EFFECTS OF PHOSPHATE RATES ON NITROGEN UPTAKE, GROWTH, YIELD AND QUALITY OF FINGER MILLET IN BUSIA, KAKAMEGA AND MAKUENI COUNTIES

WAFULA NELSON WEKHA

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DECLARATION

I declare that this thesis is my original work and has not been presented for the award of a degree in any other University or for any award.

_____ _____

Wafula Nelson Wekha Date

Department of Agricultural Science and Technology

Supervisors'

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as University supervisors.

_____ _____

Dr. Joseph Gweyi-Onyango Date

Department of Agricultural Science and Technology,

Kenyatta University

_____ _____

Dr. Nicholas Kibet Korir Date

Department of Agricultural Science and Technology,

Kenyatta University

_____ _____

Dr. Henry F. Ojulong Date

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)-Nairobi

DEDICATION

To my dear parents, Wafula and Naswa for their endless love and patience, my siblings for their encouragement, my extended family for the great support and lastly to my lovely wife, Naomi and son, Romeo for always being there for me. God bless you all abundantly.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrometry
ASL	Above Sea Level
AOAC	Association of Analytical Communities
CGIAR	Consortium Group on International Agricultural Research
DAP	Days After Planting
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
KALRO	Kenya Agricultural and Livestock Research Organization
LH_2	Lower Highland Zones
NRC	National Research Centre
SMP	Soil Management Project
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme
WAE	Weeks after Emergence
WK	Western Kenya

ABSTRACT

Finger millet *(Eleusine coracana)* is an important subsistence cereal grain grown mainly in the relatively marginal and dry areas of Kenya. The crop has particular relevance in food security as it is more resilient to abiotic and biotic stresses than other cereals and even fetches higher prices in the market. It provides valuable sources of minerals and nutrients and is recommended for pregnant and nursing mothers and infants. However, productions of the crop both in hectareage and yield have been on a general decline. Soil infertility is one of the major constraints to crops production throughout much of the Sub-Saharan Africa. Phosphorus deficiency has been identified as one of the most limiting soil nutrient after nitrogen due to continuous cultivation, soil erosion and fast reversion of soluble P whereby P fertilization is of fundamental importance in replenishing, enhancing and maintaining soil fertility. The objective of the experiment was to evaluate the effect of P application rates on nitrogen uptake and accumulation, growth, yield and quality of finger millet production. On-station experiments were conducted in Kiboko, Kakamega and Alupe research centres during the long and short rain cropping seasons of 2014/2015. The trials were laid out in a randomized complete block design in a 4×3 factorial arrangement with four levels of P (0, 12.5, 25.0 and 37.5 kg ha^{-1} P_2O_5) and three finger millet varieties (U-15, P-224 and a local check) and replicated three times.. Collected data on nitrogen uptake, N partitioning, growth, yield and nutrient content of finger millet and the soil chemical characteristics were subjected to ANOVA using GenStat statistical software and where there were statistical differences, Fischer's Protected test was used to separate means at 5% probability level. Increased N uptake was observed with increasing P rates where partitioning of N was highest in the grains. Phosphorus treatments enhanced the growth of the crop and significantly reduced the days to 50% flowering and maturity with U-15 being the earliest maturing variety in western Kenya and Ekalakala in Kiboko. Yields responded positively to P application with a maximum of 4.4 t ha^{-1} observed on the 25.0 kg ha^{-1} P_2O_5 rate in Alupe during the long rains which was a 28% increase over the control. Varietal differences were observed in terms of N uptake, partitioning, plant growth, yield and grain nutrients where P-224 yielded the highest in Kakamega and Busia while U-15 being the best in Kiboko. U-15 had the highest harvest index across all the sites. Improved varieties P-224 and U-15 had the highest partitioning of N to the grains of upto 43% while local variety Ikhulule had as low as 23%. The interaction between U-15 and 25.0 kg ha^{-1} P_2O_5 exhibited highest protein content with 15.31%. Phosphorus, Magnesium and Zinc contents in the grains did increase with P application. Increasing phosphate rates significantly ($P \leq 0.05$) increased soil available P in all the sites. Plant biomass, plant height, effective tillers, leaf blade length, seedling vigor, grains per spikelet, days to 50% flowering, days to maturity and threshability were positively and directly correlated to the grain yield. The findings from this study indicate that application of 25.0 kg ha^{-1} P_2O_5 significantly led to higher yields in finger millet under the improved varieties at Alupe and Kakamega. Further studies should be conducted on the influence long-term phosphate application on soil P availability and soil pH stability.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Finger millet (*Eleusine coracana* L. Gaertn) belongs to the *poaceae* family and is one of the most important food cereals in the Sub-Saharan Africa and South Asia regions. Indigenous to Eastern Africa, finger millet is widely grown by small scale land holders for food and as a source of income where at present it fetches a better price than maize and sorghum per kilogram (CGIAR, 2001). In Kenya it is well known as "Wimbi" and is mostly grown in the Western and parts of the Rift Valley as well as of Eastern region. This crop is one of the most nutritious (Oduori, 2005) among all the major cereals. It is rich in minerals especially in Calcium, Phosphorus and Iron; its protein contain important amino acids like methionine and valine; high dietary fibre; and also is high in carbohydrates that are important especially for infants, mothers, elderly and the sick (Joshi and Katoch, 1990).

For all its importance, however, the crop is one of the most neglected and underutilized crop worldwide and the research attention it receives compared to that carried out in wheat, rice, and maize for instance is the least (FAO, 2011). Its production has alarmingly dwindled through the years because of various constraints like poor policy making, climatic change, limited research, and low soil fertility due to poor soils, soil nutrient depletion, and inefficiency in fertilizer use. Studies done on soils in Western Kenya have shown low soil N and P contents emphasizing the need for application of inorganic fertilizers that are needed to overcome the decline or alleviate the soil nutrient deficiency (Kute and Chirchir, 2003). Phosphorus is one of the most essential macro nutrient required by plants for their metabolic processes and its deficiency adversely affects sugar and starch

utilization, photosynthesis, nucleus formation, protein metabolism and cell division, resulting to overall slow growth and delayed crop maturity (Hanson, 1992). It is very important to determine the effect of phosphorus on nitrogen uptake and its partitioning because it allows pin-point fertilizer recommendation that allows a balanced inputs and outputs, meeting the total crop demand (Marschner *et al*., 1996; Roberts, 2005; Zhang, *et al*., 2007). Both the amount applied and the timing of the application of P fertilizers are important for improving its efficiency but there is limited and inadequate information on the proper rates of phosphate fertilizers in respect to finger millet in acid Alfisols of western Kenya and the semi-arid regions of eastern parts of Kenya. There is need to seek strategies by which P fertilizers can be used more effectively in the farming systems and where its use is economically feasible and therefore this study sought to enhance the production of finger millet in the semi-arid and Western regions of Kenya through proper application of phosphorus.

1.2 Statement of the problem

According to the Soil Management Project (SMP) initiated in 1994 as an adaptive research project in KARI found that the best P fertilizer rate for finger millet is 20 kg ha^{-1} P_2O_5 and where organic fertilizers are incorporated the rate should drop to 12.5 kg ha^{-1} P_2O_5. The rate is also supported by Muriuki and Qureshi (2001) in the KARI fertilizer use manual. A Food and Agriculture Organization (2011) report stipulates that the recommended rate for finger millet farming should be 150 kg/ha inclusive of N both applied at planting time. This available information seem not to have helped in improving yields of the crop considering the dwindling production during the last few decades and where farmers have

moved from growing the crop in preference to other crops especially maize. Furthermore, most of the available information is out of date considering the depletion and degradation over time of soil P due to continuous cultivation, erosion, toxicity in the soil that increases acidity, burning of soil and inherent low soil fertility like those found in the Eastern region of Kenya (Oduori, 2005). Phosphorus fertilization is of fundamental importance for sustaining and achieving potential yields in finger millet production through replenishing, maintaining and enhancing the fertility of degraded soils. There is also need to analyze the relationships between nitrogen uptake and removal in finger millet to be able to match plant nutritional needs with nutrients from the soil and fertilizer sources. However, this has not been well researched, documented and addressed in Kenya (Jama *et al*., 1997).

1.3 Research Objectives

1.3.1 General Objective

The study aimed to enhance production of finger millet in the semi-arid and Western regions of Kenya through proper application rates of phosphate fertilizers.

1.3.2 Specific Objectives

The specific objectives of the study were:

i. To determine the effect of phosphate rates on the growth, yield and grain nutrient content components of finger millet.
ii. To analyze the influence of phosphate rates on the uptake of Nitrogen and accumulation by finger millet.
iii. To investigate the effect of phosphorus on nitrogen partitioning among different organs in three finger millet varieties.

iv. To evaluate soil chemical balances after P fertilizer applications in finger millet production.

1.4 Research Hypotheses

The study sought to test the following hypotheses:

i. There is no relationship between the rates of phosphate fertilizer application and growth, yield and quality of finger millet.
ii. There is no significant relationship between phosphate rates and nitrogen uptake and accumulation in finger millet varieties.
iii. There is no differences in nitrogen partitioning between the rates of phosphate fertilizers and nitrogen partitioning among finger millet varieties.
iv. P fertilizer application has no effect on soil chemical balances in finger millet production.

1.5 Significance of the study

Information generated from this study intends to present opportunities to farmers to be economically efficient and ensure improved agronomic management practices on phosphate fertilization. The study will shed more light on the best ways to boost soil P through proper application rates of phosphate inorganic fertilizers and understanding underlying scientific processes in nutrient uptake in relation to measured growth, yield, and quality responses and soil nutrient balances in finger millet growing. The increase in yields due to proper phosphate fertilization will motivate more farmers to adopt finger millet farming which most had abandoned due to its' low yielding capacity compared to other crops. Through this food security will be assured among the poor and boost the

nutritional benefit of millions of people who live majorly on starchy staples. The surplus can be sold and generate income that will improve the living standards of farmers and in turn help in alleviating poverty. The straw from the crop will also be used as animal feed when green or dried as hay or silage as it is found to be highly nutritious. Findings of this study will also be compared to other related research findings and additional information will particularly be of benefit to the scientific community and also add to the general pool of knowledge in relation to finger millet production.

1.6 Conceptual Framework

This study focused on effects of phosphate application rates on soil properties nitrogen uptake, growth rate patterns, yields and quality of three finger millet varieties.

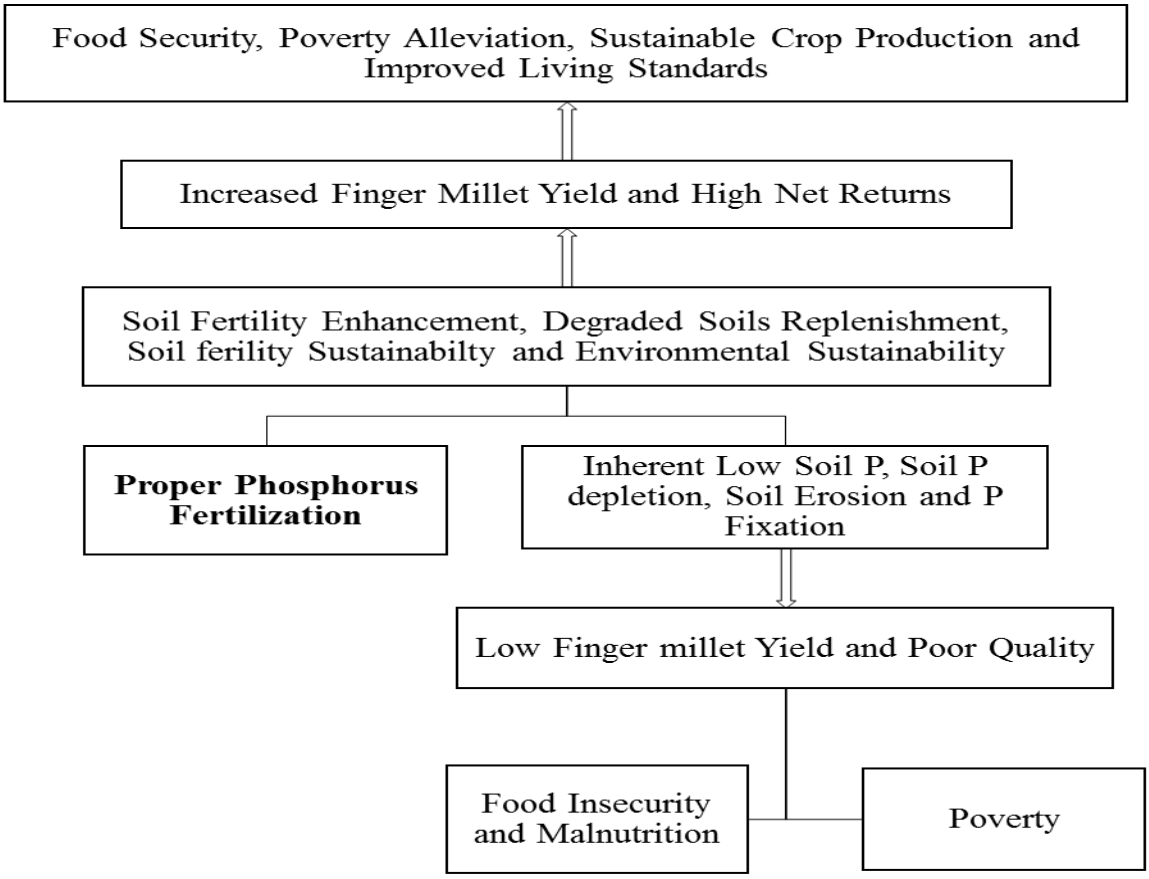

Figure 1.1: The conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The chapter offers a review of literature which highlights the potential and importance of finger millet. It also expounds on how the crop enhances household food security and income generation which definitely improves the living standards and the quality of life among most of the rural communities in Sub-Saharan Africa.

2.2 Importance and Potential of finger millet

Overcoming rural poverty and food insecurity in developing countries remains one of the biggest challenges of the 21st century albeit the remarkable advances made. About 1.2

billion people around the world live in extreme poverty today and 0.9 billion being chronically undernourished (UNDP, 2013). By increasing production through higher yields and income generating opportunities in the farming sector is one of the fundamental factors aimed to attain reduced extreme poverty and hunger. Agriculture plays the greatest part in reducing poverty compared to the other sectors in developing countries (Thirtle *et al*., 2003; Christiaensen and Demery, 2007).

Prospects of bringing new land under cultivation in order to attain food security are limited and the existing land under agriculture is increasingly subject to climate change, soil fertility depletion and water scarcity (IAASTD, 2009). Since small scale farmers occupy one of the largest share of the agricultural land worldwide, food production increase can only be achieved improving on proper land use technologies. There are two basic ways to achieve this increase in productivity where the first one is by adopting improved technologies and the second is to use the available inputs and technologies efficiently.

While most researchers and policy makers have paid little attention to traditional food crops like finger millet in recent years, it could make valuable contribution to poverty alleviation and food security in many regions of the developing world. Finger millet can withstand low soil fertility, soil nutrient depletion and degradation and climatic changes mostly in terms of erratic rainfall (Oduori, 2005). It also contains high nutritional contents and fetches a better price when sold compared to either maize or sorghum (FAO, 2011). In addition to calorie, Frison *et al.* (2006) highlight the importance of traditional crops like finger millet and sorghum in the provision of micronutrients.

Finger millet grain has a fine aroma when cooked or roasted and has many health promoting qualities. The crop’s grain has a very low rate of insect damage and therefore

can be stored for a very long period, making it particularly valuable in famine-prone areas (IFAD, 2010). Finger millet crop provides cereal grain and straw which is a valued animal feed. In the major cereal crops, finger millet is one of the most nutritious in terms of proteins, minerals and amino acids especially methionine, an amino acid lacking in the diets of millions among the poor who majorly depend on starchy foods such as rice and maize and provides about 10 times more Calcium than that found in wheat or rice (FAO, 2011) as shown on Table 2.1.

Table 2.1: Nutrient composition of finger millet per 100 g edible portion compared to other cereals at 12 % moisture content

Food	**Protein (g)**	**Fat (g)**	**Crude fibre (g)**	**Energy (kcal)**	**Ca (mg)**	**Fe (mg)**	**P (mg)**	**Mn (mg)**
Rice	7.9	2.7	1.0	362	33	1.8	160	1.0
Wheat	11.6	2.0	2.0	348	30	3.5	306	13.3
Maize	9.2	4.6	2.8	358	26	2.7	-	-
Sorghum	10.4	3.1	2.0	329	25	5.4	-	-
Pearl Millet	11.8	4.8	2.3	363	42	11.0	-	-
Finger millet	**7.7**	**1.5**	**3.6**	**336**	**350**	**3.9**	**250**	**3.5**
Foxtail millet	11.2	4.0	6.7	351	31	2.8	-	-
Common millet	12.5	3.5	5.2	364	8	2.9	-	-

Little millet	9.7	5.2	7.6	329	17	9.3	-	-
Barnyard millet	11.0	3.9	13.6	300	22	18.6	-	-
Kodo millet	9.8	3.6	5.2	353	35	1.7	-	-

Source: FAO (2011)

The grain is also used in malting and brewing because of its high amylase enzymes which convert starch into sugar and as an adjunct in beers made from maize (*Zea mays*) and sorghum (*Sorghum bicolor*) (Obilana and Manyasa, 2002a). Finger millet diets also have a high satiety value derived from the high fibre content (3.6% of crude fibre) which slows the digestion rate. The husks have fibre and are valuable in poultry feed. Being gluten free, finger millet has a global potential in sub-regions where demand for gluten free products is increasing (Lenne *et al*., 2007). The straw can be used as feed/fodder for livestock and contains up to 60% total digestible nitrogen (NRC, 1996). The finger millet carbohydrates have the unique property of slowing digestibility and can be regarded as food for long sustenance.

Commercialization of finger millet in East Africa is steadily increasing. There are a number of small, medium and large commercial millers who mill the grain into acceptable flours (pure finger millet, composite flour and porridge mixture) that are readily available in leading supermarket outlets (Obilana, 2002; Lenne *et al*., 2007). However for sustainable commercialization, effort must be put into increasing the productivity and production of finger millet. Most of the finger millet in East Africa is sold through local markets where prices are unstable, depending on supply and demand conditions. Even where large processors are involved, grain is sourced through middlemen who buy from local markets or individual farmers. Ironically, prices offered by the formal markets like

the National Cereals and Produce Board in Kenya are usually lower than what the local markets offer (Mitaru *et al*., 1993). If the constraints along the production to consumption chain are adequately addressed, finger millet could form an integral part of the agricultural cash economy in the finger millet farming systems of East Africa.

2.3 Soil fertility and management in Kenya

The Sub-Saharan Africa region faces food security challenges because of the ever decreasing per-capita food production. Inherent poor soils and increased nutrient depletion are one of the fundamental biophysical root causes of declining per capita food production in Sub-Saharan Africa (Sanchez *et al.,* 1997). Smallholder crop production is crippled in many communities, including those found in the densely-populated, grain-basket areas of Kenya. Pioneering research by Smaling *et al*. (1997) documented these nutrient losses magnitudes and also characterized smallholder practices as poor and uninformed. Outside the deserts and drylands that comprise 60% of the continent, the soil-related problems are typically inherent because much of the land is old and weathered, requiring special attention to be useful for agriculture. Extreme poverty, widespread malnutrition and environmental degradation are part of the consequences of a farming system resulting from continuous mining of generally old and nutrient-poor soils. Nutrient mining in Kenya is among the highest in Sub-Saharan Africa, with an estimated annual nutrient depletion rate of 41 kg nitrogen (N), 4 kg phosphorus (P) and 31 kg potassium (K) per hectare (Smaling *et al*., 1997). These figures represent the balance between nutrient inputs as fertiliser, manure, atmospheric deposition, biological nitrogen fixation, and sedimentation, and nutrient outputs as harvested products, crop residue removals, leaching, gaseous losses,

surface runoff and erosion. From the figures above, it is evident that nutrient inputs are limited and forms the basis that the future development and growth in agricultural production will largely depend on enhanced land management technologies.

Finger millet has a striking feature whereby it has the ability to adjust to different agro-climatic conditions including the extremes. The crop can grow under minimum water requirement of 400 mm and the temperature above 15 °C, and it therefore can be grown throughout the year (Hedge and Gowda, 1986). Finger millet is known to tolerate drought (Dass *et al.,* 2013), resist diseases (Kerr, 2014), effective in weed growth suppression (Samarajeewa *et al.*, 2006), and grows in marginalized lands mostly those with poor soil fertility.

Most traditional farmers value finger millet because it is regarded as a low fertilizer input crop but under these conditions, it rarely yields to its potential (Rurinda *et al.,* 2014). In the semi-arid regions where finger millet is largely grown, the soils are deficient of macro and micro nutrients due to continuous cropping, low use of mineral fertilizer, limited recycling of crop residues, and low rates of organic matter application that limits the yield potential (Rao *et al.,* 2012). It is therefore important to optimize nutrient management practices affecting finger millet production to attain better yields under the marginalized local growing conditions. Recommendations available for nutrient management in finger millet are however scarce compared to the other major cereal crops.

Finger millet is a hardy low-input small grain cereal that is planted by many communities in Kenya as an insurance against crop failure. Because of the popularity of maize and other crops, little research effort has been directed to finger millet improvement and as a result yields on farmer fields are low (0.5 t/ha to 0.9 t/ha) compared to potential of 5.8 t/ha

(M'Ragwa, 1986; Oduori, 2005). The combination of climatic change, poverty, continuous cultivation, removal or burning of crop residues, loss of nutrients through soil erosion, overgrazing between cropping seasons and inadequate use of inorganic fertilizers are the major causes of declining food production per capita in small holder farms (Smaling *et al.*, 1993). This has made resource poor farmers be heavily dependent on inherent soil fertility to produce their crops, which is poor in most cases leading to the declining finger millet yields thus necessitates farmers, policy makers and scientists to collaborate to reverse the trend.

