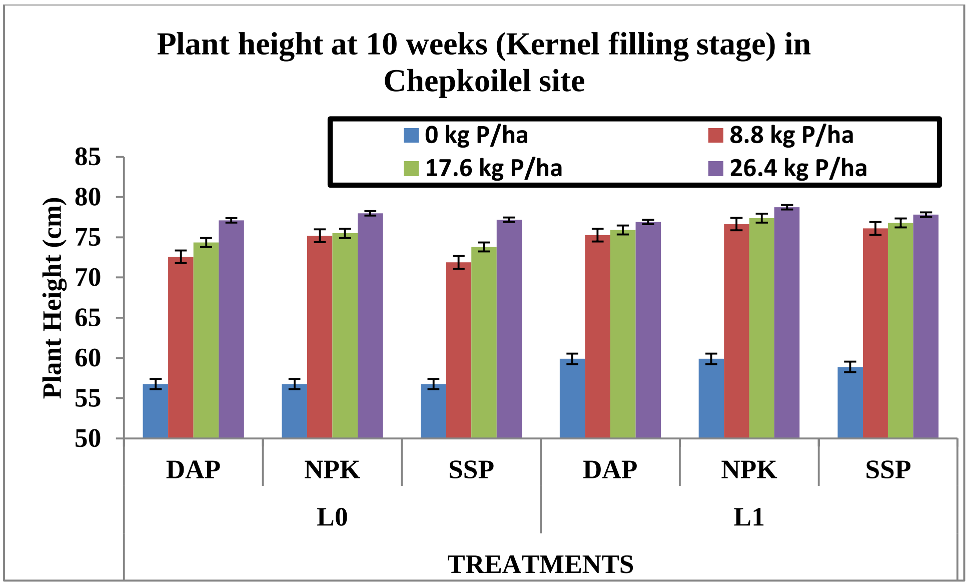


Fig 4.6: Plant height (cm) at 10 weeks stage in Chepkoilel site

At ten weeks, liming had no significant effect on plant height in Chepkoilel site (Fig 4.6). A mean of 72.52 cm was measured under L1, as compared to 70.49 cm under no-lime. The NPK (23:23:0) fertilizer recorded the highest mean of plant height at a rate of 26.4 kg P/ha (78.72 cm). There was a significant effect ($p \leq 0.001$) on plant height by fertilizer application in Chepkoilel, with NPK (23:23:0) and SSP out performing DAP (Fig 4.6).

However, NPK (23:23:0) outperformed SSP and DAP in Chepkoilel site in plant heights under lime application. The controls gave the lowest plant height measurements even with application of lime at 2 t ha^{-1}.

4.4 Effects of Lime, P fertilizer and rates on wheat yield

4.4.1 Effects of Lime, Fertilizer and P rates on wheat grain yield

Fertilizer application had a significant effect ($p \leq 0.05$) on wheat grain yield in Kipsangui. Application of fertilizers resulted into higher yield of wheat grain in Kipsangui above the control, with NPK (23:23:0) giving the highest mean grain yield

(4.87 t ha^{-1}). This was under the application rate of 26.4 kg P ha^{-1} combined with liming at 2 t/ha. P3 and P2 Phosphorus application rates differed significantly ($p \leq 0.05$) in grain yield, with P3 (26.4 kg P ha^{-1}) recording the highest mean of 4.27 t ha^{-1} in Kipsangui. Results show that NPK at a rate of 26.4 kg P ha^{-1} gave the highest wheat grain yields of 4.87 t ha^{-1} (Table 4.14). The three P application rates significantly produced high yields above the control.

Table 4.14: Wheat grain yield (t/ha) for Kipsangui site

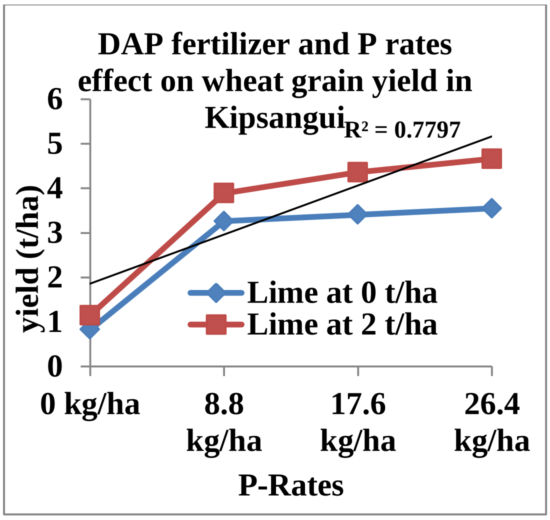
	L0				**L1**				**P-Rate Overall Mean**
Treatments	**DAP**	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	0.83	0.83	0.83	**0.83**	1.15	1.15	1.15	**1.15**	**0.99**
8.8	3.26	3.74	3.27	**3.42**	3.89	4.38	4.39	**4.22**	**3.82**
17.6	3.41	3.98	3.82	**3.74**	4.36	4.67	4.54	**4.52**	**4.13**
26.4	3.55	4.03	3.82	**3.80**	4.66	4.87	4.66	**4.73**	**4.27**
mean	**2.76**	**3.15**	**2.94**		**3.52**	**3.77**	**3.69**		
Lime mean				**2.95**				**3.66**	
Overall fertilizer mean					**3.14**	**3.46**	**3.31**		
	SE	**LSD**							
Lime	0.102	*							
Fertilizer	0.158	***							
P-Rate	0.063	***							
Lime*Fert	0.218	ns							
Lime*PRate	0.128	ns							
Fert*PRate	0.181	ns							
Lime*Fert*PRate	0.252	ns							
%CV		12.8							

**significant at $p \leq 0.05$, ***significant at $p \leq 0.001$, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

Results show lime application at 2 t ha^{-1} had a significant influence ($p \leq 0.05$) on wheat grain yields in Kipsangui site. Fertilizer application as well as rates of applied P significantly ($p \leq 0.001$) influenced wheat grain yields in Kipsangui site. The NPK

(23:23:0) fertilizer resulted into higher wheat grain yields, followed by SSP and DAP in Kipsangui site (Table 4.14).

Generally, fertilizer application increased wheat grain yields in Kipsangui in all the P sources as compared to control. However, the increase in P rates resulted to increase in grain yields with lime application performing better than no lime (Fig. 4.7, 4.8, 4.9 and 4.10)



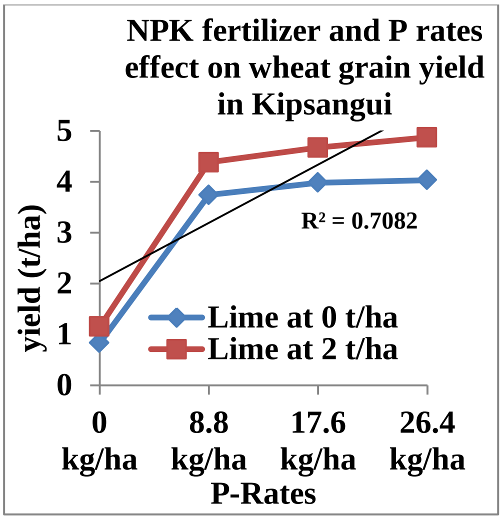
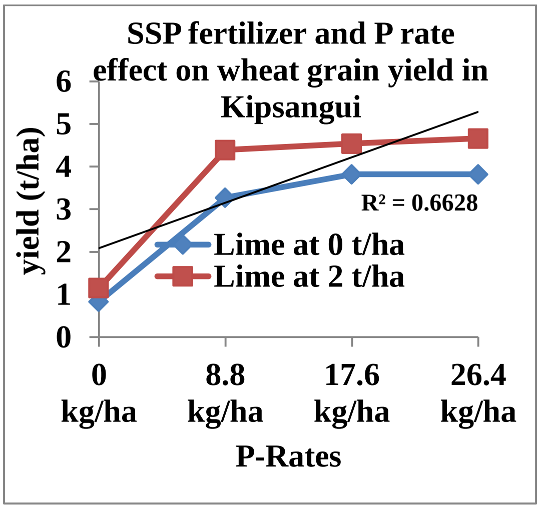


Fig 4.7: DAP effect on grain yield

Fig 4.8: NPK effect on grain yield



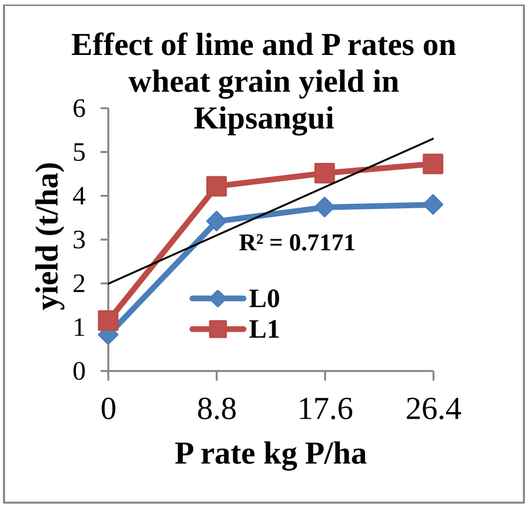


Fig 4.9: SSP effect on grain yield

Fig 4.10: Lime effect on grain yield

In Chepkoilel, P source and P rate in combination with lime application significantly influenced wheat grain yields (Table 4.15).

