INFLUENCE OF AGRICULTURAL LIME ON SOIL PROPERTIES AND WHEAT (*Triticum aestivum L.*) YIELD ON ACIDIC SOILS OF UASIN GISHU COUNTY, KENYA

BY

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DECLARATION

Declaration by the student

This thesis is my original work and has not been presented for a degree in any other University. No part of this thesis may be reproduced or copied without prior permission from the author and/or University of Eldoret.

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(Reg. No. AGR/PGS/03/08

Declaration by the supervisors

This thesis has been submitted for examination with approval as the University supervisors**.**

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Signature……………… Date………………………….

DEDICATION

To my late father and mother who made sure l acquired education .To my children Flavian and Noela for their encouragement, patience and understanding during the study. To God for the good health. May His name be glorified. AMEN.

ABSTRACT

Soil acidity, one of the contributors to soil fertility depletion, has become a matter of concern in sub- Saharan Africa. In Kenya, 13% of the soils are acidic and are considered to be low fertility due to highly weathered and leached nature. A study was carried out to investigate the effect of agricultural lime from Koru, Kisumu (21% CaO) on soil properties and wheat yield on acidic soils of Uasin Gishu county. Field trials were conducted at Chepkoilel University College farm and in Kipsangui area of Uasin Gishu district. Soils were analysed to determine their pH, available P, nitrogen and organic carbon before treatment application. The experiment was arranged in a splitplot arrangement with two wheat varieties as the main plots and the lime treatments as the subplot. The two varieties were Njoro BW 2, which is tolerant to soil acidity and KS Mwamba which is moderately tolerant to soil acidity, were compared. Phosphorus and nitrogen were applied as blankets treatment at the rates of 40 kg P_20_5/ha and 46 kg N/ha respectively. Lime was applied at the rates of 0.0, 0.5, 1.0, 1.5 and 2.0 t/ha. Soils from the two sites were acidic with low to moderate available P for Chepkoilel (pH4.9) and Kipsangui (pH5.3) respectively. Wheat was planted at the rate of 125 kg/ha. Both sites have sandy loam soils. There was a significant effect ($P<0.05$) on the growth pattern of wheat crop as influenced by agricultural lime above the control in both wheat varieties and sites. However, Kipsangui site had significantly ($P<0.05$) higher growth rate than Chepkoilel because of the fair rainfall distribution and amounts it received during the year. Wheat grain yield increased significantly ($P<0.05$) at sites due to soil acidity amendment (CaO), P and N addition above the control. Kipsangui site had higher grain yield compared to Chepkoilel site because again of the high and fair distribution of rainfall during the year. The soil nutrient levels of P and N were also highly significantly ($P<0.05$) at Kipsangui. At Kipsangui the average yield were 1.87 t/ha and 1.43 t/ha for Njoro BW 2 and KS Mwamba varieties respectively while at Chepkoilel site the wheat grain yield was 1.55 t/ha for Njoro BW 2 and 1.23 t/ha for Mwamba. The highest yield of straw of 2.18 t/ha and 1.89 t/ha of Njoro BW 2 was achieved with lime addition of 2 t/ha in Kipsangui and Chepkoilel, respectively, while KS Mwamba wheat variety also gave the highest straw yield of 1.17 t/ha at Chepkoilel and 1.27 t/ha at Kipsangui with the highest lime addition at 2 t/ha. There was a high positive correlation between wheat yields and soil available P at Kipsangui and Chepkoilel after 125 days (at harvesting). Lime increased P and N uptake in both wheat grain and straw. However, results from this study suggest probably higher rates of lime would have to be applied to achieve favourable soil pH and higher soil available P for long periods of time. From the experimental sites, it is recommended that fertilizer in combination with lime be adopted. The influence of lime on soil water retention should be monitored for a long time to get conclusive results on moisture retention in soils. High cost of inorganic inputs, low wheat grain prices and the effects of the rains made the majority of the treatments economically unviable for adaptation by farmers. However, the most profitable treatment was lime addition at 2 t/ha in Njoro BW 2 at Kipsangui site. Higher wheat yields may probably achieved from rates of lime above 2 t/ha.

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
BW	-	Bread Wheat
CAN	-	Calcium ammonium nitrate
CIMMYT	-	International Maize and Wheat Improvement Center
D	-	Dominated
DAP	-	Diammonium phosphate
FAO	-	Food and Agriculture Organization
FURP	-	Fertilizer Use Recommendation Project
GF	-	Gross Field Benefits
KARI	-	Kenya Agricultural Research Institute
KES	-	Kenya Shilling
KS	-	Kenya Seed
LR-Long	-	Rains
ML	-	KS Mwamba wheat variety and Lime
MOA	-	Ministry of Agriculture
MRR	-	Marginal Rate of Returns
NALEP	-	National Agriculture and National Extension Programme
NFB	-	Net Financial Benefit
NL	-	Njoro BW 2 wheat variety and Lime
P	-	Phosphorus
pH	-	Negative logarithm of hydrogen ion activity.
SMH	-	Smallholder Farmer
SSA-Sub	–	Saharan Africa
TVC	-	Total Variable Cost

UNESCO	-	United Nations Education, Social and Cultural Organization
USDA	-	United States Department of Agriculture
BBS	-	Broad Based Survey

ACKNOWLEDGEMENT

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To God is the glory for forever and ever. Amen

CHAPTER ONE

1.0 INTRODUCTION

Wheat (*Triticum aestivum* L.) is the first most important cereal cultivated in the world. It is the second most important cereal crop grown in Kenya after maize (Grain Economic Review, 2005). Early development of this crop in Kenya was confined to large scale farms, but this pattern is changing with small scale farmers taking up wheat farming on small plots (MOA, 2008). In contrast to sustained increases in wheat productivity in other parts of the developing world, per capita production in Kenya continues to stagnate while the consumption has been on the increase (Onsongo, 2003).

The wheat sub-sector in Kenya has been faced with challenges that have resulted in slow growth and has not been able to favourably compete both regionally and globally (Grain Economic Review, 2005). The high cost of production, lack of credit and inappropriate production technologies characterize wheat production in Kenya. These constraints make wheat production a high cost crop making the country a destination for imported wheat. The domestic cost of production varies between USD 142 to 240 (Ksh 11,984 to 20,256) per ton depending on the agro-ecological zone and the scale of production (FAO, 2003). Average wheat yield in Kenya is about 2 tons per hectare (Onsongo, 2003). Kenya's current national production of wheat is approximately 300,000 tons per annum, which meets only 50% of the national demand. The high increase in population and changing eating habits are expected to substantially increase wheat demand which is estimated to reach 850,000 tons per annum in the year 2020 (FAO, 2003). Table 1 shows the wheat production trend, both the production and imported trends from 2002-09.

Table 1: Wheat production trend, consumption and import trend (2002-09)

Year	2002	2003	2004	2005	2006	2007	2008	2009
Area (Ha)	144,794	151,135	145,359	159,477	150,488	104.176	130,273	131,994
Yield/ton/ha	2.20	2.50	2.90	2.30	2.30	2.50	**	1.67
Production(ton)	312,755	379,034	397,005	365.696	358,061	354,249	336,688	219,300
Consumption (ton)	884,350	883,120	889,020	893,120	903,120	927,956	**	1,072,000
Imports (tons)	515,180	502,115	404,060	621,839	**	601,593	**	781,700
Total value (Billion Ksh)	5.3	7.23	8.33	6.66	6.82	11.68	9.1	8.7

Source: Economic Review of Agriculture 2010, Ministry of Agriculture, Kenya

Land area currently devoted to wheat production in the high potential areas is also less than 2% of the total land area in Kenya and hence expansion in these regions is limited. Horizontal expansion of wheat production has occurred in marginal rainfall areas such as lower Narok, Naivasha, Laikipia and Machakos. However, future production must come largely from vertical expansion (Njau *et al*., 2005).

In Uasin Gishu county there has been a reduction in cereal grain production due to unpredictable weather particularly rainfall, declining soil fertility, diminishing land parcels as the consequence of rapid population growth, low and unsustained market prices for the produce and poor crop husbandry (Badiance and Delgado, 1995; World Bank 1995; MOA, 2009). High costs of inputs, mainly DAP and CAN, diseases, weeds and poor crop husbandry, also contribute significantly to low grain yields in the county. 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 (FURP, 1994).

Nitrogen, calcium and magnesium deficiencies and toxicities of aluminum and manganese, which characterize these acidic soils, also limit crop production in this county (Lwayo *et al.,* 2001). Further, continuous use of acidifying fertilizers like Di-Ammonium Phosphate (DAP) and urea, worsen an already bad situation (Neil, 1991).

Soil acidity is attributed to the abundance of mainly hydrogen (H^{+}), aluminum (Al^{3+}) manganese (Mn^{2+}) and iron (Fe^{2+}) cations in soils at levels that interfere with normal plant growth. Soil acidity has a negative effect on crops and yields mainly through from P fixation in soils whereby the Fe and Al soil components (sesquioxides) fix sizeable quantities of P. Excess Al^{3+} ions, from soil acidity, tend to accumulate in plant roots and thereby prevent P, Mo and other ions translocation to the tops from the roots, as evidenced by the inhibition of root elongation and overall retarded crop development (Kochian, 1995; Kanyanjua *et al.*, 2002: Ligeyo and Gudu, 2005). The detrimental effect of H^{+} ions is not as distinct as that of Al^{3+} cations, but excess of H^{+} ions in acid soils affects plant root membrane permeability and therefore interferes with ion transport (Ligeyo and Gudu, 2005).

Soil acidity can be corrected by neutralizing the acid present, which is done by adding a basic material normally containing Ca and Mg. While there are many basic materials which can neutralize soil acidity, most of them are too costly or difficult to manage. The most commonly used material is agricultural limestone because it is relatively inexpensive, available, easy to handle and effective (Zang *et al.,* 2000). In Kenya, agricultural lime is found in Koru (Kisumu), Athi River, Kitui, Mutomo and other areas.

Soil pH is one of the factors which influence phosphorus availability and utilization. In most soils, P availability is at maximum in the pH range of 5.5 – 6.5, decreasing as the pH drops, below 5.5 or increases above 6.5 (Zhang *et al*., 2000). In acid soils P is less available because it reacts with aluminum, iron and/or manganese which are more available in acidic soils. When phosphate reacts with these ions, the metal compounds formed are insoluble solids (such as aluminum phosphate), therefore P cannot be absorbed by plants (Zhang *et al*., 2000).

In Uasin Gishu county cultivation is done using heavy machinery which puts pressure on the soil causing physical disturbance to the soil, mainly compaction especially when done on wet soil. Compaction is high where soil calcium levels are low (White, 2006) like Uasin Gishu county. Grazing of cattle on wheat straw after harvesting also causes damage to soil structure. Lime has been known to improve soil structure (USDA, 1999). Studies have also shown that lime decreases soil hydraulic characteristics such as infiltration, water retention and hydraulic conductivity (Nicholas, 2004). These negative impacts imply potential for high runoff and sediment generation after liming, especially when the soil surface is covered with insufficient vegetation. This implies that it is important to monitor the soil physical properties as well after liming to ensure there is no damage to the soil.

The most popular varieties of wheat grown in Uasin Gishu county are Njoro BW 2 and KS Mwamba because of their outstanding characteristics. Both wheat varieties are high yielding and tolerant to diseases such leaf and stem rusts. Certified seed for these varieties are normally available with stockists during the planting season as opposed to other varieties (Chemngetich and Biwot, *personal communication, MAO Uasin Gishu county),* so are DAP and CAN.

In Kenya wheat is grown mainly in Uasin Gishu, Nakuru, Trans Nzoia Narok, Nyeri, Nyandarua, Kiambu and Meru counties. Unfortunately the wheat produced in Kenya forms an insignificant proportion for local consumption, as indicated in Table 1.

1.1 Problem Statement

Areas covered by acidic soils in Kenya are traditionally important to the economy being significant areas for the production of cash and food crops and for dairy production (Nekesa, 2007). Soil acidity is a widespread limitation to crop production in many parts of the world including sub-Saharan Africa (SSA) (van Straaten, 2002). Acid soils occupy about 40% and 29% of the total land area in the world and in SSA respectively (Eswaran *et al.,* 1997, von Uexhull and Mutert, 1995). In Kenya acid soil occupy about 13% (7.5 million ha) of the land area (Kanyanjua *et al.*, 2002), which, because of rain-fed agriculture, is of major importance. In the Kenyan highlands, particularly west of the Rift Valley which is the main maize-wheat producing area, high nutrient leaching rates due to high rainfall, parent materials of acidic origin and continuous use of acidifying chemical fertilizers such as Di-Ammonium Phosphate (DAP), account for soil acidity (Kanyanjua *et al*., 2002). In Uasin Gishu county the soil pH levels range from 4.5-5.2 showing strong acidity (FURP, 1994). The average wheat grain yield per hectare is 2430 kg/ha, but the optimum yield is between 4050-5400 kg/ha depending mainly on the variety (MOA, 2008). The difference in yields can be attributed to the consequences of acidic soils and others factors highlighted above.

There is little awareness of use of agricultural lime to correct soil acidity making it a matter of great concern (Okalebo, 2009). The condition or status of the soil is also a major limiting factor to food production. This includes physical, chemical and bio-physical limitations. Wheat improvement in Kenya has been directed into broadly adapted, high yielding germplasm with high yielding stability, durable disease resistance and acceptable end-user quality (Njau *et al*., 2005) without addressing causes of declining soil fertility. Over the years little research has been devoted to soil physical conditions, maybe due to the fact that some physical properties can be addressed by solving chemical limitations, and also the rather complex and laborious nature of the laboratory and field measurements for soil physical conditions. Moreover, in the past, researchers felt that the soils in the tropics have variable charges with low active clays, thereby reflecting no need for liming them, apart from only the very acidic soils (Russell, 1973) such as those found in western Kenya, including Uasin Gishu county.

1.2 Justification

Efforts to restore soil fertility are numerous and some have been adopted by a number of farmers in Kenya, for example use of both organic and inorganic fertilizers and crop rotation (MOA, 2007; Okalebo *et al*., 2006). However, management of acidic soils through liming to restore soil health has largely been ignored in SSA. Lime is one of the technologies or inputs recommended for amelioration of acid soils by raising the pH and restoring availability of calcium and magnesium, (Anetor and Ezekiel, 2007) but there is little awareness of this by farmers. Globally, agricultural lime applied as calcium oxide (CaO) or calcium carbonate ($CaCO_3$), has been adopted to effectively neutralize soil acidity (Kanyanjua *et al.,* 2002). Liming materials such as $CaCO_3$ and CaO (agricultural lime) are affordable and Kenya is endowed with natural deposits of these materials as mentioned above. However, farmers do not use these materials, often blaming seed and fertilizer as causes of low yields or poor crop performance (Okalebo, 2008). It is paramount that the liming package so developed should have long term effects in the soils so as to benefit the farmers particularly those who cannot afford seasonal applications.

1.3 Research Objectives

1.3.1 Main Objective

To assess the effects of agricultural lime from Koru, Kisumu, on wheat production in acid soils of Uasin Gishu county.

1.3.2 Specific Objectives

1. To test the effect of lime on soil water retention, pH and available P
2. To determine the response (growth and yield) of two wheat varieties(KS Mwamba and Njoro BW 2) to lime application
3. To evaluate the economic returns of wheat from ameliorating acid soil using lime

1.4 Hypothesis

1.4.1 Overall Hypothesis

Ha: - Use of agricultural lime from Koru, Kisumu, has effect on wheat production in acidic soil of Uasin Gishu county.

Ho: - Use of agricultural lime from Koru, Kisumu, has no effect on wheat production in acidic soil of Uasin Gishu county.

Ha: - Application of lime has effect on soil water retention, pH and available P

Ho: - Application of lime has no effect on soil water retention, pH and available P

Ha:-The growth and yield of two the wheat varieties (KS Mwamba and Njoro BW 2) is influenced by lime application

Ho:-The growth and yield of two the wheat varieties (KS Mwamba and Njoro BW 2) is not influenced by lime application

Ha: - Ameliorating soil with lime has effect on economic returns on wheat production

Ho: - Ameliorating soil with lime has on effect on economic returns on wheat production

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Liming acid soils

Liming in agriculture is the application of any Ca and/or Mg-containing material that is capable of reducing soil acidity. The usual agricultural practice is to increase the soil pH to 5.5-6.5 by addition of lime, commonly applied as, $CaCO_3$ or CaO or Ca $(OH)_2$ (Wild, 1993). The benefits of liming include enhanced nutrient availability particularly P and Mo, improved soil structure and increased rates of infiltration. Liming materials are effective when they remove H^+ and Al^{3+}cations off the exchange sites; neutralize H^+ (USDA, 1999).

2.2 Soil Acidity

Soil acidity occurs both naturally and as a result of human activity (Bell and Edwards, 1991). Other sources of acidity are the application of the acidifying nitrogen fertilizers (White *et al*., 2006; Bierman and Carl, 2005). Acid parent material and/or intense weathering have resulted in widespread natural occurrences of soil acidity throughout the world (van Straaten, 2007). Acid soils, considered to be soils with a pH of 5.5 or lower, is one of the most important limitations to agricultural production worldwide. Approximately 30% of the world's total land area consists of acid soils (Eswaran *et al*., 1997; von Uexkull and Mutert, 1995) and as much as 40% of the world's potentially arable lands are acidic, most of which are found in the tropical and subtropical regions (Haug, 1984). About 43% of tropical land area has acid soils which consist of 68, 38, and 27% of Tropical America, Tropical Asia and Tropical Africa, respectively (Pandya *et al*., 1994). The production of staple food crops, and in particular grain crops, is negatively impacted by acid soils. For example, 20% of the maize and 13% of rice produced in the world is grown on acid soils. Furthermore, the tropics and subtropics account for 60% of the acid soils in the world. Thus, acid soils limit crop yields in many developing countries where food production is critical. However, in the developed countries such as the United States, high-input farming practices such as the extensive use of ammonia fertilizers is done but liming of these soils is done before the fertilizers are applied (Jaelzold and Schmisdt, 2006).

2.2.1 Aluminium and manganese toxicities

Aluminium stress is one of the major constraints to crop production on acid soils. In soils, large amounts of Al are locked up in aluminosilicates or Al oxides of clay fractions and do not pose toxicity hazards. However, due to acidification, a fraction of Al oxides becomes soluble and are potentially toxic to plants (Viterello *et al*., 2005). In acid soils (pH<5.0) Al minerals hydrolyse to a soluble octahedral hexahydrate form, commonly called Al^{3+} cation which is believed to be the primary phytotoxic Al species, whereas $Al(OH)^{2+}$ species forms as the pH increases (Kochian,1995). At near neutral pH, the solid phase $Al(OH)_{3}$, or gibbsite, occurs whereas $Al(OH)^{-}_{4}$, or aluminate dominates in alkaline conditions. Many of these monomeric Al cations bind to various organic and inorganic ligands, such as PO_4^{3+}, SO_4^{2-}, F^- , organic acids, proteins and lipids. This phenomenon is responsible for the high P-fixation in very acidic soils thus rendering the phosphate in the soil unavailable by binding it to form aluminum phosphates (Kennedy, 1992). This is a common characteristic of the tropical croplands. Aluminium toxicity prevents plant root elongation which results in reduced and damaged root system. The apex is the target of Al toxicity, and the reduction in root growth is detected within minutes after Al addition (Kochian, 1995; Ryan *et al*., 1993). The toxic effect of Al on the plant roots has a clear consequence on the plant metabolism through the decrease of the mineral nutrition and water absorption and hence leading to mineral deficiencies and water stress (Kochian, 1995). In essence, Al toxicity causes stunting in the plant root system and makes it more sensitive to other abiotic stresses and ultimately reduces crop yield (Granados *et al*., 1993).