All the phosphorus that plants take up comes from the phosphorus dissolved in the soil solution which is key in plant nutrition. The amount of soluble phosphorus in the soil solution is very low necessitating it to be replenished by as many as 500 times during a given season when plants are grown to meet the nutritional needs of the crop (Renu, 2005). Very little phosphorus is in the soil solution at any given time but there is already existing a large amount of phosphorus in most soils where the bulk of the soil phosphorus is either in the soil organic matter or in the soil minerals. The highest percentage of the phosphorus in both of these fractions is in very stable, unavailable forms and only a smaller proportion is in available forms that can be dissolved in soil solution and taken up by plants. Available phosphorus in these fractions like the phosphorus added in fertilizer or manure in most instances can be quickly fixed into stable, unavailable forms in the soil (Marschner *et al.*, 1996). It explains why even under optimum management, phosphorus efficiency of plant uptake is very low where usually less than 20%. When the soil solution phosphorus is removed through crop uptake, the unavailable phosphorus forms are slowly released to more available forms to replenish the soil solution. The slow release can sustain plant

growth under many natural systems, but otherwise it is usually not rapid enough to maintain adequate availability in intensively managed cropping systems without supplemental phosphorus through mineral fertilizer.

Studies in Western Kenya have indicated that soils in the region are severely depleted of Phosphorus (P) and Nitrogen (N), and nutrient balance studies carried out have shown that N and P balances were negative (Smaling *et al*., 1993). On average 22 kg/ha N, 2.5 kg/ha P, and 15 kg/ha K are lost annually and losses can be as high as 112 kg/ha N, 3 kg/ha P, and 70kg/ha K in the intensely cropping systems of western Kenya. These losses are above those reported in inorganic fertilizer use around Africa of 5 kg/ha to 10 kg/ha per year (Heisly and Mwangi, 1996), thus emphasizing the need for soil fertility replenishment.

Low plant available phosphorus (P) has been specifically identified as a major contributor to low soil fertility in many cropped soils of Kenya, particularly in the western Kenya region. These soils are highly weathered, leached and are low in nutrients availability. This situation is worsened by high rates of population growth in high potential areas which has resulted into land subdivision into small unproductive plots combined with continuous cultivation without replenishing depleted nutrients (Tisdale *et al.,* 1990).

2.4 Plant growth and changes in yield components in response to phosphorus

Although P is one of the major macronutrients required by finger millet, limited research has been conducted to evaluate the significance of P on finger millet growth and yield. Phosphorus is one of the highly limited nutrients in farmers' agricultural lands in Africa (Rao *et al.,* 2012). The response of crops to phosphorus depends on the availability of phosphorus in the soil solution and the crops ability to take up phosphorus. The ability of

finger millet to take up phosphorus is largely due to its root distribution relative to phosphorus location in soil. Phosphorus is very immobile in the soil and it does not move very far in the soil to get to the roots. The diffusion to the root by only about 1/8 of an inch per year and relatively little phosphorus in soil is within that distance of the root (Wu and Ma, 2015). Thus, the roots must grow through the soil to get to the phosphorus that the plant needs. Therefore, root growth is very important to phosphorus nutrition and any factor that affects root growth will affect the ability of plant to explore more soil and get adequate phosphorus. Soil compaction and root injury can dramatically reduce the ability of the plant to get adequate phosphorus (Thakur, 1993). Young seedlings can suffer from phosphorus deficiency even in soils with high available phosphorus levels because of their limited root systems. The roots of young plants develop very slowly in cold, wet, early early-season soil conditions. This is the reason why some crops respond to applied phosphorus at planting with starter fertilizers even in relatively high phosphorus soils.

The decrease of the leaf number and size is one of the earliest and most reliable responses of P-deficiency on the plant (Lynch *et al.*, 1991). Cell multiplication and elongation of the newly formed cells in plants leads to leaf expansion and turgor pressure is a crucial factor for cell expansion (Hsiao, 1973; Munns *et al*., 2000). There are instances where P-deficiency decreases the hydraulic conductivity of water in the roots (Radin and Eidenbock, 1984; Radin, 1990; Clarkson *et al*., 2000). The decrease in hydraulic conductivity of the root and stomatal conductance of the leaf results in severe reduction of leaf expansion under P-deficiency (Radin and Boyer, 1982; Radin and Matthews, 1989; Clarkson *et al*., 2000). These studies also indicated that P-deficiency primarily restricts the

activity of meristematic sinks of the plant and lack of demand for assimilates in growth is responsible for the reduction of source activity or photo-assimilate partitioning.

In multi-location field experiments conducted in Eastern Uganda, Tenywa *et al*. (1999) concluded that application of P fertilizer (20–40 kg P_2O_5 ha^{-1}) increased the growth and yield of finger millet compared to the no fertilizer control. However, Hedge and Gowda (1986) reported a reduction in finger millet grain yields from 16.3 to 14.7 kg per kg P_2O_5 when the P application rate was increased from 30 to 60 kg ha^{-1} P_2O_5.

Many studies have not quantified the amounts of nutrients to be added in relation to the measured yield improvement in Kenya on finger millet. Phosphorus is essential for root growth and energy transfer processes in plants. Phosphorus has one of the most complicated chemistry as far as assessment of its soil levels and fertilizer application rates are concerned. Alinajati and Mirshekari (2011) noted that phosphorus deficit is the most important restrictive factor in plant growth and recognition of mechanisms that increase plant phosphorus use efficiency is important. Phosphorus is a major component in ATP that provides energy to plants for such processes such as photosynthesis, protein synthesis, nutrient translocation, and nutrient uptake and respiration. Phosphorus is also a component of compounds necessary for protein synthesis and transfer of genetic material DNA and RNA (Wilson, 2009).

Opala *et al.* (2013) found that after two seasons of field study in Western Kenya, P application rates on African Nightshade affected the plant heights, leaf numbers, leaf area and that leaf yields increased with increasing P rate although the differences between 40 kg/ha and 60 kg/ha were not significant. In another study on the effects of mineral P fertilizer on growth components of flooded lowland rice in Ethiopia, Heluf and Mulugeta

(2006) found that fertilizer levels showed significant differences for all growth components i.e. root length, number of panicles, number of spikelet's panicle, filled spikelet's panicles, panicle length, plant height, dry matter, straw yield and increased microbial activity in the rhizosphere of the plants roots.

Phosphorus application to rice increased P accumulation but did not consistently increase rice yields because flooding decreased soil P sorption and increased P diffusion. Panhawar and Othman (2011) showed that phosphorus fertilizer application has been reported to increase upland rice yield. Li *et al*. (2010) reported that application of P fertilizer is one of the most important components for crop yield. Under subtropical Indian conditions one study by Vasuki *et al.* (2006) found that a finger millet crop producing 4.6 tons grain + 6.9 tons straw absorbed 46 kg/ha P_2O_5.

Zaman *et al.* (1995) also observed increments in the number of panicles per m^2 of rice plant due to applied P by enhancing the production of effective tillers. The study continued by reporting that increasing levels of P increased dry matter yield accumulation as a result of increased vegetative growth favored by enhanced nutrient uptake. Channabasavanna and Setty (1994) and Raju and Reddy (1993) also reported that application of P increases the total number of spikelets per panicle in rice thereby contributing to increment in grain yield. Increased number of spikelets with P application is mainly attributed to an increase in the number of panicles per m^2 and panicle length. Number of spikelets was the second important yield-forming attribute of rice.

2.5 Influence of phosphorus on the grain nutrient content

Food and nutrition insecurity is majorly attributed to the poor performance of the agricultural sector; the most obvious outcome of this poverty is malnutrition. According to the World Hunger Education Service (2002), one of the senses in which the word "hunger" is used is to mean the want or scarcity of food. This lack of food leads to malnutrition and in extreme cases can lead to death. Malnutrition in turn is a term that indicates a lack of some or all nutritional elements that are necessary for human health. There are two types of malnutrition. The first is protein-energy malnutrition (PEM) and it refers basically to the lack of calories and protein. The second type of malnutrition is micro-nutrient (vitamin and mineral deficiency). Of these two types, the first is the most lethal and it is in this first sense that the word hunger is used here. This is not to downplay the importance of the second type of malnutrition but merely to recognize the fact that the majority of hungry Kenyans will readily accept any kind of food rather than asking first whether it contains this micronutrient or that vitamin. Finger millet serves as one of the best remedy to the above stated challenges and this can be achieved if there is increased production and adoption of the crop by smallholder farmers (Oduori, 1993).

The influence of phosphorus on nutritional composition of crops and specifically finger millet, is not well established. Some workers (Bressani and Elias, 1980; Marzo *et al*. 1997) reported an increase in protein content with increased P application rate, while others (e.g. Henry *et al*., 1995) found no increase in protein content. When speaking about grain N content, there should be attention drawn to the content of phosphorus in grain. A number of authors emphasize positive effects of increasing P content in grain, especially those from consumer point of view. Grain P is a valuable source of this nutrient for humans and

animals. The additional benefit of high P contents in grain is a possibility of obtaining higher grain yields with better germination capability, which is particularly important in reproduction of sowing material (Bolland and Baker, 1988; Manske *et al.*, 2001; De-Marco, 1990). A decrease of P contents results in reduction of grain anti-nutritional factors such as phytic acid (Batten, 1986).

Protein content has been found to vary due to genotype, water availability, soil fertility, temperatures and environmental conditions during grain development. In the dry highlands of Kenya, a study conducted to evaluate the effect of P on nutrient content of sorghum by Ashiona *et al*. (2005) reported that phosphorus levels beyond 30 kg/ha did not increase the crude protein content.

2.6 Phosphorus effect on Nitrogen uptake and partitioning

Although many research findings suggest that increased application rates of inorganic fertilizers improve finger millet yield and productivity, it is not a practical option for many poor finger millet farmers in Sub-Saharan Africa, as they cannot afford inorganic fertilizer. Therefore, fine-tuned nutrient management may be a sustainable option for finger millet farmers in these regions with improvements in plant performance and resource use efficiency while minimizing negative environmental impacts (Wu and Ma, 2015). These can be achieved through use of all possible sources of nutrients to meet crop demand, matching soil nutrient availability with crop demand (spatially and temporally), and minimizing nitrogen losses (Drinkwater and Snapp, 2007).

Plants require a balanced supply of nutrients throughout their development. Generally, they have accumulated most of their nutrients between flowering and ripening stages.

Approximately 50 to 90 percent of N and P in the plant at flowering moves from the leaves and stem to the developing seed (Chapin and Wardlaw, 1988). Therefore, low nitrogen uptake early in a plant's growth lowers nutrient quantity for the seed, affecting both yield and quality. The issues concerning N and P interactions have been discussed in a number of papers (Kim, 2003; Prystupa *et al.*, 2004; Sadras, 2006; Summer and Farina, 1986; Zhang *et al*., 2007). Rychter and Randall (1994) reported that prolonged P deficiency in the plant reduces the pool of energy compounds ATP, and then as a result uptake of nitrate nitrogen ($N\text{-}NO_3$) is limited. On the other hand, N excess at lacking phosphorus triggers the first symptoms of P deficiency. Under field conditions, there remains a question on a role of N/P interactions in shaping improvement of nutrient utilization. The processes of nitrogen-phosphorus interactions are determined to a big extent by soil and climatic conditions (Summer and Farina, 1986).

The role of P in energy transfer is also a role that affects the availability of other nutrient elements. Plants gather nutrients through passive absorption (nutrients enter the plant with water and other elements) or active absorption (energy is used to absorb an element) from energy supplied by ATP. Crop use of any nutrient depends on a two-step process: soil supply of that nutrient in an available form, and uptake of that available nutrient by the crop (Tandon, 1987). Selecting among the options presented by nature constitutes management. Little attention has been devoted to field research in soil fertility to study the interactions between nutrients in finger millet under uncontrolled conditions. The importance of an appropriate nutrient balance in crop production and in the maintenance and enhancement of soil fertility is recognized. Soils containing insufficient contents of plant available P not only produces economically unacceptable yields but other inputs

particularly N which is used less effectively by the plants because of their synergistic interaction (Ashiona *et al*., 2005).

Increase in yield attributing characters is associated with better nutrition and increased nutrient uptake which result in better and healthy plant growth and development (Kumar and Rao, 1992; Thakur, 1993), leading to greater dry matter production and its translocation to the sink (Dalal and Dixit, 1987). Panda *et al.* (1995) reported increased dry matter production including grain yield of rice due to increased uptake of nitrogen in response to external supply of P through fertilizers. Yang and Jacobsen (1990) proposed that increased efficiency in N uptake following P application is a result of P in cell division of the shoot and expansion of newly developed leaves. The effect of phosphorus deficiency on a meristematic sink like the shoot apex may be different from that of a storage sink like the grains. However, methods for monitoring the effects of P-deficiency on plants during fruit growth period are lacking. Phosphorus availability helps in efficiency of nitrogen use by plants (Nziguheba *et al.*, 1998).

2.7 Nutrient balances in the soil

Soil nutrient balance is an indicator of land quality describing the rate at which soil fertility changes under actual management (Smaling *et al.,* 1993). Essential information in assessing environmental impact can be deduced from the effects of cropping systems and management practices on soil properties. Assessment on the impact of agricultural technologies on soil fertility will ensure future sustainability through calculation of nutrient balances (Vlaming *et al*, 2001) especially in Sub-Saharan Africa where it is becoming

increasingly difficult to satisfy short term production needs and long-term sustainability concurrently.

Phosphorus (P) is derived from soil organic matter and minerals and is actively absorbed by plant roots as primarily $H_2PO_4^-$ or HPO_4^-. The latter is absorbed more in soils of pH 7.0 or greater. It is mobile in the plant and redistributes from older to younger plant parts as demand changes. Phosphorus forms sparingly soluble compounds in soils (Rashid and Memon, 2001) and thus the amount of phosphorus in solution at any one time is relatively very small. It has been shown that when plants are growing, the soil solution must be renewed with phosphorus several times per day in order to obtain normal plant growth. The important factor that limits phosphorus uptake by plants is the rate of renewal of phosphate in the soil solution near the plant roots (Radin and Matthews, 1989). Low solubility of phosphorus in soils is caused by phosphate reactions with iron, aluminum and calcium ions. Iron and aluminum ions fix phosphorus in acid soils and calcium ions precipitate phosphorus in alkaline soils. The total amount of phosphorus in soils ranges between 40 and 400 kg ha^{-1} in the topsoil, but the amount in the soil solution may be about .05 – 1 ppm. This illustrates the low water solubility of phosphorus in soils. The more acid the soil, the more concentrated is the iron and aluminum where freshly formed Fe and Al compounds become less soluble over time. Fixation of phosphorus is much greater below a soil pH of 5.0. In addition to soluble and exchangeable Fe and Al, soil clays are sources of iron and aluminum that are capable of reacting with phosphate ions (Munns *et al*., 2000).

In alkaline soils, high calcium dynamics encourage the formation of di-calcium phosphate. Although the solubility of di-calcium phosphate is greater than that of iron and aluminum

phosphates, its solubility is high enough to supply plants with phosphate at given periods during growth. In some alkaline soils there is an abundance of tiny lime or Calcium Carbonate crystals that adsorb phosphate ions in a similar reaction (FAO, 2006). When phosphate fertilizer is added to the soil, it reacts with the appropriate compounds depending on soil pH. The initial reaction is from soil solution to adsorption on existing crystals or solid phase. Phosphorus continues to react with the solid phase and becomes part of the crystal. Solubility decreases as the phosphate becomes an integral part of the solid phase. The period of time may be short or long, depending on the fixing capacity of the soil as reported by Havlin *et al.* (2005). Soils with high fixing capacity require larger amounts of phosphorus fertilizer and once the capacity is filled the rate of fertilizer reduces. The amount of iron, aluminum, or calcium in relation to the amount of phosphate applied or their availability determines the P fixing capacity. The phosphorus fixing capacity of many soils are satisfied from past phosphate fertilization (Brady and Weil, 2002).

It has been estimated that 1/3 of the total phosphate in native grassland agricultural soils is in organic form. The loss of organic matter by cultivation has significantly reduced the organic portion. The organic phosphorus is mineralized similarly as to that of nitrogen and once it is in the mineral form, it enters the soil solution and reacts with the mineral or solid phase. Past experiments have shown that decreases in the organic P portion of soil are related to increases in soil test P (Mahmood *et al.,* 2000). Mineralization of organic P in relation to the carbon, nitrogen, phosphorus ratio suggests that when the C: inorganic P ratio is 200:1 or less, there is a likelihood that mineralization will occur. If that ratio is

300:1 or more it is likely immobilization that will occur. The rate of dissolution and diffusion of solid phase phosphate to solution phosphate determines soil phosphate availability. It has been shown that all phosphate added to soil reacts with the solid phase. For the phosphorus to become available to the plant it must go back into solution. As phosphate ions ($H_2PO_4^-$and HPO_4^-) are taken out of solution by the plant root more must come from the solid phase. The rapidity of replenishment determines the availability of phosphorus (Waheed *et al*., 2004).

In a study carried on French beans to evaluate the effects of P fertilizer application rates by Barasa *et al*. (2010) in Uasin Gishu during the 2007 and 2008 cropping season found that the use of TSP at a rate of 40 kg/ha significantly increased soil available P between 8.7 kg/ha and 14.7kg/ha. Rafique *et al.* (2012) conducted a five year experiment on a similar type of soil, in cotton-wheat crop rotation and they observed that soil P balance was positive even when 26 kg P ha^{-1} was applied to wheat only, and cotton was grown on residual P. Sharma and Prasad (2009), observed an increase in available P from 14.2 to 18.5 ppm with application of 35 kg P ha^{-1} in a three year experiment, using mungbean *(Vigna radiata)* as test crop.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the Study Sites

3.1.1 Makueni

The field study was conducted during the 2014/15 short and long rain seasons at KALRO-Kiboko Crops Research Station on ICRISAT's experimental fields, in Kiboko Location, Makueni County (Figure 3.1). It lies within longitudes 37°38'60 E and latitudes 2°16'0 S with an elevation of 975 m above sea level. The weather conditions are as shown on Appendix 1. The soils are dark reddish brown-to dark red, well drained *Acri-Rhodic Ferrassols* (KARI, 2003) with 43% sand, 34% silt and 23% clay.

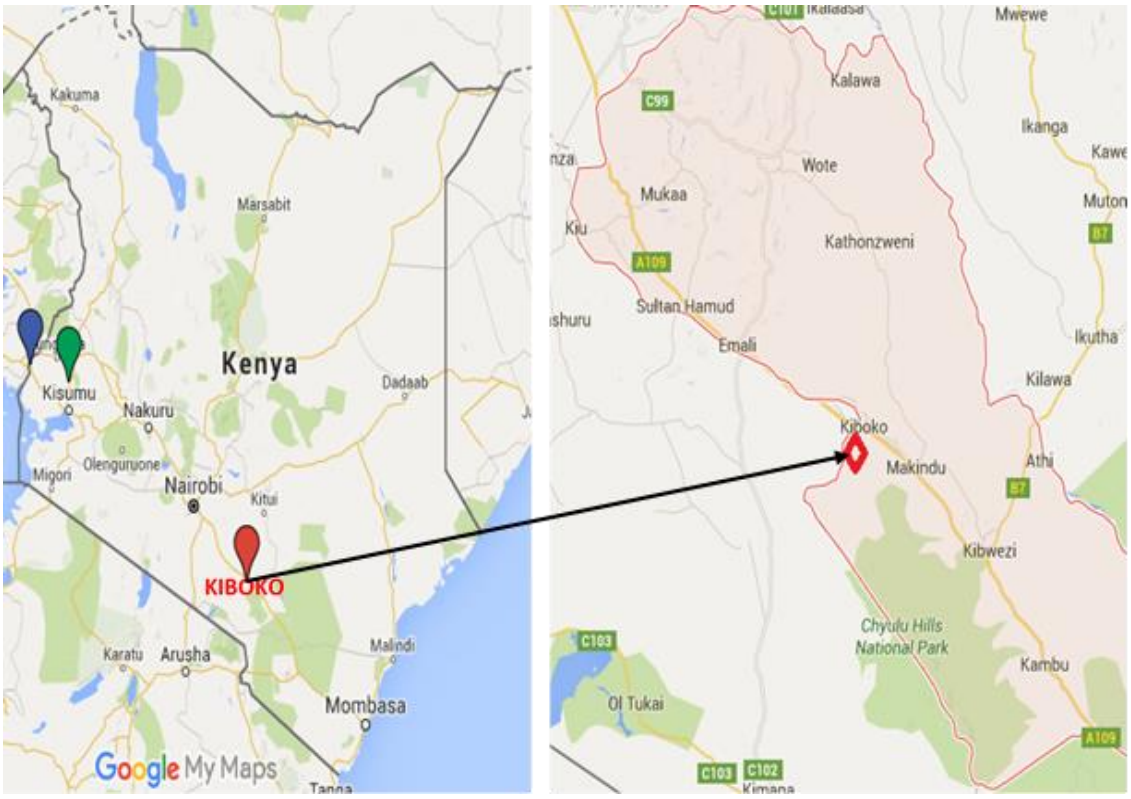

Figure 3.1. The map of Kenya showing Makueni County and the study site at KALRO-Kiboko

3.1.2 Kakamega

The trials were conducted during the 2015/2016 long and short rains cropping seasons at the Kenya Agricultural and Livestock Research Organization, Kakamega crops field station in Lurambi Location, Kakamega County (Figure 3.2). It lies within latitude 0°16'60 N, longitude 34°45'0E with an elevation of 1523 m above sea level. The soils are Ferralo-Orthic Acrisols with 53.55% sand, 32.18% silt and 14.27% clay (Jaetzold *et al.*, 2006). The weather conditions are as shown on Appendix 3.