Table 4.15: Wheat grain yield (t/ha) for Chepkoilel site

	L0				L1				P-Rate Overall Mean
Treatments	**DAP**	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	0.98	0.98	0.98	**0.98**	1.24	1.24	1.24	**1.24**	**1.11**
8.8	2.81	3.35	3.01	**3.06**	3.21	3.70	3.54	**3.48**	**3.27**
17.6	3.26	3.65	3.64	**3.52**	3.57	4.10	3.75	**3.81**	**3.66**
26.4	3.72	4.61	4.04	**4.12**	4.12	5.39	4.21	**4.57**	**4.35**
mean	**2.69**	**3.15**	**2.92**		**3.04**	**3.61**	**3.19**		
Lime mean				**2.95**				**3.66**	
Overall fertilizer mean					**2.86**	**3.38**	**3.05**		
	SE	**LSD**							
Lime	**0.049**	*							
Fertilizer	**0.108**	***							
P-Rate	**0.065**	***							
Lime*Fert	**0.141**	ns							
Lime*PRate	**0.093**	ns							
Fert*PRate	**0.142**	**							
Lime*Fert*PRate	**0.192**	ns							
%CV		**13.7**							

significant at p≤0.05,significant at p≤0.01,***significant at p≤0.001, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

In Chepkoilel, lime application significantly ($p \leq 0.05$) influenced wheat grain yields. Results show that fertilizer application had a significant ($p \leq 0.001$) influence in wheat grain yields and rates of P application also had a significant ($p \leq 0.001$) influence in wheat grain yields (Table 4.15). Interaction of fertilizer and P rates had a significant ($p \leq 0.01$) effect on wheat grain yields in this site. However, application of NPK (23:23:0) fertilizer with lime at P3 rate gave the highest mean grain yields of 5.39 t ha^{-1}. Generally, lime application in combination with fertilizers increased wheat grain yields as compared to no lime (Fig. 4.11, 4.12, 4.13 and 4.14).

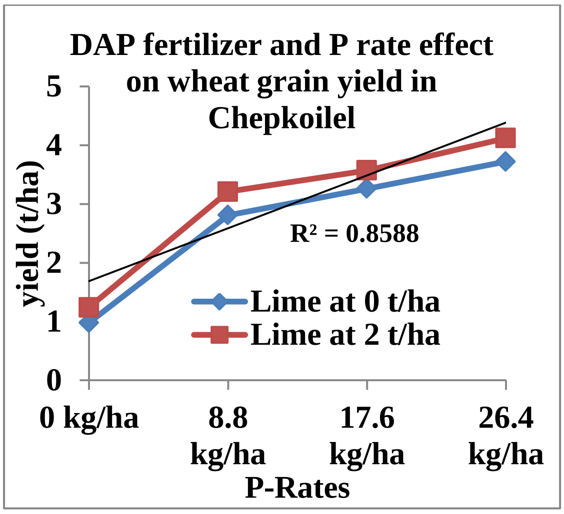


Fig 4.11: DAP effect on grain yield

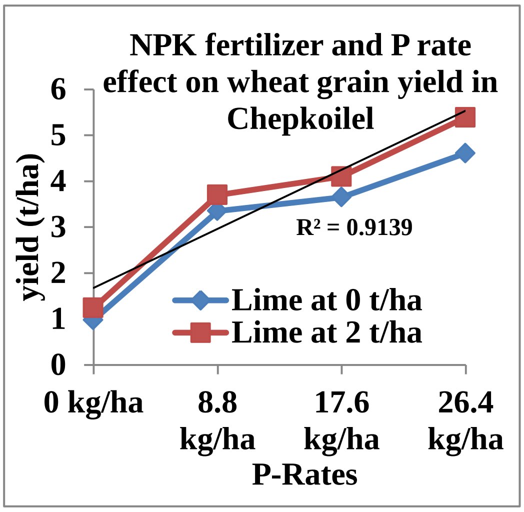


Fig 4.12: NPK effect on grain yield

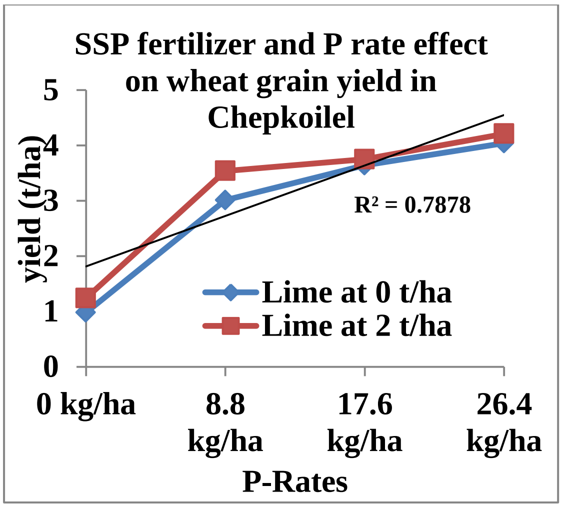


Fig 4.13: SSP effect on grain yield

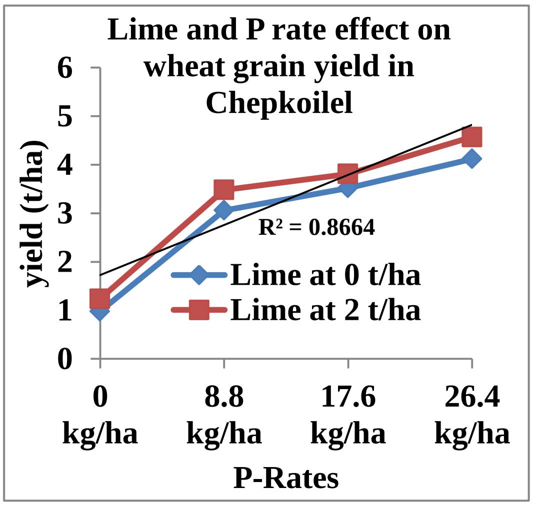


Fig 4.14: Lime effect on grain yield

Comparing P sources, NPK (23:23:0) recorded the highest wheat grain yield means in Chepkoilel outperforming SSP and DAP, with the three recording high wheat grain yield means above the controls in that order (Table 4.15). Phosphorus application at 26.4 kg P ha^{-1} resulted into higher grain yield followed by 17.6 kg P ha^{-1} and 8.8 kg P ha^{-1} in that order. Generally, liming had a significant effect on wheat grain yield in

Chepkoilel site, recording 3.66 t ha^{-1} as compared to no-lime with a mean yield of 2.95 t ha^{-1} (Table 4.15).

4.4.2 Effects of Lime, Fertilizer and P rates on wheat Straw yield

In Chepkoilel, lime application and NPK (23:23:0) fertilizer at rate P3 recorded a higher mean of wheat straw yield of 4.83 t ha^{-1} above SSP and DAP with 3.98 t ha^{-1} and 3.75 t ha^{-1} respectively. All the three fertilizers performed better than the control at 0.99 t ha in Chepkoilel (Table 4.16). Generally, phosphorus application at 26.4 kg P ha^{-1} resulted into higher means (3.91 t ha^{-1}) of wheat straw yield in Chepkoilel site, followed by 17.6 kg P ha^{-1} rate with 3.91 t ha^{-1} and 3.56 t ha^{-1} respectively (Table 4.16).

Table 4.16: Wheat straw yield (t/ha) for Chepkoilel site

	L0				**L1**				**P-Rate Overall Mean**
Treatments	**DAP**	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	0.84	0.84	0.84	**0.84**	0.99	0.99	0.99	**0.99**	**0.92**
8.8	2.39	3.01	3.12	**2.84**	2.82	3.40	3.75	**3.32**	**3.08**
17.6	2.83	3.62	3.46	**3.30**	3.40	4.18	3.87	**3.82**	**3.56**
26.4	3.08	4.11	3.73	**3.64**	3.75	4.83	3.98	**4.19**	**3.91**
mean	**2.29**	**2.90**	**2.79**		**2.74**	**3.35**	**3.15**		
Lime mean				**2.66**				**3.08**	
Overall fertilizer mean					**2.51**	**3.12**	**2.97**		

	SE	**$LSD_{0.05}$**
Lime	0.029	*
Fertilizer	0.100	***
P-Rate	0.080	***
Lime*Fert	0.126	ns
Lime*PRate	0.102	ns
Fert*PRate	0.151	*
Lime*Fert*PRate	0.203	ns
%CV		4.2

**significant at $p \le 0.05$, ***significant at $p \le 0.001$, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

From the results, lime application had a significant ($p \leq 0.05$) influence on wheat straw yield in Chepkoilel site (Table 4.16). Fertilizer, P source and rates application significantly ($p \leq 0.001$) influenced wheat straw yields in Chepkoilel study site. Also, interaction of fertilizers and their rates of applied P significantly ($p \leq 0.05$) influenced wheat straw yields in Chepkoilel (Table 4.16).

Table 4.17 presents the results on the influence of lime, fertilizer and P application rates on wheat straw yields in Kipsangui study site.

Table 4.17: Wheat straw yield (t/ha) for Kipsangui site

	L0				L1				P-Rate Overall Mean
Treatments	**DAP**	**NPK**	**SSP**	**Mean**	**DAP**	**NPK**	**SSP**	**Mean**	
P-Rate (kg P/ha)									
0	0.90	0.90	0.90	**0.90**	1.03	1.03	1.03	**1.03**	**0.97**
8.8	2.46	3.03	3.14	**2.88**	2.93	3.31	3.72	**3.32**	**3.10**
17.6	2.88	3.80	3.45	**3.38**	3.21	4.15	3.77	**3.71**	**3.54**
26.4	3.02	4.33	3.89	**3.75**	3.26	4.72	4.00	**3.99**	**3.87**
mean	**2.32**	**3.02**	**2.85**		**2.61**	**3.30**	**3.13**		
Lime mean				**2.73**				**3.01**	
Overall fertilizer mean					**2.46**	**3.16**	**2.99**		
	SE	**LSD**							
Lime	0.026	*							
Fertilizer	0.138	***							
P-Rate	0.095	***							
Lime*Fert	0.171	ns							
Lime*PRate	0.119	ns							
Fert*PRate	0.192	*							
Lime*Fert*PRate	0.255	ns							
%CV		7.0							

**significant at $p \leq 0.05$, ***significant at $p \leq 0.001$, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

Results indicate that lime application had a significant ($p \leq 0.05$) influence on wheat straw yields in Kipsangui site (Table 4.17) where liming at 2 t ha^{-1} yielded an overall mean of 3.01 t/ha as compared to no-liming at 2.73 t ha^{-1}. Fertilizer application as well as P application rates significantly ($p \leq 0.001$) influenced wheat straw yields in Kipsangui site (Table 4.17). Results further show that interaction of fertilizer and rates of applied P significantly ($p \leq 0.05$) influenced wheat straw yields in Kipsangui site (Table 4.17). Amongst the fertilizers, NPK (23:23:0) fertilizer resulted into higher wheat straw mean of 3.16 t ha^{-1}, with DAP giving a lower yield of 2.46 t ha^{-1} (Table 4.17). However, fertilizer application had more straw yield as compared to the control. P3 application rate yielded more straw per hectare in Kipsangui soils, high above P2 and P1 with control recording the lowest (0.97 t ha^{-1}) (Table 4.17).