Manganese toxicity is another crop production problem in acidic soils. The symptoms of Mn toxicity include: small stunted plants with crinkled leaves with small brown spots and black necrotic spots or streaks on leaves of cereals (Neil, 1991; Agriculture and Rural development, Alberta, Canada, 2002). Conditions favouring manganese toxicity in the soil are high total soil Mn, a pH of less than 6.0, low Ca:Mn and low oxygen levels caused by poor drainage, compaction or excessive rainfall. Toxic levels may also build up temporarily when large amounts of organic matter are added to soils, especially if the soils are poorly drained. For most crops, liming to pH 5.8 to 6.0 will correct the problem of (Bell and Edwards, 1991; Neil, 1991).

2.2.2 Removal of basic cations (Ca^{++}, Mg^{++}, Na^{+}, K^{+}) through crop harvest

In a neutral soil, the exchangeable cations that dominate the exchange capacity are the bases Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}. As a result of acidification, these bases become replaced by H^{+}, Al^{3+} and Mn^{2+} ions (Wild, 1993). The loss of basic cations is permanent if they are leached out of the root zone or removed in a harvested crop. The loss is temporary if they are taken up by plants and returned to the soil in litter or on death of the plants (Wild, 1993). Some of the basic cations taken up by trees are held in woody tissues where they are effectively removed from the soil for many years (Kim, 1994). Soils under grass are low in Ca^{+2}, Mg^{2+}, K^{+}, N and P due to the continuous nutrient mining through grazing and extensive root system (Kanyanjua *et al*., 2002). The amounts of these nutrients removed by cropping depends on crops grown, part of crop harvested, and stage of growth at harvest; for example wheat crop yielding about 3.4 t/ha^{-1} removes 67 kg N, 11.4 kg P, 16.6 kg K and about 5 kg of S/ha in grain alone (Spies *et al*., 2007). Hence, if these cations are not replaced, soils will become acidic with time.

2.3 Influence of soil acidity on yields of crops

Soil reaction (pH) affects the physical, chemical and biological properties of soils and crop yields. Soil acidity is attributed to the abundance of mainly hydrogen (H^{+}) and aluminum (Al^{3+}) cations in soils at levels that interfere with the normal plant growth. Soil acidity has a negative effect on crop yields mainly through reduced P availability through Fe and Al fixation of P (Okalebo, 2009). Excess Al^{3+} ions, from soil acidity 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). The detrimental effect of H^{+} ions is not as distinct as that of Al^{3+} cations, but excess H^{+} ions in acid soils affect plant root membrane permeability and therefore interfere with ion transport (Gudu *et al* ., 2005).

Constraints limiting agricultural productivity in the high rainfall areas and other tropical lands are soil acidity and soil fertility depletion mainly, phosphorus (P), nitrogen (N) and low organic matter (Buresh *et al*., 1997; Kanyanjua *et al.*, 2002; Gudu *et al*., 2009; Kisinyo *et al*., 2009; Opala *et al*., 2010). In Kenya, grains are grown on acid soils in which, aluminium (Al) toxicity, deficiencies of P and N reduce grain yields by about 16, 28 and 30%, respectively (Ligeyo *et al*., 2009).

One of the multiple characteristics of the acidic soils is the low volume of basic cations, such as calcium and magnesium. These elements are essential nutrients for plants, in other words, there must be enough quantity of each nutrient in order to assure the development and production of the crop (Haynes *et al*., 2001).

2.3.1 Availability of P in soil

Soil phosphorus (P) is present in the soil as mineral or inorganic (P) forms, usually in amounts ranging from 0.1 to 0.4 per cent total P, but values of up to 0.7 per cent have been found in some arable soils of East Africa (Okalebo, 1987). Soil P is found in the organic, inorganic and solution forms. Organic forms of P are found in humus and other organic compounds which may or may not be associated with organic compounds. Phosphorus in inorganic materials are released by a mineralization process involving soil organisms. The inorganic fraction occurs in combination with Al (e.g variscite ($AlPO_4.2H_2O$), Fe (e.g. strengite ($FePO_4.2H_2O$) Ca (e.g. dicalcium phosphate (Ca_3PO_4), tricalcium phosphate ($Ca_3(PO_4)_2$ and other elements (Tisdale *et al*., 1990) The solubility of the various inorganic phosphorus compounds directly affects the availability of phosphorus for plant growth. The solubility is influenced by the soil pH. Soil pH greatly affects P availability to plants, becoming insoluble at low pH (<4) due to fixation by Fe and Al hydroxides and oxides and at high pH (>8) due to fixation by Ca and Mg (Sanginga and Woomer, 2009). Soil phosphorus is most available for plant use at pH values of 6 to 7 (Mississippi State University, 2010).

Almost all phosphorus (P) fractions in soils converted to phosphate ions are taken up by plants. While $H_2PO_4^-$ is the prevailing P form in acidic soils, HPO_4^{2-} is the predominant form in alkaline soils (Schilling, 2000, Blume *et al*., 2002). The total P content in soils also varies considerably, mainly as a result of the influence of underlying parent material, climatic variations and additions as fertilizers and manures. The P in the soils and plants is ultimately obtained from rocks and minerals released to the soil through the process of weathering. The contents of the water-extractable P fraction in soil, closely related to yields, reach only 0.8–8.0 mg P/kg (Marschner 1995). Mobile phosphate contents in non-fertilized soils vary significantly (10–100 mg P/kg) (Marschner 1995). In plant nutrition, the total P in soil is less important than the available P, the portion of P in the soil that can be taken up by plants. The application of lime to acid soil can affect biological, chemical and physical properties of the soils (Agriculture and Rural Development, Alberta. Canada 2010). The increase in soil pH resulting from the application of lime provides a more favourable environment for microbiological activity which increases the release of plant nutrients, particularly nitrogen. Reduced soil acidity following liming also increases the availability of several plant nutrients, notably phosphorus and molybdenum. Only about 20% of fertilizer phosphorus is taken up by a crop in the year of application. The remainder is fixed in the soil in various degrees of availability to succeeding crops. On acid soils (pH<6.0) the fixed phosphorus is retained in less available forms than on slightly acid and neutral soils (pH6.0 to 7.5). Therefore one of the benefits of liming acid soils is the increased utilization of the residual fertilizer phosphorus by crops (Government of Alberta Canada, 2002).

About 84% of soils in Uasin Gishu district have P levels below 10 mg kg^{-1}, the critical level reflecting the need for P fertilizer to increase maize and wheat production, (Lwayo *et al*., 2001) which is the main activity in the district. This clearly shows that the soils in this district are P deficiency. Figure 1 shows the frequency distribution of available P mg

kg^{-1} (Olsen *et al.*, 1954) extraction in the surface (0-20 cm) soils in 100 farms from Uasin Gishu county.

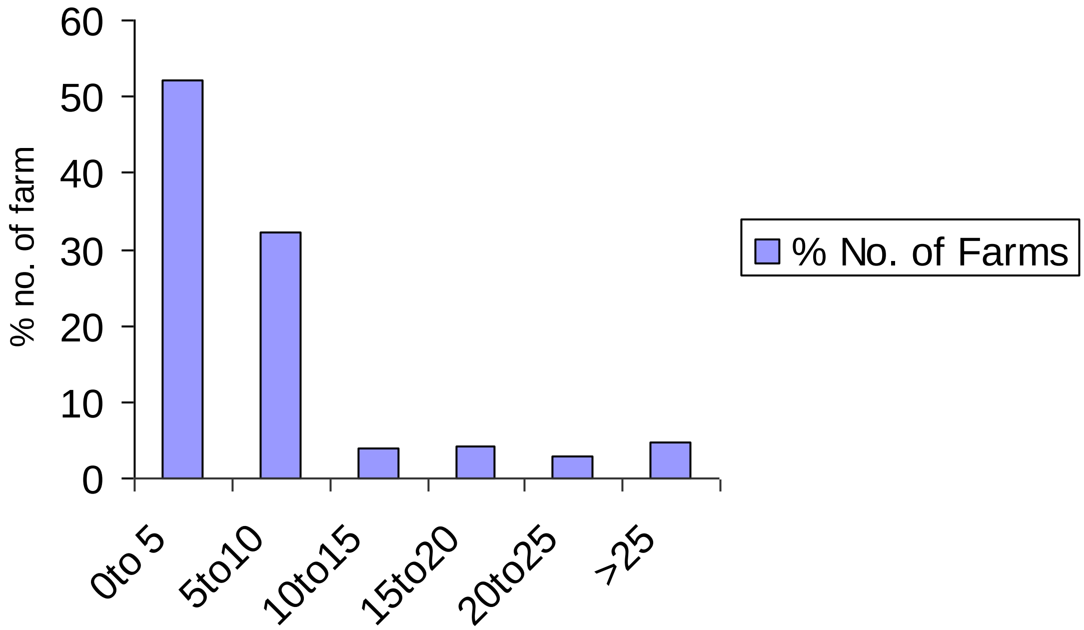


Figure 1: Frequency distribution of available P mg kg Olsen et al., (1954) extraction in the surface (0-20 cm) soils in 100 farms from Uasin Gishu county *(Lwayo et al,.2001)*

Therefore, this necessitates application of phosphatic fertilizers during the planting and liming.

2.3.2 Functions of P in plants

Phosphorus has a vital role in the plant life processes such as photosynthesis, synthesis and breakdown of carbohydrates and the transfer of energy within the plant. Phosphorus is a key component in the molecules adenosine triphosphate (ATP) and adenosine diphosphate (ADP), which are integral to most energy transport processes in the living organism. P is a vital constituent of chromosomes. P is essential for the formation of proteins; enzymes as well as deoxyribonucleic acid (DNA). Phospholipids play a vital role in the formation of the cell membranes. Phosphorus stimulates the development of roots which will proliferate extensively in areas with high P concentrations (Mullin, 2009). It is needed in the final growth stages of plant for seed and fruits. The P reserve in the seed is concentrated in the form of phytin, the inosital hexaphosphate. Sufficient P strengthens the straw in cereals. Phosphorus is relatively mobile in plants and will translocate from older to younger plant tissues (Van Staaten, 2007). Phosphorus deficiency would generally decrease plant biomass accumulation by limiting leaf size and growth, hence interfering with interception of radiation (Neil, 1991)

2.4 Management of Soil Acidity

Acid soils may be managed in several ways which include using crop species that are tolerant to high levels of exchangeable Al (Viterello *et al*., 2005) or by amelioration of the soils through amendments that counteract the effects of soil acidity (Biswas and Makerjee, 1994). Traditionally, use of mulch from agro-forestry tree species, burning of sites to produce ash and use of animal wastes, such as poultry manure, have been reported (Young, 1989). However, such materials are not available in adequate amounts. Further, in most cases, the materials are too bulky and variable in quality (Probert *et al.*, 1992, Woomer *et al.*, 1999). Apart from the agricultural lime, PRs have a liming effect; however many end users recognize their phosphate benefits, but not the liming effect. The application of lime can also improve the physical properties of some soils. It improves the soil tilth which results in less soil crusting, soil buffering capacity and emergence of small seeded crops such as canola. Reduced power requirements for tillage have been noted as a result of lime additions (Agriculture and Rural Development, Alberta. Canada, 2002).

2.4.1 The planting of crop cultivars tolerant to soil acidity

Over the past several decades, there has been a shift by plant breeders to develop crop genotypes that are tolerant to specific factors, such as drought, P deficiency and Al stresses without sacrificing high yields (Gudu *et al.*, 2005). Wheat producers now routinely use Al tolerant cultivars as one cost effective means of reducing risks associated with acidic soils (Sheng *et al*., 2007).These genotypes have high P use efficiency even from sparingly soluble P forms. Their high use efficiency from sparingly P soluble sources is related to their potential to enhance microbial colonization and symbiosis with P solubilizing microorganisms in the rhizosphere (Oliveira *et al*., 2006; Ndungu Mogiroi, 2011). In Kenya wheat genotypes have been screened and bred towards Al toxicity, for example Njoro BW 2 variety. However, studies done in other regions show that continued use of these genotypes is not recommended as the options to grow different species are reduced as pH continues to decline. Eventually soil pH will be too low for even acid tolerant crops (Bill, 1989). Planting tolerant species allows production to continue on the acidic soils but does not change the acidity. In many soils the best results are contained from the combined use of tolerance and lime.

The long term goal should therefore be to lime soils to a value best suited to crops being grown. After a desired soil pH has been achieved, the amount of lime required to maintain soils in a suitable pH range depends on fertilizer rates, soil types and cropping practices (Agriculture and Rural development, Alberta Canada, 2002)

Crops and their genotypes differ in their tolerance to Al toxicity; the grain legumes (pulses) being more sensitive compared to cereals (Maron *et al*., 2009). In a study which compared the performance of bean varieties on acid ferralsols of Chepkoilel Campus farm, Eldoret, there was no nodulation in a bean crop reflecting the absence of N-fixation by the crop as a result of soil acidity (pH<5). Concurrently, low bean yields (0.3 t/ha) were recorded in this study (Birech *et al.*, 2000). These soils are also characterized by high Al levels above 30 percent saturation (Schulze and Santana, 2002).

2.4.2 Correction of Soil acidity through liming

Correcting soil acidity by use of agricultural lime is the foundation of a good soil fertility program (Synder, 2004). Its direct effect is soil pH increase (The *et al*., 2006). In Kenya, management of soil acidity through liming is highly recommended (Kanyanjua *et al*., 2002; Kisinyo, 2011). Lime reduces Al, H, Mn, Fe ion toxicities and increases availability of P, Mg, Ca and Mo ions in acid soils (Kamprath, 1984; Kanyanjua *et al.*, 2002; Moody *et al.*, 1998). It also increases the uptake of P and N by plants (Raij and Quaggio, 1997; Van Straaten, 2007). Reduction of soil exchangeable Al and Fe results in less P fixation thus making the native and applied P fertilizers available for plant uptake. Where acid soils are causing reduction of wheat production, plant growth and yield significantly, the condition can be improved by liming these soils and raising the pH to an optimum range (Bill, 2011).

Application of lime can affect biological and physical and chemical properties of the soil. Thus increase in soil pH resulting from the application of lime provides a more favourable environment for microbiological activities which increase the rate of release of plant nutrients, particularly nitrogen (Agriculture and Rural Development, Alberta. Canada, 2009 – 2010)

Liming corrects magnesium and calcium deficiencies (Bell *et al.,* 1991; Neil 1991).

In a past research (FURP, 1987 – 1994), results obtained after 5 years of experimentation could not be conclusively used to give fertilizer recommendations (Kanyanjua *et al.*, 2002), because twenty-three sites (39% of the total) where the field trials failed, had acid soils with pH levels less than 5.5 and would require to be amended through liming if crops were to be grown profitably (Kanyanjua *et al.,* 2002). Similarly, in a case study of Rwandan oxisol with subsoil pH of 4.0, liming improved the conditions for plant growth by raising soil pH, decreasing the amount of exchangeable Al and increasing the supply of Ca and Mg (Yamoah, 1992). Liming, especially in continuously cropped lands, is paramount to maintaining a conducive pH necessary for production of maize, wheat and legumes.

2.4.2.1 Residual effect of lime

Although not permanent, the effect of lime lasts longer than the other amendments such as organic or inorganic materials. The residual effect of lime on soil acidity is dependent on the type of liming material and rates applied (Kisinyo, 2011). The residual effect also depends on how the Ca^{2+} and Mg^{2+} ions are being displaced by residual acidity ($Al^{3+}$and H^{+}) of nitrogen fertilizers (Sanchez, 1976). Lime has been reported to be effective in controlling soil acidity of upto a period of five years, therefore, it is rarely necessary to lime more frequently than every five years. The residual effect of liming soils with waste materials is greater than the fine material because large particles react slowly with acidity and remain in the soil longer (Neil, 1991). Where coarser liming materials are used, longer residual effect is possible. Coarser liming materials take longer time to release Ca and/or to react with soil acidity (Al^{3+} and H^+ ions) compared to finer particles (Neil, 1991). Therefore, lime reapplication depends on the ability of the material to keep the exchangeable Al^{3+} ions below the acceptable limits and/or when the crop yields begin to decline due to soil acidity related constraints. Large lime rates normally have longer residual effect than lower ones, but may also lead to negative effects like soil acidity (Abruna *et al.*, 1964)

2.5 Effects of lime on soil physical properties

2.5.1 Soil structure

Tillage opens up the soil surface and lets water in freely at first, but the structure of bare soils is vulnerable to damage from falling rain. The consequent breakdown of aggregates can lead to surface sealing of the immediate surface, with serious reduction in potential infiltration rate. Treatment with organic matter, gypsum and other materials can make soil structure more stable (Marshall *et al.,* 1991) for crop production. Benefits of liming include nutrient availability, improved soil structure and increased rate of infiltration (USDA, 1991).

2.5.2 Infiltration

Infiltration is the process of water entry from the surface sources such as rainfall, snow melt or irrigation into the soil. The infiltration is a component in the overall unsaturated redistribution process that results in the soil moisture availability, chemical transport and ground water recharge (Paul, 2003). Infiltration is related to soil structure. Any practice that degrades structure of the soil will have an adverse effect on infiltration, and therefore monitoring infiltration rates under different soil management regimes is a good indication of how the practice will influence the rate at which water can enter into the soil (Cooperative Research Centre for Viticulture, 2006). The management steps available to help maintain yields can be either chemical or physical. Chemical practices involve changing the soil or the property of water that influences soil infiltration rates.

2.6 Water holding capacity

Water holding capacity is the ability of a given volume of soil to hold water under one atmospheric pressure. It measures the potential benefit of reducing the required frequency of irrigation, as well as gross water requirements. The water holding capacity should be known to allow the end users to monitor or estimate the effect of their watering regime and growing media. It is measured as a percent of dry soil weight. Soil is compacted by the passage of farm machinery, such as wheat growing areas of Uasin Gishu county. Cultivation remedies compaction in the topsoil layer but increases compaction in the subsoil layers immediately below the cultivation depth. Compacted soil slows root penetration or prevents it altogether. Subsoil compaction can be reversed by deep ripping but this is an expensive and rather temporary remedy if the causes of compaction are not also addressed. An increase in soil calcium (especially with clay soils) and of organic matter (greater earthworm activity) render most soils less prone to compaction. Compaction damage from farm machinery is worst when soils are wet. Heavy and compacted soils suffer poor drainage and so are more likely to become anaerobic in wet weather. This will quickly kill fine roots (especially when the soil is warm) and soil acidity will rise. Raising soil calcium improves drainage and aeration in heavy clay soils. Low infiltration rates are evident in Uasin Gishu district during the rainy season where wheat and maize are planted.