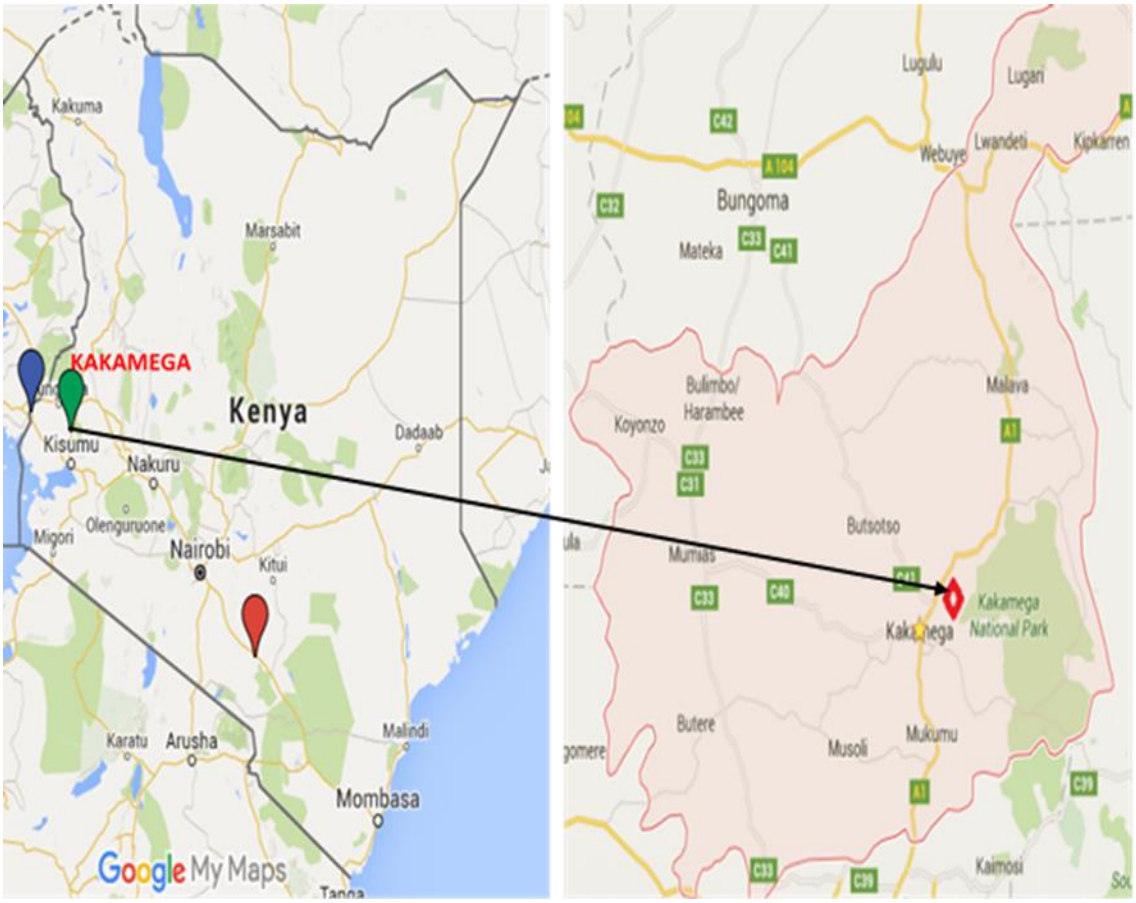

Figure 3.2. The map of Kenya showing Kakamega County and the study site at KALRO-Kakamega

3.1.3 Busia

The trials were conducted at the Kenya Agricultural and Livestock Research Organization, Alupe Crops Research Station in North Teso location, Busia County (Figure 3.3) during the long and short rain seasons of 2015/2016. It lies within latitude 0°30" N, longitude 34°07'50" E with an elevation of 1157 m above sea level. It is in the LM1 (Humid Lower Midland) agro-ecological zone. The weather conditions in the station are as shown on Appendix 2 during the period which the study was conducted. The soils were classified as Orthic-Ferralsols with 47.57% sand, 35.76% silt/loam and 16.67 % clay (Jaetzold *et al.*, 2006).

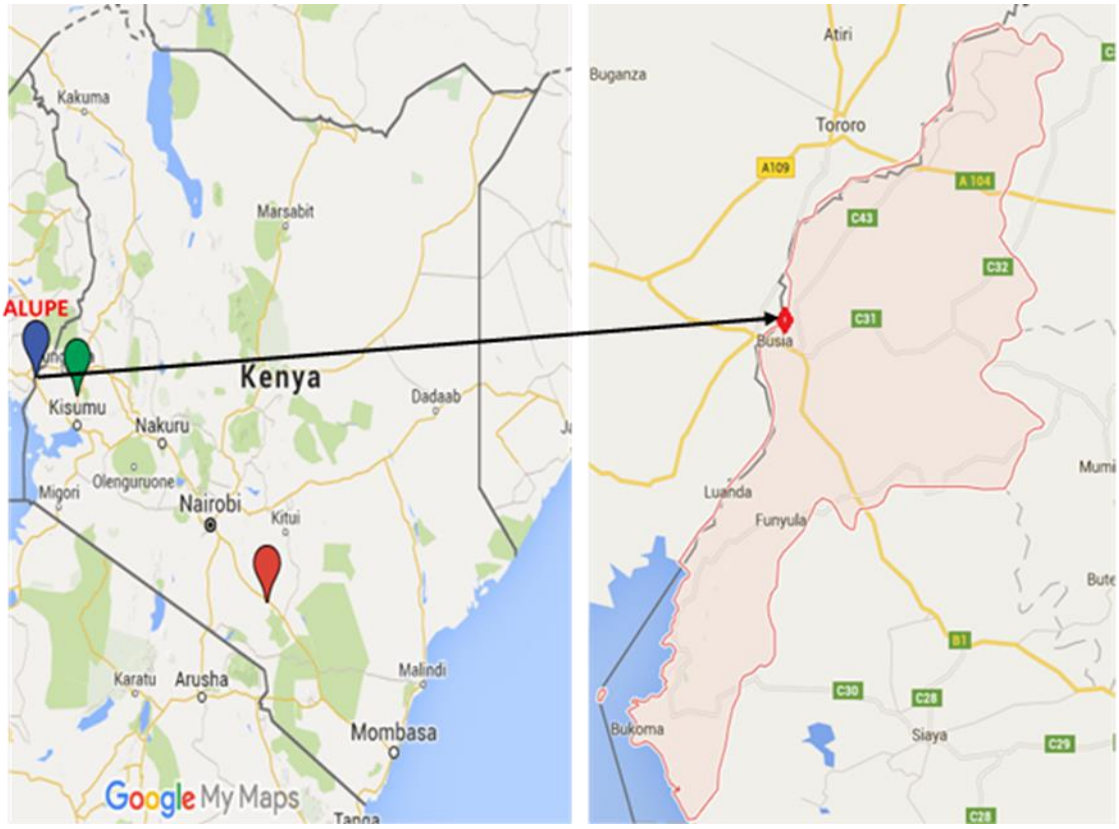

Figure 3.3. The Map of Kenya showing Busia County and the study site at KALRO-Alupe

3.2 Experimental design and treatments

The experiments were laid out in a Randomized Complete Block Design with a 4×3 factorial arrangement with four levels of phosphate fertilizer (0, 12.5, 25.0 and 37.5 kg ha^{-1} P_2O_5) and three finger millet varieties (U-15, P-224 and a local check) and replicated three times. The 0 kg ha^{-1} P_2O_5 treatment was the control. The phosphate fertilizer was supplied as Triple Superphosphate (TSP) and the local check variety in Makueni was Ekalakala while Ikhulule was used in Kakamega and Busia.

Table 3.1. The experimental treatments

Treatment	**Variety**	**Fertilizer Level (kg ha^{-1} P_2O_5)**
V_1P_0	U-15	0
V_1P_1		12.5
V_1P_2		25.0
V_1P_3		37.5
V_2P_0	P-224	0
V_2P_1		12.5
V_2P_2		25.0
V_2P_3		37.5
V_3P_0	Local Check	0
V_3P_1		12.5
V_3P_2		25.0
V_3P_3		37.5

†V_1-U-15, V_2-P-224, V_3-Local Check, P_0-Control, P_1-12.5 kg ha^{-1} P_2O, P_2-25.0 kg ha^{-1} P_2O, P_3-37.5 kg ha^{-1} P_2O

The experimental units measured 4m by 2m with a 1m pathway between every experimental unit. The total area of the experimental field measured 44m long and 11m wide.

3.3 Field management practices

Land preparation was done prior to the onset of each cropping season. Land was cleared of previous crop residues and tractor-drawn disc plough was used during the first ploughing and re-ploughing. Tractor-drawn tandem harrow was used to obtain a fine tilth in Kiboko while hand harrowing was done in Kakamega and Alupe. The experimental fields were measured and demarcated into experimental units measuring 4 metres long by 2 metres wide with a 1 metre pathway between each plot. The gross experimental field area was 484m^2.

Plate 1: A prepared field of finger millet at Kiboko site during the short rains in 2014

Five furrows were opened using hand furrow-openers in each plot with an inter-row spacing of 0.5m. Triple Superphosphate (TSP) fertilizer was applied at the rate of 21.74g per plot (4.35g per row) for 12.5 kg ha^{-1} P_2O_5 treatment, 43.48g per plot (8.7g per row) for 25.0 kg ha^{-1} P_2O_5 and 65.22g per plot (13.04g per row) for 37.5 kg ha^{-1} P_2O_5 evenly along

the furrows and thoroughly mixed with the soil while no fertilizer was applied in the control plots. Seeds supplied by ICRISAT were drilled in the furrows evenly and covered with loose soil. Supplementary irrigation was done using sprinklers whenever necessary in Kiboko. Insecticides with active ingredient Imidacloprid and Alphacypermethrin with trade names Confidor® and Fastac® respectively were applied at a rate of 5 ml per 20 litres of water to control pests. The pesticides were sprayed once a week. For the control of diseases, particularly blast, a rate of 10 ml Ortiva® (active ingredient Azoxystrobin) per 20 litres of water and 50 g of Sancozeb® (active ingredient Mancozeb) per 20 litres of water were sprayed in case of neck, leaf and head blast incidences.

The experimental field was kept weed free by carrying out two hand weedings and earthing up was done at the second weeding to ensure strong establishment of the crop in the soil. Thinning was done 4 weeks after planting at a spacing of 0.1m between plants thereafter followed by a blanket top dressing with Urea (46-0-0) fertilizer at the recommended rate of 50 kg ha^{-1} N translating to 86.96g per plot (17.4g per row).

The crop was harvested at physiological maturity when 90% browning of the heads was observed. A net area of $3m^2$ on the 3 middle rows was harvested by cutting the panicles using knives. The panicles were dried until a constant dry weight was achieved then threshed, winnowed and packed in gunny bags. The fodder was cut just above-ground for fresh weight determination and dried for dry weight determination.

3.4 Soil Sampling and Analysis

3.4.1 Soil sampling

At the start of the experiment after demarcation of the experimental units, soil sub-samples were collected using a soil auger in a zigzag pattern from 3 spots on the three furrows at a depth of 0-30 cm from each. The 3 sub-samples were considered to be representatives of the soil chemical condition of the plots. The sub-samples were mixed to obtain a composite sample which were air-dried in a well-ventilated room for 3 days then grounded and passed through a 2-mm sieve. They were packed in plastic bags, labelled and analyzed at the National Agricultural Research Laboratories, Nairobi. The samples were used to assess the initial soil fertility status for the experiment. At harvesting, 3 soil sub-samples were collected from 3 spots on the 3 middle rows of each experimental unit and the same procedure as for the initial soil samples preparation was done and taken for analysis to assess the changes in soil chemical properties in respect to treatment applications.

3.4.2 Soil Analysis

The soil samples were analyzed for the following chemical properties using the described procedures:

i. Soil pH

The pH of soil samples was determined electrometrically both in water (pH water) and in 0.01 M CaCl2 (pH CaCl2) at a (1: 2) soil: solution ratio (weight /volume) as outlined by Okalebo *et al*, (1993). About 10g of air – dry soil samples were added to 25 ml of distilled water and the mixture shaken at 260 reciprocations per minute for 10 minutes and allowed to settle for 30 minutes. The pH of the soil suspension was recorded thereafter, using a pH meter (Model SG78) on a glass electrode.

ii. Mineral Nitrogen

Nitrogen was obtained by modified Kjeldahl method (Ryan *et al*., 2001). The procedure involved digestion and distillation. The fraction of Nitrate N (NO_3 –N) in the soil was reduced and subsequently distilled. Finely ground soil sample (15 mm) was uniformly mixed and spread in a thin layer on a sheet of paper. A representative sample containing 3 g of N was taken. 0.01 g of the sample was placed into a 250 ml digestion tube that was calibrated and10 ml distilled water added and thoroughly swirled and let to stand for 30 minutes.

Blank digest was prepared and 0.1 g EDTA (Ethylene-Diamine-Tetraacetic Acid) standard digest weighed to 0.1 g with each batch. Potassium permanganate (10 ml) solution was added and swirled well, left to stand for 30 seconds, and the digestion tube held at 45^o angle while 20 ml 50% sulphuric acid was slowly and carefully added so that it washed down material adhering to the tube neck. It was left to stand for 15 minutes then swirled. A few pumice boiling granules was added to the blank, EDTA, and sample digest tubes. Reduced iron (2.5 g) was added through a long-stem funnel and a 5 cm internal diameter glass funnel with a removed stem was immediately placed in tube neck, and swirled. Excessive frothing at this stage was halted by pouring 5 ml distilled water through the 5 cm glass funnel. The tubes were allowed to stand overnight. The samples were pre-digested by placing them on the cold block and heating at 100°C for an hour. After 45 minutes from removing the samples from the block-digester, the samples were swirled and left to cool. A mixture catalyst of about 5 g was added through a long stem funnel and 25 ml concentrated sulphuric acid added to each tube, and swirled. The tubes were pre-heated on the block-digester to 100°C, and block temperature setting increased to 240°C, and

funnels removed. Funnels were systematically arranged so as to be placed afterwards into the same digestion tube. Water was boiled for 1 hour after reaching 240°C. Funnels were replaced after removing the water and the temperature raised to 380°C. The tubes were removed from the block-digester after digestion for 4 hours and 50 ml of DI (De-Ionized) water added mixed with a vortex mixture. A glass rod was used to break the solid precipitate remaining in the tubes. After cooling, DI water was added to the 250 ml mark.

For the distillation procedure, the digestion tube was shaken thoroughly and 50 ml pipetted into a 250 ml distillation flask. Acid digests were distilled with excess NaOH. One ml distilled water and 1 ml saturated boric acid solution were dispensed into a 100-ml Pyrex evaporating dish and placed underneath the condenser tip with the tip touching the solution surface. Volume of 10 N NaOH was then carefully dispensed on the flask with the digest at a 50° angle. The flask was attached to the distillation unit and the distillation started until 3 minutes elapsed. The dish was lowered and distillate let to drain freely into the dish.

After 4 minutes, when about 35 ml distillate was collected, steam supply was turned off and tip of the condenser washed into the evaporating dish with a small amount of DI water. The distillate was titrated to pH 5.0 with standardized 0.01 N H_2SO_4 using the Auto-Titrator. After titration, the Teflon-coated magnetic stirring bar, the burette tip and the combined electrode were washed into the dish. Distillations between different samples were steamed out. Distillation flasks containing the digest sample and NaOH were disconnected, a 100-ml empty distillation flask attached to distillation unit, and a 100 ml empty beaker placed underneath the condenser tip, cooling water supply turned off and steamed out for 90 seconds. Each distillation contained at least two standards and two blanks.

iii. Total Organic Carbon

Organic carbon content was determined using modified Walkley and Black wet oxidation procedure described by Ryan *et al.* (2001). Half a gram of air dried soil passed through 0.5 mm sieve were weighed into 500 ml wide mouth conical flasks and 10 ml of 1 N potassium dichromate added into the flasks using a burette. In a fume cupboard, 15 ml concentrated sulphuric acid was rapidly added directing the stream into the suspension. The flasks were swirled gently at first until all soil and reagents mixed and then more vigorously for about one minute. They were then allowed to stand for exactly 30 minutes. About 150 ml of distilled water was added and allowed to cool, after which 10 ml 85% orthophosphoric acid and finally 10 drops diphenylamine indicator were added. The solutions were titrated with 0.5 N ammonium ferrous sulphate.

iv. Available Phosphorus

The analysis of P was done by the Olsen P method as described by Olsen and Sommers (1982). A strong acid was used to digest the soil sample where P determination involved digestion and the dissolution of all insoluble inorganic minerals and organic P forms. In the digestion chamber, 2 g air-dry soil was weighed into a 250 ml calibrated digestion tube, 30 ml 60% perchloric acid and a few pumice-boiling granules were added and mixed well. Tubes rack was placed in the block-digester and gently heated to about 100°C. Block-digester temperature was slowly increased to 180°C and the samples digested until dense white fumes of acid appeared. If necessary, perchloric acid was the medium used in washing the sides of the digestion tube. The total digestion with perchloric acid lasted about 40 minutes.

The mixture was cooled and distilled water added to obtain a volume of 250 ml, contents mixed and filtered through Whatman No. 1 filter paper. About 5 ml of the sample digest was pipetted into a 50 ml volumetric flask, 10 ml ammonium-vanadomolybdate reagent added, and diluted to volume with DI water. A blank was made with ten ml of ammonium-vanadomolybdate reagent was used to make the blank, and preceded as for the samples. Standards, absorbance of blank and samples were read after 10 minutes. A calibration curve was prepared for standards, plotting absorbance against the respective P concentrations.

v. Potassium

The method used was flame photometer (Ryan *et al*., 2001) whereby a neutral salt solution replaced cations present on the soil exchange complex. Air-dry 5 g soil (< 2 mm) was weighed into a 50 ml centrifuge tube, 33 ml ammonium acetate solution added, and shaken for 5 minutes on a shaker. The tubes were fitted with a clean rubber stopper and centrifuged until the supernatant was clear and the extract collected in a 100 ml volumetric flask through a filter paper to exclude any soil particles. The process was repeated two more times and extract collected each time. Hundred ml with 1 N ammonium acetate solution was diluted to the combined ammonium acetate extracts. Standards were run for the suitable potassium and a calibration curve drawn.

vi. Extractable nutrients (Ca, Mg, Mn, Cu, Fe, Zn, and Na)

The Diethylenetriamine Pentaacetic Acid (DTPA) method as described by Lindsay and Norvell (1978) was used. Ten gram soil samples were mixed with 20 ml DTPA (0.005 M,

adjusted to pH 7.3 with Triethanolamine), then shaken for 2 hours before filtering. The micronutrients were then measured with an AAS (Atomic Absorption Spectrophotometer).

vii. Electrical Conductivity (EC)

Soil samples weighing 50-g were placed in a 100-ml disposable plastic cups; 50 ml of deionized water was added to each. The slurry was shaken on a reciprocating shaker for 45 minutes, and then filtered. Electrical conductivity of the filtrate was then read with a conductivity bridge (Beckman RC 1682 model).

3.5 Data Collection

Data was collected as described according to the descriptors for finger millet (IBPGR, 1985).

3.5.1 Growth parameters

i. Planting date and days to emergence

The planting date was recorded and when 75% of the crop was visually observed to have emerged from the soil the phenological stage of days to emergence was recorded.

ii. Stand vigor

The crop was visually observed at 3 weeks after emergence on its vigor and scored on a scale of 1-5; 1 for the most vigorous, 2 for vigorous, 3 for intermediate, 4 for poor and 5 for very poor.

iii. Plant Height

The plant height was measured using a standard ruler from the stem base to the top node where the leaves segregate. Six plants were tagged and atleast 5 plants were measured and the average recorded after every 2 weeks till dough stage and at harvesting.

iv. Leaf blade length

The leaf blade length of 5 plants of the 6 tagged plants was measured from the ligule to tip and the average recorded on the 4th leaf from the top (flag leaf) after every 4 weeks. Leaf area was measured using an L-2000 plant canopy analyzer (CI-203 portable) that measured the leaf areas on each plot and the average was recorded.

v. Number of leaves

The number of leaves on main tiller of the 5 tagged plants was counted and average recorded after 4 weeks of planting and at dough stage.

vi. Stand count

The total number of plants on the three centre rows was counted and recorded after thinning and at harvesting.

vii. Number of basal tillers

The average number of basal tillers on five plants from every plot in the middle rows was counted and average recorded at dough stage.

viii. Number of aerial tillers

The total number of aerial tillers in every plot was counted and recorded at 10 weeks after planting and at harvesting.

ix. Days to 50% flowering

The date of flowering on every plot was carefully observed and recorded when 50 % of the heads had flowered.

x. Days to maturity

The calendar date when 90% of the heads were observed to be brown or if the seeds did not crash between the fingers for each plot was recorded.

xi. Lodging

The number of lodged plants were counted and from the middle rows from every plot and recorded.

xii. Productive aerial tillers

The total number of aerial tillers that had harvestable heads were counted in every plot on the middle rows and recorded.

xiii. Productive basal tillers

The average number of basal tillers with harvestable panicles on 5 plants from every plot were counted and recorded.

xiv. Finger width

The average width was recorded after measuring across the centre of 5 longest fingers of the main tillers on the tagged plants from every plot using a standard ruler at dough stage.

xv. Finger Length

The average length was recorded after measuring the longest spike (finger) from base to tip of 5 main tillers from every plot on tagged plants using a standard ruler at dough stage.