4.5 Effects of Lime, Fertilizer and P rates on % P and % N in wheat grain and Straw

4.5.1 Effects of Lime, Fertilizer and P rates on % P and % N in wheat grain and Straw in Chepkoilel site

From the results, liming at 2 t ha^{-1} gave high levels of percent P, 0.629 g kg^{-1} in grains than no lime 0.599 although there was no significant difference ($p \leq 0.05$) in Chepkoilel study site. The results were within the range of that in Liu *et al*, (2006) where the P content in wheat grains ranged between 5.16 – 9.87 g kg^{-1} although Zlatko *et al*, (2007) found lower levels of grain P content ranging between 4.43 – 4.89 g/kg. Results further show that fertilizer application and rates of applied P did not significantly influence the levels of % P in Chepkoilel grains. Results further showed that lime application in combination with fertilizers and P rates did not significantly influence the levels of percent P in wheat straw in Chepkoilel

Table 4.18 presents the results on the effects of lime, fertilizer and P rates on total N (%)

Table 4.18: Total N (%) in wheat grains in Chepkoilel

Treatments	L0				L1				P-Rate Overall Mean
	DAP	NPK	SSP	Mean	DAP	NPK	SSP	Mean	
P-Rate (kg P/ha)									
0	2.280	2.281	2.280	**2.280**	2.345	2.346	2.345	**2.345**	**2.313**
8.8	2.400	2.420	2.420	**2.413**	2.440	2.604	2.429	**2.491**	**2.452**
17.6	2.470	2.520	2.448	**2.479**	2.622	2.714	2.585	**2.640**	**2.560**
26.4	2.530	2.640	2.520	**2.563**	2.736	2.822	2.672	**2.743**	**2.653**
mean	**2.420**	**2.465**	**2.417**		**2.536**	**3.132**	**2.508**		
Lime mean				**2.434**				**2.628**	
Overall fertilizer mean					**2.478**	**2.543**	**2.462**		

	SE	$LSD_{(0.05)}$
Lime	0.039	ns
Fertilizer	0.042	ns
P-Rate	0.020	ns
Lime*Fert	0.065	ns
Lime*PRate	0.046	ns
Fert*PRate	0.050	ns
Lime*Fert*PRate	0.076	*
%CV		10.2

**significant at p≤0.05, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

The results show that lime application had no significant influence on the levels of total N in wheat grains of Chepkoilel (Table 4.18). Fertilizer application as well as P application rates did not significantly influence the levels of total N in wheat grains of Chepkoilel (Table 4.18). However, interaction of lime, fertilizer and P rates had only a significant ($p \leq 0.05$) influence on the levels of percent N in Chepkoilel wheat grains (Table 4.18).

Results on effects of lime, fertilizer and P rates on total N in Chepkoilel straw are presented in Table 4.19.

Table 4.19: Total N (%) in straw in Chepkoilel

Treatments	L0				L1				P-Rate Overall Mean
	DAP	NPK	SSP	Mean	DAP	NPK	SSP	Mean	
P-Rate (Kg P/Ha) 0	0.970	0.970	0.970	**0.970**	0.981	0.984	0.984	**0.983**	**0.977**
8.8	0.995	1.000	0.995	**0.996**	1.026	1.011	0.998	**1.012**	**1.004**
17.6	1.010	1.016	0.998	**1.008**	1.079	1.040	1.011	**1.043**	**1.025**
26.4	1.015	1.116	1.007	**1.046**	1.082	1.126	1.108	**1.105**	**1.076**
mean	**0.998**	**1.025**	**0.993**		**1.042**	**1.040**	**1.025**		
Lime mean				**1.005**				**1.036**	
Overall fertilizer mean					**1.020**	**1.033**	**1.009**		
	SE	**$LSD_{(0.05)}$**							
Lime	0.002	ns							
Fertilizer	0.009	*							
P-Rate	0.013	ns							
Lime*Fert	0.011	ns							
Lime*PRate	0.016	ns							
Fert*PRate	0.02	ns							
Lime*Fert*PRate	0.028	ns							
%CV		14.1							

**significant at p≤0.05, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t ha^{-1})*

Lime application at 2 t ha^{-1} in Chepkoilel site had no significant influence on total N levels in the wheat straw (Table 4.19).

Percent total nitrogen in wheat straw was significantly influenced (p≤0.05) by the type of fertilizer in Chepkoilel, i.e. NPK (23:23:0) recorded a higher mean of 1.033 % N, while DAP and SSP gave 1.020% N and 1.009 % N respectively. There was however no significant (p≤0.05) difference between the rates of applied P on percent total N.

4.5.2 Effects of lime, fertilizer and P rates on total P and total N in wheat grain and Stover in Kipsangui site

Lime, fertilizer and P rates application did not significantly influence ($p \leq 0.05$) the percentage of total P in wheat grain in Kipsangui site. The results were within the range of that in Liu *et al.*, (2006) where the P content in wheat grains ranged between 5.16 – 9.87 g kg^{-1} although Zlatko *et al*, (2007) found lower levels of grain P content ranging between 4.43 – 4.89 g kg^{-1}. Likewise, application of fertilizer and P rate in combination with lime did not significantly influence the levels of total P in Kipsangui wheat straw.

Results on the influence of lime, fertilizer in combination with P application rates on percent total N in Kipsangui wheat grains are presented in Table 4.20.

Table 4.20: Total N (%) in grains in Kipsangui

Treatments	L0				L1				P-Rate Overall Mean
	DAP	NPK	SSP	Mean	DAP	NPK	SSP	Mean	
P-Rate (kg P/ha)									
0	2.340	2.528	2.212	**2.360**	2.415	2.399	2.415	**2.410**	**2.385**
8.8	2.415	2.624	2.282	**2.440**	2.595	2.673	2.579	**2.616**	**2.528**
17.6	2.624	2.768	2.254	**2.549**	2.704	2.856	2.624	**2.728**	**2.638**
26.4	2.737	2.769	2.338	**2.615**	2.880	2.988	2.865	**2.911**	**2.763**
mean	**2.529**	**2.672**	**2.272**		**2.649**	**2.729**	**2.621**		
Lime mean				**2.491**				**2.666**	
Overall fertilizer mean					**2.589**	**2.701**	**2.446**		
	SE	**LSD$_{(0.05)}$**							
Lime	0.070	ns							
Fertilizer	0.110	ns							
P-Rate	0.050	ns							
Lime*Fert	0.152	ns							
Lime*PRate	0.093	ns							
Fert*PRate	0.131	ns							
Lime*Fert*PRate	0.182	*							
%CV		10.9							

**significant at p≤0.05, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

Lime application had an increase in the recovered percent total N in the wheat grain in Kipsangui site although this was not significant (p≤0.05) (Table 4.36). The NPK (23:23:0) fertilizer recorded the highest means of percent total N in wheat grain although this was not significantly different (p≤0.05) as well. In the wheat grain analysis for total N, the results indicate a significant effect (p≤0.05) of treatment interactions of lime, fertilizers and P rates on the % N in the tissues.

Results on the influence of lime, fertilizer in combination with P application rates on percent N in Kipsangui wheat straw are presented in Table 4.21.

Table 4.21: Total N (%) in wheat straw in Kipsangui

Treatments	L0				L1				P-Rate Overall Mean
	DAP	NPK	SSP	Mean	DAP	NPK	SSP	Mean	
P-Rate (kg P/ha)									
0	0.949	0.949	0.952	**0.950**	1.007	1.011	1.011	**1.010**	**0.980**
8.8	0.974	0.998	0.974	**0.982**	1.014	1.038	0.987	**1.013**	**0.997**
17.6	0.993	1.039	0.977	**1.003**	1.034	1.067	1.088	**1.063**	**1.033**
26.4	1.008	1.108	0.991	**1.035**	1.050	1.092	1.095	**1.079**	**1.057**
mean	**0.981**	**1.023**	**0.973**		**1.026**	**1.052**	**1.045**		
Lime mean				**0.992**				**1.041**	
Overall fertilizer mean					**1.004**	**1.038**	**1.009**		

	SE	LSD(0.05)
Lime	0.007	*
Fertilizer	0.032	ns
P-Rate	0.029	ns
Lime*Fert	0.04	ns
Lime*PRate	0.036	ns
Fert*PRate	0.052	ns
Lime*Fert*PRate	0.07	ns
%CV		10.6

**significant at p≤0.05, ns; not significant (DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha)*

In the wheat straw analysis for total N, the results indicate a significant effect (p≤0.05) of lime on the % N in the plant tissues. Liming at 2 t ha^{-1} yielded 1.041% N as compared to no-lime treatment at 0.992% (Table 4.21). Application of fertilizers as well as rates of applied P had no significant influence on percent total N levels of wheat straw in Kipsangui site.