2.7 Wheat production

2.7.1 Climatic conditions, soils and water management

Wheat is essentially a temperate-climate crop. Land preparation should start within one to two months after harvesting, to control weeds and conserve moisture for the next season's crop. Early seedbed preparation allows weed to germinate with the first rains, followed by shallow harrowing which greatly reduces the amount of weeds in the wheat crop. Optimum temperatures for development are 10-24^{0}C. Temperatures above 35^{0}C stop photosynthesis and growth and at 40^{0}C the crop dies off. The minimum amount of water required for an acceptable crop is 250 mm in the top 1.5m of soil. Areas with 700 mm to 1000 mm rain per year will be able to grow rain-fed wheat. (MOA, 2002).

Wheat is propagated by seed. It requires a fine seed-bed that is free of weeds. Sowing depth varies from 2 cm-12 cm, with deeper planting required in dry conditions to reach the moist soil. Seed rate varies from 100-150 kg/ha, resulting in 250-300 plants/m^2. The seed rate depends on the tillering ability of the cultivar (MOA, 2002). Wheat responds well to the use of fertilizer and application in optimum quantities is essential to boost its yield. Nitrogen and phosphorus are the most important nutrients required by wheat. However, the availability and response to these nutrients are influenced by soil reaction, organic matter, fertility schedule and cropping pattern (KARI, 1992). Fertilizer recommendation (mainly DAP) depend on specification by the breeder or KARI recommendation of which also depends on the previous land use and application of foliar feed at boot stage to supplement nitrogen in the DAP (unless specification are made by the breeder). In areas with acid soils, acid tolerant varieties and liming are recommended MOA, 2002).

Weeds effectively compete with wheat for nutrients, water and light and are the biggest constraint to good yield. Herbicides are used to control weeds. Spraying of herbicides should be done a month from the time of sowing preferably at 4-leaf stage. Insecticides can be incorporated with herbicides if there is infestation by insects. Diseases, mainly the rusts for example stem and leaf rusts, are controlled using fungicides in the district. Control of diseases in wheat is a common practice in the district.

Wheat is harvested at physiological maturity when a dark layer of cells had formed along the crease of the wheat kernels. At this stage the crop has also lost the green colour from the peduncle, kernel (including crease) and glumes. Harvesting is done using a combine harvester. The wheat is then dried to a maximum moisture content of 13%.

2.7.2 KS Mwamba wheat variety

KS Mwamba was developed in the 1990s and was released on 18th October 2001 in Kenya. It has proven to be the most outstanding variety amongst Kenya Seed Company wheat seeds. This variety has the following characteristics; it is a medium maturity variety which grows to a height of approximately 72 cm. The wheat grain is red in colour and takes 125 days to mature. KS Mwamba is resistant to stem, yellow, leaf rust and lodging. It also has good tillering capacity and does well in all altitudes. Kenya Seed Company recommends DAP and MAP at planting fertilizer at the rate of 25 kg P, 22.5 kg N/ha and Bayfalon which is a foliar feed should be used at or just before booting stage. The seed rate is 125 kg /ha giving a potential yield of 42 bags of 90 kg/ha.(Kenya Seed Company, 2001)

2.7.3 Njoro BW 2 wheat variety

This variety grows well in high altitude areas, 1800 m to 2400 m above sea level (www.infonet.biovision.org). It takes 120 days to mature. Njoro BW 2 wheat variety performs well in acidic soils and can produce upto 35 bags/acre (Grain production in Kenya, 2005). The wheat variety is resistant to stem rust and lodging (www.infonet.biovision.org),

2.8 Economic analysis

Economic evaluation of new technologies is done to assess performance of prospective technologies under farmers environmental, economic and managerial conditions with the aim of implementation or revision of the proposed technology to make it more consistent with farmers' conditions and thus facilitate adaption (Kipsat, 2002). After analyzing the agronomic viability of several treatment combinations that yield the greatest benefit and which provide the basic element for adaption (CIMMYT, 1993). The most commonly used methods for economic analysis of treatment combinations include costs and return analysis method which is used to determine the impact of a new technology (Barlow e*t al*., 1983). Some of the 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 make annual evaluation of on-going or existing projects and is defined as gross output less variable costs. GM is used to determine profitability of enterprises produced under alternative technologies or treatments. Return to land, labour and capital productivities respectively, and are used as measures of performance of technologies. Value to cost ratio refers to the ratio of the total revenue and total variable costs. It is often 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 sunk capital are ignored (Barlow *et al*., 1983). 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

3.0 MATERIALS AND METHODS

3.1 Field trials

3.2 Uasin Gishu County

The county lies between longitudes 34^{o} 50' and 35^{o} 37' East and latitudes South and 0^{o} 55' North. It is a highland plateau. Its terrain varies greatly with altitude which ranges between 1500 metres above sea level at Kipkaren in the West to 2,100 metres above sea level at Timboroa in the East. Eldoret Town, the capital of Uasin Gishu county, is at an altitude of 2085 metres, marks the boundary between the highest and the lowest altitudes of the county. The county's general landscape is that of undulating plateau with no significant mountains or valleys. The land is higher in the East and declines towards its Western border. The average rainfall is between 900 mm -1200 mm. Due to high altitude in the county, temperatures are relatively low. The highest is 24^{0}C and the lowest is about 8.8^{0}C. Humidity is moderate, averaging 56%. The average temperatures in the county are 18^{0}C during the wet season with a maximum of 26.1^{0}C during the dry season (Republic of Kenya, 2001-2004).

The types of soils and land use pattern in the county have been influenced by variation in altitude, rainfall, and temperature and underlying geology. The county has four noticeable soil types: red clay, brown clay, and brown loam soils. Due to favourable topographical and climatic conditions, the entire county has a high potential for agricultural and livestock production (MAO, 2006).

3.2.2 Experimental sites

Field trials were conducted in Kipsangui area of Soy division and at the Crop, Seed and Horticultural Sciences Department Field (Chepkoilel University College) – Moi University in Moiben division. The two divisions have been identified as having acidic soils with P and N deficiencies due mainly to continuous cultivation for a long time, with the use of acidifying fertilizers, mainly DAP and Urea (Mwangi *et al.*, 1999, Lwayo *et al.,* 2001, Nekesa, 2007). These sites however, are located in areas with favourable climatic conditions for crop production with adequate rainfall distribution.

3.2.2.1 Chepkoilel University College

The experiment was carried out at the Crop Seed and Horticultural Science Department Field in Moiben division. The soils of Chepkoilel University College belong to a group of soils found on plateaus and high level structural plains. The soils are of igneous origin, acidic (pH: 4.5-5.0), and of low fertility and are underlain with murram. They are classified as Rhodic Ferralsols according to the FAO/UNESCO classification and Oxisols according to the USDA classification (Jaetzold and Schmidt, 2006; FURP, 1994)

3.2.2.2 Kipsangui

The experiment was also concurrently carried out at Mrs Selina Maswai's farm in Kongasis location, Kipsangui sub-location, Soy division of Uasin Gishu county. The area receives a unimodal rainfall distribution pattern. The average amount of rains received in the area for the last ten years is 1171 mm. 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 Oxisols according to the USDA classification (Jaetzold and Schmidt, 2006, FURP, 1994).

3.3 Treatments

The experiment recognized and focused on the correction of soil acidity of Uasin Gishu county soils. Hence it evaluated the liming effects of agricultural lime (21% CaO) from Koru, Kisumu, which is readily available. Lime was applied at the rates of 0.0, 0.5, 1.0, 1.5, and 2.0 ton/ha as CaO. These rates were selected taking into consideration the need to develop affordable input by farmers. DAP fertilizer was applied as a blanket treatment at rate of 40 kg P_2O_5/ha (17.6 P kg/ha). This is the KARI – recommendation of 1992. Effects of different rates of Agricultural lime was tested and compared with control (DAP without lime). N- was applied at the rate of 46 kg N/ha (KARI – recommendation of 1992). The experiment was laid down in a split plot design with the two wheat varieties as the main plots, replicated three times and the lime levels as the subplots as described in table 3.

Table 2: Liming Treatments as Applied at two study sites in Uasin Gishu County

Treatment No.	Description	Treatment Code
1. KS Mwamba)+0.0t/ha	0.0t/ha KL+40P_2O_5/ha+46N/ha	**ML0**
2. KS Mwamba +0.5t/ha	0.5t/ha KL +40P_2O_5/ha +46N/ha	**ML1**
3. KS Mwamba +1.0t/ha	1.0t/ha KL + 40P_2O_5/ha+ 46N/ha	**ML2**
4. KS Mwamba +1.5t/ha	1.5t/ha KL + 40P_2O_5/ha +46N/ha	**ML3**
5. KS Mwamba +2.0t/ha	2.0t/ha KL +40P_2O_5/ha+46N/ha	**ML4**
6. Njoro BW2 +0.0	0.0t/ha KL+40P_2O_5/ha+46N/ha	**NL0**
7. Njoro BW2 +1.0	0.5t/ha KL +40P_2O_5/ha +46N/ha	**NL1**
8. Njoro BW2 +1.0	1.0t/ha KL + 40P_2O_5/ha+ 46N/ha	**NL2**
9. Njoro BW2 +1.5	1.5t/ha KL + 40P_2O_5/ha +46N/ha	**NL3**
10. Njoro BW2 +2.0	2.0t/ha KL +40P_2O_5/ha+46N/ha	**NL4**

Where; KL-Koru Lime; Source of P_2O_5 was DAP, while DAP and also foliar N feed supplied N at 46 kg/ha, KS Mwamba and Njoro BW 2 are wheat cultivars, KL0-KS Mwamba+no lime(control), KL1-KS Mwamba+0.5t/ha lime, KL2-KS Mwamba+1.0t/ha lime, KL3-KS Mwamba+1.5t/ha lime KL4-KS Mwamba+2.0t/ha lime,NL0- Njoro BW 2+0.0t/ha(control) lime, NL1-Njoro BW 2+0.5t/ha lime, NL2- Njoro BW 2+1.0t/ha lime, NL3- Njoro BW 2+1.5t/ha lime, NL2- Njoro BW 2+2.0t/ha

3.3.1 Installation and management of the experiment

3.3.1.1 Application of treatments.

The treatments in Table 2 were replicated three times for each site and applied in plots measuring 4 m x4 m giving plot areas of 16 m^2 in each site. Ploughing of the land had been done before the onset of the rains. Harrowing was done before planting. Lime and DAP were broadcast evenly within the plots on a fine seedbed and then incorporated into the soil using a hoe as shown in the plate 1.

Plate 1: Incorporating the nutrient replenishment inputs into the soil before planting

(Author, 2013)

Urea foliar feed (46% N) was used to supplement the N in DAP at the rate of 28 kg N/ha. The seed rate was125 kg/ha as recommended by Kenya Seed Company (2001) and KARI, (1992). Herbicide (Puma Complete) was sprayed a month after planting i.e. 4 leaf stage at the rate of 0.75 litres/ha. Fungicide (Nativo 300 SC 0.75 litres/ha) was also applied at 4 weeks after planting and foliar feed was sprayed just before tillering stage.

3.3.1.2 Wheat planting

The seeds were drilled by hand at the recommended spacing row of 25 cm by drill. The placement within the row by hand was predetermined prior to planting by running a mechanical drill planter and observing /noting the closeness of the spacing. The depth of placement was established at 2.5 -3 cm deep. After sowing, seeds were covered with topsoil and slightly compressed to ensure close seed-soil contact. This was done to ensure a rapid and even germination (Acland, 1971).

3.4. Soil sampling and preparation

In the experimental plot of 16 m^2 , a composite surface soil (0-15 cm) sample was collected from random ten sampling points, mixed and sub-samples taken to the greenhouse, air dried and passed through a 2mm sieve, to determine, particle size, soil pH, and soil available P. The soil was further ground lightly and passed through a 0.02 mm sieve for determination of organic carbon (C %) and total (N %). The parameters analysed at Chepkoilel laboratory, were used to characterize the soil at the beginning of the experiment for each site. After application of the treatments, soil samples were taken at six weeks after planting and at harvesting (at the end of experiment) to monitor mainly the changes in pH and available P which were determined in the laboratory according to methods described by (Okalebo *et al*., 2002).

3.5 Heights

Four plants per raw were selected in each plot at random, tagged and monitored for growth rate. The heights of the tagged plants were measured at the intervals of two weeks from the 6^{th} week after planting to the 10^{th} week.

3.6 Crop Harvesting Procedures

Harvesting of wheat was done at physiological maturity when a dark layer of cells had formed along the crease of the wheat kernels. At this stage the crop had also lost the green colour from the peduncle, kernel (including crease) and glumes. Harvesting was done on centre rows of each plot at final harvest by discarding outer rows per plot. Thus the inner rows were harvested by hand giving an effective area of 14 m^2. The ends of plots plants were also discarded. In the harvested area, total heads, fresh weights and sub samples weights were taken and recorded. The wheat was threshed manually (by beating using a stick) .The sub-samples were dried in the greenhouse and weights of grains recorded for estimates of dry weights or yields. The straw within the harvested area was cut at ground level at harvest and its weight taken. Sub-samples from the straw were taken randomly from each plot and cut into small pieces and mixed thoroughly and weighed a fresh. All samples were air dried (in the absence of oven) and their fresh (initial) and dry weights recorded and used to compute yields per plot (grain and straw).These samples were then ground (0.2 mm) for plant tissue analysis to determine N and P contents. Yield was calculated using the relationship.

$$\text{Yield/plot} = \left(\frac{\text{Total dry weight}}{\text{Total fresh weight}}\right) * \text{dry sample weight}$$

$$\text{Yield (kg ha)} = \frac{\text{Yield/plot} * 10{,}000\ m^2}{\text{Effective area } (m^2)}$$

3.7 Laboratory Analyses

The analyses were carried out according to the procedures outlined in Okalebo *et al*., (2002). These consisted of both soil and plant tissue analysis.(viz for soil pH, soil particle analysis, C, Olsen P, total N and P).

3.7.1 Detailed soil analysis

3.7.1.1 Determination of soil particle size composition

This involved the dispersion of soil particles into different constituents using sodium hexametaphosphate solution (calgon) and subsequent sedimentation of the particles in a cylinder. This allowed the particles to settle at the bottom of the cylinder according to their size, density, viscosity and temperature of the liquid (Stokes Law). Sand settled first (40 seconds), then silt (2 hrs)

3.7.1.2 Determination of soil pH

Measurement of soil pH is expressed as the inverse log of the hydrogen ion concentration. The pH of the soil solution controls the form and solubility of many plant nutrients. Soil pH is measured on 2.5:1 water to soil suspension.

3.7.1.3 Determination of extractable soil phosphorus: The Olsen method

The soil is extracted with 0.5 M solution of sodium bicarbonate at pH 8.5.In calcareous, alkaline or neutral soils containing calcium phosphate, this extractant decreases the P concentration of Ca in solution by precipitating Ca as $CaCO_3$. The result in an increase of the concentration of the solution. The Olsen method is suitable for a wide range of soil types and pH values. In acid soils containing Al and Fe phosphate, the P concentration in the solution increases and as the pH rises. Precipitation reactions in acid and calcareous soils are reduced to a minimum because the concentration of Al, Ca and Fe remain at low level in this extractant.

3.7.1.4 Determination of total nitrogen and phosphorus in plants and soils

The content of total nitrogen and phosphorus is measured in a digest obtained by treating soil or plant sample with hydrogen peroxide + sulphuric acid + selenium + salicylic acid + lithium sulphate. The principle takes into account the possible omission of nitrates by coupling them with salicylic acid in an acid media to form 3-nitrosalicylic and or 4-nitrosalicylic. The compounds are reduced to their corresponding amino acid forms by the soil organic matter the analysis; of total nutrients requires complete oxidation of organic matter. The peroxide oxidizes the organic matter while the selenium compound acts as catalyst for the process and the H_2SO_4 completes the digestion at elevated temperatures as well as the inclusion of $LiSO_4$.

The main advantage of this method are that single digestion is required (for either soil or plant material) to bring nearly all nutrients into solution; no volatilization of metals, N and P takes place and the method is simple and rapid.

3.7.1.2 Determination of moisture retention

Pressure plate apparatus for matrix potential (um) range from 0-50 m four plastic retaining rings were arranged on the saturated pressure plate in the pressure chamber. A scoop was used to pour oven dry and sieved soil into the retaining rings. A small pile was made the ring. When the sample was in place, the water level of the pressure plate was raised slowly to cover the plate's surface and to saturate the soil samples from the bottom (the samples were left overnight for saturation).

After saturation was completed, the flow tube and the seal of the chamber were collected by fastening the cover bolts. A single pressure of 25 m of water (2.45 bars or 0.245Mpa) was applied. The samples were then removed from the pressure plate to pre-weighed drying dishes, the wet samples were weighed and the drying dish was then placed in the oven to determine the gravimetric water content at 105^{0}C . (Co-operative Research Centre for Viticulture, 2006).

3.8 Economic analysis of yield data

The most economically acceptable were 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. In partial budgeting only costs that vary from the control are used referred to as total costs that vary (TCV).The prices of lime, DAP, urea foliar fungicide and pesticide, bags for storing wheat, transport and wheat grain were determined through market survey at each of the two sites during the research period. Labour wage rates for applying lime, fertilizers and shelling of the grain were also determined through market survey to estimate the labour costs that vary. 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. 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.

The net accrued net financial benefits (NFBs) and TCV were then compared across the treatments dominance analysis the formula shown below.

The first step in partial budgeting is the calculation of the NFBs as shown in the formula below

NFB=(Y*P)-TCV…………………………………………………………………(2.1)

Where Y*P=Gross Field Benefit (GFB), Y=Yield per ha and P=Field price per unit of the crop.

The second step was dominance analysis in which the treatments were listed in order of increasing (TCV). Treatment with NFB less than or equal to treatment with lower TCV are dominated and were marked a "D" while ones with higher NFB than the treatments and lower TCV are undominated. The dominated treatments were eliminated from the further consideration since no farmer would choose a treatment(s) with higher TCV and receive lower NFB (CIMMYT, 1988). The marginal rate of return (MRR) analysis was carried out on the undominated treatments in a stepwise manner, starting from one treatment with the lower TCV to the next using the formula shown below.

$$MRR(\%)=\frac{\text{Change in NFB (NFBb-NFBa)*100}}{\text{Change in TCV } (TCV_b - TCV_a)} \text{………………………………}(2,2)$$

where $NFB_{a=}$ NFB with the immediate lower TCV, NFB_b =NFB with the next higher TCV,TCV_a= the immediate lower TCV&TCV_b =the next highest TCV

Change in NFB and TCV also referred to as marginal benefits and costs, respectively. MRR indicates what farmers can expect to gain on the average, in return to their investment when they decide to change from one practice (or set of practices) to another with increase in cost. To make farmer recommendation(s) from the marginal analysis, the minimum rate of return acceptable to farmers was estimated. Experience and empirical evidences have shown that in most cases the minimum rate of returns acceptable to farmers to change from one technology/treatment to another is between 50% and 100% (CIMMYT,1988, Dillion and Hardaker, 1993). A minimum rate of criteria 50% was set for the MRR analysis as adequate for changing from one treatment to another that does not require the farmers to learn new skills or use new equipment (CIMMTY, 1988). Therefore any treatment combination that produced MRR above 50% was considered worth an investment by farmers.