3.5.2 Yield parameters

i. Number of harvested panicles

The total number of panicles harvested from each net plot was counted and recorded.

ii. Number of fingers per panicle

The number of fingers on 5 main ear panicles from each plot was counted and the average recorded.

iii. Number of grain per spikelet

The average number of grains on 5 spikelets was recorded after the spikelets had been carefully removed from the finger and counted. Four grains or less were considered low, 5-7 were considered intermediate and above 8 as high.

iv. Biomass Fresh weight

Immediately after harvesting, the above ground biomass was cut and the fresh weight of the panicles and straw were weighed using an Avery scale (Tronix-model) and recorded for every plot. The total fresh biomass was calculated from the sum of both.

v. Total dry biomass

The straw and panicles harvested were dried in the oven for 48 hours at 70° C until a constant weight was achieved then measured for the dry straw weight and the dry panicle weight. The total dry weights were taken as the sum of both.

vi. 1000-grain weight (g)

One thousand grains for each experimental unit were counted using the Elmo-C1 STE-10A model seed counter then weighed using a digital Avery (Tronix-model) scale and recorded.

vii. Grain yield (g)

The grain yield from the net plot of every experimental unit was weighed on an Avery scale (Tronix-model) and recorded at 13.5% moisture content.

viii. Threshing %

The threshability of panicles from each net plot was calculated by taking the grain yield weight divided by the dry panicle weight, then converted into a percentage by multiplying by 100.

ix. Grain yield (t/ha)

This was extrapolated by taking the grain yield representing net area of the harvest of $3m^2$ and equating it to a hectare which is $10,000m^2$ where:

Grain yield (t/ha) = [Grain yield (g) × $10,000m^2/3m^2$]/100, 0000

3.5.3 Nitrogen uptake and Partitioning

Nitrogen uptake was calculated from soil mineral N content (NO_3-N and NH_4^+-N) difference before planting and at harvest and total N in the plant parts. Since most of mineral N measured in the study was in the form of NO_3-N and NH^+_4-N that might have been lost through denitrification, nitrification, leaching and N from mineralization of organic matter was assumed to be constant and thus the available soil N was based on the N uptake in the plant parts and soil N balances.

Five plant samples from each experimental unit were dug out by a shovel at physiological maturity. All visible root tissues were collected from the soil. Plants were washed free of soil and separated into leaf, root, stem and panicle. Before grinding and passing on a 2-mm sieve with a Wiley mill, the samples were placed in a draft oven at 55°C for at least 12 hours Weights of 0.50-g samples were dry-ashed in porcelain crucible for 4–6 hours at 500°C in a muffle furnace. In case the ashing was judged incomplete, then the ash was cooled, dissolved in 1 M nitric acid, evaporated to dryness, then ashed again for 1 hour. The residue was then dissolved in 25 ml of 1 M hydrochloric acid.

A 0.250-g sample of ground tissue was mixed with 2 g of Na_2SO_4 and 7 ml of digestion mixture of concentrated sulphuric acid, salicylic acid, and selenium. After 2 hours, 3–4 drops of sodium thiosulfate solution was added. The mixture was allowed to stand for 45 minutes, and 4ml of 30% hydrogen peroxide was added. Digestion of the mixture at 410°C was done until a clear liquid was obtained after around 45 minutes. The liquid was cooled, and then diluted with water. Nitrogen % in the solution was measured colorimetrically by an auto-analyzer.

To evaluate partitioning, the N contents measured in the plant components: stem; leaf; root; and panicle at physiological maturity was divided by the total amount of N in the whole plant then converted to percentage by being multiplied by 100. Nitrogen uptake in plant parts was estimated by multiplying the nutrients' concentration accumulated in all tissues and the amount of total dry matter accumulation.

3.5.4 Grain Quality Parameters

Representative samples of 250 g grain from each experimental unit were taken and analyzed for the nutrient contents. This represented the quality of the grain. The following procedures were undertaken:

i. Protein content analysis

Nitrogen concentration was converted into protein by multiplying it with the protein factor 6.25 (N×6.25). Defatted samples were taken for the estimation.

ii. Tissue Nitrogen determination

Nitrogen content was determined following the Micro Kjeldahl method described in AOAC (2007).

iii. Tissue Phosphorus determination

Tissue phosphorus was determined by the Colorimetric method following the procedure as described by the AOAC (2007) after being extracted using the wet oxidation method.

iv. Extractable nutrients

Analyses for grain potassium content (%), grain calcium content (%), grain magnesium content (%), grain iron content (DW%), grain manganese content (mg//kg), grain copper content (mg/kg), and grain zinc content (mg/kg) were done on the ash solution, using an ICP spectrophotometer. The procedure is described by Jones and Case (1990).

3.6 Statistical analyses

Data collected were compiled, cleaned and tabulated for statistical analysis. Two-way analysis of variance (ANOVA) using GenStat 15.1 Version (2015) was used to test levels of significance due to treatments and their interactions. Where there were significant differences, Fischer's Protected LSD tests were performed to separate the treatment means at 5% probability level. Correlation and regression analyses were carried out to estimate the associations between the variables.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Influence of phosphorus and variety on growth of finger millet

The stand vigor, stand count, plant height, leaf blade length, number of leaves, leaf area, days to 50% flowering, days to maturity and lodging parameters were significantly influenced ($P \leq 0.05$) by phosphate rates for the two seasons in Kakamega and Alupe but otherwise in Kiboko due to optimal availability of P in the study soils (Table 4.15) while varieties responded differently across the sites. Interaction between variety and phosphorus were revealed in the stand vigor, leaf blade length and lodging.

4.1.1 Days to emergence

The days to emergence did not differ significantly due to the P treatments and variety for both seasons in all sites as shown on Table 4.1. The shortest days to emergence were observed in Alupe in the short rain season with 6 days while the longest period was during the long rain season in Alupe and short rain season in Kakamega with 14 days.

Table 4.1. Varietal and phosphate rates influence on the days to emergence

Kg ha^{-1} P_2O_5	Days to Emergence					
	Kiboko		Kakamega		Alupe	
	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
Control	5a	5a	14a	8a	6a	14a
12.5	5a	5a	14a	8a	6a	14a
25.0	5a	5a	14a	8a	6a	14a
37.5	5a	5a	14a	8a	6a	14a
Variety						
U-15	5a	5a	14a	8a	6a	14a
P-224	5a	5a	14a	8a	6a	14a
L. Variety	5a	5a	14a	8a	6a	14a
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
PR×V	NS	NS	NS	NS	NS	NS

†Values with the same letter(s) within the column are not significantly different

The long rain season in Kakamega took 8 days for the crop to emerge while during the short rain season it took 14 days. In Alupe, it took 6 days for the crop to emerge during the short rain and 14 days during the long rain cropping season. This was majorly due to the rainfall regimes experienced in the different sites for the different seasons as shown in Appendices 1, 2 and 3. Kiboko had a stable irrigation regime that led to the number of days to emergence of the crop to be standard while Kakamega and Alupe depended on rainfall which led to longer period to emergence in case of inadequate rainfall and on the other hand heavy rainfall led to compaction of soil making emergence of the germinating plant slow and hard. The interaction between variety and phosphate fertilizer rates did not significantly influence the days to emergence of finger millet. The indifference in the days to emergence is probably because during germination, seedlings mostly depend on stored food than on external nutrient supplement. This is in conformity with finding of Shrivasta and Solanki (1994) who reported that plants depends mostly on stored food than on external nutrients for germination. It has also been reported by White and Veneklaas

(2012) that cereals have large P reserves enough to sustain seedling requirement of P during few weeks of early growth. Grains with higher indigenous P reserves can support seedling growth for a longer period of time (Nadeem *et al.*, 2012a) especially on soils with low inherent P levels. This can also be due to the uniform seed rate and availability of optimum moisture conditions across all the treatments. These findings are in tandem with those of Rubailhayo *et al.* (2000), who found uniform emergence m^{-2} with optimum moisture availability in sorghum.

4.1.2 Stand vigor

Significant differences ($P \leq 0.05$) were observed in Kakamega and Alupe on the stand vigor for both seasons due to phosphate rates whereas in Kiboko there were no significant differences because of the optimal availability of P in the soils. The greatest vigor was observed on the highest rate of 37.5 kg ha^{-1} P_2O_5 in both seasons for the two sites of Alupe and Kakamega in Western Kenya (Table 4.2).

Table 4.2. Influence of phosphorus and variety on the stand vigor of finger millet in three sites

Variety	Stand Vigor					
	Kiboko		Kakamega		Alupe	
	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
U-15	3.58a	2.58a	2.75b	2.75c	2.08a	3.00a
P-224	3.58a	3.25a	3.33ab	3.75a	2.58a	3.17a
L. Variety	3.50a	3.00a	3.92a	3.25b	2.33a	2.67a
$LSD_{0.05}$	NS	NS	0.718	0.396	NS	NS
CV%	21.7	30.1	36.4	14.4	36.5	26.9

Kg ha^{-1} P_2O_5	Stand Vigor					
	Kiboko		Kakamega		Alupe	
	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR

Control	3.67a	3.00a	2.78a	3.44a	3.33a	3.44a
12.5	3.67a	2.89a	2.44a	3.56a	2.22b	2.67ab
25.0	3.44a	3.00a	2.44a	3.11a	1.89b	3.56a
37.5	3.44a	2.89a	1.67b	2.89b	1.89b	2.11b
$LSD_{0.05}$	NS	NS	0.829	0.458	0.834	0.774
CV%	21.7	30.1	36.4	14.4	36.5	26.9

†Values with the same letter(s) within the column are not significantly different

Deficiency of P has been found to be one of the most important restrictive factor in plant growth and promotes root development that enhanced uptake of other essential elements (Alinajati and Mirshekari, 2011) and therefore the increased vigor in Kakamega and Alupe was due to optimal availability of phosphorus.

Plate 2: Phosphorus deficiency manifestation in Alupe (Left) and Kakamega (Right) on finger millet

Varietal differences ($P \leq 0.05$) were observed in Kakamega for both seasons where the improved variety, U-15 had greater vigor than the other varieties because of its ability to establish faster after emerging. The other sites did not indicate varietal differences on the

stand vigor in both seasons. Interactions were revealed between phosphate rates and varieties on vigor at Kakamega and Alupe sites for the long rains season where several interactions exhibited faster establishment while the interaction between P-224 and 37.5 kg ha^{-1} P_2O_5 consistently had the poorest vigor.

4.1.3 Stand Count

Significant differences were observed in Kakamega where the control had the lowest number of plants per net plot and in Alupe the highest rate of 37.5 kg ha^{-1} P_2O_5 had the lowest number of plants for both seasons at thinning (Figure 4.1). At harvesting, the control showed the lowest number of plants per plot indicating the greatest decrease from that of the number of plants recorded at thinning in Kakamega and Alupe for both seasons. The 25.0 kg ha^{-1} P_2O_5 treatment had a significantly higher number of plants per net plot during both seasons in Kakamega.

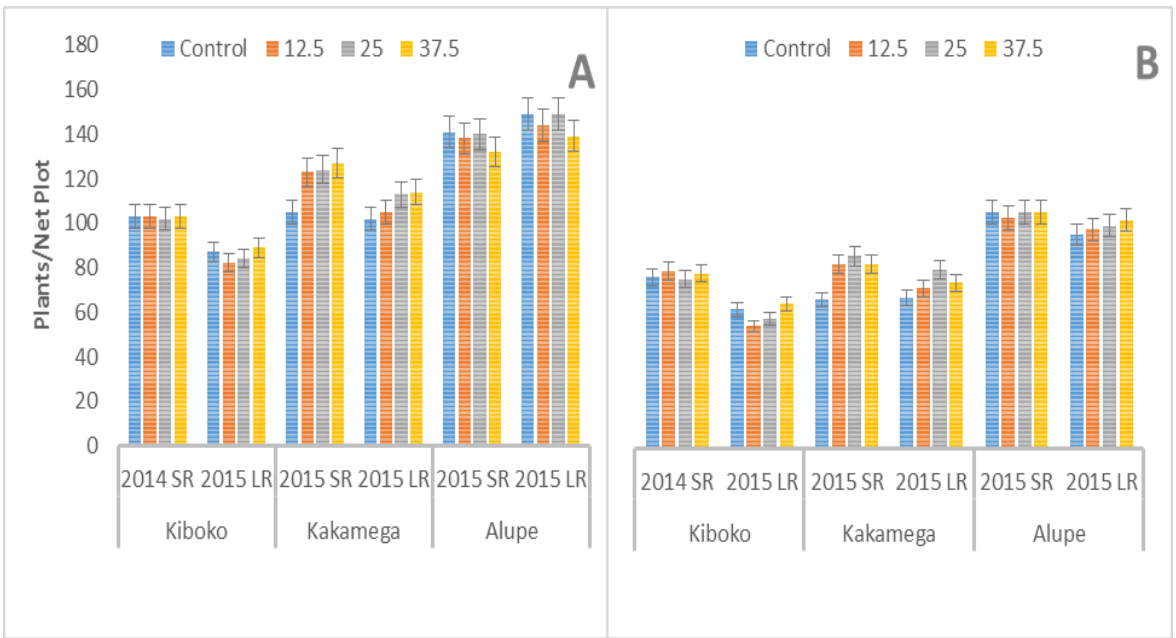

Figure 4.1. Stand counts in Kiboko, Kakamega, and Alupe after thinning (A) and at harvesting (B)

Phosphorus is important in crop establishment and that was observed on the control where poor establishment led to reduction in the plant count as the crop developed to maturity. Watanabe *et al*. (1965) and Millikan (1963) reported similar findings on toxic effect of excessive P. There was no P fertilizer effect or varietal differences ($P \leq 0.05$) at Kiboko site in both stages for both seasons on the stand count. This was due to the limited rainfall (Appendix 1) which may have interfered negatively with the solubility and uptake of phosphorus and optimal availability of P in the study site soils. This indicated that during the early development of the seedlings the crop did not depend upon the external nutrition added and established on the seed reserves as well as the optimal available phosphorus. At harvesting the stand count was insignificantly different for the P application rates and interaction but significant differences among the varieties where the local variety Ekalakala had the lowest plants while P-224 had the highest and U-15 being insignificantly different from the other varieties during the short rains.

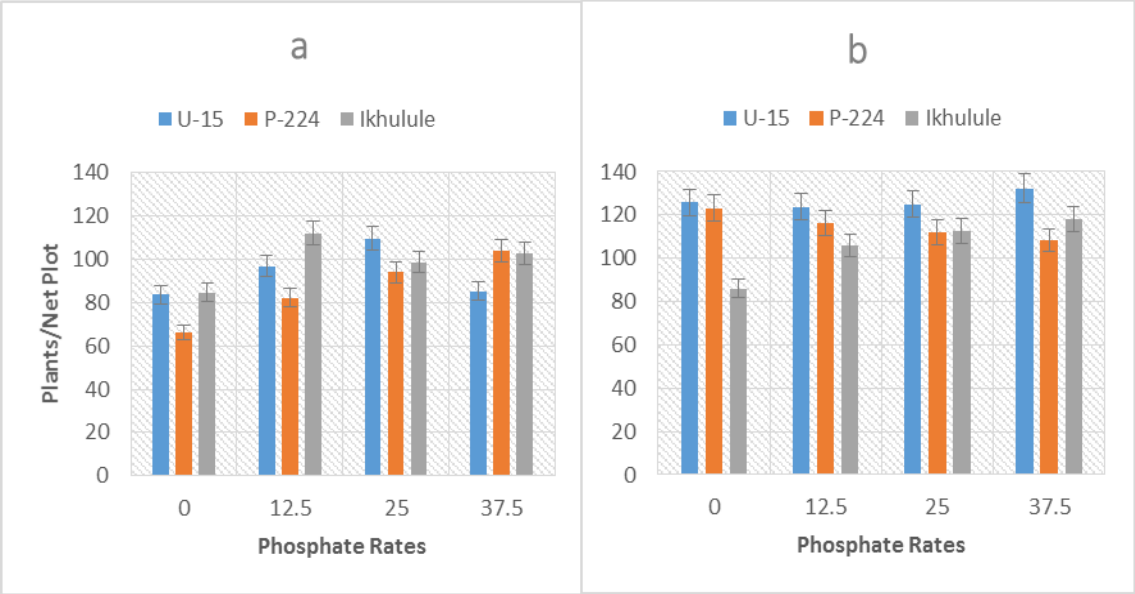

Figure 4.2. Varietal and P rate interaction on the stand count at thinning during the short rains in Kakamega (a), and at harvesting during the long rains in Alupe (b)

4.1.4 Plant Height

Phosphate rates significantly ($P \leq 0.05$) influence plant height at Kakamega and Alupe sites for both seasons where 25.0 kg ha^{-1} P_2O_5 treatment led to the greatest plant height (which is a measure of growth) during the reproductive stages, while 37.5 kg ha^{-1} P_2O_5 had the greatest in early vegetative stages. This may be the mechanism by plants to take up most P according to availability and most availability led to greater uptake during the crops establishment stage. The control elicited the lowest growth in terms of height for both sites in western Kenya. This is described on Figure 4.3, 4.4 and 4.5 below.

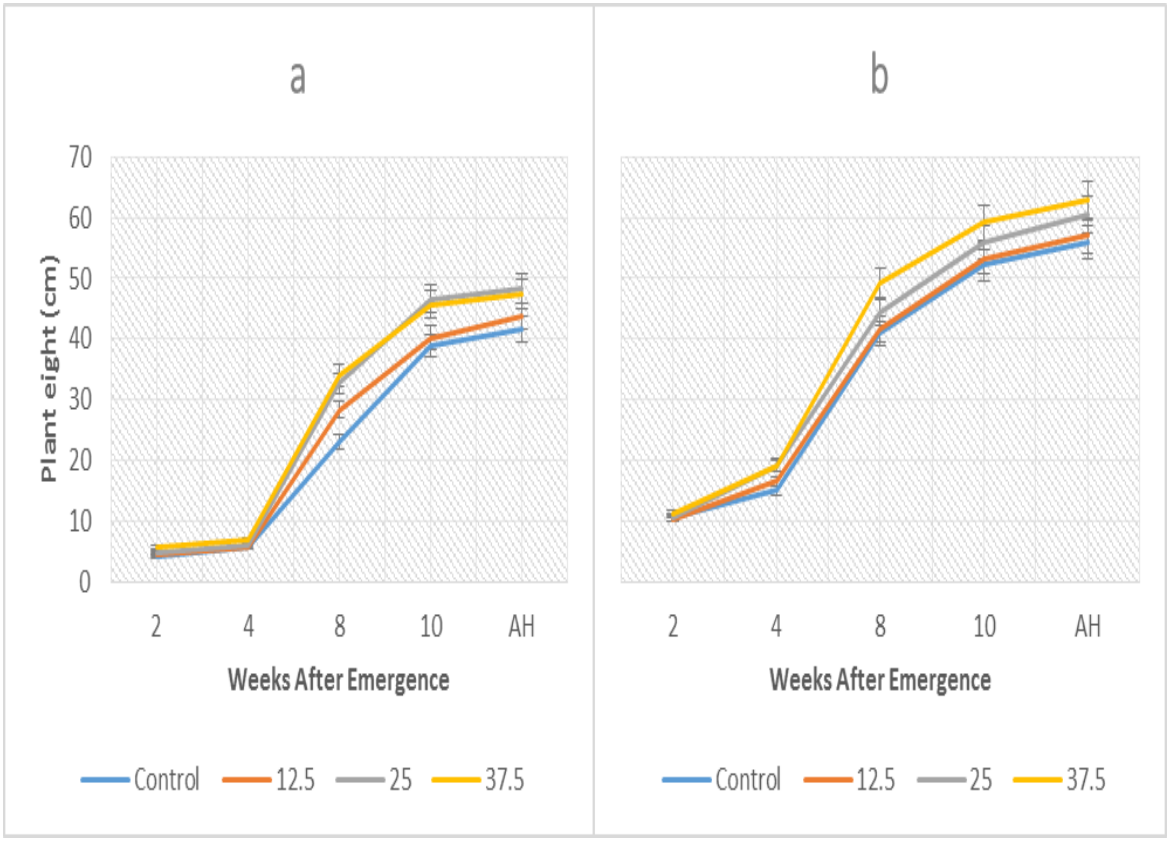

Figure 4.3. Influence of phosphate rates on height during the short rains (a) and long rains (b) in Kakamega

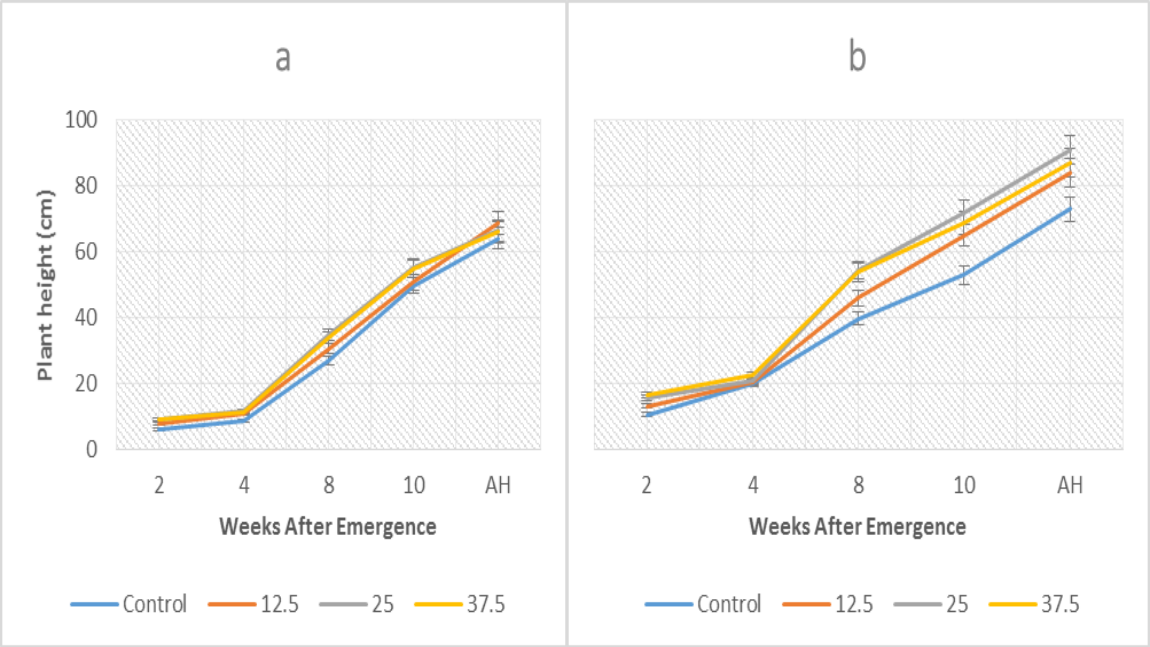

Figure 4.4. Influence of phosphate rates on plant height during the short rains (a) and long rains (b) in Alupe

Plate 3. Effect of phosphate rate application on the plant height in Kakamega between the control and 25.0 kg ha^{-1} P_2O_5

Phosphorus may have improved the root development which had a great effect on the plant height, probably due to advanced root system that increased nutrient absorption (Hussain *et al.*, 2006). Minimal varietal differences were observed on height during the early stages of growth but highly significant ($P \leq 0.05$) from 8 weeks after emergence onwards. The local variety, Ikhulule was tallest in western Kenya (Kakamega and Alupe) for both seasons at harvesting while U-15 was the shortest due to its early maturing characteristic and genetic makeup thus did not concentrate its nutrients for growth but rather for reproduction from dough stage (Figure 4.5). In another study by Khalid and Muhammad *et al*. (2003), similar results were reported where application of phosphorus fertilizer increased plant height gradually, stem diameter, number of leaves, leaf area and the total fodder yield (in two sorghum cultivars. The importance of P application was realized on the increase in the height in the P applied treatments over the control which could be due to the increase in the uptake efficiency of different crop varieties in terms of nutrients that likely contributed to increased plant height. These findings are in conformity with those of Okalebo and Probert (1992) and Sahoo and Panda (2001) who found significant increase in height of maize with P application over that of the control.