Table 4.22 presents the results on Phosphorus Use Efficiency for the two sites

Table 4.22: Phosphorus Use Efficiency (PUE) in Kipsangui and Chepkoilel sites

TREATMENTS			PUE (kg ha^{-1})					
			CHEPKOILEL			KIPSANGUI		
			Grain	Straw	Total	Grain	Straw	Total
L0	Control	Control	6.21	0.67	6.88	4.98	0.72	5.70
	DAP	P1	15.27	1.43	16.70	16.01	1.57	17.58
		P2	16.86	2.06	18.92	17.46	2.30	19.76
		P3	17.20	2.46	19.66	18.08	2.42	20.50
	NPK	P1	16.11	2.11	18.22	17.07	2.02	19.09
		P2	16.44	2.26	18.70	17.29	2.42	19.71
		P3	17.84	2.69	20.53	18.18	3.10	21.28
	SSP	P1	15.06	2.10	17.16	15.54	2.83	18.37
		P2	16.14	2.42	18.57	17.02	2.45	19.47
		P3	17.24	3.06	20.30	17.68	3.11	20.79
L1	Control	Control	7.56	1.58	9.14	6.79	0.82	7.61
	DAP	P1	15.96	2.54	18.50	15.73	2.34	18.07
		P2	16.85	3.27	20.12	17.94	2.57	20.51
		P3	18.37	1.70	20.07	18.63	2.61	21.24
	NPK	P1	17.20	2.38	19.58	17.76	2.65	20.41
		P2	17.78	2.93	20.71	18.35	3.32	21.67
		P3	18.82	3.86	22.69	18.55	3.78	22.33
	SSP	P1	16.72	2.88	19.60	16.60	2.98	19.58
		P2	17.67	2.71	20.38	18.06	3.39	21.45
		P3	18.04	3.28	21.32	18.93	3.59	22.52
KEY: L1-Lime applied at 2 t/ha, L0-No lime applied								

There was a higher PUE of P element under P3 application rate, coupled with lime application in Chepkoilel study site where NPK (23:23:0) fertilizer resulted in the highest levels of PUE at 22.69 kg ha^{-1} at P3 rate of application (Table 4.38). In Kipsangui study site, SSP at an application rate of 26.4 kg P ha^{-1} with lime at 2 t ha^{-1} gave the highest levels of PUE of 22.52 kg ha^{-1}. These were high above the controls in both Kipsangui and Chepkoilel sites.

4.5.2.2 Agronomic Efficiency (AE)

Table 4.23 presents the results on AE of Chepkoilel and Kipsangui sites.

Table 4.23: Agronomic Efficiency (AE) in Kipsangui and Chepkoilel sites

TREATMENTS			AGRONOMIC EFFICIENCY (kg/ha)	
			CHEPKOILEL	KIPSANGUI
			Increase in grain yield (kg/ha) of applied nutrient	Increase in grain yield (kg/ha) of applied nutrient
L0	Control	Control	-	-
	DAP	P1	210	280
		P2	130	150
		P3	100	100
	NPK	P1	270	330
		P2	150	180
		P3	210	120
	SSP	P1	200	280
		P2	150	170
		P3	120	110
L1	Control	Control	-	-
	DAP	P1	220	310
		P2	130	180
		P3	110	130
	NPK	P1	280	360
		P2	160	200
		P3	160	140
	SSP	P1	260	370
		P2	140	190
		P3	110	130
KEY: L1-Lime applied at 2 t/ha, L0-No lime applied				

Results showed that there was a greater nutrient recovery at fertilizer application rate of 8.8 kg P ha^{-1} with lime application at 2 t ha^{-1} in both Chepkoilel and Kipsangui sites and this was significant at ($p \leq 0.001$). Kipsangui site showed greater nutrient recoveries than Chepkoilel site (Table 4.23). SSP fertilizer at application rate of 8.8 kg P ha^{-1} with lime application at 2 t ha^{-1} recorded the highest AE with an increase in wheat grain yield of 370 kg ha^{-1} in Kipsangui. Results further showed that agronomic efficiency was higher at lower rates of applied kg P ha^{-1} and decreased with increase in rates of applied P ha^{-1} but higher when lime was applied, which is similar to findings of Alam, *et al*., (2003) who found that AE was higher when lower rates of P application in wheat crop was applied and Kisinyo, (2011) whose findings were similar in maize crop.

4.6 Economic analysis of grain yield from the treatments on crop production in Chepkoilel and Kipsangui soils

Economic analysis reveals that fertilizer use is economical as compared to no use of fertilizer as it is evident in the total cost value (TCV) (Table 4.24). With marginal rate of return (MRR) of 326%, DAP had less net financial benefit (NFB) as compared to NPK (23:23:0) that recorded above one hundred thousand Kenya shillings (Table 4.40). Fertilizer NPK (23:23:0) at P application rate of 26.4 kg P ha^{-1} was the most dominating treatment in the entire experimental period in Chepkoilel site where high gross financial benefit (GFB), of Ksh. 150, 381 was recorded in Chepkoilel (Table 4.24). Liming proved to be most economical in Chepkoilel as compared to no-liming in general. All the limed plots recorded high GFB as compared to the control. It was evident from the results that use of fertilizer is more economical in Chepkoilel than the lack of it, since even the limed plots without any fertilizer addition recorded less amounts of GFB in this site.

Table 4.24: Economic analyses for Chepkoilel

LIME	FERTILIZER	PHOSPHORUS	GFB (KES)	TCV	NFB	MRR (%)
L0	CONTROL	P0	27342	539	26803	
L0	DAP	P1	78399	12510	65889	326
L0	NPK (23:23:0)	P1	93465	14303	79162	740
L0	SSP	P1	83979	15227	68752	D
L0	DAP	P2	90954	14681	76273	D
L0	NPK (23:23:0)	P2	101835	18390	83445	D
L0	SSP	P2	101556	20084	81472	D
L0	DAP	P3	103788	16962	86826	288
L0	NPK (23:23:0)	P3	128619	25242	103377	36
L0	SSP	P3	112716	24814	87902	14
L1	CONTROL	P0	34596	20482	14114	D
L1	DAP	P1	89559	32530	57029	D
L1	NPK (23:23:0)	P1	103230	34296	68934	D
L1	SSP	P1	98766	35319	63447	D
L1	DAP	P2	99603	34651	64952	D
L1	NPK (23:23:0)	P2	114390	38437	75953	D
L1	SSP	P2	104625	39944	64681	D
L1	DAP	P3	114948	36982	77966	D
L1	NPK (23:23:0)	P3	150381	45471	104910	8
L1	SSP	P3	117459	44707	72752	D

(DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha, P1; 8.8 kg P/ha, P2; 17.6 kg P/ha, P3; 26.4 kg P/ha)

Economic analyses for Kipsangui study site are presented in Table 4.24

Lime application at 2 t ha^{-1} proved more economical in Kipsangui as it resulted in more net financial benefit (NFB) as compared to no-lime. P application rate at 26.4 kg P ha^{-1} resulted into increased benefits above 17.6 kg P ha^{-1} and 8.8 kg P ha^{-1} in Kipsangui. DAP was the most economical fertilizer in Kipsangui recording high net financial benefit (NFB) at P3 rate of application in combination with lime application.

Table 4.25: Economic analyses for Kipsangui

LIME	FERTILIZER	PHOSPHORUS	GFB (KES)	TCV	NFB	MRR (%)
L0	CONTROL	P0	23157	457	22701	
L0	DAP	P1	90954	12890	78064	445
L0	NPK (23:23:0)	P1	104346	14650	89696	661
L0	SSP	P1	91233	15568	75665	D
L0	DAP	P2	95139	14895	80244	D
L0	NPK (23:23:0)	P2	111042	18736	92306	64
L0	SSP	P2	106578	20447	86131	D
L0	DAP	P3	99045	17034	82012	D
L0	NPK (23:23:0)	P3	112437	25121	87316	D
L0	SSP	P3	106578	25023	81555	D
L1	CONTROL	P0	32085	21753	10333	D
L1	DAP	P1	108531	34356	74175	D
L1	NPK (23:23:0)	P1	122202	36122	86080	D
L1	SSP	P1	122481	37304	85177	D
L1	DAP	P2	121644	36538	85106	D
L1	NPK (23:23:0)	P2	130293	40236	90057	D
L1	SSP	P2	126666	41963	84703	D
L1	DAP	P3	130014	38764	91250	D
L1	NPK (23:23:0)	P3	135873	46703	89170	D
L1	SSP	P3	130014	46605	83409	D

(DAP – Di ammonium phosphate, SSP – Single super phosphate, NPK – Nitrogen phosphorus potassium 23:23:0; L0-no-lime, L1-Lime application at 2 t/ha, P1; 8.8 kg P/ha, P2; 17.6 kg P/ha, P3; 26.4 kg P/ha)

In terms of total cost value (TCV), NPK (23:23:0) at 26.4 kg P ha^{-1} with lime application at 2 t ha^{-1} resulted into increased TCV at Kipsangui site.

CHAPTER FIVE

DISCUSSION

5.1 Effects of P rates, P fertilizer sources and agricultural lime on soil nutrients

Application of lime at 2 t ha^{-1} with fertilizers resulted into higher levels of available soil P at both vegetative and harvesting stages in both Kipsangui and Chepkoilel sites. The level of supplied phosphorus is dependent on the P fertilizer sources used. P rich fertilizers NPK (23:23:0) and DAP supplied higher levels of P in both Kipsangui and Chepkoilel soils resulting into improved available soil P levels as compared to the initial soil status at the onset of the experiment.

The addition of lime to the soil resulted in the largest increase in plant growth due to an increase in soil pH that resulted in the possible decrease in levels of toxic forms of Al in the soil solution. Liming also resulted into increased plant growth due likely to lower concentrations of iron and manganese in the soil solution. The results suggest that incorporation of lime would be the most effective method for ameliorating subsoil acidity in ferralsol soil type in the field (Beegle and Durst, 2012).