3.9 Statistical analysis of data

Statistical analysis was done considering the split plot design following the model

$Xjklm = \mu + 2j + \beta k + \varepsilon jk + ni + yil + \varepsilon jklm$

Xjklm = Plot observation

μ = Mean of observations

xj = Main treatment effect

βk = Block/replication effect

εjk = Error (1)

τij = Sub treatment effect (Lime)

λil = Interaction main treatment and substreament (between variety and lime)

εjklm = Error (2)

Table 3: General layout ANOVA for the effects of P fertilizer and lime on soil and wheat yields

Source of variation	DF	Sum of square	Mean of sum	F_{value}	Pr>F
Replicate	r- 1				
Main plot factor A	a-1				
Whole plot error (a)	(r-1) (a-1)				
Sub plot factor B	b-1				
A*B	(a-1) (b-1)				
Split- plot error (b)	a(b-1) (r-1)				
Total	n-1				

Factor A –Variety

a-2 levels

Factor B-Lime levels

b-5 lime levels

r-blocking factor (replicates)

CHAPTER FOUR

4.0 RESULTS

4.1 Soil physical and chemical characteristics of the study sites

Some physio-chemical properties of the surface soils (0-15 cm) of the experimental sites are given in Table 4. The soils in these study areas were acidic with pH of 4.9 (Strongly acidic) for soils at Chepkoilel and 5.3 at Kipsangui (Moderately acidic), as rated by KARI's National Agricultural Research Laboratories (NARL), in Nairobi (Kanyanjua *et al.*, 2002). The soils from Chepkoilel had low organic carbon of 1.7% while those from Kipsangui had moderate organic carbon of 2.7% giving a constant C: N ratio of 10:1 for both sites mostly found in the cultivated soils. The soil available P for both sites was within the critical level of 10 mg kg reflecting the need for P fertilizer for adequate crop growth (Okalebo *et al.*, 2002). For the soil particle size analysis, the soils from both sites were classified as sandy loam indicating that the soil had high capacity to store soil nutrients and moisture (Kolay, 1993).

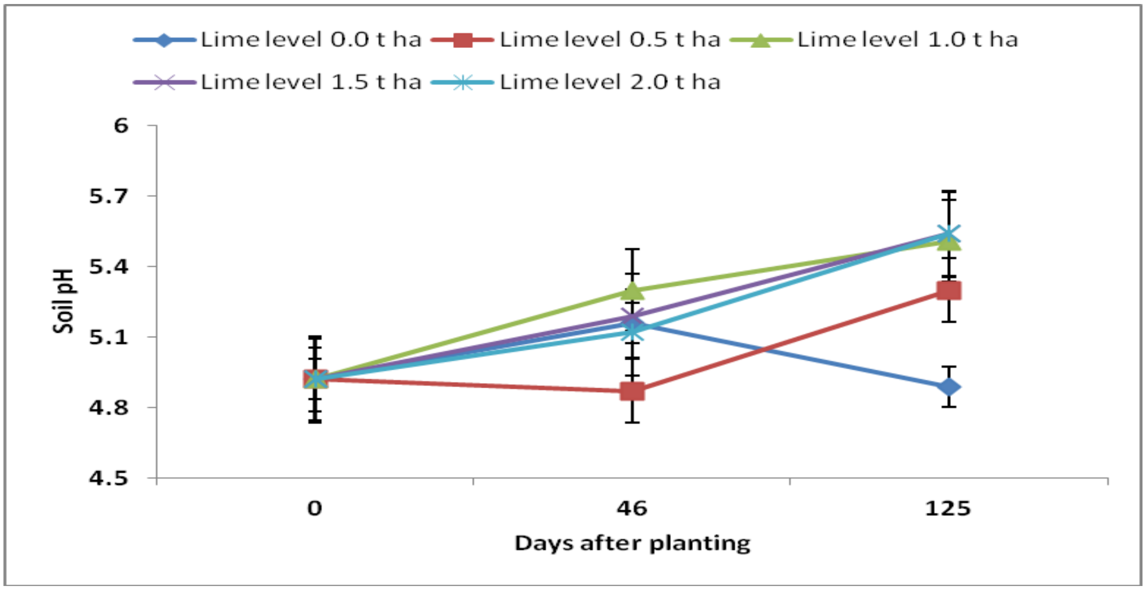
Table 4: Soil physical and chemical characteristics of surface (0-15 cm) soils taken before planting (2009 LR) at two study sites in Uasin Gishu county, Kenya

Soil Property	Chepkoilel site	Kipsangui site
%Sand	60	60
%Silt	16	18
%Clay	24	22
Textural class	Sandy loam	Sandy loam
pH (1:2.5 soil: water)	4.9	5.3
%N	0.2	0.3
%C	1.7	2.7
C: N	10.1	10.1
Olsen P (mg kg^{-1})	9.9	10.4
Soil water content (% water) at1/3 bar	22.0	23.5

4.2 Effects of lime additions on soil pH during wheat growth

The effect of application of Koru lime on the pH values of the soil samples taken at different time intervals of 46 and 125 days after planting for the Chepkoilel and Kipsangui sites are given in Figure 2 and 3 respectively. There was an increase in soil pH at Chepkoilel site at both sampling dates with lime additions of 1.0, 1.5 t/ha and 2.0 t/ha in both wheat varieties. The soil pH in the control increased at 46 days after planting then reduced at 125 days after planting from Njoro BW 2 wheat variety. In the same variety the pH decreased with lime additions of 0.5 then increased at 125 days after planting. In KS Mwamba wheat variety there was an increase in soil pH in the control at 46 days after planting then a decrease at harvesting. There was also an increase in soil pH with lime additions of 0.5, 1.0, 1.5 and 2.0 t/ha in both varieties at Kipsangui site at 125 days after planting. The pH also increased in the control treatment in both varieties at this site. However, at 125 days after planting the pH decreased with lime additions 0.5 t/ha and the control treatment in Njoro BW 2 wheat variety.

Chepkoilel site-Njoro BW 2 wheat variety



Chepkoilel site-KS Mwamba wheat variety

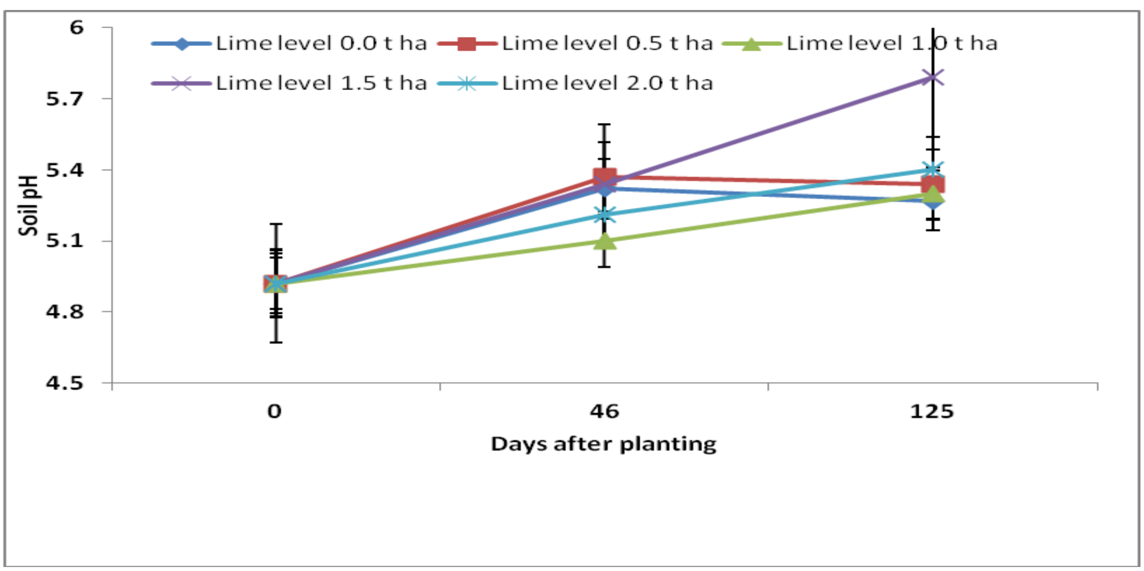
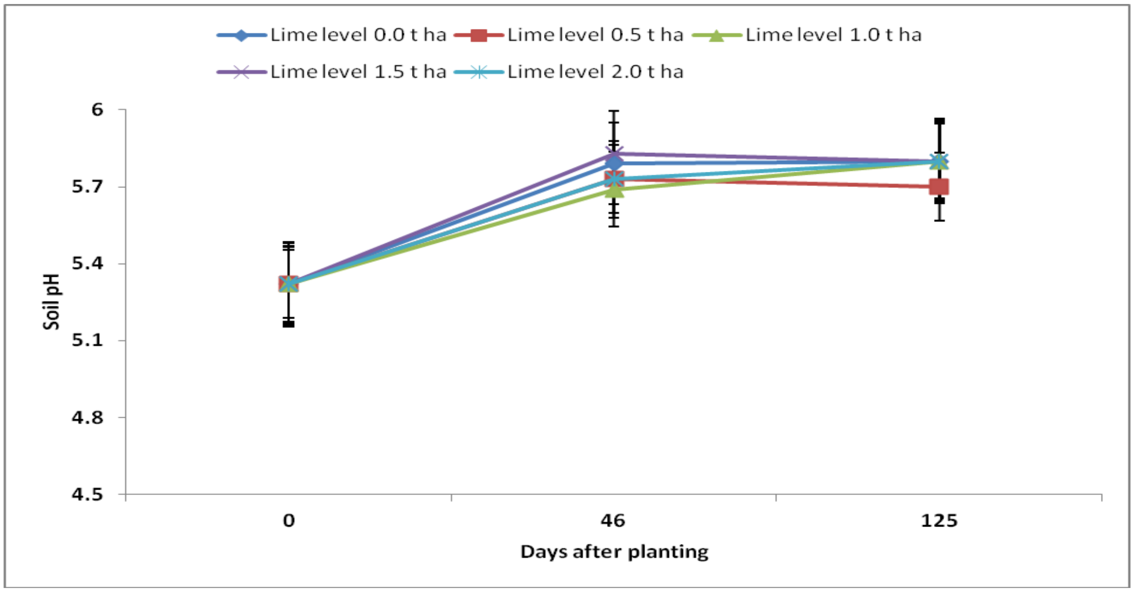


Figure 2: Soil pH changes during the 2009 LR season for Chepkoilel sites as affected by treatment application

Kipsangui site-Njoro BW 2



Kipsangui site-KS Mwamba

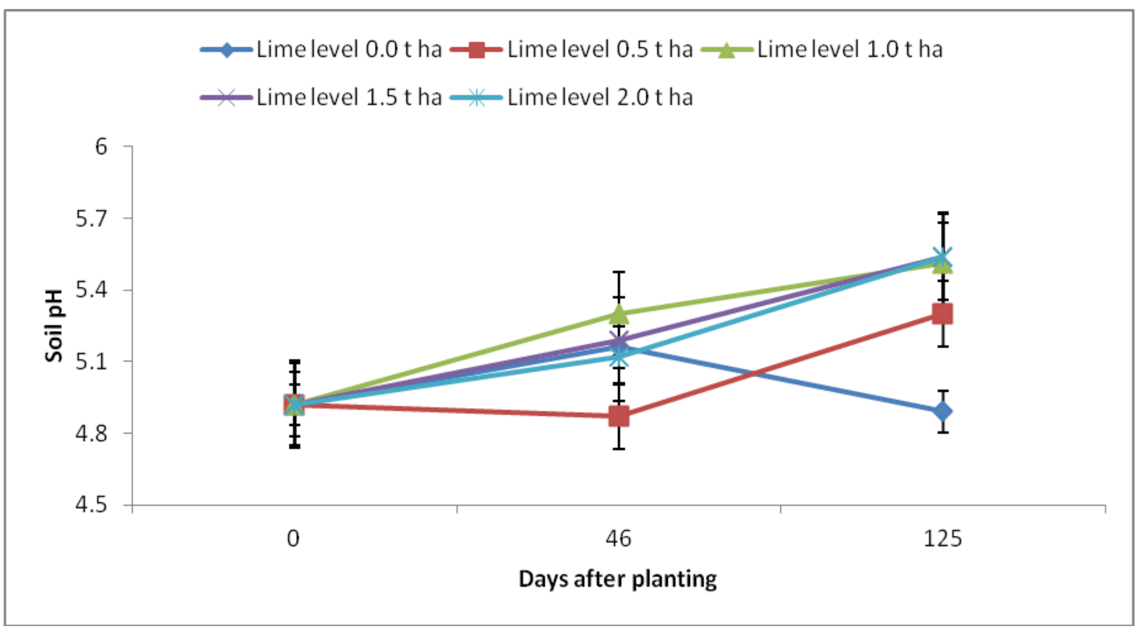


Figure 3: Soil pH changes during the 2009 LR season for Kipsangui sites as affected by treatment application

4.3 Effect of lime on soil available P taken at wheat harvest

The results of available P taken at harvesting (125 days after planting) for Chepkoilel and Kipsangui sites as affected by lime and blanket P and N additions are shown in the Figure 4. There was a significant difference ($p < 0.05$) of soil available P with increase in the lime rate applied. The soil available P at Kipsangui site was higher than that at Chepkoilel site in both wheat varieties with the increase of lime level at 0.5, 1.0 and 2 t/ha (Figure 4). The soil available (P mg/kg) at both sites was lower in the control treatment when compared to all levels of lime additions. At both sites, soil available P showed an increasing trend above the control. The soil available P was highest with lime addition of 2 t/ha in both varieties and sites.

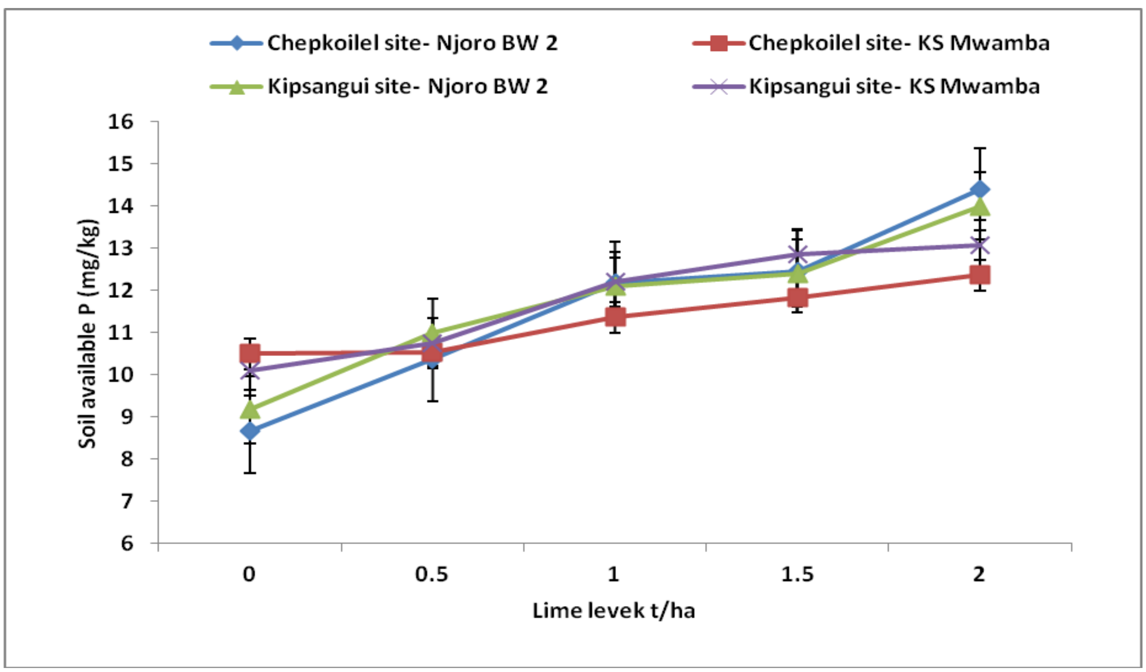


Figure 4: Changes in soil available P (mg kg) at harvesting due to lime and P application during the 2009 LR for Chepkoilel and Kipsangui sites 125 days after application.

4.4 Effects of soil amendment on wheat growth pattern (heights)

Wheat heights were taken at six, eight and ten weeks after planting to monitor growth status of the crop as affected by lime additions are shown in Figure 5 and 6. The addition of lime increased heights significantly ($p<0.05$) in Njoro BW 2 variety at Chepkoilel site in week eight and ten. However, there was no significant increase in height at week six. There was no significant difference in the heights of KS Mwamba wheat variety at week six and eight as compared to Njoro BW 2. At Kipsangui site, there was a significant difference ($p<0.05$) in the heights of Njoro BW 2 variety with lime additions of 1 t/ha to 2 t/ha at weeks eight and ten. For the KS Mwamba wheat variety at Kipsangui site, the height increased with the increase of lime additions but there was no significant increase in height between weeks six and eight. The control gave the lowest height across both the experimental sites and varieties except at week six in Njoro BW 2 in Kipsangui.