The phosphate fertilizer treatments did not show significant influence on the plant height at all stages for both seasons in Kiboko. These results are in accordance with findings by Majanbu *et al*. (1989), who observed that maize plant heights did not increase with increasing phosphorus levels due to optimum available P in the study sites. The varieties showed differences at ten weeks after emergence and at harvesting for both seasons while significant differences were observed during the long rains season at four and eight weeks after emergence.

At early stages of development, Ekalakala was the tallest and at later stages it was the same as P-224 during the later stages while U-15 was the shortest throughout.

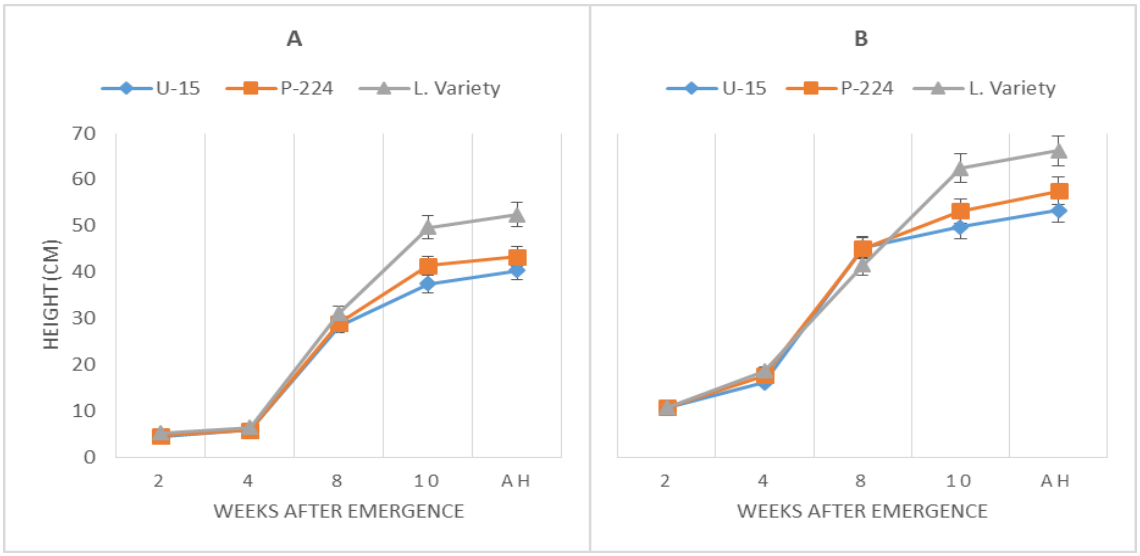

Figure 4.5. Influence of variety on height during the short (A) and long (B) rains in Kakamega

4.1.5 Leaf blade length

The leaf blade length had significant differences at P≤0.05 at Kakamega and Alupe due to phosphate rates at 2 weeks after emergence and at harvesting. Treatments without P showed the lowest blade length at all the stages of finger millet varieties with 25.0 kg ha^{-1} P_2O_5 and 37.5 kg ha^{-1} P_2O_5 having the longest in Kakamega and Alupe respectively at both stages (Table 4.3). This might be due to the energy balance provided by P which enhanced photosynthesis which may have led to longer leaves which in turn increased the photosynthetic area of the crop. In Alupe, the greatest length was realized at 25.0 kg ha^{-1} P_2O_5 and further increase of P showed a drop while in Kakamega P supply at 37.5 kg ha^{-1} P_2O_5 there was still leaf elongation in both seasons at all stages of sampling. Phosphate rates did not prompt significant effects on the leaf blade length at all the stages at Kiboko.

The varieties did not differ significantly on the leaf length at two weeks after emergence (WAE) for both seasons except in Kakamega during the short rain season. However, this differed at physiological maturity (12 WAE) for both seasons in Kiboko. Variety P-224 had the longest leaves at eight weeks after emergence (8 WAE) and at physiological maturity for both seasons in Kiboko. The interactions were observed on the leaf length during the short rains in Kiboko at eight weeks after emergence (8 WAE), with P-224 variety receiving P at 37.5 kg ha^{-1} P_2O_5 and showing the greatest blade length of 53 cm.

Table 4.3. Effect of phosphorus fertilizer and variety on leaf blade length at two weeks after emergence (2 WAE) and 12 weeks after emergence (12 WAE)

	Leaf Blade Length (cm)											
Kg ha^{-1} P_2O_5	**2 WAE**						**12 WAE**					
	Kiboko		**Kakamega**		**Alupe**		**Kiboko**		**Kakamega**		**Alupe**	
	2014 SR	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	**2015 LR**	**2014 SR**	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	**2015 LR**
Control	10.6a	9.2a	12.6b	11.3ab	36.8c	14.6b	47.7a	45.7a	38.8b	46.3b	53.8a	52.7b
12.5	12.78a	8.9a	14.4b	10.5b	39.8b	19.5a	47.9a	46.1a	42.1a	48.8ab	54.3a	55.3ab
25.0	10.89a	8.5a	14.3b	11.2ab	44.6a	23.2a	48.3a	49.2a	42.7a	49.2a	54.1a	58.0a
37.5	12.44a	10a	18.0a	11.7a	42.1a	22.5a	49.0a	49.3a	43.8a	51.4a	53.3a	57.6a
$LSD_{0.05}$	NS	NS	1.70	0.94	3.29	2.79	NS	NS	4.19	3.16	NS	2.35
Variety												
U-15	11.5a	9.0a	13.4b	11.1a	40.8a	20.6a	51.6b	47.5ab	40.9a	48.5a	54.2a	55.2a
P-224	11.1a	10.0a	15.5a	11.2a	41.2a	20.2a	54.2a	49.5a	42.6a	48.8a	55.1a	56.8a
L. Variety	12.4a	8.5a	15.8a	11.2a	40.5a	19.1a	50.3b	45.8b	42.0a	49.5a	52.3a	55.8a
$LSD_{0.05}$	NS	NS	1.48	NS	NS	NS	1.93	2.85	NS	NS	NS	NS
CV%	31.7	18.6	11.7	8.6	8.3	14.3	4.6	7.1	10.3	6.6	9	4.3

†Values with different letter(s) within a column are significantly different

Similar findings were reported by Payne (1990) that P fertilizer increased the leaf length of rice. It has also been found that when the hydraulic conductivity reduces in the root and

decrease in stomatal conductance of the leaf, they cause severe reduction of leaf expansion under P-deficiency (Clarkson *et al*., 2000). The leaf blade length elongation was lowest in the controls at all sites. This was due to the reduced supply of P compared to the other treatments leading to low energy support in the plant. This result is supported by a study by Plenet *et al.* (2000) who found that low biomass accumulation was mainly due to the effect of P deficiency on leaf growth.

4.1.6 Number of leaves

Positive responses were observed in the number of leaves per plant due to application of phosphorus at Kakamega and Alupe sites at 2 weeks after emergence and also at harvesting as shown in Table 4.4. Increasing P rates increased the number of leaves upto 25.0 kg ha^{-1} P_2O_5 where it tailed off.

Table 4.4. Effect of phosphate rates and variety on number of leaves per plant at 2 WAE (Weeks after emergence) and at harvesting

Kg ha^{-1} P_2O_5	**Number of Leaves per plant**											
	2 WAE						**At Harvesting**					
	Kiboko		**Kakamega**		**Alupe**		**Kiboko**		**Kakamega**		**Alupe**	
	2014	**2015**	**2015**	**2015**	**2015**	**2015**	**2014**	**2015**	**2015**	**2015**	**2015**	**2015**
	SR	**LR**	**SR**	**LR**	**SR**	**LR**	**SR**	**LR**	**SR**	**LR**	**SR**	**LR**
Control	6a	7a	5c	6a	11b	7b	13a	13b	12a	12c	16a	14b
12.5	6a	7a	6b	6a	12a	8a	13a	13b	12a	12c	16a	15ab
25.0	6a	7a	6b	6a	12a	8a	13a	14a	12a	14a	16a	16a
37.5	6a	7a	7a	6a	12a	8a	13a	14a	12a	13b	16a	16a
$LSD_{0.05}$	NS	NS	0.44	NS	0.92	0.71	NS	0.74	NS	1.03	NS	0.80
Variety												
U-15	6a	6b	6a	6a	12a	7a	13b	13b	11b	13a	15b	15b
P-224	6a	7a	6a	6a	12a	7a	14a	15a	12a	13a	17a	15ab
L. Var.	6a	7a	6a	6a	11b	7a	13b	14b	12a	13a	17a	16a
$LSD_{0.05}$	NS	0.48	NS	NS	0.80	NS	0.93	0.75	0.70	NS	0.59	0.70
CV%	13.2	8.3	7.4	3.9	8.2	9.9	8.3	6.5	7.1	9.0	1.2	5.7

†Values with the same letters within the column are not significantly different

The varieties elicited differences on the number of leaves at harvesting for both seasons in Kiboko and Alupe. Variety P-224 had the highest number of leaves per plant during both

seasons at the two stages in Kiboko while P-224 and Ikhulule showed the highest leaf number per plant in Alupe and Kakamega. There were no significant interactions between the phosphate rates and varieties on the number of leaves per plant at all the sampling stages for both seasons in all the locations.

The increment in the number of leaves was probably due to the importance of phosphorus in cell division activity, leading to an increase in leaf number where optimal P was applied. This conforms to findings by Tesfaye *et al.* (2007) who studied P stress in legumes. The number of leaves per plant differed ($P \leq 0.05$) at harvesting during the long rain season in Kiboko. The phosphate rates did not influence the number of leaves per plant on the two stages for each season in each site at harvesting. This could be due to the plants mechanism to switch from using most of its energy for vegetative development and redirecting it to the reproductive organs development. This result is similar to those reported by Birhan (2006), who illustrated a non-significant response of leaf number to P application in common bean. The decrease in leaf number and size is one of the earliest and most reliable responses of plants to P-deficiency (Lynch *et al*., 1991). This is so because leaf expansion occurs due to the multiplication of cells and elongation of the newly formed cells where P plays a crucial role in supplying the energy as well as enhancing the turgor pressure which is important in the cycle (Hsiao, 1973; Munns *et al*., 2000).

4.1.7 Leaf area

The leaf area increased significantly ($P \leq 0.05$) between eight weeks after emergence (WAE) and at harvesting during the long rain season in Kakamega with no significant differences observed between the treatments at the other sites for both seasons. Phosphorus

application influenced the leaf area only during the long rains season in Kakamega with 37.5 kg ha^{-1} P_2O_5 showing the highest (51.56 cm^2) leaf area (Figure 4.6).

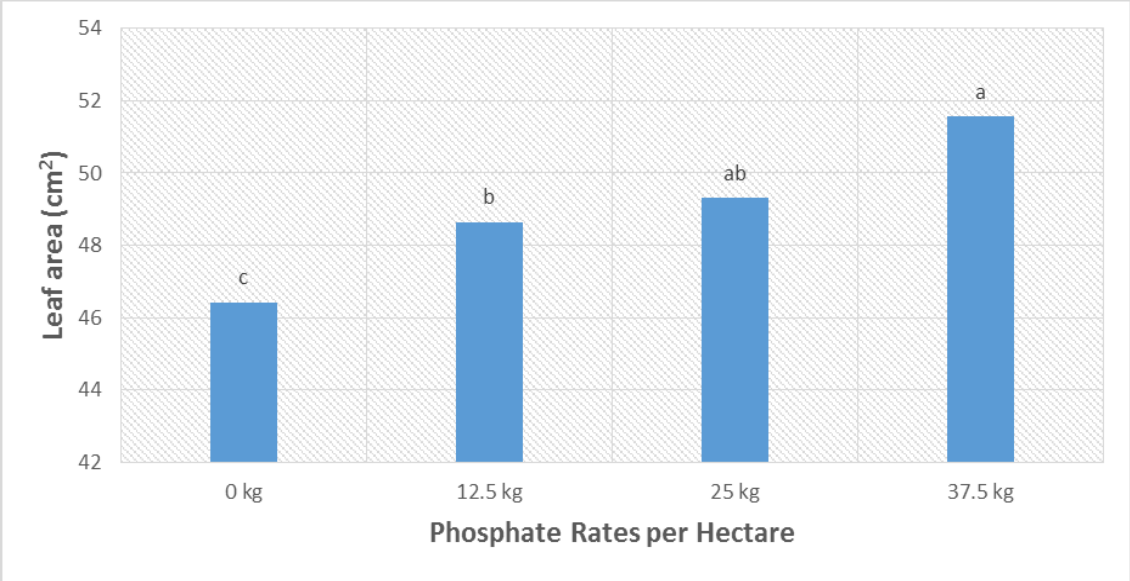

Figure 4.6. Effect of phosphate rates on the leaf area in Kakamega during the long rains

Similarly, Veeresh (2003) found significant increase in leaf area with increment in P application. However, for the current experiment, the control had the lowest leaf area at all sites except in Kiboko compared to those treated with P, this might be due to P response which depended on the amount of available P in the study site. The leaf area of the varieties differed significantly with P-224 showing the largest leaf area in Kiboko and Kakamega at 8 weeks after emergence during the long rain seasons. Increase in the leaf area in the P-applied plots over the zero P control plots has been reported by Sahoo and Panda (2001) and Okalebo and Probert (1992) in maize. Moreover, application of DAP leading to increase in maize leaf area had also been earlier reported by Singh (1984) which are contrary to the findings of the study at Kiboko, probably due to the availability of adequate P in the study soils.

4.1.8 Days to 50% flowering

The days to 50% flowering were significantly different (P≤0.05) among the P application rates in Kakamega and Alupe for both seasons as shown on Table 4.5. The shortest period to flowering was observed with the application of 25.0 kg ha^{-1} P_2O_5 treatment while the longest period was on the control.

Table 4.5. Influence of phosphorus fertilizer and variety on the days to 50% flowering

Kg ha^{-1} P_2O_5	**Days to 50% Flowering**					
	Kiboko		**Kakamega**		**Alupe**	
	2014 SR	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	**2015 LR**
Control	78a	62a	98a	82a	77a	76a
12.5	78a	63a	96b	82a	72b	72b
25.0	77a	62a	94c	79b	72b	70c
37.5	77a	62a	93c	82a	72b	71ab
$LSD_{0.05}$	NS	NS	2.50	2.99	2.29	1.40
Variety						
U-15	76b	61b	92c	75c	67c	66c
P-224	82a	68a	96b	82b	75b	73b
L. Variety	74c	59c	98a	87a	78a	78a
$LSD_{0.05}$	1.13	1.46	2.16	2.59	1.98	1.20
CV%	1.70	2.80	2.70	3.80	3.20	1.90
PR×V	NS	NS	NS	NS	NS	NS

†Values with the same letters within the column are not significantly different

This observed difference between control and 25 kg ha^{-1} P_2O_5 could be due to the high energy level supplemented by optimum P for reproduction which placed a high energy demand on the plant while delayed flowering due to low energy levels produced by the crops in the case of the control. This was in agreement with the findings of Panhawar and Othman (2011) which seem to suggest that phosphorus promoted root growth, tillering in cereals, and earliness in flowering and performed important functions like metabolic activities in particular synthesis of protein.

The varieties had a significant effect (P≤0.05) on flowering days in all the sites for both seasons. The local check in Kiboko, Ekalakala took the shortest period to flower and was

followed by U-15 and finally P-224 in both seasons. In western Kenya, U-15 took the fewest days to flower followed by P-224 while the local variety, Ikhulule took the longest period to flower. This trend was observed in both seasons. This could be due to the genetic make-up of the varieties to mature early while others late (Bendale *et al.,* 2002). There were no interactions between the phosphate levels and varieties in both sites for both seasons on days to 50% flowering.

4.1.9 Days to maturity

There were significant differences ($P \leq 0.05$) on the days to maturity as influenced by phosphorus application levels (Table 4.6). Treatments with P had the shortest maturation periods compared to the controls in Kakamega and Alupe while in Kiboko there were no significant differences, which could be due to the optimal P in the calcareous soils. Varietal differences were observed at all sites for both seasons with the local variety, Ekalakala taking the shortest period to mature with a mean of 101 days during the short rain and 100 days during the long rain cropping season in Kiboko. Improved variety, U-15 matured the earliest at Kakamega and Alupe sites during both seasons (Table 4.6). Maturity in finger millet is a genetic character of a given variety but its potential can be achieved under adequate crop management as is in this findings (Bendale *et al*., 2002).

Table 4.6. Varietal and phosphate fertilizer effect on days to maturity

Kg ha^{-1} P_2O_5	Days to Maturity					
	Kiboko		Kakamega		Alupe	
	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
Control	103a	103a	140a	121a	120a	117a
12.5	103a	103a	133b	120ab	116b	115ab
25.0	103a	102a	129b	119b	117b	114b
37.5	103a	103a	130b	119ab	116b	114b
$LSD_{0.05}$	NS	NS	8.07	1.83	3.09	2.31
Variety						
U-15	103b	103b	123b	115c	110b	108b
P-224	105a	106a	137a	120b	121a	119a
L. Variety	101c	100c	138a	125a	122a	120a
$LSD_{0.05}$	0.83	1.73	6.99	1.59	2.67	0.96
CV%	1.00	2.00	6.20	1.60	2.70	2.00
PR×V	NS	NS	NS	NS	NS	NS

†Values with the same letters within the column are not significantly different

Phosphorus is an important component in many physiological activities that occur within developing and maturing plants where it is involved in various enzymatic reactions in the crop. Phosphorus is a constituent element of nucleoproteins essential for cell division and cell reproduction processes (Brady and Weil, 2002). Phosphorus is also essential in the reactions of carbohydrate synthesis and degradation as a chemical component. Seed and fruit formation and crop maturation are also highly dependent on the phosphorus supply. Research conducted in Oklahoma showed that P speeds maturity of wheat by as much as 4-7 days and similar results were observed in Kansas and Texas (Potash and Phosphate Institute, 1999). The role of P as a plant nutrient is manifested in its usefulness effect on flowering, seed formation and maturation and deficiency of P results in a delay in maturity (FAO, 1984).

4.1.10 Effect of phosphorus and variety on lodging

Varietal differences were observed on the lodging count per plot in Western Kenyan sites where P-224 had the highest number of lodged plants at Kakamega site for both seasons

while Ikhulule showed the highest lodging in Alupe on the P-applied treatments (Appendix 4). Interactions between the phosphate rates and varieties were revealed on the lodging count at Alupe and Kakamega during the long rain seasons where the highest rate and the local variety, Ikhulule had the highest number of lodging per plot in Kakamega, while the highest lodging was observed with P-224 at the highest fertilizer rate at Alupe (Appendix 4).

Lodging has been considered as a major yield limiting factor in finger millet production where it has a potential to slow harvest, and to reduce yield and quality (Oduori, 2005). Significant differences ($P \leq 0.05$) were observed on the lodging count per plot due to phosphate rates in Kakamega during the long rains cropping season with highest rates showing the highest lodging. This agrees with the report that under optimal fertilizer application and an expected optimum fertilizer application, high incidences of lodging occurs (Oduori, 2005). Plant height is known to be positively correlated to lodging which makes the plant vulnerable to strong winds and rainfall as well as supporting its own weight and that is why the lowest lodging was recorded on the shorter variety, U-15. This agrees with Mohr *et al.* (2007) who found that higher lodging scores under fertilized conditions which were likely due to taller and/or denser plant stands and heavier panicle densities in oats. Another report in Tef concluded that the development of improved tef seed with semi-dwarf structure would increase lodging resistance and responsiveness towards fertilizer application (Esfeld *et al.,* 2009).