Lime markedly increased wheat straw weight compared with the unamended control soil.

Lime treatment, thereby likely decreased the level of acidity. This enabled availability and better nutrient uptake from the acidic soils of Chepkoilel and Kipsangui. This made the fixed macronutrients including P, readily available to the growing wheat crop.

This improved the soil nutrient status e.g. available P levels in the soil, exchangeable cations among others as it is evident in the respective results. The addition of P rich fertilizers further improved the nutrient status of the soil in these two sites. It is likely therefore that the magnitude of the increase in wheat plant growth following liming and P fertilizer addition at 26.4 kg P ha^{-1} is higher than would be expected if planted without soil amendments.

Fertilizer application plus lime at 2 t ha^{-1} resulted into higher levels of N, P, K, Na, Ca, SOC, Mg and reduced soil acidity in these soils indicating that fertilizer and lime application in Chepkoilel and Kipsangui soils improves soil nutrients status of the soil as compared to the control. NPK 23:23:0 fertilizer at a rate of 26.4 kg P ha^{-1} recorded higher levels of soil nutrients more than DAP and SSP fertilizers.

5.2 Effects of fertilizer, P application rates and liming on plant growth

Phosphorus fertilizer is applied at planting to ensure that sufficient P is available to optimize plant growth and development, crop yield and maturity. The importance of adequate tissue P concentrations during early-season growth has been reported in many different crop species (Grant *et al*., 2001). Studies in Ontario Canada have shown that maize grain yield was strongly affected by P supply and tissue P concentration at vegetative stage, rather than by P concentration later in growth (Batjes, 2001; Bekele and Hofner, 2004). This was as a result of use of P fertilizer at planting to enable its use during growth and development. Amanullah *et al*., (2010) reported that enhanced early-season P nutrition in wheat increased the dry matter partitioning to the grain at later development stages. Similarly, in wheat (Jaetzold *et al*., 2006), P supply prior to sixth week of growth had a much greater effect on final grain yield than P supply in later growth. The crop was able to take up the available P and enhanced better growth and development of the growing wheat crop. This was evident in the resulting higher wheat grain and straw yields in both Kipsangui and Chepkoilel sites.

The phosphorus taken up by the crop at early stage of growth supply of P to the crop is influenced by soil P and P application as well as by soil and environmental conditions e.g. soil pH, which affects P availability and root growth. Application of lime at 2 t ha^{-1} possibly eliminated Al toxicity thus improving soil pH to the optimum levels thus improving uptake of soil nutrients. Through lime application, the acidity levels in form of Al toxicity are highly reduced resulting into availability of soil macronutrients necessary for plant growth and development.

Roots absorb P ions from the soil solution. The ability of the plant to absorb P depends on the concentration of P ions in the soil solution at the root surface and the area of absorbing surface in contact with the solution. This is made available by supply of adequate phosphorus at planting, and from the results of this study, higher responses were obtained at P application rates of 26.4 kg P ha^{-1}. The above results are in line with a study by Batjes, (2001) Driekmann and Fishbeck, (2005) who reported increased plant heights in plots supplied with higher rates of P and reduced with a reduction in P supply at low rates. Therefore it is important that P management balances the goal of providing sufficient P to the crop to optimize crop yield with the goal of avoiding excess P and environmental risk. Where plant-available P in the soil is low, efficient applications of P rich fertilizers at adequate rates i.e. 26.4 kg P ha^{-1} may improve crop P levels in the study areas. The results also depicted that balanced ratio of nitrogen: phosphorus (N: P) is essential to obtain higher yield of wheat against the common farmer’s practice. The use of N: P: K balanced ratio fertilizers results into a better growing crop e.g. in terms of plant height, translating into improved yields of both wheat grain and straw yield recorded in this study. Similar results have also been reported by Fageria *et al*. (2008).

5.3 Effects of fertilizer, P application rates and liming on grain and straw yield

Application of fertilizer resulted into high yields above the control as a result of availability of soil nutrients for plant growth and development indicating that fertilizer application in Chepkoilel and Kipsangui soils improves soil nutrients status of the soil. Reduction of soil acidity in these soils by application of lime at 2 t ha^{-1} realized an increase in the uptake of P and N by the growing wheat crop. This was later reflected into increased yields of wheat. This was evident in the Analysis of Variance which showed that fertilizer application at adequate rate of 26.4 kg P ha^{-1} significantly ($p \leq 0.05$) influenced a rise in the wheat grain yield in both sites, with all the three treatments (fertilizer, P application rate and lime application) having a significant ($p \leq 0.05$) influence on grain yield in both Chepkoilel and Kipsangui experimental sites. However, the overall yield means at Kipsangui show that at P application rate of 8.8 kg P ha^{-1} the response was 2.83 t ha^{-1}, the additional 8.8 kg P ha^{-1} (17.6 kg P ha^{-1}) it dropped to 0.31 t ha^{-1} and the next additional 8.8 kg P ha^{-1} (26.4 kg P ha^{-1}) showed a further drop to 0.14 t ha^{-1}. At the Chepkoilel site, overall yield means indicate that at P application rate of 8.8 kg P ha^{-1} the response was 2.16 t ha^{-1}, the additional 8.8 kg P ha^{-1} (17.6 kg P ha^{-1}) gave 0.39 t ha^{-1} and the next additional 8.8 kg P ha^{-1} (26.4 kg P ha^{-1}) show a response of 0.69 t ha^{-1}. These indicate that in the two sites, P application rate of 8.8 kg P ha^{-1} recorded the highest response above the control. The use of a compound fertilizer with balanced ratios of nutrients i.e. NPK and DAP, results into an increase in yield as compared to straight fertilizers in this case SSP. Butorac *et al.* (2005) found that P and K application has significant role in increasing water use efficiency of the wheat crop. The uptake of water by plants results into the uptake of the nutrients therewith in the solution. This includes the exchangeable cations (K, Ca, Mg, Na) thereby improving soil fertility and in turn wheat grain and straw yield. The difference in the levels of P uptake between Chepkoilel and Kipsangui could be due to the acidic nature of the soils in the two sites. With higher P uptake levels in Chepkoilel, this is an indicator of high P fixed in these soils. This was possibly released after lime application and hence high P levels in the soil (Giller *et al.*, 2002). The additional nutrients supply via P fertilizers' application resulted in a significant ($p \leq 0.05$) increase in available P content in the soil during the elongation i.e. plant height, heading and maturity stages. This resulted into a better growing and performing crop. This increase in P content was accompanied with higher wheat grain as well as straw yield. This resulted into a better growing crop which reflects better yields.

5.4 Economic analyses of fertilizer, P application rates and liming on wheat production in Kipsangui and Chepkoilel sites

NPK (23:23:0) and DAP were the most economical fertilizers for wheat production at Kipsangui. Fertilizer NPK (23:23:0) was the most economical for wheat production at Chepkoilel while DAP was the most economical for wheat production at Kipsangui. NPK fertilizer applied at 26.4 kg P ha^{-1} was the most profitable in both sites. Application of compound fertilizers proved to be economical in Chepkoilel and Kipsangui. The NPK (23:23:0) fertilizer was the most economical as it gave high grain and straw yield with improved soil fertility status.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

- Effective soil P management is important to optimize crop yield potential as well as reduction of production costs. Plants require adequate P from the very early stages of growth for optimum crop production. Phosphorus supply to the crop is affected by soil P and by soil and environmental conditions influencing P phyto-availability and root growth.

- Fertilizer use in wheat production played a major role towards improving wheat production in both Chepkoilel and Kipsangui. When coupled with lime application at rate of 2 t ha^{-1} as it proved more economical at Chepkoilel and Kipsangui sites.

- The most economical fertilizer was NPK (23:23:0) for Chepkoilel site while DAP was the most economically viable fertilizer to use for wheat production in Kipsangui but since there was no significant difference between the two fertilizers, a less acidifying fertilizer NPK (23:230) could be the most effective fertilizer for wheat production in Chepkoilel and Kipsangui sites. The economical rate of P application was 26.4 kg P ha^{-1} in both sites as this would not only boost wheat production, but will play a major role in soil fertility replenishment although P application rate of 8.8 kg P ha^{-1} showed the highest response.

6.2 RECOMMENDATIONS

- The study recommends use of P rich soluble fertilizers with lime application for wheat production in Kipsangui and Chepkoilel. Further, the study recommends NPK (23:23:0) fertilizer at both Chepkoilel and Kipsangui sites for wheat production, with lime application. NPK fertilizer is less acidifying, and it did not reduce soil pH but resulted into improved soil P levels. P applied at rate of 26.4 kg P ha^{-1} plus lime at 2 t ha^{-1} proved most productive and economical at both Kipsangui and Chepkoilel but since P application rate of 8.8 kg P ha^{-1} showed the highest responses, micro-dose application of P fertilizer for wheat production in Uasin Gishu county could be more economical than the presently recommended rate of 17.6 kg P ha^{-1} and is therefore highly recommended.
- More studies should be done on different rates of lime application using varied rates of lime application besides 2 t ha^{-1}, so as to quantify the profitability of these rates in Chepkoilel and Kipsangui although the study advocates for lower rates of lime application which are economical and good for soil health.
- More research studies on the length of period after which application of lime should be stopped so as to establish residual effects of lime especially when high rates are applied is recommended as this was not included in this study.
- The study also recommends further research on fertilizer use and lime requirement to further increase wheat grain yields from 5.39 t ha^{-1} to the optimum of 7.2 t ha^{-1}, as the study only managed a 43.0% wheat grain increase.

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APPENDICES

Appendix i: Comparative rainfall report during the year 2010 at Chepkoilel and Kipsangui sites.