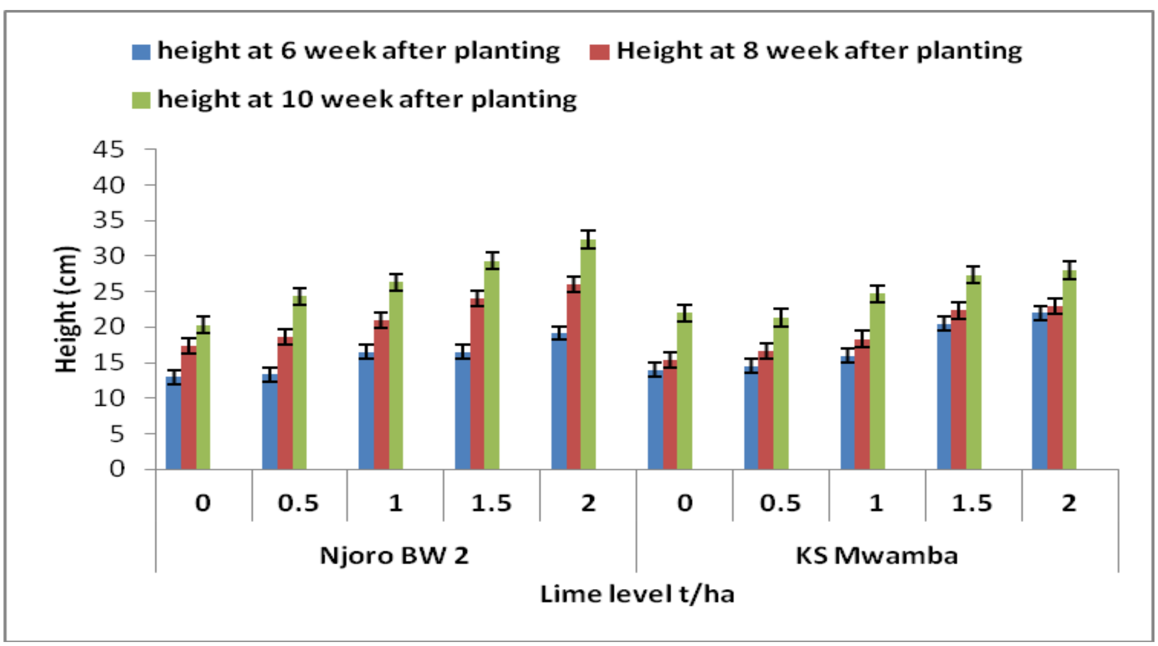


Figure 5: Wheat growth pattern for Chepkoilel site as affected by treatment applications during the long rains 2009

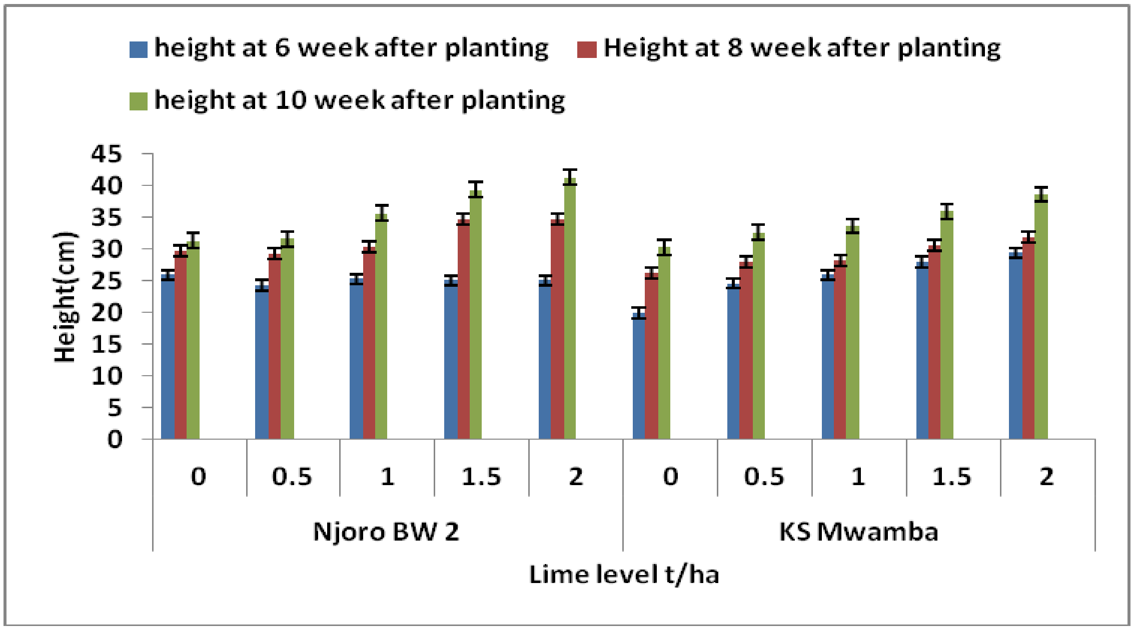


Figure 6: Wheat growth pattern for Kipsangui site as affected by treatment applications during the long rains 2009

4.4 Effects of soil amendments on wheat yield

Yields obtained from the test crop as a result of application of the soil amendment material during the year 2009 LR are given in Figure 7 for Chepkoilel and Kipsangui sites. Amendment of soil acidity with lime, increased grain yield significantly ($p<0.05$) in Chepkoilel and Kipsangui. The lowest grain yield in Njoro BW 2 wheat variety of 1.18t/ha in Chepkoilel site and 1.27t/ha in Kipsangui site were found on control where there was only P and N additions without lime. The lowest grain yields in KS Mwamba variety of 0.78t/ha at Chepkoilel and 0.84t/ha at Kipsangui sites were found on the control treatment. The sites differed significantly from each other in terms of wheat grain yields. Results obtained per site showed that Kipsangui gave the highest yields of 2.46 t/ha in Njoro BW 2 and 2.02 t/ha KS Mwamba varieties. Chepkoilel site gave the highest yield of 1.68 t/ha in both varieties as a result of soil amendments. The lowest wheat yield was obtained from KS Mwamba variety. However, the treatments applied increased grain yield in each variety.

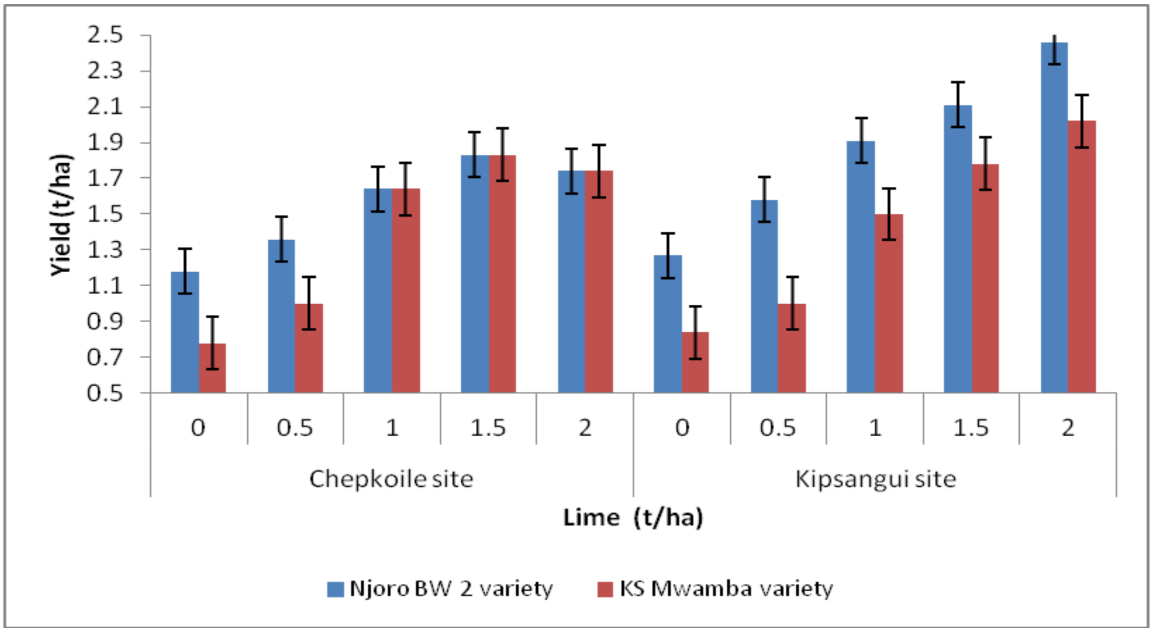


Figure 7: Wheat grain yields (t/ha) per site as affected by treatment application for both sites during the long rains 2009.

4.5 Effects of soil amendment on wheat straw yield

Figure 8 shows wheat straw yield as affected by lime additions at Chepkoilel and Kipsangui sites. Lime gave significant ($p<0.05$) increases in straw yield at both sites and varieties. The control gave the lowest straw yield across both experimental sites and in both varieties apart from Njoro BW 2 variety with lime addition at the rate of 0.5 t/ha at Kipsangui site. The highest yield of straw of 2.18 t/ha and 1.89 t/ha in Njoro BW 2 wheat variety was achieved with lime addition of 2 t/ha in Kipsangui and Chepkoilel sites respectively. KS Mwamba wheat variety also gave the highest straw yield of 1.17 t/ha in Chepkoilel and 1.27 t/ha at Kipsangui with the highest lime additions of 2 t/ha as shown in Figure 8. Performance in terms of wheat straw yield at Kipsangui varied significantly ($p<0.05$) from the performance at Chepkoilel site in both wheat varieties.

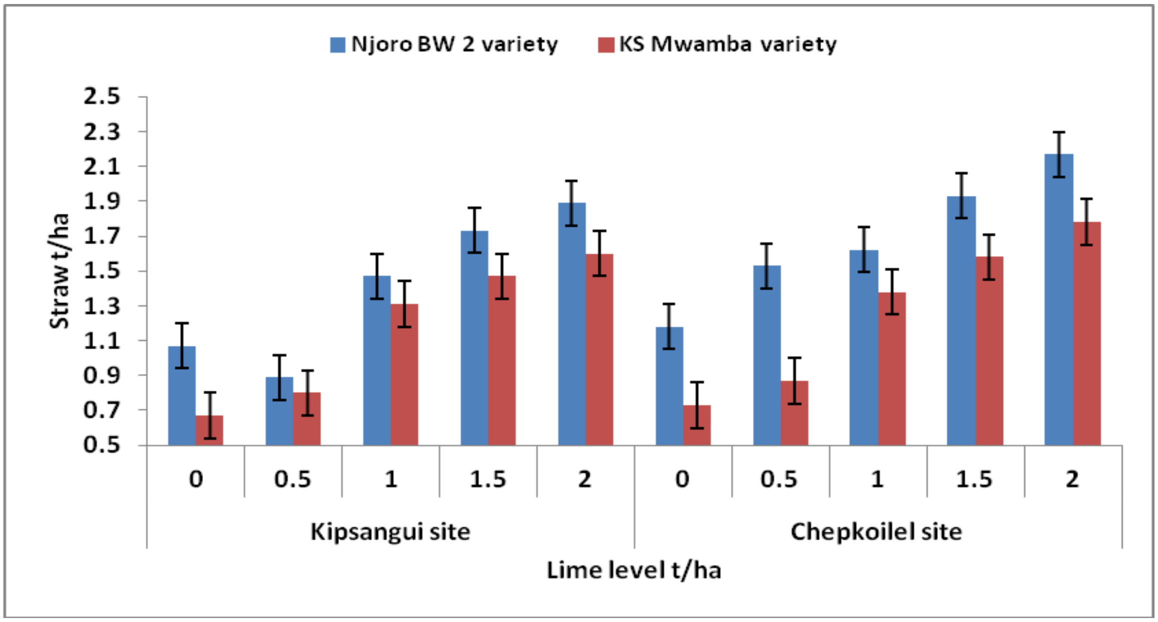


Figure 8: Wheat straw yields (t/ha) per site as affected by treatment application for Chepkoilel and Kipsangui during the long rains 2009.

4.6 Effect of lime on soil water content

The effect of application of lime on the soil water content (% water) is given in Figures 9 and 10. The soil water content at Chepkoilel site increased with lime addition at the rate of 0.5, 1.0 and 1.5 t/ha at 0.33 bar. However, there was a decrease in the soil water content with lime addition of 2 t/ha. At the same site the soil water content decreased with lime addition at the rate of 0.5 and 1.0 t/ha below the control treatment at 5 bar.

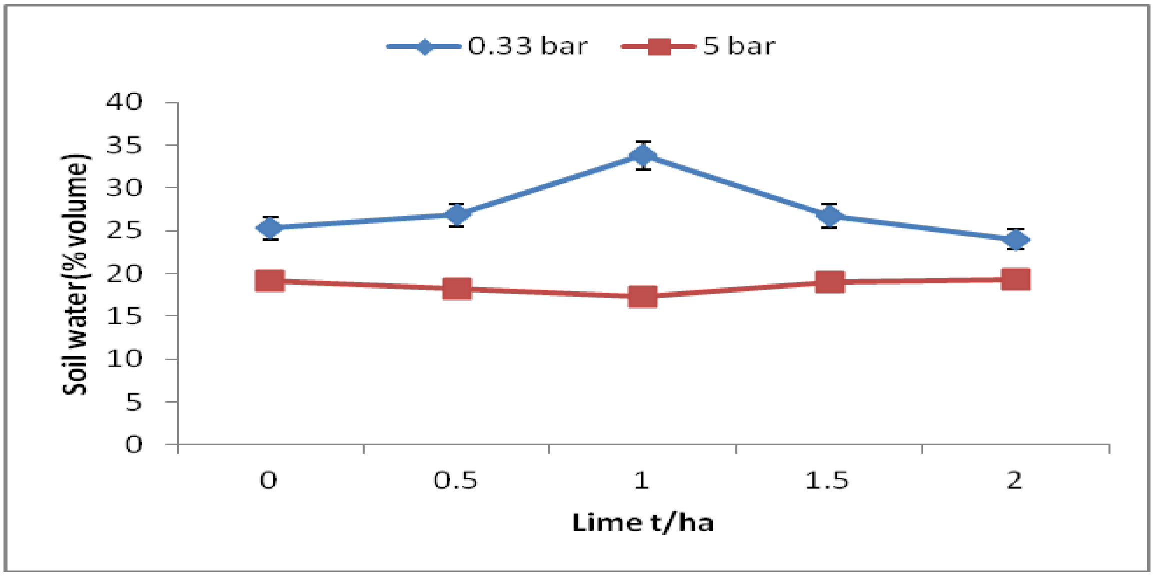


Figure 9: Soil water content (at harvesting) for Chepkoilel site as affected by treatment application during the long rains 2009

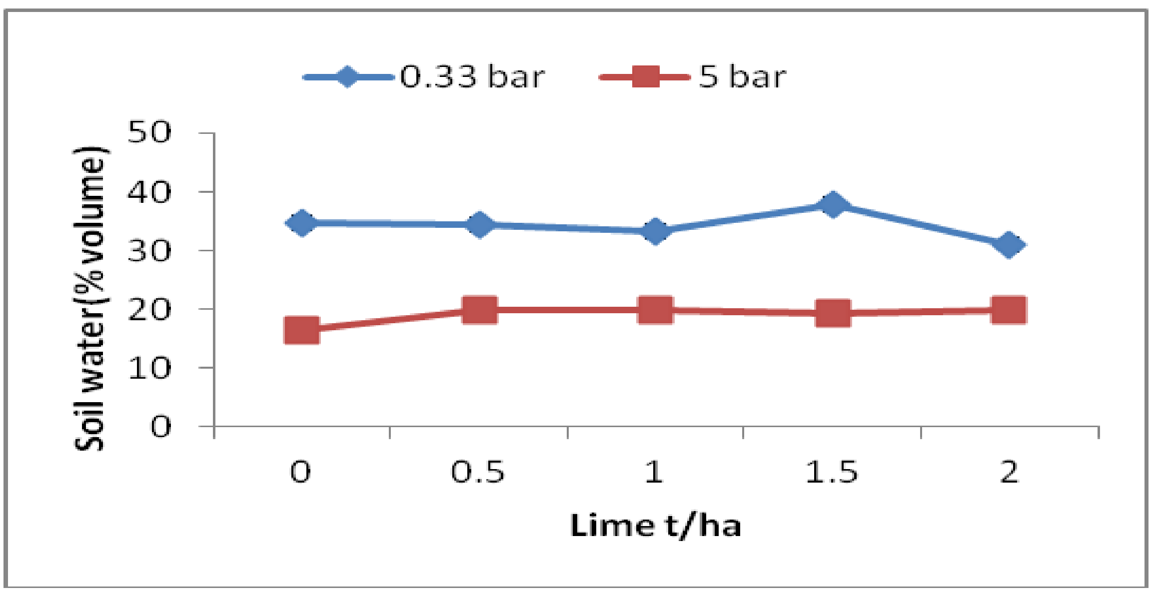
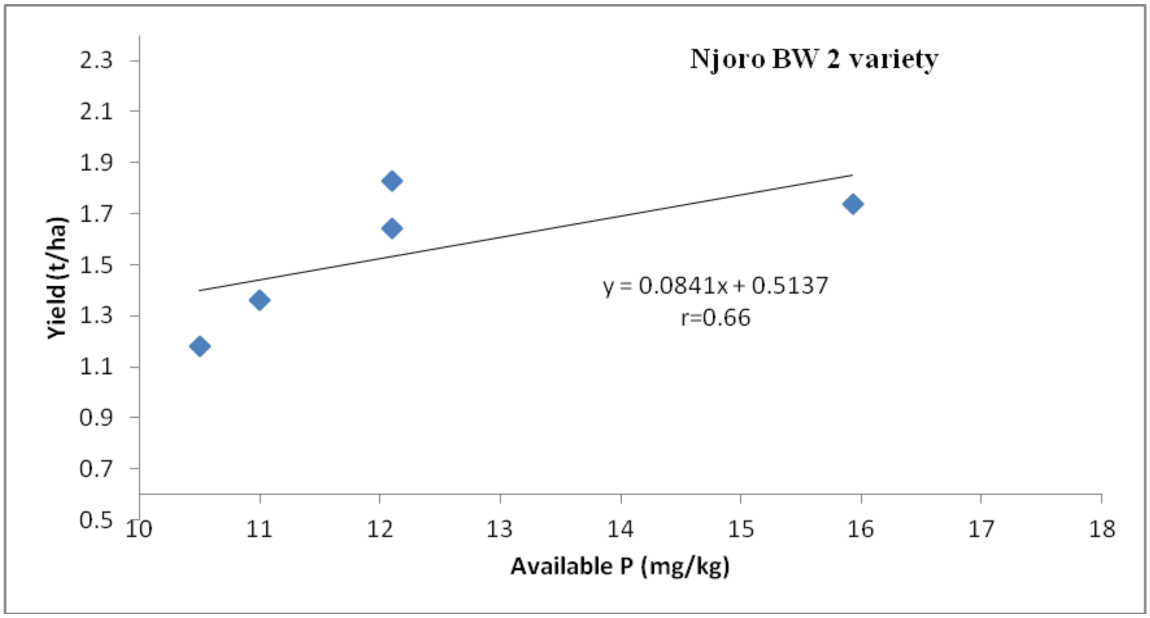


Figure 10: Soil water content (at harvesting) for Kipsangui site as affected by treatment application during the long rains 2009

4.7 Correlation between wheat yields and soil available P at wheat harvest

Correlation analysis was conducted between crop (wheat) yields and soil available P at harvesting and the results obtained are given in Figure 11 and 12 and Tables 5 and 6. There was highly a positive and significant correlation between soil available P and grain yields i.e. r =0.97 and r =0.94 for KS Mwamba wheat variety at Chepkoilel and Kipsangui sites respectively. The correlation between soil available P and grain yields was also positive i.e. r =0.66 and r=0.97 for Njoro BW 2 wheat variety at Chepkoilel and Kipsangui sites respectively.