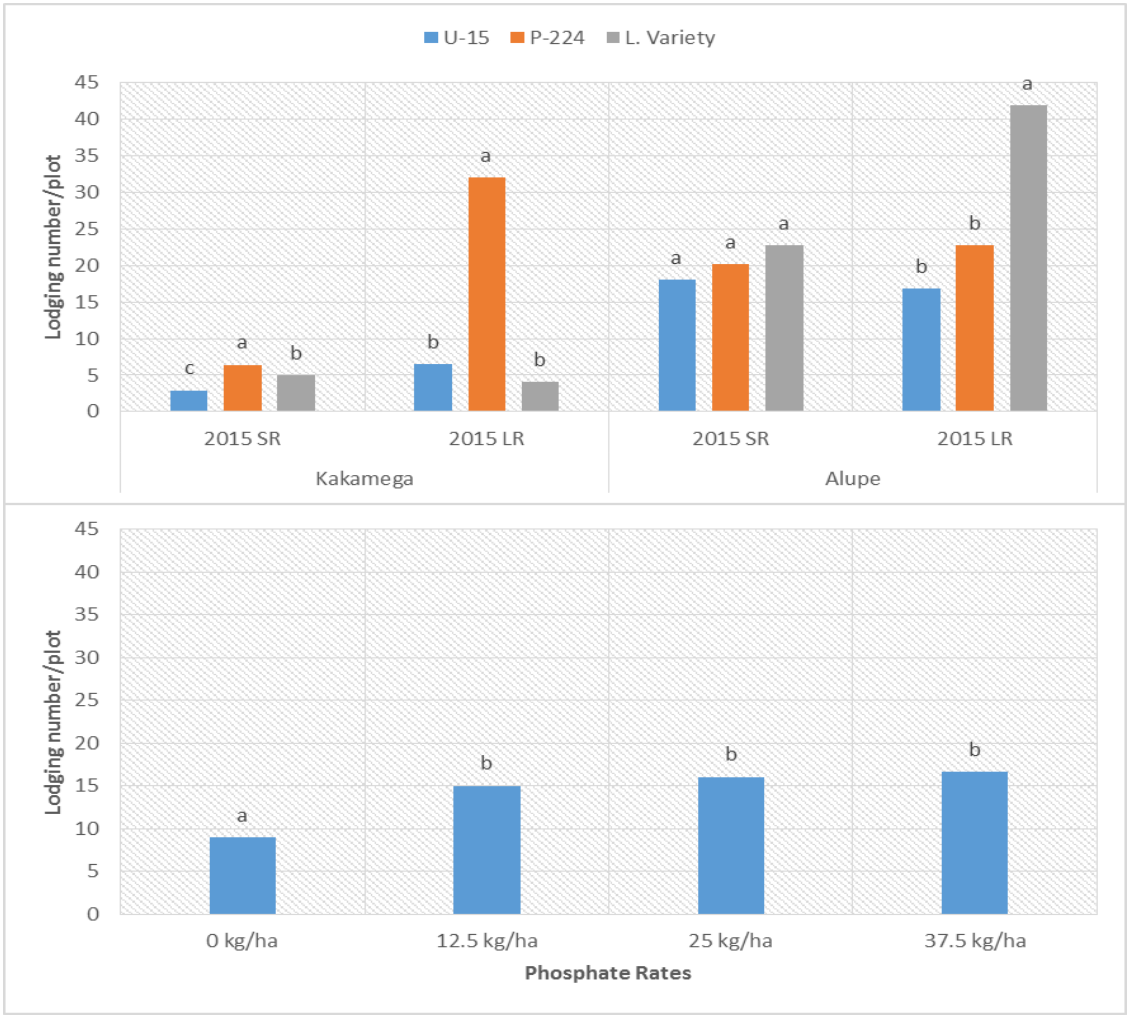

Figure 4.7. Varietal differences (top) in Kakamega and Alupe and phosphate rates differences (bottom) in Kakamega during the long rains on the lodging count

4.2 Yield Parameters

Yield and yield components were significantly influenced ($P \leq 0.05$) by phosphate rates in Kakamega and Alupe but only finger width showed significant response at Kiboko during the short rains, which could be due to optimal availability of P in the study soils while varieties responded differently across all the sites. Interaction between variety and phosphorus were revealed on grain yield, panicles harvested and panicle weight in Alupe, finger width and threshability in Kiboko, and finger width in Kakamega.

4.2.1 Tillers

The 25.0 kg ha^{-1} P_2O_5 rate of phosphorus application had the highest number of productive basal tillers for both seasons in Alupe and during the short rain seasons in Kakamega and Kiboko (Figure 4.8). On the other hand, significant differences were observed on the number of aerial tillers per plot with the control showing the lowest number, while 25.0 kg ha^{-1} P_2O_5 had the maximum number of aerial tillers at Kakamega site during the long rain and Alupe during the short rain seasons (Figure 4.8). The findings on tillering agree with those by Renu *et al.* (2005) which showed that the number of tillers per plant were more where phosphorus fertilizer was applied compared to no application in the case of wheat crop. The findings are in conformity with studies by Alam *et al*. (2005) who found a significant increase in the number of tillers per plant with the increase of Single Superphosphate level from 0 to 150 mg P kg^{-1} of soil. In another study, Alinajoata and Mirshekari (2011) reported that phosphorus was essential for tiller development and root growth in wheat. Chaturvedi (2005) concluded that the number of tillers in a given unit area is one of the most important components of yield whereby the more the number of tillers, the more the yield, especially fertile tillers in hybrid rice and concluded that reduced tillering is often a characteristic of P-deficient in small grains.

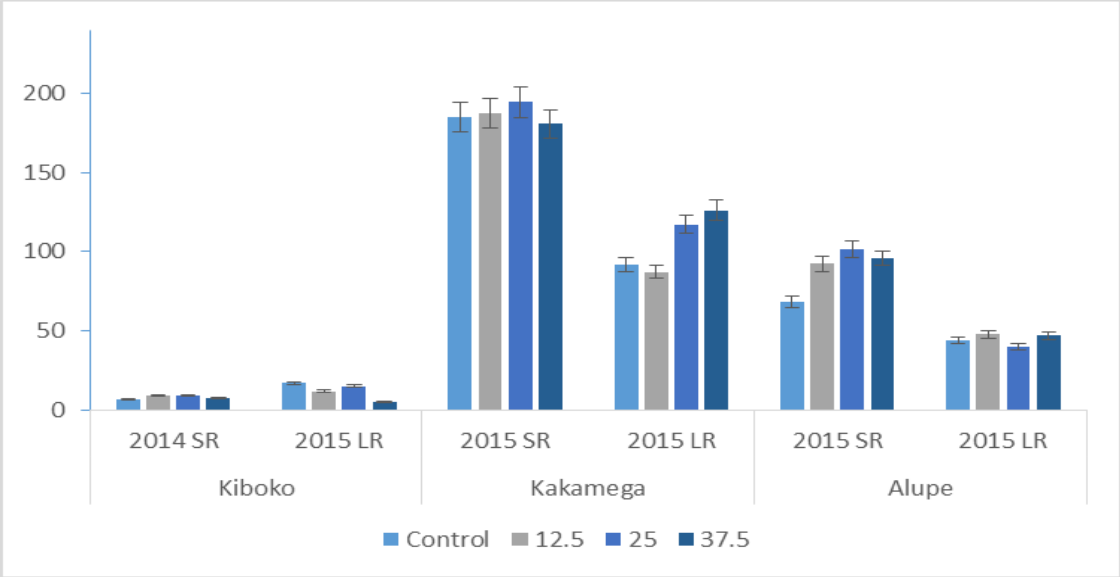

Figure 4.8. Varietal differences on the number of total aerial tillers per plot

The P-applied treatments exhibited significantly a higher number of aerial tillers compared to the control at Kakamega site during the long rain season and at Alupe site during the short rain season. Formation of aerial tillers is reported to be regulated through phytohormonal mechanism where the ratio of cytokinins produced in the root apices and auxins produced in the shoot apices had special significances (Langer *et al*., 1973). Increased cytokinin production and transport to the shoot enhances aerial tillering (Michael and Beringer, 1980) where P plays a pivotal role. This results are similar to the studies by Jamwal and Bhagat (2004) who reported significantly higher number of effective aerial tillers under plots with basal application of the recommended dose of DAP.

Plate 4. Basal tillering on main tiller at Kakamega for Ikhulule variety during the long rains season

Significantly higher effective basal tillers were observed with 25.0 kg ha^{-1} P_2O_5 treatment at Kakamega site during the short rain and at Alupe site for both seasons (Figure 4.9). At Kakamega, the 37.5 kg ha^{-1} P_2O_5 treatment had the lowest number of effective basal tillers during the long rain season implying that application of P beyond a certain threshold may lead to reduction of tillering.

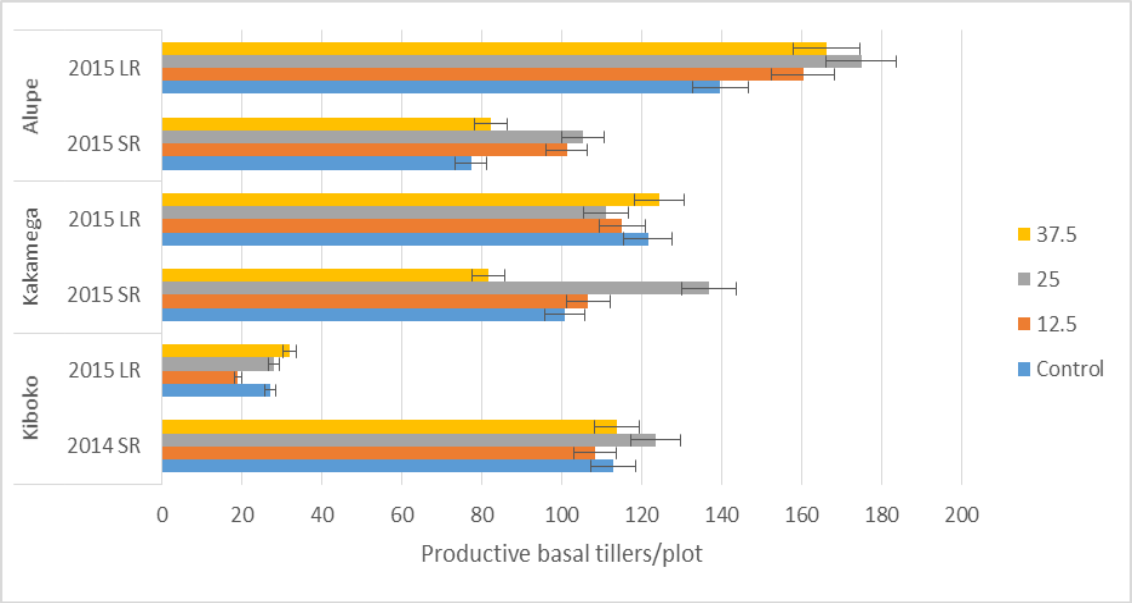

Figure 4.9. Effect of phosphate rates on total number of productive basal tillers per plot at Kiboko, Kakamega and Alupe sites during short and long rain (SR and LR respectively)

The reduction of tillers with increase in P might have been due the high interactive character of phosphate with other elements causing reduced translocation of other nutrients which is consistent with findings by Ogembo (2015) in African Nightshade. Similar tends where yield increased and then reduced with increase in P after reaching optimal level had been previously reported by a number of authors (Baon *et al.*, 1992; Bertrand *et al.*, 2003; and Glassop *et al.*, 2005). Application of phosphatic fertilizers is therefore suggested at early growth stages in order to support the lateral growth stages of crops to enhance productivity as per their given potentials (Glassop *et al.*, 2005). The long rain season in Kakamega showed differences among P treatments on the number of productive aerial tillers with 37.5 kg ha^{-1} P_2O_5 showing the highest number with 142 per net plot. The other seasons showed the lowest number of productive aerial tillers in the control but were not significantly different from the P treatments except in Alupe and Kiboko during the long rain season where 37.5 kg ha^{-1} P_2O_5 had the lowest.

The varieties showed differences in the number of productive basal tillers in all the sites (Figure 4.10).

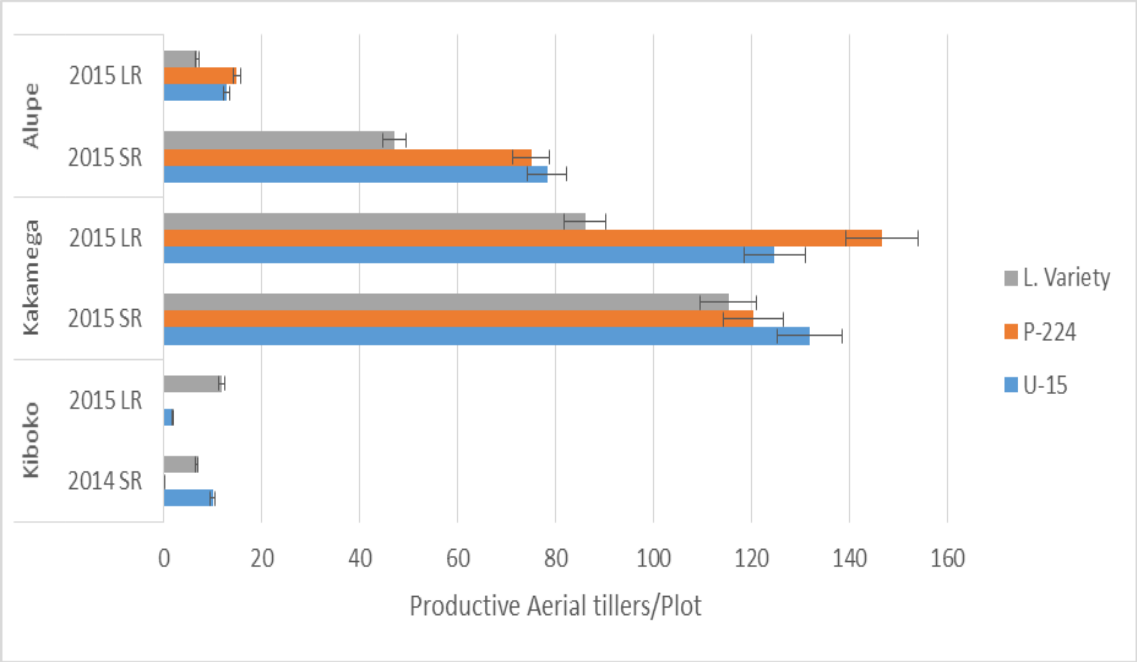

Figure 4.10. Varietal differences on the total number of productive aerial tillers per plot

U-15 and Ekalakala had the highest number during the short and long rain seasons respectively in Kiboko while P-224 had the highest number of productive aerial tillers in Alupe and Kakamega during the long rain seasons and U-15 during the short rain seasons though insignificantly different from P-224 (Figure 4.10).

4.2.2 Finger Length

Phosphorus application did not influence the finger length significantly in both seasons at all sites. On the other hand, the varieties significantly influenced the finger length during both seasons in all the sites with P-224 having the longest fingers in all the sites for both seasons.

Table 4.7. Varietal differences on the finger length and width at Kiboko, Kakamega and Alupe during the short and long rain seasons

Variety	Kiboko		Kakamega		Alupe	
	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
Finger Length (cm)						
U-15	8.3b	6.0b	6.6b	5.6b	8.4a	8.2b
P-224	9.0a	6.8a	7.3a	6.4a	8.5a	9.1a
Local Check	7.3c	6.4ab	6.3b	5.1b	6.9b	6.9c
$LSD_{0.05}$	0.51	0.49	0.56	0.45	0.86	0.44
CV%	7.3	9.1	9.8	10.0	12.8	6.4
Finger Width (cm)						
U-15	1.20a	0.90a	0.94b	0.98b	1.12a	1.01b
P-224	1.20a	0.94a	1.04a	1.10a	1.18a	1.15a
Local Check	1.20a	0.98a	0.99b	1.04b	1.08a	1.11a
$LSD_{0.05}$	NS	NS	0.05	0.08	NS	0.04
CV%	4.7	13.7	6.3	7.3	14.1	4.3

†Values with the same letters within the column are not significantly different

4.2.3 Finger width

The results revealed interactions between phosphorus and variety in terms of the finger width at Kiboko during the short rains and at Kakamega during the long rains. At Kiboko, the interaction between variety U-15 with phosphate rate of 25.0 kg ha^{-1} P_2O_5 had the widest fingers at 1.32 cm while the control and the local check, Ekalakala led to suppressed width of fingers, thus resulting in the least width (1.0 cm). At Kakamega site, the 12.5 kg ha^{-1} P_2O_5 treatment and P-224 had the widest fingers width (1.19 cm) while the lowest was observed on the highest rate and U-15 (0.84 cm). The finger width did not differ significantly between varieties in response to application rates of P in all sites during both seasons except at Kiboko during the short rain season where 25.0 kg ha^{-1} P_2O_5 rate had the widest fingers (1.25 cm) and the least was observed on the control together with the 37.5 kg ha^{-1} P_2O_5 rate (1.14 and 1.16 cm respectively). The varieties showed significant differences ($P \leq 0.05$) on the width of fingers where P-224 was superior (Table 4.7). This

could be due to its genetic ability to have longer fingers with higher grain filling capability that expands the fingers than the other varieties (Oduori, 2008).

4.2.4 Effect of phosphorus rates and variety on panicle number

The number of harvested panicles on the 3 m^2 net plot varied significantly in Alupe during the short rain season with the control and 37.5 kg ha^{-1} P_2O_5 eliciting the lowest number of panicles (275 and 261 respectively) while 12.5 kg ha^{-1} P_2O_5 and 25.0 kg ha^{-1} P_2O_5 were higher (308 and 289 respectively) but not significantly different from each other (Figure 4.11). The second season at Alupe showed the same trend though without significant differences between the phosphorus levels. The varieties exhibited significant differences on the panicles number harvested at Kiboko with U-15 having the highest number (270) during the short rains season while at Alupe P-224 had the highest (303) during the short rains then U-15 (292) and Ikhulule (255). Interactions between the phosphate fertilizer rates and varieties were revealed on the number of panicles per plot in Alupe during the short rains cropping season where variety U-15 and 12.5 kg ha^{-1} P_2O_5 had the highest number (402) of panicles harvested from the net plot.

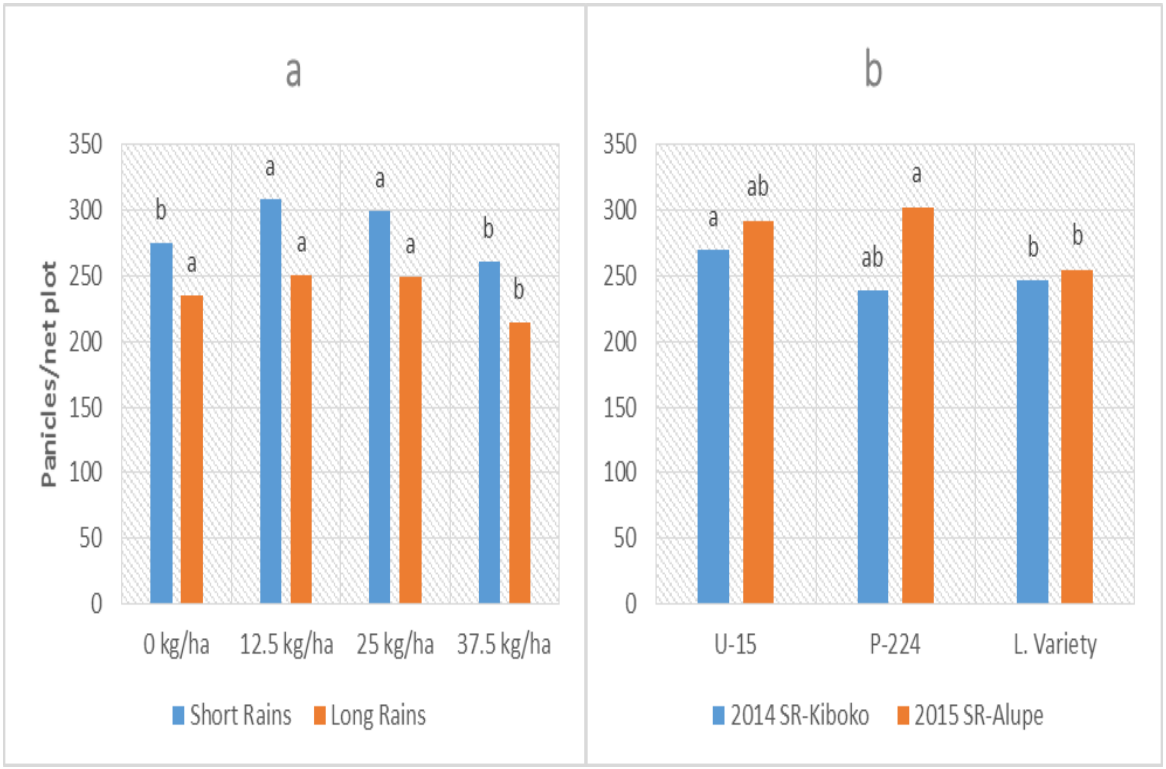

Figure 4.11. Phosphorus fertilizer rate (a) in Alupe and varietal (b) differences on the number of panicles per plot in Kiboko and Alupe

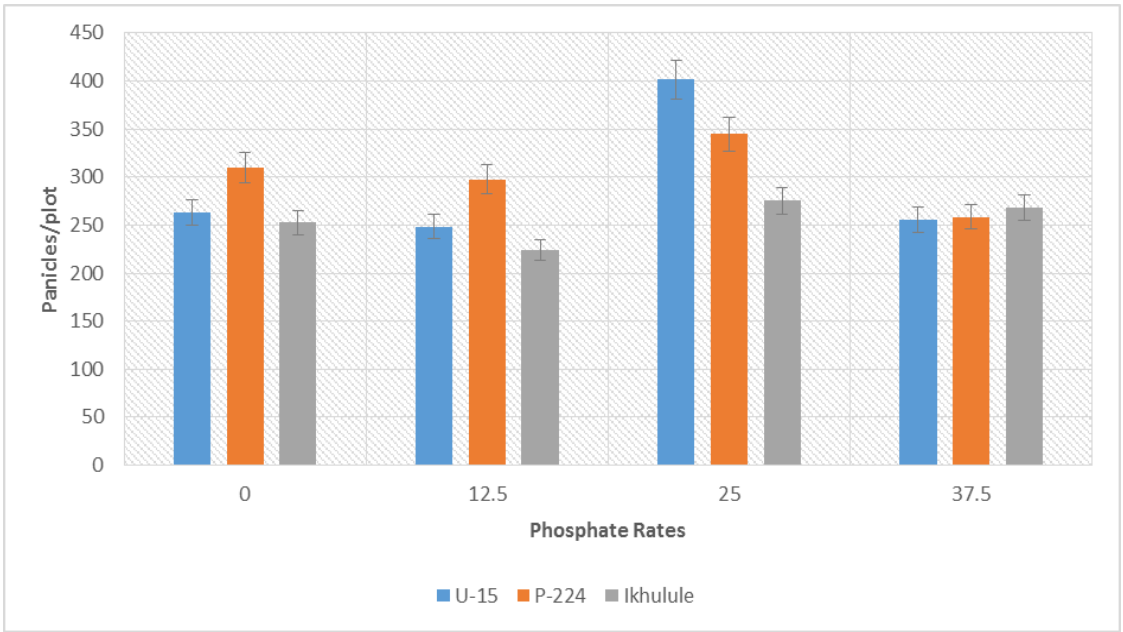

Figure 4.12. Influence of combined treatments on the number of harvested panicles in Alupe during the short rain season

Thakur (1993) noted that panicle number per m^2 increased with increasing P application rates and concluded that it is one of the most important factor that causes variation in the grain yield of rice and this argument concurs with the results of this study. Increase in the magnitude of panicles per plot is associated with better root development and increased uptake of P and other nutrients favoring better growth of the crop

4.2.5 Fingers per panicle as affected by phosphorus and varieties

The number of fingers per head were highly responsive to phosphate rates in Alupe for both seasons and during the long rains cropping season in Kakamega (Figure 4.13). The control had the lowest number of fingers per panicle while the P-treatments exhibiting higher fingers per panicle which were not significantly different from each other. For both seasons in western Kenya, the varieties showed significantly different number of fingers per panicle with U-15 having the highest in Alupe for both seasons and during the long rains in Kakamega.