MONTH	UNIVERSITY OF ELDORET - CHEPKOILEL SITE		MAJI MAZURI FARM – KIPSANGUI SITE	
	Rainy days	Amount (mm)	Rainy Days	Amount (mm)
Jan	6	53.1	3	67
Feb	8	62.7	12	138
March	13	110	11	174
April	10	125.2	7	88
May	13	184.6	16	277
June	24	58.5	12	153
July	23	307	14	171
August	15	265.9	14	301
Sept.	18	64.6	4	187.5
Oct.	17	58.1	10	98
Nov.	7	26.5	4	64.5
Dec	4	18.4	1	12.5
Total	**148**	**1334.6**	**108**	**1731.5**

Appendix ii: Analysis of variance tables

VARIATE: SOIL pH CHEPKOILEL VEGETATIVE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.253658	0.126829	0.70	
Replicate.Limelevel Stratum					
Limelevel	1	0.027005	0.027005	0.15	0.736ns
Residual	2	0.361139	0.180570	0.98	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	0.149976	0.049992	0.27	0.846 ns
Limelevel.Fertilizer	3	0.148511	0.049504	0.27	0.848 ns
Residual	12	2.221884	0.185157	1.91	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	0.497442	0.165814	1.71	0.192 ns
Limelevel.Prate	3	0.807215	0.269072	2.77	0.063 ns
Fertilizer.Prate	3	0.968251	0.322750	3.33	0.037 ns
Limelevel.Fertilizer.Prate	3	0.072063	0.024021	0.25	0.862 ns
Residual	24	2.328074	0.097003	14.89	
Rep.Lime.Fert.Prate	108	0.703667	0.006515		
Total	167	8.538885			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL pH CHEPKOILEL HARVESTING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	2.7611619	1.3805810	8.43	
Replicate.Limelevel Stratum					
Limelevel	1	0.1110857	0.1110857	0.68	0.497ns
Residual	2	0.3276000	0.1638000	7.69	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	0.0170161	0.0056720	0.27	0.848ns
Limelevel.Fertilizer	3	0.0693995	0.0231332	1.09	0.392ns
Residual	12	0.2557122	0.0213093	0.24	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	0.0010272	0.0003424	0.00	1.000ns
Limelevel.Prate	3	0.0822864	0.0274288	0.31	0.818ns
Fertilizer.Prate	3	0.1359877	0.0453292	0.51	0.678ns
Limelevel.Fertilizer.Prate	3	0.4169951	0.1389984	1.57	0.223ns
Residual	24	2.1284593	0.0886858	472.60	
Rep.Lime.Fert.Prate	108	0.0202667	0.0001877		
Total	167	6.3269976			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL pH KIPSANGUI VEGETATIVE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.55673	0.27836	1.45	
Replicate.Limelevel Stratum					
Limelevel	1	8.33486	8.33486	43.56	0.022*
Residual	2	0.38265	0.19132	1.17	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	1.71228	0.57076	3.50	0.050*
Limelevel.Fertilizer	3	0.26369	0.08790	0.54	0.665ns
Residual	12	1.95833	0.16319	2.11	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	0.20043	0.06681	0.86	0.474ns
Limelevel.Prate	3	0.13232	0.04411	0.57	0.640ns
Fertilizer.Prate	3	0.42868	0.14289	1.85	0.166ns
Limelevel.Fertilizer.Prate	3	0.38543	0.12848	1.66	0.202ns
Residual	24	1.85836	0.07743	2.83	
Rep.Limelevel.Fert.Prate	108	2.95967	0.02740		
Total	167	19.17343			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL pH KIPSANGUI HARVESTING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.07969	0.03984	0.28	
Replicate.Limelevel Stratum					
Limelevel	1	1.49160	1.49160	10.39	0.084ns
Residual	2	0.28702	0.14351	3.82	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	0.64786	0.21595	5.74	0.011*
Limelevel.Fertilizer	3	0.01893	0.00631	0.17	0.916ns
Residual	12	0.45117	0.03760	0.88	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	0.14216	0.04739	1.11	0.363ns
Limelevel.Prate	3	0.24379	0.08126	1.91	0.155ns
Fertilizer.Prate	3	0.12680	0.04227	0.99	0.413ns
Limelevel.Fertilizer.Prate	3	0.05657	0.01886	0.44	0.724ns
Residual	24	1.02170	0.04257	2.72	
Rep.Lime.Fert.Prate	108	1.68913	0.01564		
Total	167	6.25643			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL TOTAL N KIPSANGUI VEGETATIVE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.00757410	0.00378705	4.83	
Replicate.Limelevel Stratum					
Limelevel	1	0.00316209	0.00316209	4.03	0.183ns
Residual	2	0.00156948	0.00078474	1.51	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	0.00774751	0.00258250	4.96	0.018*
Limelevel.Fertilizer	3	0.00232594	0.00077531	1.49	0.268ns
Residual	12	0.00625401	0.00052117	0.95	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	0.00210483	0.00070161	1.28	0.303ns
Limelevel.Prate	3	0.00313669	0.00104556	1.91	0.155ns
Fertilizer.Prate	3	0.00228974	0.00076325	1.39	0.269ns
Limelevel.Fertilizer.Prate	3	0.00348433	0.00116144	2.12	0.124ns
Residual	24	0.01313137	0.00054714	8.88	
Rep.Lime.Fert.Prate	108	0.00665688	0.00006164		
Total	167	0.05943698			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL ORGANIC CARBON CHEPKOILEL VEGETATIVE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.02227	0.01113	2.68	
Replicate.Limelevel Stratum					
Limelevel	1	0.00999	0.00999	2.40	0.261ns
Residual	2	0.00831	0.00416	0.88	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	0.07942	0.02647	5.63	0.012*
Limelevel.Fertilizer	3	0.23397	0.07799	16.58	<.001***
Residual	12	0.05645	0.00470	0.41	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	0.02271	0.00757	0.67	0.581ns
Limelevel.Prate	3	0.14654	0.04885	4.30	0.015*
Fertilizer.Prate	3	0.04357	0.01452	1.28	0.304ns
Limelevel.Fertilizer.Prate	3	0.17120	0.05707	5.02	0.008*
Residual	24	0.27269	0.01136	1.11	
Rep.Lime.Fert.Prate	108	1.10608	0.01024		
Total	167	2.17320			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL ORGANIC CARBON KIPSANGUI VEGETATIVE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.037919	0.018960	0.59	
Replicate.Limelevel Stratum					
Limelevel	1	0.230288	0.230288	7.15	0.116ns
Residual	2	0.064433	0.032217	0.57	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	0.282430	0.094143	1.67	0.227ns
Limelevel.Fertilizer	3	0.579512	0.193171	3.42	0.053ns
Residual	12	0.678507	0.056542	1.17	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	0.303946	0.101315	2.09	0.128ns
Limelevel.Prate	3	0.340844	0.113615	2.34	0.098ns
Fertilizer.Prate	3	0.063802	0.021267	0.44	0.728ns
Limelevel.Fertilizer.Prate	3	0.486044	0.162015	3.34	0.036*
Residual	24	1.164119	0.048505	9.58	
Replicate.Limel.Fert.Prate	108	0.546667	0.005062		
Total	167	4.778512			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL ORGANIC CARBON CHEPKOILEL HARVESTING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.03877	0.01938	0.48	
Replicate.Limelevel Stratum					
Limelevel	1	0.02855	0.02855	0.70	0.490ns
Residual	2	0.08114	0.04057	7.77	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	1.46323	0.48774	93.37	<.001***
Limelevel.Fertilizer	3	0.90207	0.30069	57.56	<.001***
Residual	12	0.06269	0.00522	0.08	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	0.37135	0.12378	1.93	0.152ns
Limelevel.Prate	3	0.25845	0.08615	1.34	0.284ns
Fertilizer.Prate	3	0.25023	0.08341	1.30	0.297ns
Limelevel.Fertilizer.Prate	3	1.23487	0.41162	6.42	0.002**
Residual	24	1.53861	0.06411	4.40	
Rep.Lime.Fert.Prate	108	1.57493	0.01458		
Total	167	7.80489			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL ORGANIC CARBON KIPSANGUI HARVESTING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.061429	0.030714	0.32	
Replicate.Limelevel Stratum					
Limelevel	1	0.099086	0.099086	1.03	0.417ns
Residual	2	0.192400	0.096200	1.54	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	1.487062	0.495687	7.94	0.003**
Limelevel.Fertilizer	3	0.312366	0.104122	1.67	0.226ns
Residual	12	0.748749	0.062396	1.37	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	0.125072	0.041691	0.92	0.448ns
Limelevel.Prate	3	0.356479	0.118826	2.61	0.075ns
Fertilizer.Prate	3	0.169136	0.056379	1.24	0.317ns
Limelevel.Fertilizer.Prate	3	0.049402	0.016467	0.36	0.781ns
Residual	24	1.091467	0.045478	35.83	
Rep.Lime.Fert.Prate	108	0.137067	0.001269		
Total	167	4.829714			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL AVAILABLE P CHEPKOILEL VEGETATIVE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.10714	0.05357	0.01	
Replicate.Limelevel Stratum					
Limelevel	1	224.38166	224.38166	37.73	0.025*