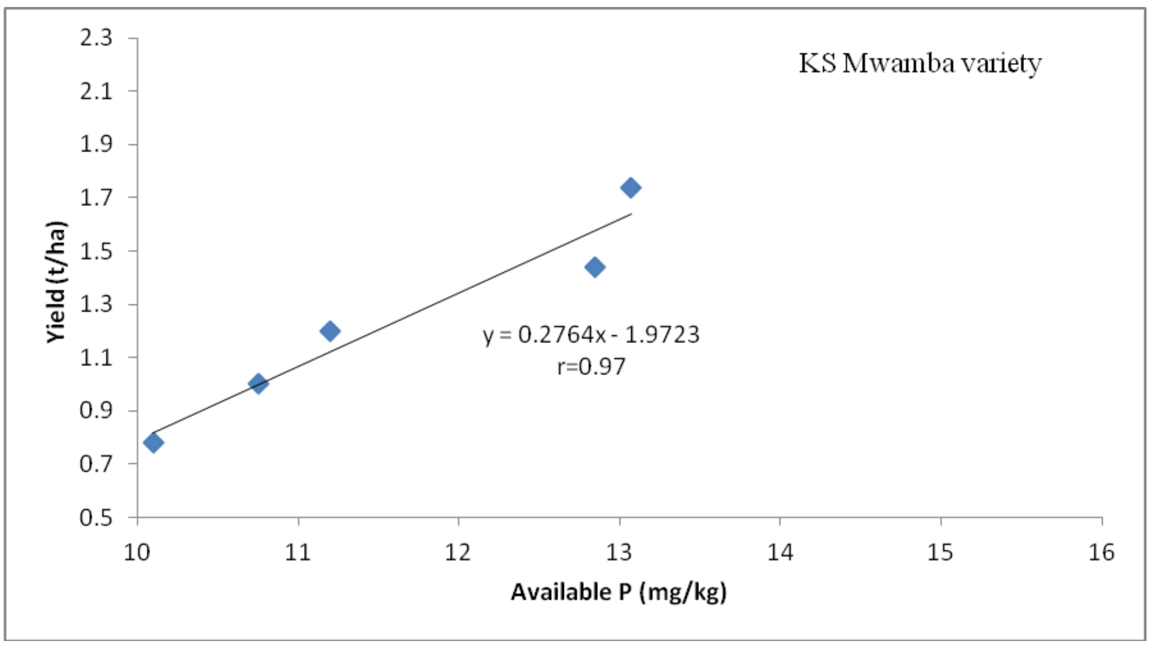
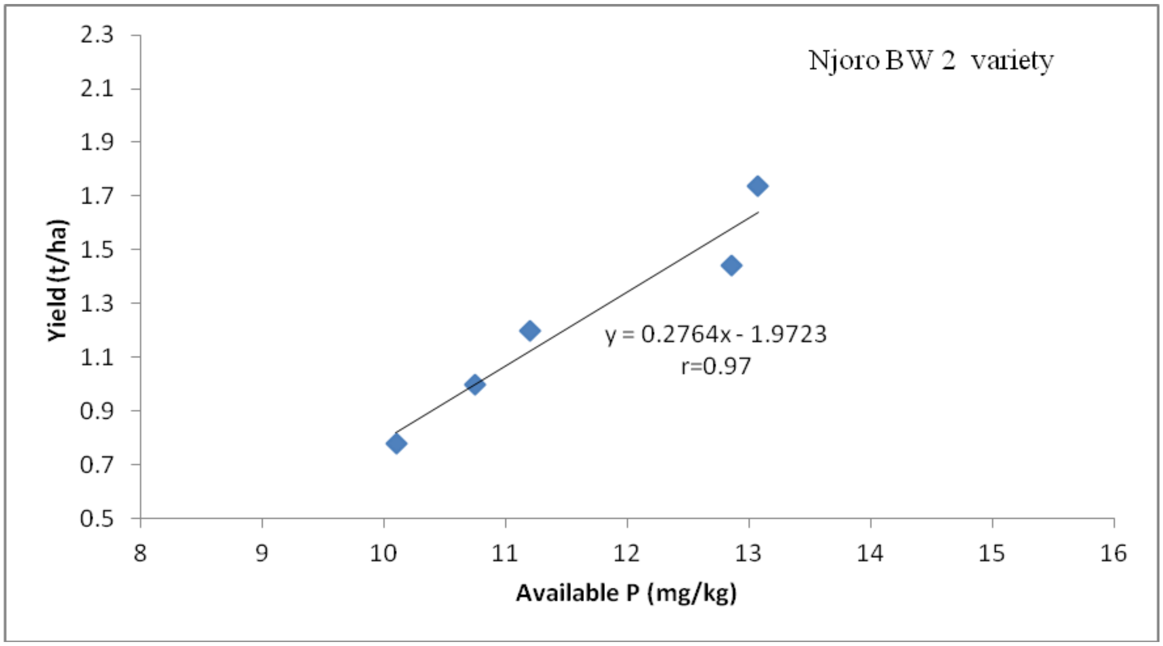


Figure 11: Relationship between soil available P (mg/kg) and wheat grain yields (t/ha) as observed at harvesting during 2009 LR for Chepkoilel site for Njoro BW 2 and KS Mwamba.



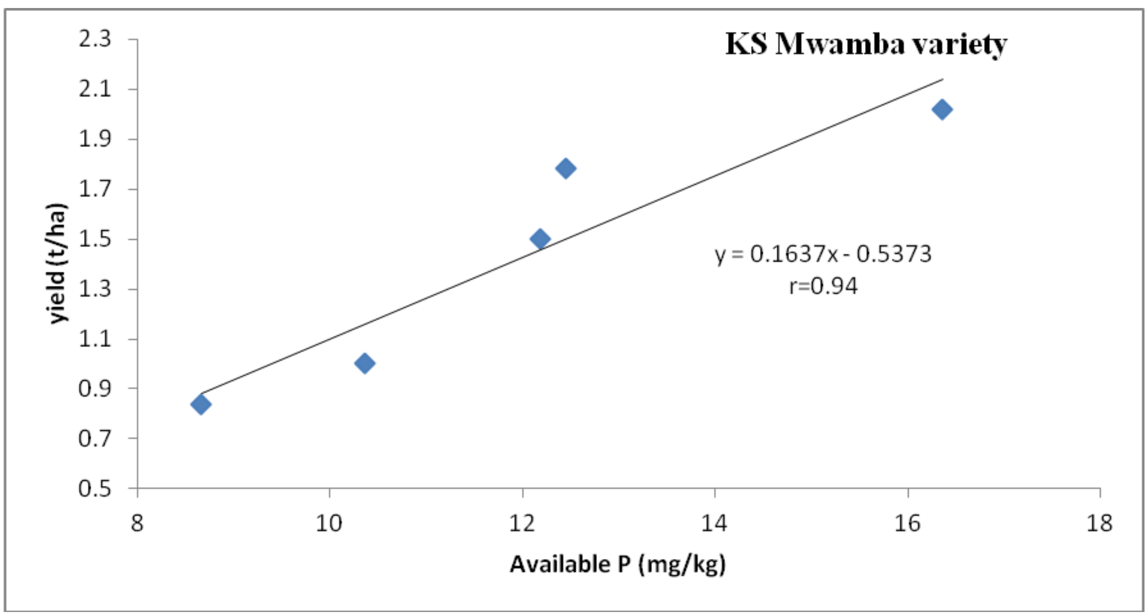
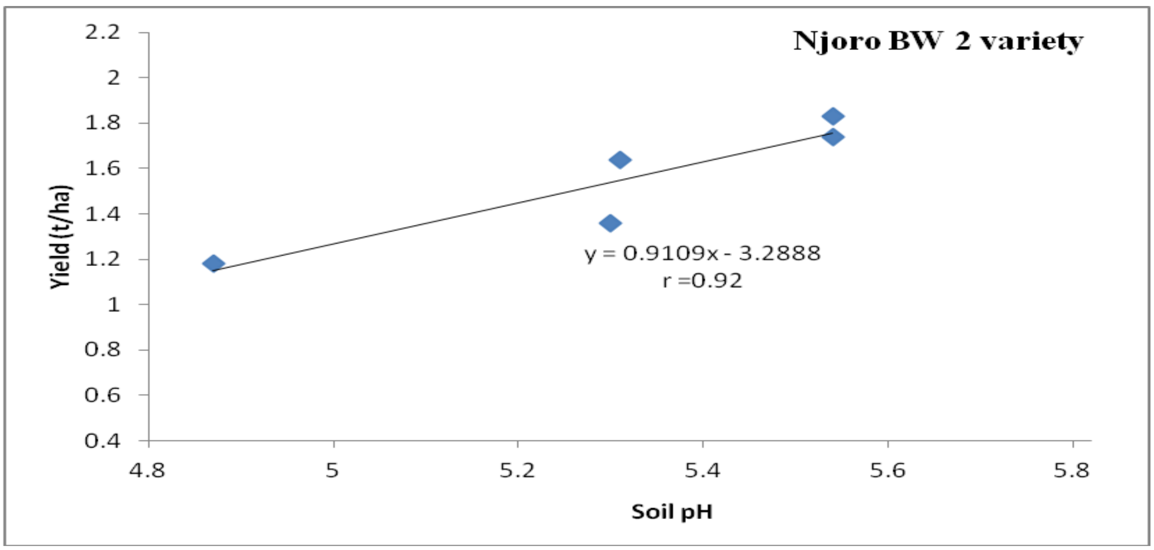


Figure 12: Relationships between soil available P(mg kg) and wheat grain yields (t/ha) as observed at harvesting during 2009 LR for Kipsangui site for Njoro BW 2 and KS Mwamba.

4.8 Correlation between wheat yields and soil pH

Figures 13 and 14 and Tables 5 and 6 show the relationships between crop (wheat) yields and soil pH at harvesting (125 days after planting). There was a highly significant positive correlation between wheat grain yield and soil pH i.e. r=0.92 and 0.77 for Njoro BW 2 wheat variety for Chepkoilel and Kipsangui sites respectively, and r=0.71 for KS Mwamba at Kipsangui. However there was weak correlation for KS Mwamba at Chepkoilel site i.e. r=0.47.



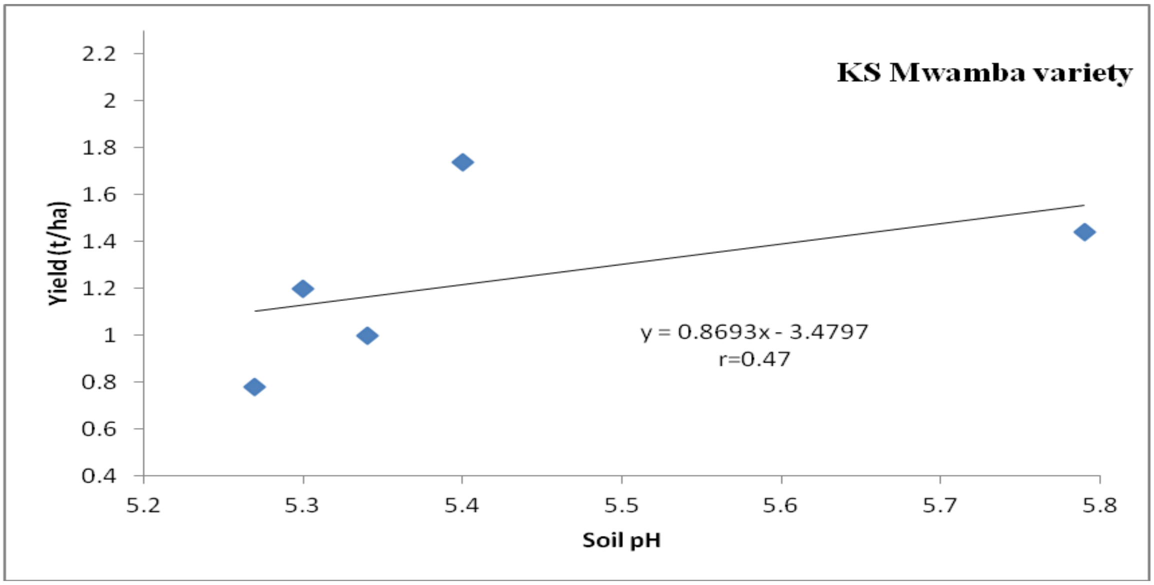
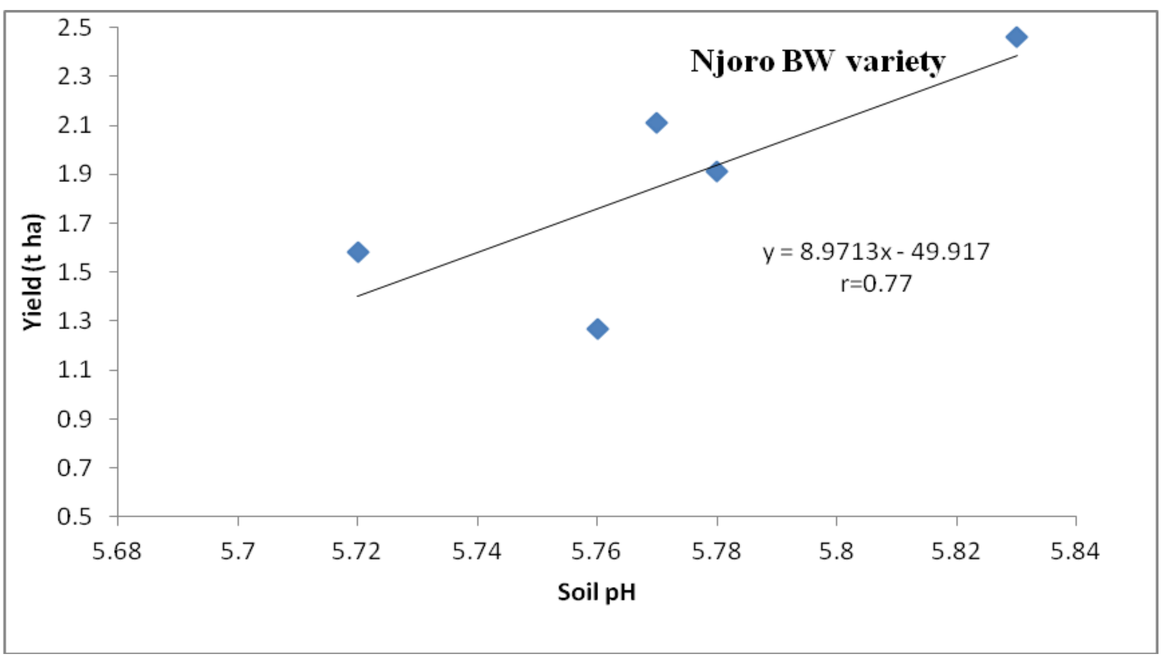


Figure 13: Relationships between soil pH and wheat grain yields (t/ha) as observed at harvesting during 2009 LR for Chepkoilel site for Njoro BW 2 and KS Mwamba.



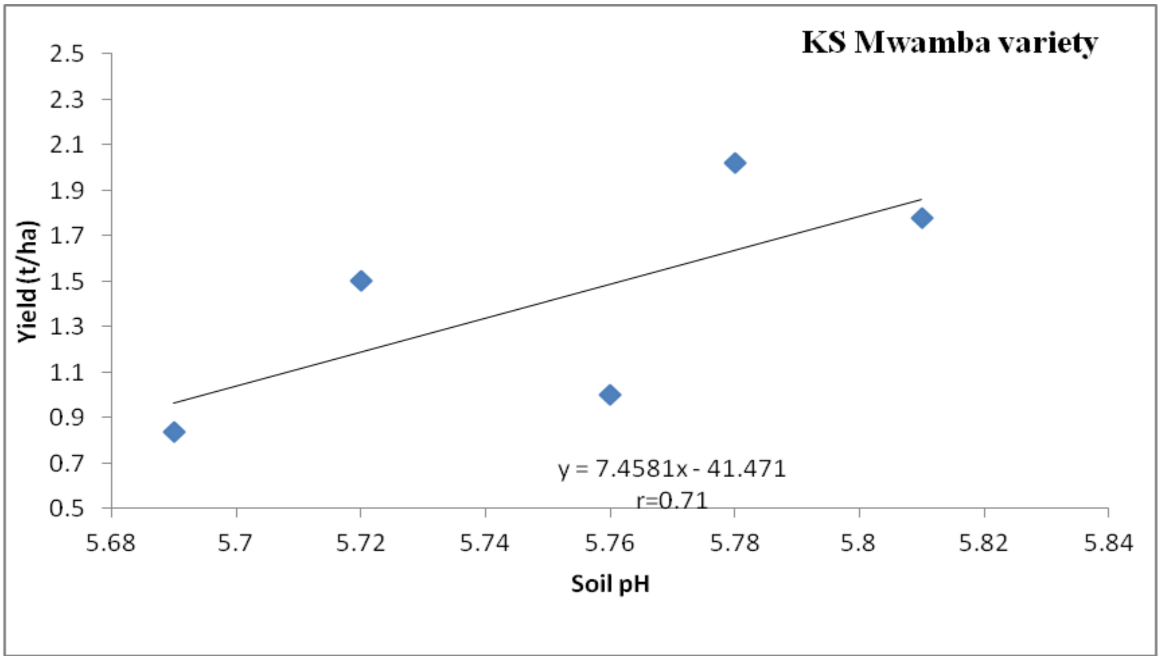


Figure 14: Relationship between soil pH and wheat grain yields (t/ha) as observed at harvesting during 2009 LR for Kipsangui site for Njoro BW 2 and KS Mwamba.

Table 5: Correlation coefficient (matrix) between wheat yields (t/ha) soil available P (mg/kg) and soil pH at harvesting for Chepkoilel site during the 2009 long rains

Chepkoilel site-Njoro BW 2

	Yield	Soil available P	Soil pH
Yield	1		
Soil available P	0.66	1	
Soil pH	0.92	0.68	1

Chepkoilel site- KS Mwamba

	Yield	Soil available P	Soil pH
Yield	1		
Soil available P	0.97	1	
Soil pH	0.49	0.70	1

Table 6: Correlation coefficient (matrix) between wheat yields (t/ha) soil available P (mg/kg) and soil pH at harvesting for Kipsangui site during the 2009 long rains

Kipsangui site-Njoro BW 2

	Yield	Soil available P	Soil pH
Yield	**1**		
Soil available P	**0.97**	**1**	
Soil pH	**0.77**	**0.64**	**1**

Kipsangui site- KS Mwamba

	Yield	Soil available P	Soil pH
Yield	**1**		
Soil available P	**0.94**	**1**	
Soil pH	**0.71**	**0.61**	**1**

4.8.1 Uptake of P in wheat

Figure 15 and 16 show the effect of lime on the wheat grain and straw P uptake. Lime had a significant ($p<0.05$) effect on grain and straw P uptake. The wheat grain had greater uptake than the straw at both sites and in both wheat varieties as P goes more to grain than to the straw. In both varieties and sites there was an increase in P uptake with increase in quantity of lime additions for the grain and straw yield.