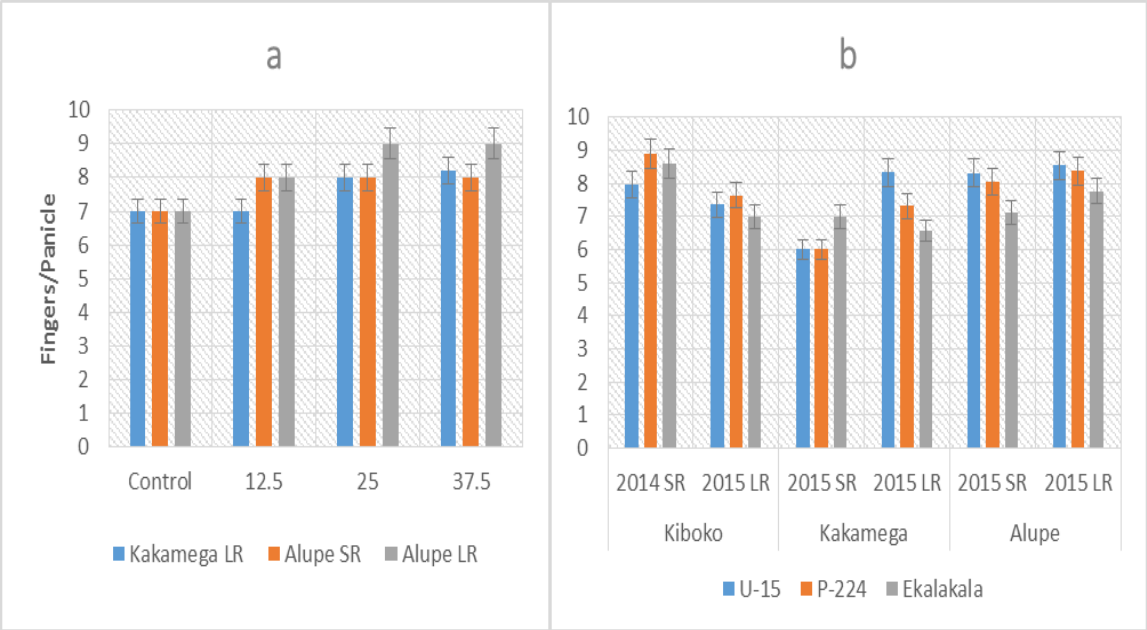

Figure 4.13. Number of fingers per panicle as influenced by phosphate rates (a) and varieties (b)

The increase in the number of fingers per panicle is an indication of how vital P is in the formation of grain compartments in plants. Channabasavanna and Setty (1994) and Raju and Reddy (1993) reported that application of P increases the total number of spikes per panicle in rice thereby agreeing with the findings of this study.

4.2.6 Grains per spikelet as affected by phosphorus and varieties

The number of grains per spikelet was not responsive to phosphorus fertilizer application rates in all the sites for both seasons. This might be because that this trait is highly dependent on the genetic make-up of the varieties and therefore the P rates influence was limited. The varieties differed significantly in Kiboko and Alupe where P-224 had the highest number (7 grains per spikelet) compared to U-15 and the local checks which had 6 grains per spikelet at both sites respectively (Appendix 5). These findings on P disagrees with the results of Heluf and Mulugeta (2006) who found that application of both N and P fertilizers reduced the number of filled spikelets in a panicle while increasing the

proportion of unfilled spikelets in panicles of rice. They concluded that increasing the levels of P fertilizers led to vigorous growth of the rice crop resulting in competition for metabolic supply among spikelets thus affecting the production of spikelets that are fertile. Hasegawa *et al*. (1994) and Wu *et al.* (1998) concluded that by increasing soil fertility, the number of filled spikelets per panicle reduced while the number of unfilled spikelets increased. In another study it was found that phosphatic fertilizer application led to significantly higher number of grains per spike that ultimately increased the grain and straw yields of triticale (Poulsen *et al.,* 2005). Similar results were reported by other various scientists (Ravnskov and Jacobsen, 1995; Reuter *et al.,* 1995).

4.2.7 Plant fresh weight as affected by phosphorus and varieties

Phosphate rates showed significant differences ($P \leq 0.05$) on the fresh panicle biomass during the long rain cropping season in Alupe (Figure 4.14). Interaction effect between variety and phosphate rates were also observed where optimal fresh panicle weight on the local variety, Ikhulule was exhibited at the 12.5 kg ha^{-1} P_2O_5 rate while optimal production on the improved varieties, U-15 and P-224 was observed with the 25 kg ha^{-1} P_2O_5 application rate with further increase resulting to a decrease.

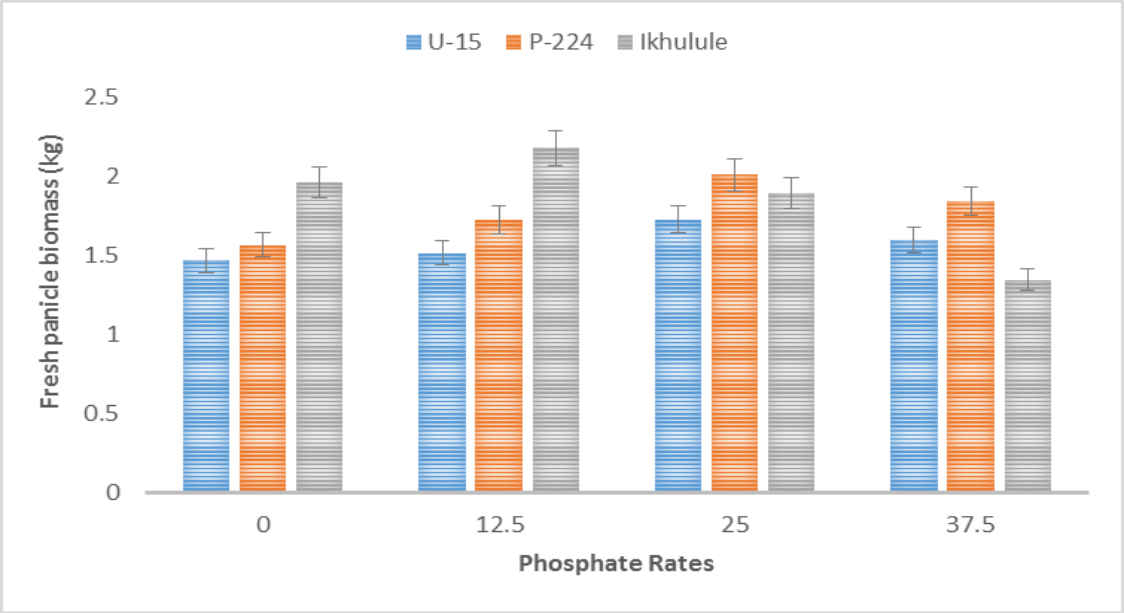

Figure 4.14. Interaction effect between variety and phosphate rates on the fresh panicles biomass in Alupe during the short rains

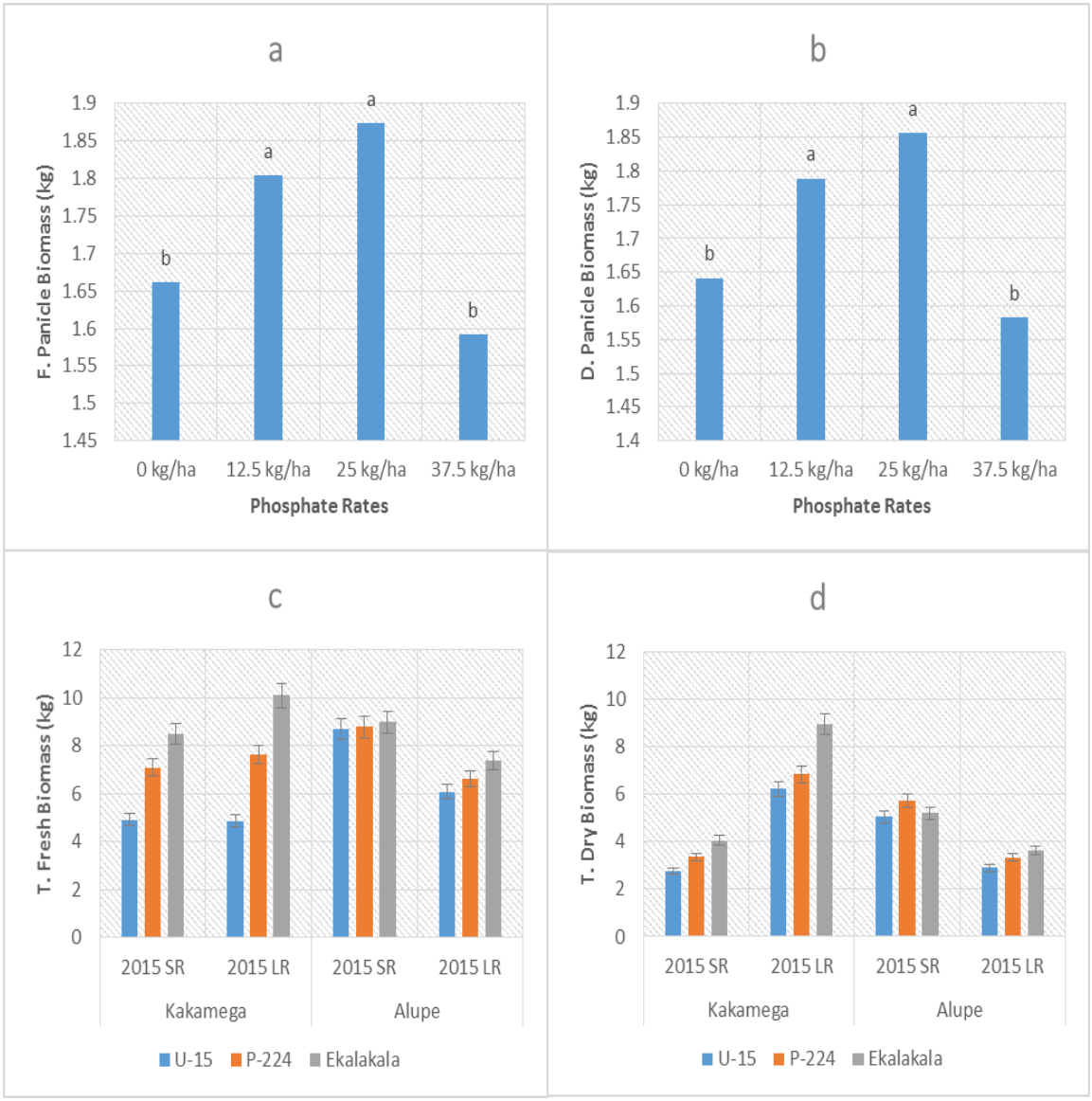

Figure 4.15. Fresh (a) and dry (b) panicle biomass in Alupe during the long rains as influenced by phosphate rates and Varietal influence on total fresh (c) and dry (d) biomass in western Kenya

The increase on the fresh panicle fresh weight for the P-applied treatments across the varieties shows that low or no P reduces lateral growth of the crop whereas an excess interacts negatively with other nutrients and reduces vegetative growth. Some authors reported that it may not be toxicity per se but indirectly by making some micro-nutrients not being available at high soil P (Ogembo 2015; Boyhan *et al.*, 2007). The increase in

yield with P fertilization is in line with findings by Yaseen *et al.* (1998) who found that where phosphorus fertilizer was applied the straw yield was higher in wheat crop. They argued that it was due to the role of P in modifying soil and plant environment that is conducive for better growth. The findings are also in agreement with those by Khalid *et al.* (2003), who found that application of phosphorus fertilizers gradually increased fodder yield of sorghum (*Sorghum bicolor* L. Moench). Positive correlation between fodder yield of Pangola grass and P fertilizers were reported in another study by Bhardwaj *et al.* (1995). Khot *et al.* (1997) reported that green forage yield increased significantly with increasing levels of phosphatic fertilizers and the total yield of green forage increased with the increasing level of P fertilizer also reported by Abdullah *et al.* (2000). The results of the present findings contradicts those reported earlier by Malak (2005) in German grass and Islam (2007) in Napier grass. The P treatments did not influence the fresh biomass of the crop for both seasons in Kiboko. The findings of the current study in Kiboko is in conformity with those of Gupta (1999) who reported that application of 24 and 0 kg P_2O_5 ha^{-1} gave statistically identical straw yields.

4.2.8 Plant dry weight as affected by phosphorus and varieties

The dry straw biomass was responsive to P levels in Alupe where the control showed significantly lower dry biomass per plot (3.41 kg) during the short rain season while the highest was observed with the 37.5 kg ha^{-1} P_2O_5 treatment (4.75 kg) which was followed by 25.0 kg ha^{-1} P_2O_5 treatment (4.24 kg). During the long rains, the 25.0 kg ha^{-1} P_2O_5 treatment had the highest dry panicle biomass (1.86 kg) while the control, as expected had the lowest (1.60 kg). The total dry biomass per plot was significantly influenced with 25.0 kg ha^{-1} P_2O_5 treatment and 37.5 kg ha^{-1} P_2O_5 treatment, with the later having the highest

(6.0 kg) during the short rain, while the control had the lowest (4.51 kg). The same trend was observed in the second season, though the treatments differences were not significant.

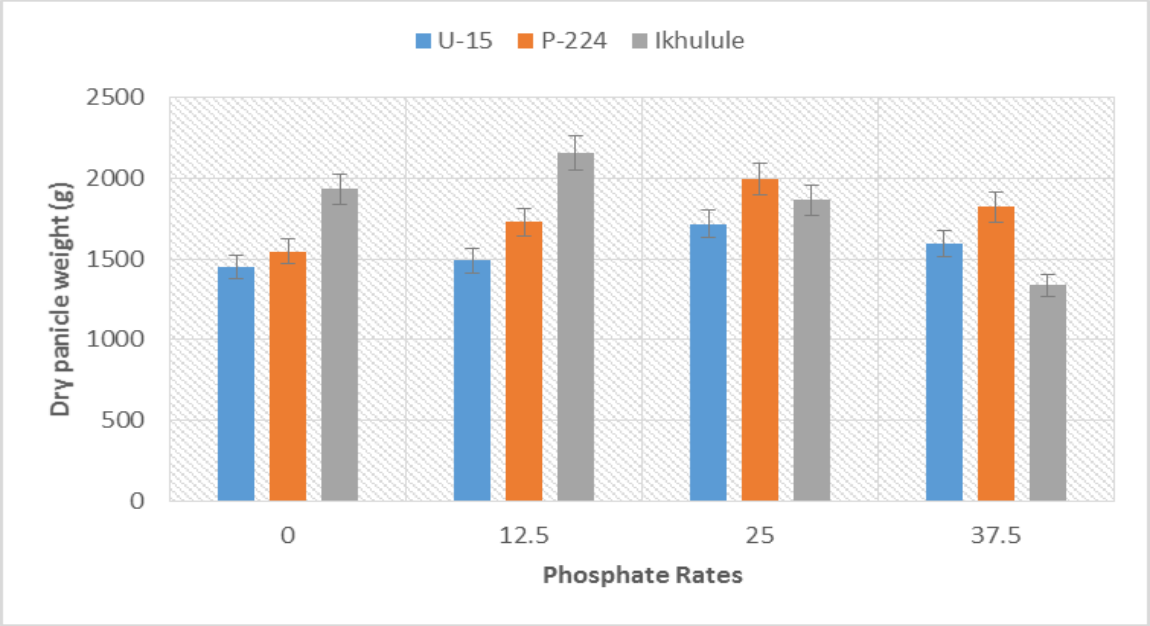

Figure 4.16. Interactions between phosphate rates and varieties for dry panicle weight at Alupe in the long rains

Among the varieties, as observed on the fresh biomass the local variety, Ikhulule was superior in Alupe during the long rain season (Figure 4.16). The findings agree with those of Shah (2006) and Xie *et al.* (2007) who reported variation in biomass production with variety, which led to differences in straw yields in rice. The panicle weight was highly and positively correlated with the number of panicles harvested. Zaman *et al.* (1999) reported increments in the number of panicles per m^2 of rice plants due to applied P and concluded that it enhanced production of grain yield.

4.2.9 1000-grain weight

The phosphate rates did not have significant influence on the weight of 1000-grains in all the sites for both seasons (Appendix 6). The lack of significant P fertilizer effects in seed weight in both varieties in this experiment was in agreement with the findings of Marzo *et al.* (1997) in peas. This findings however disagree with studies by Shah (2006) who reported that application of 30 kg ha^{-1} P gave the highest 1000-grain mass which was different from all other doses; Parsamotlagh (2011) reported that by application of phosphorus fertilizer maize seed weight increased. During the short rains, U-15 had the highest mass while in the long rains it had a significantly same mean as Ekalakala while P-224 was the lowest for both season in Kiboko. The 1000-grains mass of the local variety, Ekalakala was heaviest at Alupe site during the short rain season.

4.2.10 Threshability

Phosphate fertilizer rates led to significant effect on the threshing percentage of finger millet at Kakamega during the short rain season. Lowest threshability was observed on the control with 58.2%, 12.5 kg ha^{-1} P_2O_5 (63.4%), 25.0 kg ha^{-1} P_2O_5 (65.8%) and 37.5 kg ha^{-1} P_2O_5 led to 65.9% threshability (Figure 4.17). This might be due to the vital activity of P in enhancing maturity and in this case no P or low P led to slower maturation and grain filling which may have rendered them to have lower threshability at harvesting. In the other sites, P application rates did not result to significant differences in the threshing percentage. The findings are in line with a study done by Tenywa *et al*. (1999) who did not observe significant effects ($P \leq 0.05$) of fertilizer treatment on threshing percentage of finger millet which ranged from 76% to 85%.

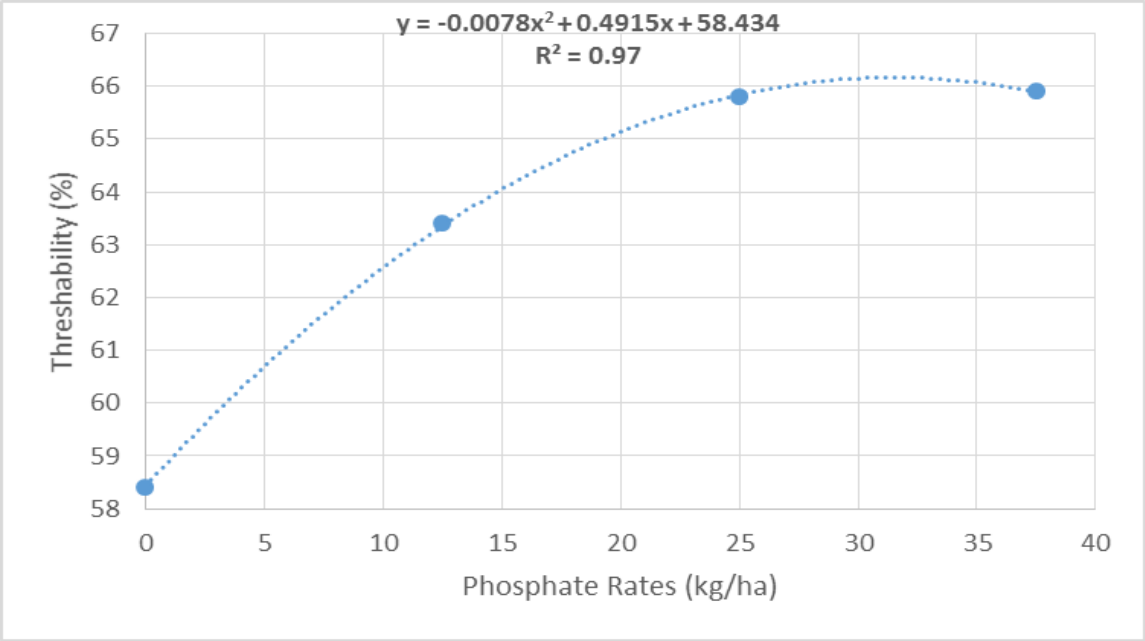

Figure 4.17. The threshing percentage as influences by phosphate rate application at Kakamega site during the long rain season

Among the varieties, U-15 had the highest threshing percentage in all the sites with the local variety being the poorest in western Kenya sites and P-224 in Kiboko (Table 4.8). This is majorly because of the difference in the maturation period of the varieties whereby U-15 is a fast maturing variety and had better drying ability. Interaction between variety U-15 and the control (no P) exhibited the highest threshability percentage in Kiboko during the long rains.