Residual	2	11.89286	5.94643	2.18	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	387.63967	129.21322	47.47	<.001***
Limelevel.Fertilizer	3	1616.10031	538.70010	197.89	<.001***
Residual	12	32.66667	2.72222	0.80	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	42.27061	14.09020	4.16	0.017**
Limelevel.Prate	3	205.97916	68.65972	20.26	<.001***
Fertilizer.Prate	3	288.30264	96.10088	28.36	<.001***
Limelevel.Fertilizer.Prate	3	66.75426	22.25142	6.57	0.002**
Residual	24	81.33333	3.38889	79.08	
Rep.Lime.Fert.Prate	108	4.62835	0.04286		
Total	167	2962.05666			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL AVAILABLE P CHEPKOILEL HARVESTING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	4.4405	2.2202	4.01	
Replicate.Limelevel Stratum					
Limelevel	1	261.5030	261.5030	472.39	0.002**
Residual	2	1.1071	0.5536	3.44	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	1678.9393	559.6464	3472.72	<.001***
Limelevel.Fertilizer	3	236.8114	78.9371	489.82	<.001***
Residual	12	1.9339	0.1612	0.66	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	406.0690	135.3563	555.13	<.001***
Limelevel.Prate	3	58.8548	19.6183	80.46	<.001***
Fertilizer.Prate	3	157.6164	52.5388	215.48	<.001***
Limelevel.Fertilizer.Prate	3	197.0159	65.6720	269.34	<.001***
Residual	24	5.8519	0.2438	0.79	
Rep.Lime.Fert.Prate	108	33.2095	0.3075		
Total	167	3043.3527			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL AVAILABLE P KIPSANGUI VEGETATIVE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	83.58942	41.79471	7.67	
Replicate.Limelevel Stratum					
Limelevel	1	0.11618	0.11618	0.02	0.897ns
Residual	2	10.89748	5.44874	0.89	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	75.02025	25.00675	4.08	0.033*
Limelevel.Fertilizer	3	2.53896	0.84632	0.14	0.935ns
Residual	12	73.58808	6.13234	1.89	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	12.79478	4.26493	1.32	0.292ns
Limelevel.Prate	3	6.42022	2.14007	0.66	0.584ns
Fertilizer.Prate	3	59.35839	19.78613	6.11	0.003**
Limelevel.Fertilizer.Prate	3	12.60156	4.20052	1.30	0.298ns
Residual	24	77.67418	3.23642	35.86	
Replicate.Lime.Fert.Prate	108	9.74757	0.09026		
Total	167	424.34707			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: SOIL AVAILABLE P KIPSANGUI HARVESTING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	1.19453	0.59726	1.67	
Replicate.Limelevel Stratum					
Limelevel	1	0.26140	0.26140	0.73	0.482ns
Residual	2	0.71334	0.35667	0.13	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	6.66699	2.22233	0.81	0.511ns
Limelevel.Fertilizer	3	29.23364	9.74455	3.56	0.047*
Residual	12	32.82021	2.73502	0.92	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	35.47867	11.82622	3.98	0.020*
Limelevel.Prate	3	7.54955	2.51652	0.85	0.481ns
Fertilizer.Prate	3	13.08285	4.36095	1.47	0.248ns
Limelevel.Fertilizer.Prate	3	33.10661	11.03554	3.72	0.025*
Residual	24	71.24583	2.96858	209.44	
Rep.Lime.Fert.Prate	108	1.53080	0.01417		
Total	167	232.88441			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: KIPSNAGUI PLANT HEIGHT AT 6 WEEKS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.0433	0.0216	0.00	
Replicate.Lime_Level Stratum					
Lime_Level	1	23.7602	23.7602	4.65	0.164ns
Residual	2	10.2125	5.1063	0.36	
Replicate.Lime_Level.Fertilizer Stratum					
Fertilizer	3	474.9656	158.3219	11.28	<.001***
Lime_Level.Fertilizer	3	24.2597	8.0866	0.58	0.642ns
Residual	12	168.4368	14.0364	4.75	
Replicate.Lime_Level.Fertilizer.P_Rate Stratum					
P_Rate	3	115.2979	38.4326	13.01	<.001***
Lime_Level.P_Rate	3	4.0294	1.3431	0.45	0.716ns
Fertilizer.P_Rate	3	34.4598	11.4866	3.89	0.021*
Lime_Level.Fertilizer.P_Rate	3	60.7042	20.2347	6.85	0.002**
Residual	24	70.9017	2.9542	16.88	
Rep.Lime.Fert.Prate	108	18.9002	0.1750		
Total	167	1005.9713			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: KIPSNAGUI PLANT HEIGHT AT 8 WEEKS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	56.8231	28.4115	1.35	
Replicate.Lime_Level Stratum					
Lime_Level	1	8.3705	8.3705	0.40	0.592ns
Residual	2	41.9760	20.9880	1.57	
Replicate.Lime_Level.Fertilizer Stratum					
Fertilizer	3	1647.8676	549.2892	41.13	<.001***
Lime_Level.Fertilizer	3	4.7526	1.5842	0.12	0.947ns
Residual	12	160.2785	13.3565	1.45	
Replicate.Lime_Level.Fertilizer.P_Rate Stratum					
P_Rate	3	195.5626	65.1875	7.07	0.001***
Lime_Level.P_Rate	3	52.9718	17.6573	1.91	0.154ns
Fertilizer.P_Rate	3	62.6873	20.8958	2.27	0.107ns
Lime_Level.Fertilizer.P_Rate	3	13.1270	4.3757	0.47	0.703ns
Residual	24	221.3476	9.2228	12.27	
Rep.Lime.Fert.Prate	108	81.1739	0.7516		
Total	167	2546.9386			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: KIPSNAGUI PLANT HEIGHT AT 10 WEEKS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	6.1162	3.0581	0.12	
Replicate.Lime_Level Stratum					
Lime_Level	1	54.5148	54.5148	2.07	0.287ns
Residual	2	52.5900	26.2950	0.63	
Replicate.Lime_Level.Fertilizer Stratum					
Fertilizer	3	2188.8083	729.6028	17.35	<.001***
Lime_Level.Fertilizer	3	158.3665	52.7888	1.26	0.333ns
Residual	12	504.5442	42.0453	16.26	
Replicate.Lime_Level.Fertilizer.P_Rate Stratum					
P_Rate	3	258.3659	86.1220	33.30	<.001***
Lime_Level.P_Rate	3	20.8020	6.9340	2.68	0.070ns
Fertilizer.P_Rate	3	17.0085	5.6695	2.19	0.115ns
Lime_Level.Fertilizer. P Rate	3	8.7028	2.9009	1.12	0.360ns
Residual	24	62.0607	2.5859	12.29	
Rep.Lime.Fert.Prate	108	22.7200	0.2104		
Total	167	3354.5999			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: CHEPKOILEL PLANT HEIGHT AT 6 WEEKS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	8.0649	4.0325	0.10	
Replicate.Lime_Level Stratum					
Lime_Level	1	0.0034	0.0034	0.00	0.994ns
Residual	2	82.8697	41.4348	1.69	
Replicate.Lime_Level.Fertilizer Stratum					
Fertilizer	3	330.9441	110.3147	4.51	0.024*
Lime_Level.Fertilizer	3	56.8297	18.9432	0.77	0.530ns
Residual	12	293.3686	24.4474	3.34	
Replicate.Lime_Level.Fertilizer.P_Rate Stratum					
P_Rate	3	67.9226	22.6409	3.09	0.046*
Lime_Level.P_Rate	3	9.5243	3.1748	0.43	0.731ns
Fertilizer.P_Rate	3	12.0564	4.0188	0.55	0.654ns
Lime_Level.Fertilizer.P_Rate	3	32.2273	10.7424	1.47	0.248ns
Residual	24	175.7027	7.3209	13.75	
Rep.Lime.Fert.Prate	108	57.4971	0.5324		
Total	167	1127.0108			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: CHEPKOILEL PLANT HEIGHT AT 8 WEEKS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	135.054	67.527	2.79	
Replicate.Lime_Level Stratum					
Lime_Level	1	178.974	178.974	7.40	0.113ns
Residual	2	48.361	24.180	0.70	
Replicate.Lime_Level.Fertilizer Stratum					
Fertilizer	3	490.501	163.500	4.70	0.021*
Lime_Level.Fertilizer	3	196.702	65.567	1.89	0.186ns
Residual	12	417.011	34.751	3.37	
Replicate.Lime_Level.Fertilizer.P_Rate Stratum					
P_Rate	3	293.586	97.862	9.49	<.001***
Lime_Level.P_Rate	3	4.348	1.449	0.14	0.935ns
Fertilizer.P_Rate	3	145.955	48.652	4.72	0.010*
Lime_Level.Fertilizer.P_Rate	3	58.892	19.631	1.90	0.156ns
Residual	24	247.546	10.314	1.94	
Rep.Lime.Fert.Prate	108	575.170	5.326		
Total	167	2792.100			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: CHEPKOILEL PLANT HEIGHT AT 10 WEEKS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	246.115	123.057	0.78	
Replicate.Lime_Level Stratum					
Lime_Level	1	302.975	302.975	1.93	0.299ns
Residual	2	313.803	156.901	2.24	
Replicate.Lime_Level.Fertilizer Stratum					
Fertilizer	3	3423.380	1141.127	16.28	<.001***
Lime_Level.Fertilizer	3	249.123	83.041	1.18	0.357ns
Residual	12	841.307	70.109	8.19	
Replicate.Lime_Level.Fertilizer.P_Rate Stratum					
P_Rate	3	636.432	212.144	24.79	<.001***
Lime_Level.P_Rate	3	2.142	0.714	0.08	0.968ns
Fertilizer.P_Rate	3	38.409	12.803	1.50	0.241ns
Lime_Level.Fertilizer.P_Rate	3	18.633	6.211	0.73	0.546ns
Residual	24	205.347	8.556	5.16	
Rep.Lime.Fert.Prate	108	179.198	1.659		
Total	167	6456.866			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: KIPSANGUI GRAIN YIELD