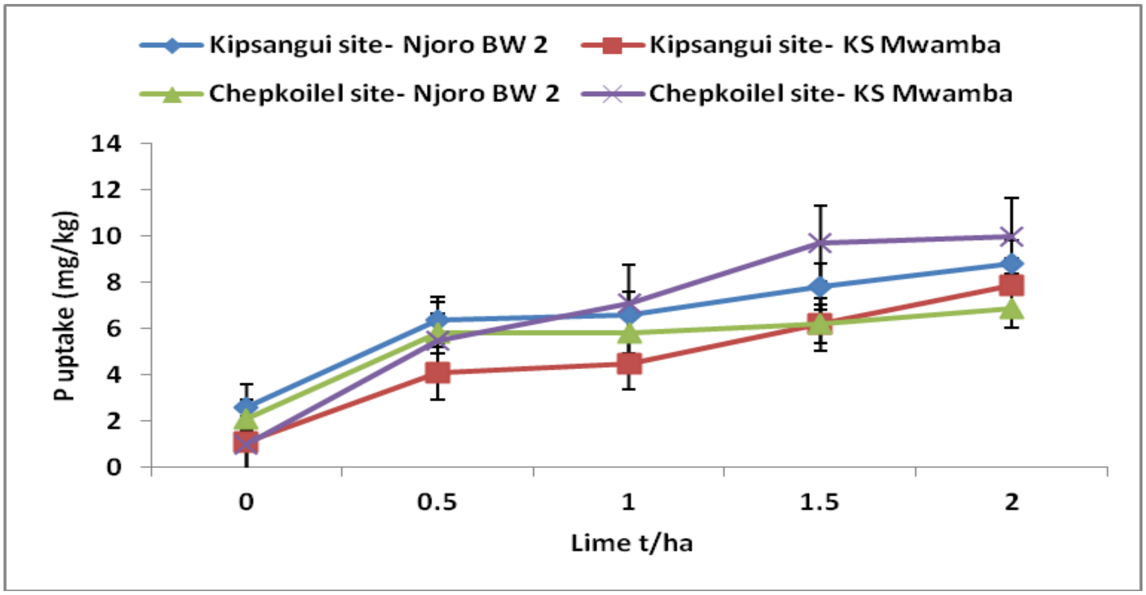


Figure 15: Nutrient P uptake (kg P/ha) for wheat grain as affected by treatment application for the Chepkoilel and Kipsangui sites

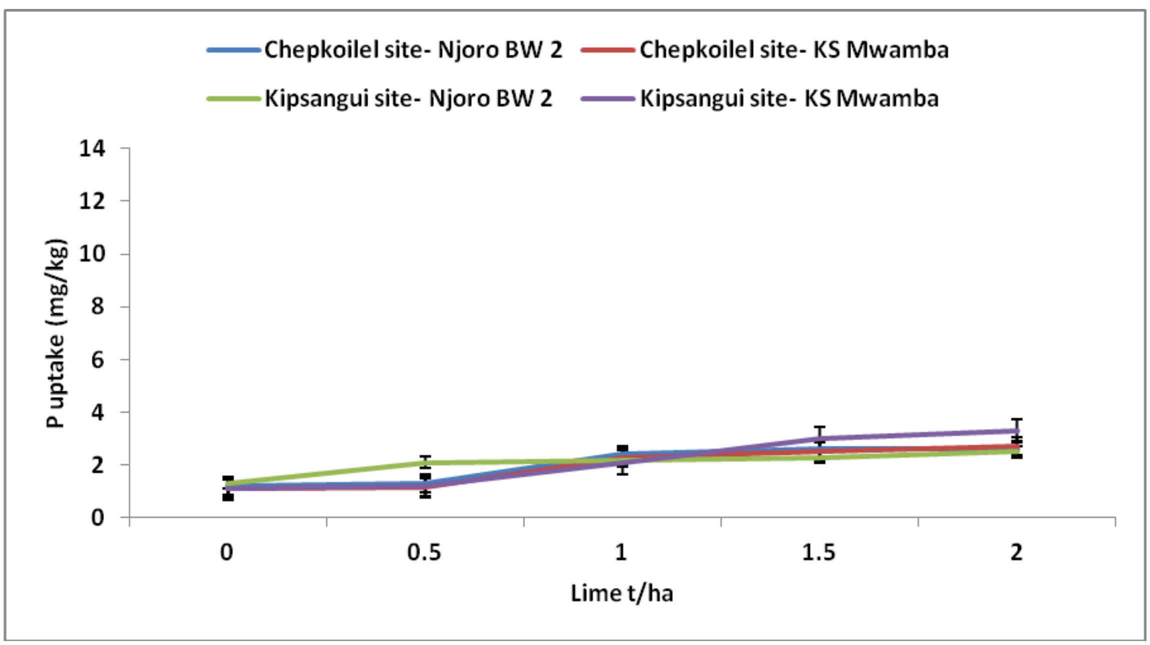


Figure 16: Nutrient P uptake (kg P/ha) for wheat straw as affected by treatment application for Chepkoilel and Kipsangui sites.

4.8.2 Uptake of N in the test crop.

The uptake of N by wheat grain and straw as reflected in the harvested produce is given in Figures 17 and 18. Lime gave significantly ($p<0.05$) higher N uptake value in both grain and straw. The wheat grains had a higher N uptake for the nutrient than the wheat straw at both sites as shown in figure 17. However, there was no significant ($p<0.05$) difference in the N uptake between the two varieties. Crop in the control gave the lowest uptake of N nutrient at both sites. Kipsangui site gave the highest N uptake in the grain in both wheat varieties. There was a significant ($p<0.05$) difference in uptake of N in the wheat straw between the varieties. Uptake of N in the wheat straw was highest at both sites in Njoro BW 2 as show in figure 18.

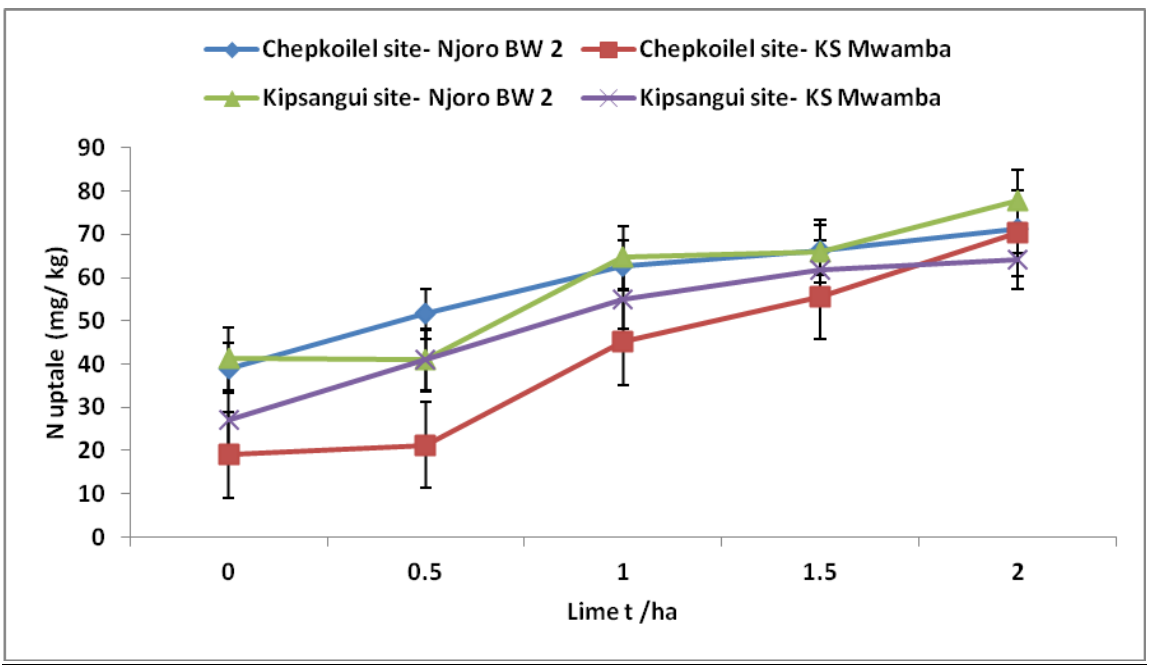


Figure 17: Nutrient N uptake (kg N/ha) for wheat grain as affected by treatment application for the Chepkoilel and Kipsangui sites

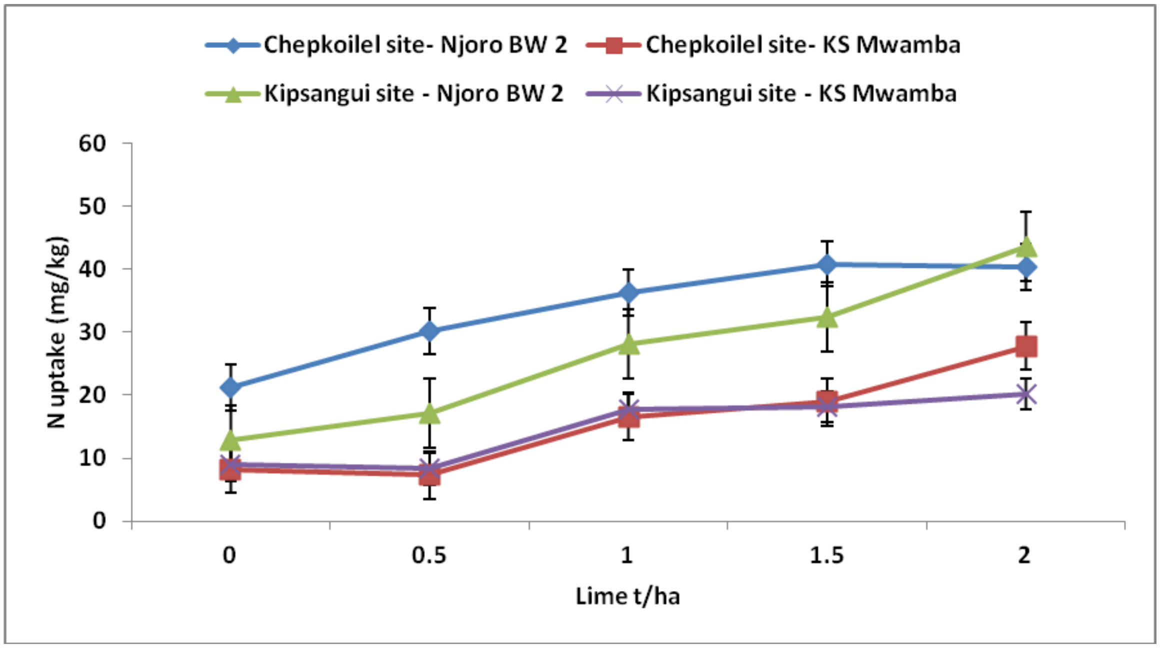


Figure 18: Nutrient N uptake (kg N/ha) for wheat straw as affected by treatment application for Kipsangui and Chepkoilel sites

4.9 Economic Analysis

Table 5 and 6 show economic analysis data of benefits, costs and marginal rate of return (MMR) of treatments using partial budget techniques. The Gross Field benefits (GFBs), Net financial benefit (NFBs), and Total Variable Cost (TVC) to investment were different among the sites. Treatments that produced high GFBs and /or NFBs were not necessarily economically viable for implementation because the MRR accrued by changing from a nominated option with lower TVC to the next produced below 50% MRR considered suitable for investment. Further treatments that produced lower NFBs were not worth for investment. They are known as dominated and were marked ”D”.

Most of the treatments did not realize economically viable returns. As a result, in most treatments the MRR accrued by changing from one undominated treatment with immediate lower TVC produced < 50% MRR which was below the acceptable minimum rate of 50% (CIMMYT, 1993). However, at Kipsangui for Njoro BW 2 wheat variety with treatment combination of 40 P_2O_5 + 46 N + 2.0 tons KL/ha and NFBs of Ksh 34,010 per ha was the only viable treatment option (Table 7). At Chepkoilel site there was no viable treatment.

Table 7: Economic analysis of wheat yields of the soil amendment materials incorporated into the soil during 2009 LR for Kipsangui site

Treatments	GFP(Ksh)	TVC (Ksh)	NFB (Ksh)	MRR(%)
Njoro BW 2 wheat variety				
40 P_2O_5 + 46 N + 0.0 tons KL/ha	34,290	5,786	27,926	
40 P_2O_5 + 46 N + 0.5 tons KL/ha	42,660	15,292	25,838	D
40 P_2O_5 + 46 N + 1.0 tons KL/ha	51,570	20,183	29,369	9
40 P_2O_5 + 46 N + 1.5 tons KL/ha	56,970	24,482	30,040	14
40 P_2O_5 + 46 N + 2.0 tons KL/ha	**66,420**	**29,494**	**34,010**	**72**
KS Mwamba wheat variety				
40 P_2O_5 + 46 N + 0.0 tons KL/ha	22,680	3,827	18,471	
40 P_2O_5 + 46N + 0.5 tons KL/ha	27,000	12,650	13,085	D
40 P_2O_5 + 46 N + 1.0 tons KL/ha	40,500	18,315	20,353	12
40 P_2O_5 + 46 N + 1.5 tons KL/ha	48,060	22,978	22,784	47
40 P_2O_5 + 46 N + 2.0 tons KL/ha	54,540	27,459	24,353	31

Table 8: Economic analysis of wheat yields of the soil amendment materials incorporated into the soil during 2009 LR for Chepkoilel site

Treatments	GFB(Ksh)	TVC (Ksh)	NFB (Ksh)	MRR(%)
Njoro BW 2 wheat variety				
40 P_2O_5 + 46 N + 0.0 tons KL/ha	31,860	5,376	25,947	
40 P_2O + 46 N + 0.5 tons KL/ha	36,720	14,290	21,001	D
40 P_2O_5 + 46 N + 1.0 tons KL/ha	44,280	18,953	23,432	D
40P_2O_5 + 46 N + 1.5 tons KL/ha	49,410	23,206	23,883	D
40P_2O_5 + 46 N + 2.0 tons KL/ha	46,980	26,184	18,178	D
KS Mwamba wheat variety				
40 P_2O_5 + 46 N + 0.0 tons KL/ha	22,680	3,827	18,470	
40P_2O_5 + 46 N + 0.5 tons KL/ha	27,000	12,650	13,085	D
40 P_2O_5 + 46 N + 1.0 tons KL/ha	32,400	16,949	13,756	D
40 P_2O_5 + 46 N + 1.5 tons KL/ha	38,880	21,430	15,308	D
40 P_2O_5 + 46 N + 2.0 tons KL/ha	46,980	26,184	18,178	D

GFB=Gross field benefits, TCV = Total variable cost, NFB = Net financial benefits, MRR = Marginal rate of return, KL = Koru Lime as CaO, D = dominated treatment (i.e. with less than or equal to treatment with lower TVC that were eliminated from further consideration since no farmer choose a treatment(s) with higher TVC and receive lower NFB), bold and underlined indicate economically viable treatment.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Initial characterization of soils from the study sites

The soils at the sites were developed on igneous rock and are fairly well-drained and highly weathered with high P fixing capacity (Waigwa *et al.*, 2003; Kifuko, 2002). The main soil class found in both sites is a ferralsol (oxisol) (FURP, 1994; Jaetzold and Schmidt, 2006). The low soil pH in both sites indicates that the acidic levels require to be amended through liming if optimum crop yield is to be achieved. According to Mamo *et al.*, (2009), liming can neutralize soil acidity and most field crops perform best at a soil pH level between 5.5 and 6.0. This pH range provides the best balance of available nutrients. Soil available P value for Chepkoilel was below the critical level of 10 mg P/kg (Okalebo *et al.*, 2002), with the amount of 9.9 mg P/Kg while available P at Kipsangui was at critical level of 10.1 mg P/kg. The low available P in the soils suggested the need for supplementary P addition for increased crop yields (Ndung'u *et al.*, 2006). The soils would therefore respond to available P and lime additions. On acid soils, P is fixed by oxides of Al, Mn and Fe thereby making it unavailable to growing plants hence contributing to severe crop yield reduction if the soils are not amended. In relation to P and pH values, these soils are P depleted and would therefore respond well to minimum application of inputs $CaCO_3$ and CaO and P (Okalebo *et al*., 2002). The C:N ratios of both sites were stable having the same value of 10:1. Soil organic matter holds together soil aggregates and hence adequate water holding capacity (Okalebo *et al.*, 2002). This therefore points out the need of enhancing the level of soil organic matter which can be achieved through crop residue incorporation (Waigwa *et al*., 2003) or any other mechanism to increase the soil organic matter content. According to soil particle size analysis, both Chepkoilel and Kipsangui areas have sandy loam soils showing rather heavy soils which have the capacity to restore nutrients and store soil moisture (Kolay, 1993).

5.2 Effects of lime addition on soil pH

There was increased soil pH due to addition of lime to the acid soils. This was because lime likely increased the Ca^{2+} ions, which it contains, displaced the Al^{3+}, H^{+}, Fe^{3+} , ions, prevalent in acid soils such as described by (Bado *et al*.,2004; Moody *et a*l., 1998; The *et al*., 2006). In wheat variety Njoro BW 2, there was the highest increase in pH with an increase of lime addition of 2 t/ha at harvesting time as opposed to KS Mwamba which did not show any trend. This indicates that Njoro BW2 required higher rates of lime for significant increase of pH to be realized. On the other hand, KS Mwamba did not show any significant differences in pH levels at all the rates. This shows that a farmer planting KS Mwamba can achieve an equally favourable pH in the farm by application of lime at any level above the control treatment. The increase in soil pH at Kipsangui site more than in Chepkoilel soil pH in both wheat varieties. There was also an increase in soil pH in the control treatment at both sites. The increase of soil pH at Kipsangui and in the control treatment could be attributed to management history of the two sites. Prior management confirmed use of Single Super phosphate type of fertilizer and crop rotation, whereby the farmer alternates wheat production with maize intercrop with beans at Kipsangui site. At Chepkoilel site, the land was used by university students for research purposes and it was difficult to establish the different inorganic, organic fertilizers and soil amendment materials. Increased soil pH, due to lime has been reported by others and attributed to the effect of applied treatment (Ernani *et al*., 2002; White *et al*., 2006).

5.3 Effects of lime on available P in soils

There were significant changes in the soil available P with the increase of lime additions. Lime application increased both the native soil P and P fertilizer availabilities which were taken up by plant possibly decreased soil sorption capacity (not measured). In highly weathered soils of the tropical and subtropical acid soils, the applied P fertilizers readily react with Al and Fe sesquioxides to form sparingly soluble P forms. This normally results to very low soil available P for plant absorption (Keerthisinghe *et al*., 2001; Kochian *et al*., 2004). These authors suggest that application of large P fertilizer quantities is necessary to rectify the problem. Certainly, this is not an option for small holder farmers (SHF) and medium scale farmers in the developing countries such, as Kenya, who cannot afford the recommended high fertilizer rates for high crop production. Despite the differences in the genetic makeup of the two wheat varieties, there was no significant difference in terms of changes in available P in soils suggesting that a farmer could plant any of the varieties and achieve the same result.

5.4 Effects of lime on growth pattern of wheat

Generally, there was a significant increase in heights of both wheat varieties at both sites as a result of treatment additions. Results indicated that lime improved the soil condition by making P available to the crop which in turn boosted the rate of growth and subsequent height increases in the crop (Figure 5 and 6). The significant increases in plots with lime compared to those in the control indicated that in acid soils and nutrient deficient (N and P) soils, such as found in the study sites, application of lime is necessary for healthy wheat growth.

In general the wheat crop in both sites and varieties did not grow to the normal height of about 72 cm despite lime additions. This was due to the severity of the drought in 2009 as shown in rainfall figures in Appendix 1 which led to restricted plant growth throughout the season. This observation proves (Heyland *et al*., 1999) that cereal growth is mainly influenced by temperature and precipitation. If these fall outside the desirable limits, the resultant adverse effect cannot in general be compensated by use of fertilizers (particularly if spikelet primordia are reduced as a result of excessive temperatures at the booting stage). Initial soil characterization indicates that the soils in both sites are acidic and in acid soils, there are increased levels of aluminium and manganese available to the plant, causing toxicity damage to sensitive plants. Simultaneously, the availability of some essential nutrients for plant growth (phosphorus, calcium, magnesium and molybdenum) is decreased. This may lead to poor plant establishment and persistence; patchy growth in crop.

5.5 Effect of lime on wheat grain yield

Wheat grain yield increased above the control at both sites due to soil amendment addition. These findings corroborated with those of (Bill, 2011) who reported that where acid soils are causing reduction of wheat production, plant growth and yield significantly, the condition can be improved by liming these soils and raising the pH to an optimum range.