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
replicate stratum	2	0.412825	0.206413	0.11	
replicate.limelevel stratum					
limelevel	1	28.085215	28.085215	14.80	0.061*
Residual	2	3.796344	1.898172	1.67	
replicate.limelevel.fertilizer stratum					
fertilizer	3	60.052472	20.017491	17.60	<.001***
limelevel.fertilizer	3	0.628335	0.209445	0.18	0.905ns
Residual	12	13.645075	1.137090	5.33	
replicate.limelevel.fertilizer.PRate stratum					
PRate	3	5.661842	1.887281	8.84	<.001***
limelevel.PRate	3	0.173412	0.057804	0.27	0.846ns
fertilizer.PRate	3	0.173069	0.057690	0.27	0.846ns
limelevel.fertilizer.PRate	3	0.837588	0.279196	1.31	0.295ns
Residual	24	5.123089	0.213462	23.96	
rep.lime.fert.prate	108	0.962200	0.008909		
Total	167	119.551466			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: CHEPKOILEL GRAIN YIELDS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	39.933	19.966	2.92	
Replicate.Limelevel Stratum					
Limelevel	1	27.475	27.475	4.02	0.183*
Residual	2	13.680	6.840	1.35	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	73.218	24.406	4.83	0.020***
Limelevel.Fertilizer	3	12.476	4.159	0.82	0.506ns
Residual	12	60.591	5.049	0.63	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	40.785	13.595	1.69	0.196***
Limelevel.Prate	3	12.434	4.145	0.51	0.676ns
Fertilizer.Prate	3	41.283	13.761	1.71	0.192ns
Limelevel.Fertilizer.Prate	3	29.920	9.973	1.24	0.318ns
Residual	24	193.220	8.051	1.02	
Rep.Lime.Fert.Prate	108	855.301	7.919		
Total 167 1400.315					

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: CHEPKOILEL STRAW YIELD

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	16.45919	8.22959	88.77	
Replicate.Limelevel Stratum					
Limelevel	1	8.53653	8.53653	92.08	0.011*
Residual	2	0.18541	0.09270	0.21	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	62.31000	20.77000	46.57	<.001***
Limelevel.Fertilizer	3	0.36100	0.12033	0.27	0.846ns
Residual	12	5.35214	0.44601	1.31	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	16.23539	5.41180	15.85	<.001***
Limelevel.Prate	3	0.01569	0.00523	0.02	0.997ns
Fertilizer.Prate	3	3.54877	1.18292	3.46	0.032*
Limelevel.Fertilizer.Prate	3	0.59750	0.19917	0.58	0.632ns
Residual	24	8.19660	0.34152	21.75	
Rep.Lime.Fert.Prate	108	1.69607	0.01570		
Total	167	123.49429			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: KIPSANGUI STRAW YIELD

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	39.853	19.926	2.90	
Replicate.Limelevel Stratum					
Limelevel	1	27.362	27.362	3.98	0.184*
Residual	2	13.755	6.877	1.36	
Replicate.Limelevel.Fertilizer Stratum					
Fertilizer	3	72.436	24.145	4.79	0.020***
Limelevel.Fertilizer	3	12.559	4.186	0.83	0.503ns
Residual	12	60.548	5.046	0.63	
Replicate.Limelevel.Fertilizer.Prate Stratum					
Prate	3	40.785	13.595	1.69	0.196***
Limelevel.Prate	3	12.434	4.145	0.51	0.676ns
Fertilizer.Prate	3	41.283	13.761	1.71	0.192*
Limelevel.Fertilizer.Prate	3	29.920	9.973	1.24	0.318ns
Residual	24	193.220	8.051	1.02	
Rep.Lime.Fert.Prate	108	855.301	7.919		
Total 167 1399.456					

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: CHEPKOILEL GRAINS TOTAL P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.0298961	0.0149481	0.41	
Replicate.Lime Stratum					
Lime	1	0.0068342	0.0068342	0.19	0.708ns
Residual	2	0.0730917	0.0365459	3.35	
Replicate.Lime.Fertilizer Stratum					
Fertilizer	3	0.0192310	0.0064103	0.59	0.635ns
Lime.Fertilizer	3	0.0253769	0.0084590	0.77	0.530ns
Residual	12	0.1309775	0.0109148	1.20	
Replicate.Lime.Fertilizer.Prate Stratum					
Prate	3	0.0094345	0.0031448	0.35	0.792ns
Lime.Prate	3	0.0131781	0.0043927	0.48	0.696ns
Fertilizer.Prate	3	0.0402140	0.0134047	1.48	0.245ns
Lime.Fertilizer.Prate	3	0.0426265	0.0142088	1.57	0.223ns
Residual	24	0.2175882	0.0090662		
Rep.Lime.Fert.Prate	108	0.0000000	0.0000000		
Total	167	0.6084487			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: CHEPKOILEL STRAW TOTAL P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.0277074	0.0138537	0.48	
Replicate.Lime_1 Stratum					
Lime_1	1	0.0234358	0.0234358	0.82	0.461ns
Residual	2	0.0572491	0.0286246	1.51	
Replicate.Lime_1.Fertilizer Stratum					
Fertilizer	3	0.0513730	0.0171243	0.90	0.468ns
Lime_1.Fertilizer	3	0.0588457	0.0196152	1.04	0.412ns
Residual	12	0.2273457	0.0189455	0.97	
Replicate.Lime_1.Fertilizer.Prate Stratum					
Prate	3	0.0428787	0.0142929	0.73	0.545ns
Lime_1.Prate	3	0.0597776	0.0199259	1.02	0.403ns
Fertilizer.Prate	3	0.0891406	0.0297135	1.51	0.236ns
Lime_1.Fertilizer.Prate	3	0.0858009	0.0286003	1.46	0.251ns
Residual	24	0.4708290	0.0196179		
Rep.Lime.Fert.Prate	108	0.0000000	0.0000000		
Total	167	1.1943835			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: KIPSANGUI STRAW TOTAL N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	2.138	1.069	3.84	
Replicate.Lime Stratum					
Lime	1	1.175	1.175	4.22	0.176ns
Residual	2	5.571	2.785	0.82	
Replicate.Lime.Fertilizer Stratum					
Fertilizer	3	2.485	8.284	2.45	0.114ns
Lime.Fertilizer	3	5.780	1.927	0.57	0.646ns
Residual	12	4.064	3.387	0.76	
Replicate.Lime.Fertilizer.Prate Stratum					
Prate	3	1.215	4.049	0.91	0.450ns
Lime.Prate	3	2.346	7.821	1.76	0.182ns
Fertilizer.Prate	3	7.417	2.472	0.56	0.649ns
Lime.Fertilizer.Prate	3	4.714	1.571	0.35	0.787ns
Residual	24	1.066	4.443	6288.88	
Rep.Lime.Fert.Prate	108	7.631	7.065		
Total	167	2.644			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: KIPSANGUI GRAINS TOTAL N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.560667	0.280333	0.50	
Replicate.Lime Stratum					
Lime	1	0.436160	0.436160	0.79	0.469ns
Residual	2	1.110748	0.555374	0.91	
Replicate.Lime.Fertilizer Stratum					
Fertilizer	3	0.939975	0.313325	0.51	0.681ns
Lime.Fertilizer	3	0.981629	0.327210	0.54	0.667ns
Residual	12	7.331358	0.610946	4.58	
Replicate.Lime.Fertilizer.Prate Stratum					
Prate	3	0.280062	0.093354	0.70	0.562ns
Lime.Prate	3	0.493795	0.164598	1.23	0.319ns
Fertilizer.Prate	3	0.903339	0.301113	2.26	0.108ns
Lime.Fertilizer.Prate	3	1.511261	0.503754	3.77	0.024*
Residual	24	3.202990	0.133458	91.39	
Rep.Lime.Fert.Prate	108	0.157713	0.001460		
Total	167	17.909696			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: KIPSANGUI GRAINS TOTAL P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.0106067	0.0053034	0.58	
Replicate.Lime Stratum					
Lime	1	0.0128466	0.0128466	1.40	0.358ns
Residual	2	0.0183199	0.0091600	1.23	
Replicate.Lime.Fertilizer Stratum					
Fertilizer	3	0.0260087	0.0086696	1.16	0.364ns
Lime.Fertilizer	3	0.0035707	0.0011902	0.16	0.921ns
Residual	12	0.0894303	0.0074525	0.86	
Replicate.Lime.Fertilizer.Prate Stratum					
Prate	3	0.0338558	0.0112853	1.31	0.295ns
Lime.Prate	3	0.0388133	0.0129378	1.50	0.240ns
Fertilizer.Prate	3	0.0238666	0.0079555	0.92	0.445ns
Lime.Fertilizer.Prate	3	0.0010647	0.0003549	0.04	0.989ns
Residual	24	0.2070313	0.0086263		
Rep.Lime.Fert.Prate	108	0.0000000	0.0000000		
Total	167	0.4654146			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

VARIATE: CHEPKOILEL STRAW TOTAL N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate Stratum	2	0.15466063	0.07733032	3.61	
Replicate.Lime_1 Stratum					
Lime level	1	0.06772350	0.06772350	3.17	0.217ns
Residual	2	0.04279398	0.02139699	0.84	
Replicate.Lime_1.Fertilizer Stratum					
Fertilizer	3	0.14744519	0.04914840	1.94	0.177ns
Lime_1.Fertilizer	3	0.13899577	0.04633192	1.83	0.196ns
Residual	12	0.30430879	0.02535907	1.22	
Replicate.Lime_1.Fertilizer.Prate Stratum					
Prate	3	0.06655654	0.02218551	1.07	0.381ns
Lime_1.Prate	3	0.11130218	0.03710073	1.79	0.177ns
Fertilizer.Prate	3	0.12986189	0.04328730	2.08	0.129ns
Lime_1.Fertilizer.Prate	3	0.18992876	0.06330959	3.05	0.048*
Residual	24	0.49874529	0.02078105	828.81	
Rep.Lime.Fert.Prate	108	0.00270792	0.00002507		
Total	167	1.85503045			

*significant at p≤0.05,**significant at p≤0.01,***significant at p≤0.001, ns; not significant

Appendix iii: Photographs of the study sites

Soil sampling at vegetative stage

\Vegetative stage of the test crop

Harvesting of the test crop

Weighing harvested above ground wheat biomass

Soil sampling at harvesting