These yield trends suggest also that, irrespective of wheat cultivar, external additions of nutrients; including liming acid soils are needed to improve soil properties and hence boost the production in fertility depleted acid soils as reported for maize by Gudu *et al*., (2005). Therefore planting tolerant species allows production to continue on the acidic soils but does not change the acidity. In many soils the best results are obtained from the combined use of acid tolerance and lime (Grains Research and Development Corporation, 2007). On the other hand, the highest yield from Njoro BW 2 is partly attributed to its genetic make up as it is a higher yielding variety as compared to KS Mwamba. When comparing the Chepkoilel and Kipsangui sites, the wheat crop performed better in Kipsangui compared to Chepkoilel because of mainly the amount of rain received and its even distribution during the grain filling and vegetative stages in the area as shown in the rainfall figures given in appendix 1. However, the general low grain yields in this research is attributed to poor and uneven rainfall distribution experienced that year (2009) again as shown in the rainfall figures in appendix 1.This trend also confirms the fact that if the growth of wheat at any stage is limited by a specific factor such as nutrient supply, water, light or temperature, then the grain yield is limited irrecoverably unless it can be compensated by modifying a yield component occurring at a later stage of development (Heyland *et al*., 1999). For instance, if the number of tillers per unit area is reduced by a deficiency in nutrient supply in the early stages, then the resultant reduction in ear density can, in theory, be compensated by improving the nutrient supply in time to promote spikelet initiation and to diminish the reduction in florets. The difficulty in practice lies in estimating the true supply of a nutrient from the soil and in making due allowance for any delay in availability of fertilizer nutrient in unfavourable weather conditions, as well as for location-specific variations from one part of the field to another (Heyland *et al*., 1999).

5.6 Effect of lime on wheat straw yield

Application of lime at the rates of 1.0 t/ha, 1.5 t/ha and 2 t/ha led to a significant ($p<0.05$) increase in wheat straw in both varieties and sites above control. This indicates that liming acid soils increases both wheat yield as shown earlier in this thesis and also straw yield. This confirms the work done by (Bhat *et al*., 2007) whose results showed that application of lime caused a significant increase in straw yield of wheat. The magnitude of the increase of straw yields due to lime addition at 2 t/ha was 18.6 per cent over the no lime treatment (Bhat *et al*., 2007). The increase in forage yield translates into the increase in wheat straw. But, although there was an increase in straw yield with the increase in lime additions in this research, the yield was generally low as compared to other research work done in other countries. For example, a study carried out in Oklahoma, U.S.A during 1997-1999 showed that the straw yield increased significantly with the increase of lime rates upto 3 t/ha**.** The reduced straw yield could be attributed to the low and uneven distribution of the rains experienced during the year 2009 as indicated earlier in this thesis. According to (Nawaz *et al*., 2011) water stress experienced by a wheat crop during tillering, booting earing, and anthesis results in the reduction of total biomass compared to well watered crop.

5.7 Effects of lime on soil water content

The increase in water content with lime addition of 1 t/ha and 1.5 t/ha for Chepkoilel and Kipsangui respectively at field capacity (1/3 bar). Application of lime at lower doses contributes less organic matter that may help in physical changes (soil water retention included) in the soil and finally benefit the crop (Medhy *et al*.,2007) as observed in this study. The increase in soil water was probably because lime improved soil structure and friability, thus reducing crusting and clodding of the soils. The higher soil water content at Kipsangui site is due to higher organic carbon content and other chemical properties as compared to Chepkoilel site at planting.

5.8 Correlation between wheat yields and soil available P

There was a positive correlation between available P and crop yields in KS Mwamba wheat variety at Chepkoilel and Kipsangui sites. Due to the addition of lime, the crop was able to take up nutrients which are reflected in the yields. The analysis in this study suggests increased wheat yield is due to increase in available P in the soil from P and lime additions at planting. According to Calba *et al*., (2004) there exists a link between H, Al and Ca and their effects on grain yields, therefore wheat cultivation in the tropics must focus on greater understanding of Al, H and Ca dynamics and their management to improve grain yield. Further, in the past two decades worldwide, significant progress has been made in understanding soil, rhizosphere, and plant processes associated with soil P transformation, P mobilization and acquisition, and P-deficiency responses. However, many aspects of overall P dynamics in the soil/rhizosphere-plant continuum are not thoroughly understood, including regulation of P acquisition and P-starvation rescue mechanisms in plants, the complex coordination of root morphology, physiological and biochemical responses under varying P availability, and plant sensing of heterogeneous P supply in soil (Shen *et al.*, 2011). Given the importance of P to plants and its importance as a strategic resource, a better understanding of P dynamics in the soil/rhizosphere-plant continuum is necessary to guide establishment of integrated P-management strategies involving manipulation of soil and rhizosphere processes, development of P-efficient crops, and improving P-recycling efficiency in the future (Shen *et al.*, 2011). Further, (McGechan *et al*., 2002) also found that the determination of P availability is complicated since P applied as mineral fertilizers can be effectively sorbed.

5.9 Correlation between wheat yields and soil pH

High positive correlation between wheat yields and soil pH was observed in the present study. This is probably because lime increased the overall pH which led to the enhanced availability of phosphorus. Soil reaction (pH) affects the physical, chemical and biological properties of soils and crop yields. Soil acidity has a negative effect on crop yields mainly through reduced P availability though Fe and Al fixation of P (Okalebo, 2009). A study carried out in Olkahoma U.S.A, (Raun, 2006) found that the increase of soil pH resulted in a significant increase in grain yields. Grain yields responded to changes in soil acidity but at different magnitudes.

5.10 Uptake of P nutrient in wheat

Soil amendment increased significantly ($p>0.5$) P uptake in both grain and straw for both the sites and varieties. The mean P uptake for the wheat grain in Njoro BW 2 variety was 6.39 kg P/ha and 5.35 kg P/ha for Chepkoilel and Kipsangui sites respectively means from all treatments. Increased P uptakes with lime addition has been reported by other workers (Newton and Valdinei1997, Lelei 1999, Busari *et al.,* 2005). This has been attributed to better soil amelioration by the amendments (Miranda and Rowell, 1987). Sharma *et al.,* (2002) observed increased root volume, root mass density and root length due to phosphorus which enhanced nutrient (especially P uptake) after lime application thereby significantly promoting the productivity of wheat in terms of dry matter and grain yields as stated earlier in this thesis.

In acid tropical soils, only 10-20% of the applied P is recovered in the first year of application due to high P sorption by Al and Fe sesquioxides (Keerthisinghe, 2001). Similar variations of P uptake have been reported between sites in Nigeria acid soils. Fofana *et al*., (2007). However, the high uptake in Njoro BW 2 wheat variety can also be attributed to the genetic variety makeup suggesting the presence of a possible mechanism in the variety by which it may acquire more available P from the soils. It is to be noted that the Njoro BW 2 variety out yielded KS Mwamba variety.

5.11 Uptake of N in wheat

Soil amendment (lime) increased N uptake in both wheat grain and straw in both sites. This is probably the uptake of N was enhanced by CaO application to the soil. According to (Rowell, 1994), acidic conditions reduce the rate of release of mineral-N from organic-N. Liming however, increases the rate of mineralization and hence improves the supply of mineral-N by the plants Ligeyo *et al*., 2006. Liming has been known to relieve plants from Al phytotoxicity which led to good root growth, necessary for efficient nutrient uptake and utilization by plants (He *et al*,. 1996; Kochian, 1995: Ligeyo *et al*., 2006). In both sites and varieties, the N uptake was higher in the wheat grain compared to the straw because nitrogen uptake during the grain-fill period is relatively high compared to uptake during the stem elongation phase of growth. Plant tissue N is mobilized and translocated to the grain during this period with only small additions coming from available soil N (Alley *et al*., 2009).

Lime also increased N fertilizer uptake primarily by restoring soil pH to levels that are favourable for plant growth and microbial activity. It likely eliminated toxic elements such as Fe^{2+} Al^{+3} and H^{+3} and ensured the availability of essential elements like P, Ca and

Mg. Under such optimal growth conditions, crops are able to absorb and use N more efficiently (Adams, 1984). Therefore it is evident from this study that higher N fertilizer uptake and utilization by wheat can be enhanced in acid soils with lime application without necessarily increasing N fertilizer rates.

5.12 Economic analysis

For farmers to adopt new technologies, Total Revenue (TR) should be higher than Total Value Cost. Based on economic returns, the best treatment in Kipsangui site was (Njoro BW 2 variety with 2 t/ha Koru lime). Liming of the acid soil increased the pH thus enabling the crop to absorb and utilize plant nutrients such as N, P and probably others not measured. The return in Njoro BW 2 could also be because was higher yielding variety compared to KS Mwamba. In this study the majority of the treatments did not realize economically viable returns to investment due to high cost of inorganic inputs and low wheat prices offered in the year 2009. In Kenya and other developing countries, farm inputs especially the inorganic fertilizers are very expensive. This study confirms a report by (Okalebo *et al*., 2007) that SHF farmers rarely apply the recommend fertilizer rates and types because their costs are prohibitive. Further, the situation was made worse by the low and poor distribution of the rain as earlier stated in this thesis affecting the absorption of the nutrients in the soil. At Chepkoilel site there was no viable treatment probably because poor chemical properties as indicated on the initial soil characterization suggesting that higher rates the nutrients may be required.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

- Lime reduced soil pH, reduced exchangeable Al^{3+}, resulting in increased soil available P that led to good plant growth and high grain yield.
- The increase in soil water content was probably because lime improved soil structure and friability, thus reducing crusting and clodding of the soils.
- The combination between Njoro BW 2 variety and lime at the rate of 2 t/ha (plus P and N) gave the highest grain yield and thus viable economic returns.

6. 2 Recommendations

- Use of N, P fertilizers and lime has the potential to increase wheat grain production
- The influence of lime on soil water content should be monitored for a long time to get conclusive results.
- Due to the nature of the rather low lime response of the wheat varieties to lime application, there is need to apply lime above 2 t/ha rate to obtain a full response curve.

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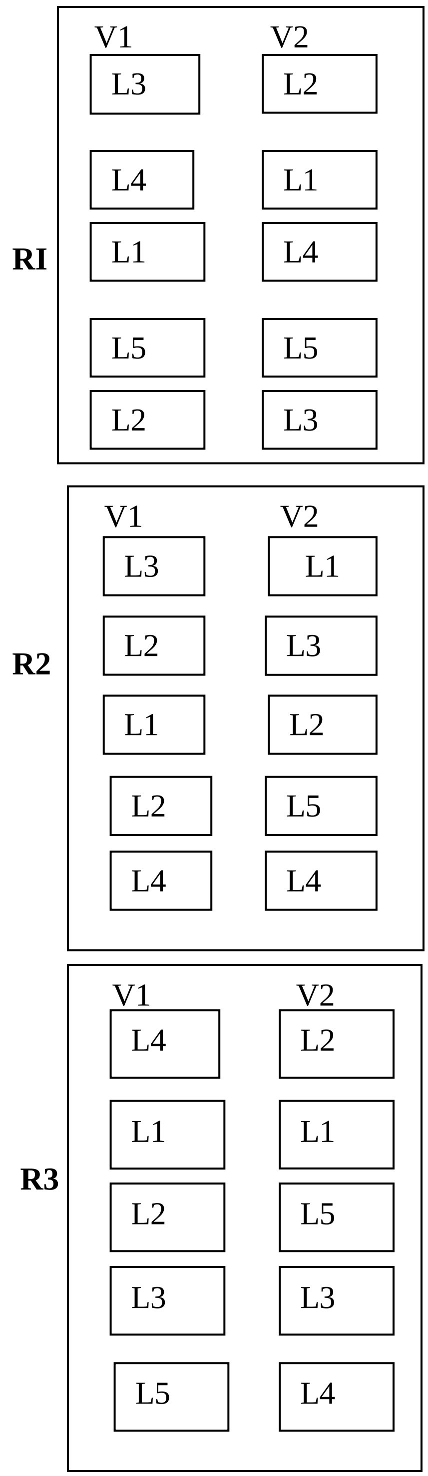
APPENDIX 1: Experimental layout



Note: V1=Njoro BW2 variety of wheat L1=0.0t/ha, L2=0.5t/ha, L3=1.0t/ha, L4=1.5t/ha, L5=2t/ha V2=KS Mwamba.

Appendix 2: Rainfall distribution (mm) during the year 2009 at Maji Mazuri station Soy Division (Kipsangui Area) and Chepkoilel University College sites

MONTH	MAJI MAZURI FARM SOY DIVISION		CHEPKOILEL	
	2009		2009	
	Rainy days	Amount (mm)	Rainy days	Amount (mm)
Jan	3	40	7	34
Feb	1	8.3	5	5.7
March	Nil	Nil	Nil	Nil
April	11	120	13	120.8
May	11	209.5	14	118.8
June	3	22.5	3	9.6
July	9	87	4	88.1
August	13	145.5	8	47.4
Sept.	6	47.5	9	50.7
Oct.	6	91	13	93.6
Nov.	9	50	6	13.8
Dec	9	210	11	235.3
Total	81	1031	93	817.8

Appendix 3: Comparative weather report during the year 2009/2010 at Chepkoilel and Kipsangui sites.

MONTH	CHEPKOILEL UNIVERSITY COLLEGE				MAJI MAZURI FARM – SOY DIVISION			
	2009		2010		2009		2010	
	Rainy Days	Amount (mm)	Rainy days	Amount (mm)	Rainy Days	Amount (mm)	Rainy Days	Amount (mm)
Jan	7	34	6	53.1	3	40	3	67
Feb	5	5.7	8	62.7	1	8.3	12	138
March	Nil	Nil	13	110	0	0	11	174
April	13	120.8	10	125.2	11	120	7	88
May	14	118.8	13	184.6	11	209.5	16	277
June	3	9.6	24	58.5	3	22.5	12	153
July	4	88.1	23	307	9	87	14	171
August	8	47.4	15	265.9	13	145.5	14	301
Sept.	9	50.7	18	64.6	6	47.5	4	187.5
Oct.	13	93.6	17	58.1	6	91	10	98
Nov.	6	13.8	7	26.5	9	50	4	64.5
Dec	11	235.3	4	18.4	9	210	1	12.5
Total	93	817.8	148	1334.6	81	1031	108	1731.5

Appendix 4: ANOVA for the available P

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Site	1		2.748	2.748	0.96	0.333
Variety	1		0.191	0.191	0.07	0.798
Lime level	4		152.843	38.211	13.36	<.001
Site. Variety	1		12.314	12.314	4.31	0.045
Site. Lime level	4		8.893	2.223	0.78	0.547
Variety. Lime level	4		6.389	1.597	0.56	0.694
Site .Variety. Lime level.	4		34.165	8.541	2.99	0.031
Residual	37	(3)	105.814	2.860		
Total	56	(3)	320.753			

Appendix 5: ANOVA for wheat yield

Variate: Grain yield t/ha **Source of variation**	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0.38295	0.19147	1.75	
Variety	1	2.13228	2.13228	19.53	0.048
Residual	2	0.21837	0.10919	1.71	
Lime levels	4	7.57963	1.89491	29.75	<.001
Variety x 1ime_levels	4	0.10323	0.02581	0.41	0.802
Residual (a)	16	1.01915	0.0637	0.84	
Site	1	0.97841	0.97841	12.93	0.002
Variety x Site	1	0.05615	0.05615	0.74	0.399
%1ime_levels x Site	4	0.35528	0.08882	1.17	0.352
Variety x %1ime_levels x Site	4	0.13056	0.03264	0.43	0.784
Residual (b)	20	1.51299	0.07565		
Total	59	14.469			

Appendix 6: ANOVA for wheat straw yield

Variate: Straw yield t/ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.08747	0.04373	0.16	
Variety	1	1.643	1.643	5.95	0.135
Residual	2	0.55258	0.27629	5.95	
Lime_levels	4	8.05531	2.01383	43.38	<.001
Variety.1ime_levels	4	0.08405	0.02101	0.45	0.769
Residual (a)	16	0.74283	0.04643	2.12	
Site	1	0.53283	0.53283	24.29	<.001
Variety.site	1	0.12462	0.12462	5.68	0.027
Variety.1ime_levels.site	4	0.14816	0.03704	1.69	
Residual(b)	20	0.43873	0.02194		
Total	59	12.55062			

Appendix 7: ANOVA of the effect of lime on the uptake of P by the wheat grain

Variate:Grain P_uptake (mg/kg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Rep stratum	2	71.23	35.62	0.39	
Variety	1	1.11261	1.1261	3.43	0.138
Residual	4	1.13136	0.3284	2.39	
Lime_level	4	16.2208	4.0552	29.53	< 001
Variety.lime_level	4	0.205	0.0513	0.37	0.824
Residual (a)	16	2.1297	0.1337	1.05	
Site	1	0.8449	0.8449	6.45	0.019
Variety.site	1	0.0224	0.0224	0.17	0.683
Lime_level.site	4	0.119	0.0298	0.23	0.92
Variety.lime_level.site	4	2.619	0.047	0.36	0.835
Residual (b)	20	2.619	0.1309		
Total	59	24.8561			

Appendix 8: ANOVA of the effect of lime on the uptake of P by the wheat straw

Variate:Straw P_uptake (mg/kg)					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Variety	1	7.35	7.35	2.23	0.21
Residual	4	13.2133	3.3033	6.63	
Lime_level	4	79.166	19.7915	39.7	<001
Variety.lime_level	4	1.5033	0.3758	0.75	0.57
Residual (a)	16	7.9767	0.4985	1.35	
Site	1	15.8107	15.8107	42.83	<001
Variety.site	1	1.4727	1.4727	3.99	0.06
Lime_level.site	4	1.306	0.3265	0.88	0.491
Variety.lime_level.site	4	0.4073	0.1018	0.28	0.89
Residual (b)	20	7.3833	0.3692		
Total	59	135.5893			

Appendix 9: ANOVA of the effect of lime on the uptake of N by the wheat grain

Variate:Grain N_uptake (mg/kg)					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	71.23	35.62	0.39	
Variety	1	1983.75	1983.75	21.53	0.043
Residual	2	184.3	92.15	0.51	
Lime_level	4	12253.07	3063.27	16.79	<.001
Variety.lime_level	4	565.67	141.42	0.78	0.557
Residual (a)	16	2919.47	182.47	2.07	
Site	1	58.02	58.02	0.66	0.427
Variety.site	1	268.82	268.82	3.05	0.096
Lime_level.site	4	231.07	57.77	0.66	0.629
Variety.lime_level.site	4	280.6	70.15	0.8	0.541
Residual (b)	20	1761	88.05		
Total	59	20576.98			

Appendix 10: ANOVA of the effect of lime on the uptake of N by the wheat straw

Variate:Straw N_uptake (mg/kg)					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Variety	1	7.35	7.35	2.23	0.21
Residual	4	13.2133	3.3033	6.63	
Lime_level	4	79.166	19.7915	39.7	<.001
Variety.lime_level	4	1.5033	0.3758	0.75	0.57
Residual (a)	16	7.9767	0.4985	1.35	
Site	1	15.8107	15.8107	42.83	<.001
Variety.site	1	1.4727	1.4727	3.99	0.06
Lime_level.site	4	1.306	0.3265	0.88	0.491
Variety.lime_level.site	4	0.4073	0.1018	0.28	0.89
Residual (b)	20	7.3833	0.3692		
Total	59	135.589			