Table 4.8. Varietal differences on the threshing per cent in Kiboko, Kakamega and Alupe

Variety	Threshability (%)					
	Kiboko		Kakamega		Alupe	
	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
U-15	65.9a	81.7a	68.2a	75.5a	74.8a	72.5a
P-224	63.0a	72.6b	63.5ab	73.9a	72.9a	68.7ab
L. Variety	66.5a	79.3a	58.5b	72.4a	67.6b	67.1b
$LSD_{0.05}$	NS	3.11	5.25	NS	3.02	3.77
CV%	7.4	4.7	9.8	8.2	5.0	6.4
PR×V	NS	**	NS	NS	NS	NS

†Values with the same letters within the column are not significantly different

4.2.11 Grain yield

The grain yield of finger millet showed highly positive response to application rates of phosphorus in Alupe for both seasons (Figure 4.18). The 25.0 kg ha^{-1} P_2O_5 application rate showed the highest yield while the control and 37.5 kg ha^{-1} P_2O_5 were the lowest for both seasons. The same trend was observed in Kakamega for both seasons. There was an increase on the grain yield with increasing phosphate rates in Kiboko though with no significant differences between treatments. Interactions between phosphate rates and varieties were revealed at Alupe during the long rains where variety P-224 at the 25.0 kg ha^{-1} P_2O_5 rate, and the local variety at the 12.5 kg ha^{-1} P_2O_5 rate had the highest grain yield (Figure 4.19). This is mainly due to the role of optimum P in energy provision for seed formation and grain filling. Higher amounts of P in certain environments may directly lead to interaction with other nutrients, particularly micronutrients, hence lowering yields at higher rates (Ogembo 2015, Boyhan et al 2007). Zaman *et al.* (1999) found significant increase in grain yield with P application over the control, while Tandon (1987) reported that the application of 26 kg ha^{-1} increased paddy rice yield by 2.5 t ha^{-1} in Kharif and 5.7 t ha^{-1} in Rabi. Matsuo *et al*. (1996) also found significant differences in grain yield of rice varieties with variable P levels.

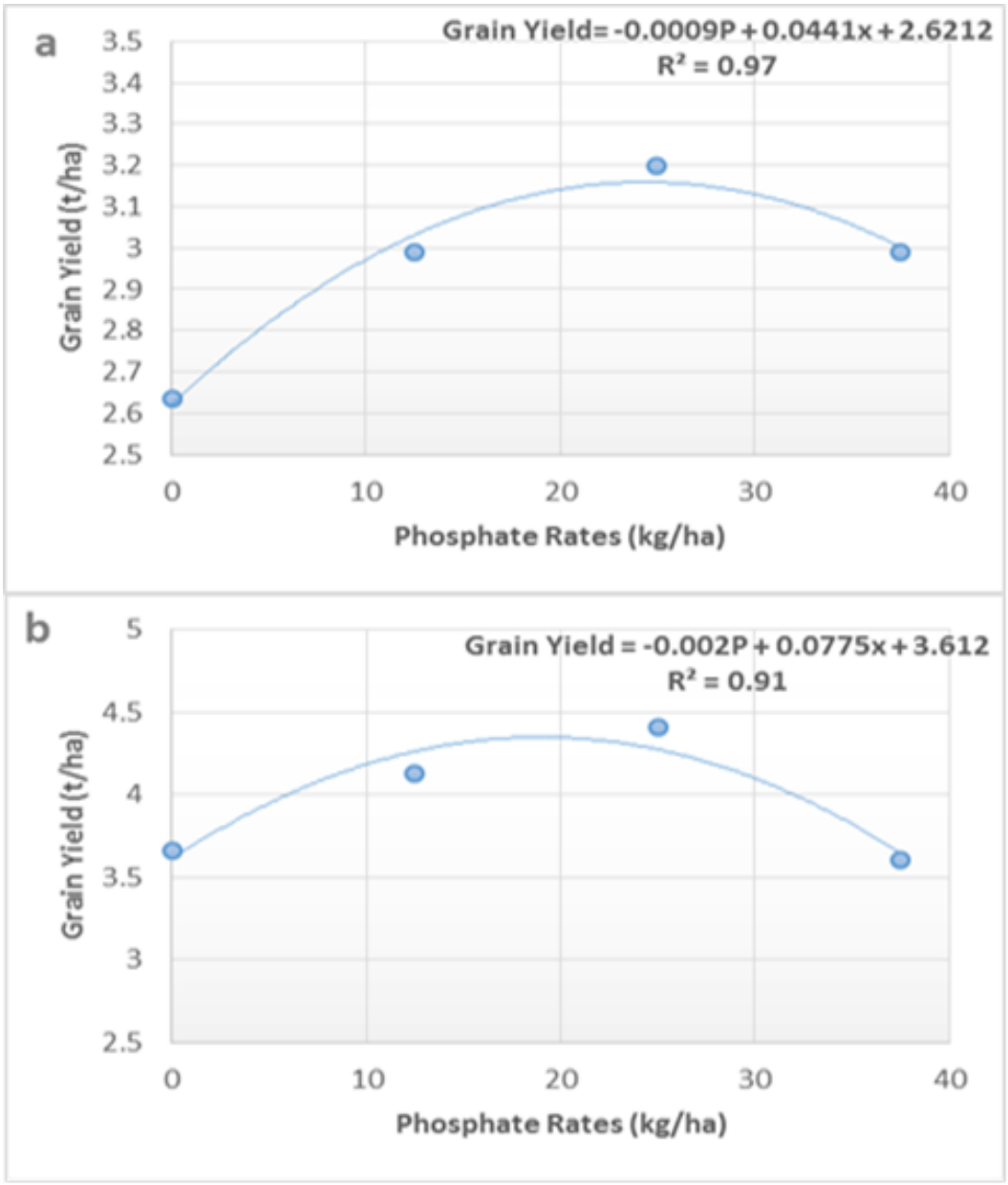

Figure 4.18. Mean grain yield as a polynomial function of phosphate rates for finger millet during the short (a) and long (b) rain seasons in Alupe

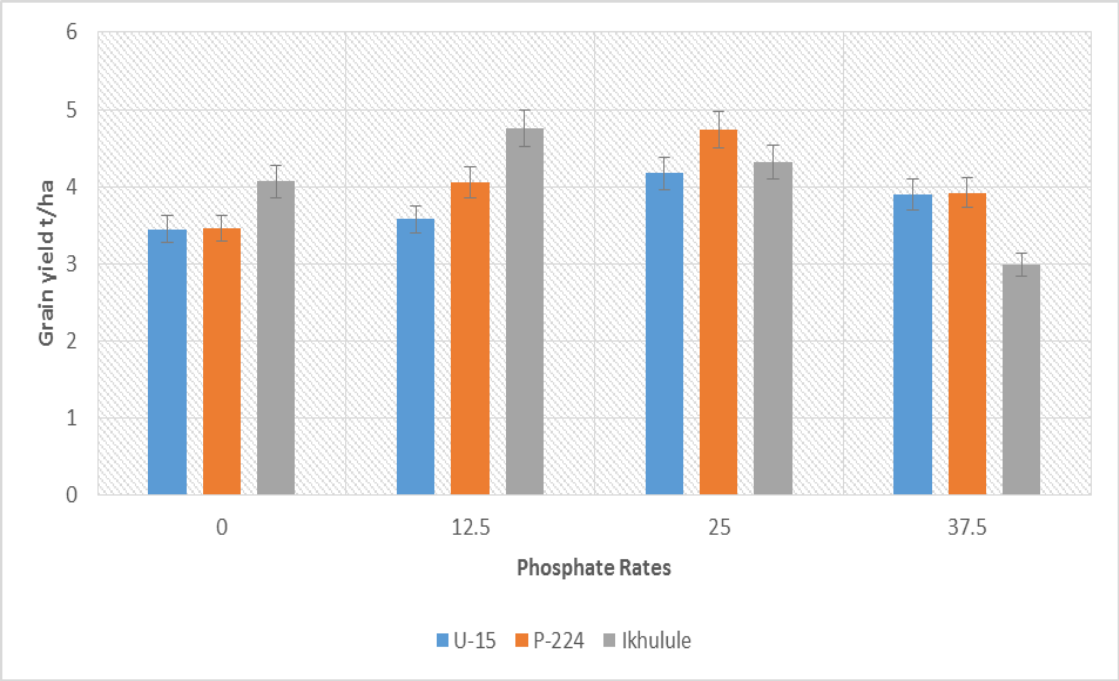

Figure 4.19. Interaction influence between variety and phosphate rates on the grain yield in Alupe during the long rains

Yields of between 3.8-4.0 t ha^{-1} had been observed in field trials on yield in Kenya (Oduori, 2005) while in Uganda 1.8 t ha^{-1} was regarded as average and yields from trials range between 1-4 t ha^{-1} while in Tanzania, where low yields were experienced on the local varieties that are commonly grown but selected varieties yielded between 1-2.5 t ha^{-1} in yield trials (Chambo, 1993). In Africa the yields are generally low and efforts are to be improved to get to those reported in India of between 5-6 t ha^{-1} under ideal conditions (NRC, 1996). Khanvilkar and Mahadkar (1988) reported that finger millet grain yields increased from 0.87 to 1.30 t ha^{-1} with increasing P rates. They further concluded that 50 kg N + 40 kg P ha^{-1} gave the highest grain yields of 1.43 t ha^{-1} compared with 0.44 t ha^{-1} without P. These findings however disagree with studies done by Kute and Kalama (1995) who found that there were no differences in yields of various finger millet varieties.

There were no significant effect by phosphate rates in Kiboko on the grain yield for both seasons due to optimal available P in the soils The findings agree with those by the Manitoba Agriculture, Food and Rural Initiatives (2006a) which reported that P fertilizers did not result in a significant increase in grain yields of oats where selected sites showed moderate soil test for P levels in cereal production.

4.2.12 Harvest index

Significant differences were observed on the harvest index due to P rates in Kakamega during the short rains season where the highest HI was observed on the 25.0 kg ha^{-1} P_2O_5 and 37.5 kg ha^{-1} P_2O_5 with an index of 0.31 while the control had the least with 0.27 (Appendix 7). In Alupe and Kiboko it was not observed with no consistent trends of the harvest index. In similar to this, Okalebo *et al*. (1990) had shown that an increase in grain yield with increased P levels but suggested that HI was unstable across P levels while genotypes stability for HI was maintained. Cereal improvement over the years is mainly attributed to the increased harvest index (HI). So far this trait has not been exploited in finger millet. Of the various factors influencing the HI, mineral nutrition is of utmost importance (Shankar *et al*., 1990). Contradicting this finding, in a study by Reddy *et al*. (2004) on the effect of P on stability of HI with two contrasting genotypes of finger millet it found that as P level increased from 20 to 80 kg ha^{-1} there was a significant increase in biomass and grain yield. However, the HI and partitioning percentage decreased significantly with further increase in P levels.

Table 4.9. Harvest index as influenced by variety in Kiboko, Kakamega and Alupe

Variety	Harvest Index					
	Kiboko		Kakamega		Alupe	
	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
U-15	0.36a	0.40a	0.35a	0.38a	0.23a	0.40a
P-224	0.31b	0.36b	0.30b	0.38a	0.24a	0.37ab
L. Variety	0.33a	0.38ab	0.23c	0.28b	0.21a	0.34b
$LSD_{0.05}$	0.03	0.02	0.03	0.03	NS	0.03
CV%	11.5	7.8	9.9	11.6	18.3	10.7

†Values with the same letters within the column are not significantly different

Varietal differences were observed on the harvest index at all the sites (Table 4.9). Variety U-15 had the highest HI index followed by P-224 then the local variety. Similar results to the findings of this study were reported by IRRI (1974) where improved rice varieties had superior harvest indices than the local rice varieties in the Philippines. In general, the HI was higher in improved variety, probably implying efficient translocation of assimilates for grain production, which is an economic yield component.

4.3 Grain nutrient contents

The grain nutrient levels of finger millet differed significantly between P treatments and varieties where increase in P levels led to increase in the protein contents, with the same trend also observed on phosphorus, potassium, magnesium, calcium and zinc elements.

4.3.1 Protein

The 25.0 kg ha^{-1} P_2O_5 application rate showed significantly ($P \leq 0.05$) the highest protein content compared to the other treatments with the control showing the lowest protein content at all the sites (Table 4.10). Application of phosphate fertilizer enhanced the protein content of finger millet with conclusive trends observed where it peaked at 25.0 kg ha^{-1} P_2O_5 and then dropped afterwards.

Table 4.10. Interaction effect between varieties and phosphate rates on protein content of finger millet at Kiboko, Kakamega and Alupe during the short and long rain seasons

	Protein g/100g					
	Kiboko		Kakamega		Alupe	
	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
V_1P_0	8.79b	6.56c	8.92c	10.94c	8.75b	10.94c
V_1P_1	8.83b	8.75b	9.75b	13.13b	8.70b	15.31a
V_1P_2	11.00a	8.75b	11.8a	15.31a	10.94a	13.12b
V_1P_3	8.854b	8.75c	10.95a	10.94c	8.75b	10.94c
V_2P_0	6.60c	4.38d	8.46c	8.88d	4.36b	8.75d
V_2P_1	6.62c	8.75b	9.16b	13.13b	10.93a	10.94c
V_2P_2	10.96a	8.75b	9.78b	15.31a	8.73b	15.31a
V_2P_3	8.81b	8.75b	9.51b	13.13b	8.72b	13.12b
V_3P_0	8.81b	6.56b	9.12b	10.80c	8.75b	10.94c
V_3P_1	8.79b	8.75b	9.49b	10.94c	10.93a	10.94c
V_3P_2	10.98a	10.94a	11.48a	13.13b	10.94a	13.12b
V_3P_3	10.96a	10.94a	10.67a	13.13b	10.91a	10.94c

† V_1-U-15, V_2-P-224, V_3-Local check, P_0-Control, P_1-12.5 kg/ha, P_2-25.0 kg/ha, P_3-37.5 kg/ha P_2O_5Values with the same letter(s) within the column are not significantly different

Varietal differences were observed at all sites in both seasons with the local variety being superior in Kiboko while P-224 was superior in Kakamega and Alupe. Interactions at $P \leq 0.05$ were also observed in all the locations where different combinations had the highest protein content although no definite patterns could be conclusively drawn.

The composition of proteins in finger millet was influenced by cultivar, climatic conditions, stage of maturity and many agro-climatic conditions. The increase is due to the significance on the P effect on synthesis of protein in grains where it acts as an important building part in the amino acids and provision of energy in the uptake and transfer of N in the grains of finger millet. The grains endosperm are the primary sinks for Carbon and N compounds (Balconi *et al.,* 1997) and this enhanced the protein content as per N uptakes in the plants. These findings are however not in tandem with those by Takkar *et al.* (1976)

who found that in a field trial with maize broadcasted with P application led to a decrease in grain protein concentration. It has also been reported by Ortiz-Monasterio (2001) that increased yields led to decreased protein concentration.

4.3.2 Phosphorus

Significant differences (P≤0.05) were observed on the phosphorus nutrient content in the grains due to application of phosphate rates. The highest content was observed on the highest rate in all the sites for both seasons (Figure 4.20). The highest amount was observed in Kiboko during the long rains cropping season with 589.3 mg/100 g.

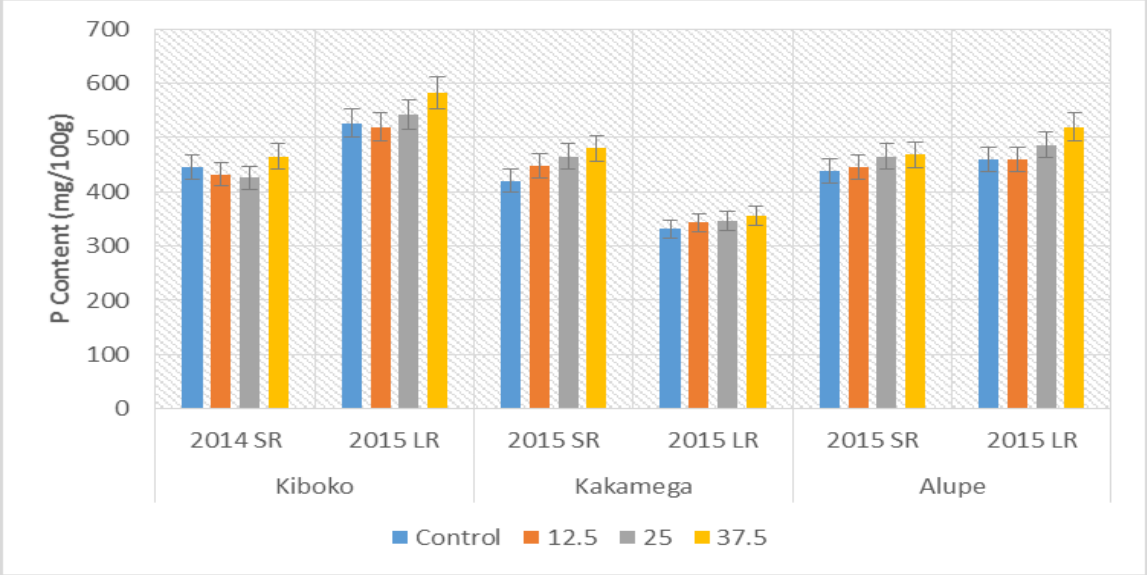

Figure 4.20. Phosphate rates influence on the phosphorus nutrient content in finger millet grain

Varietal differences were observed on the phosphorus content in the grains with the local variety being superior in Kiboko (449 mg/100 g and 542 mg/100 g during the short and long rain seasons, respectively), U-15 was superior in Kakamega during the long and short rain seasons with 355 and 409 mg/100 g respectively while P-224 was superior in Alupe with 420 and 436 mg/100 g during the short and long rain seasons, respectively. These findings agree with those by other scientists that the phosphorus concentrations in given

species seeds vary with inherent soil P status, cultivar and climatic conditions (Miller *et al.*, 1980; Raboy *et al.*, 2001; Horvatic and Baliat, 1996). Interactions were revealed but with the trend changing between season and location. This might be due to the soil inherent properties of the locations with Kiboko having already optimal P in the soil and application of extra P might have led to increased uptake and even luxurious consumption. Phosphorus application increased the availability of P thereby nutrition of plant and uptake was manifested in the increased concentration in the grains. These results are in accordance with those by Raut *et al.* (2000). In another study it has been reported that the P content in plants can also be constringent to the interaction between the soil and water-soluble P whose dependence is shaped by the soil reaction to a big extend (Bar-Yosef, 2003).

4.3.3 Potassium

Finger millet grain indicated significant differences ($P \leq 0.05$) between the P rates on the K content of grains in Kiboko and Alupe during the short rain seasons. In Kiboko, highest amounts were found on the interaction between 25.0 kg ha^{-1} P_2O_5 rate under U-15 variety as well as 12.5 kg ha^{-1} P_2O_5 application rate with P-224 (Figure 4.21). The same trend was observed in Alupe but with various interactions showing highest concentration of potassium except for 25.0 kg ha^{-1} P_2O_5 rate under variety P-224 which had a significantly lower K content in the grains. Varietal differences were observed at all sites but without any consistency where the varieties had differing contents of K in every season and sites. This was probably due to the environmental conditions and their interaction with the varietal genetic makeup. The same trend was observed in Alupe during the long rains season.

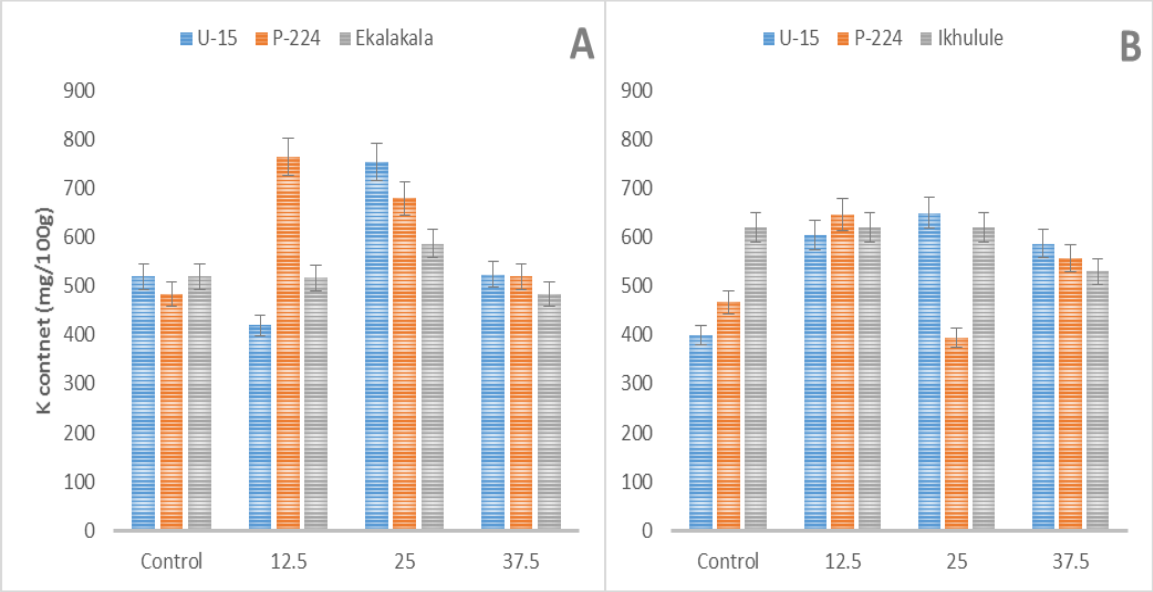

Figure 4.21. Phosphorus and variety influence on the potassium grain content in Kiboko short rains (a) and Alupe short rains (b)

The increase in K contents in the grain was probably due to the positive effect of phosphorus in energy provision for transfer of nutrients in the grain filling process and differs with the findings by Kunzova & Hejcman (2010) who found that there was no direct relationship between the content of available P and K forms in the soil and the contents of these elements in winter wheat plant.

4.3.4 Calcium

Increase in P rates increased the calcium nutrient content in Kiboko during the short rain season while no consistent trend could be drawn from the other sites. The 25.0 kg ha^{-1} P_2O_5 and P-224 had the highest calcium content while highest rate with all the varieties showed the lowest Calcium content (Figure 4.22). Varietal differences were observed but without consistency on the control while on the P treatments P-224 had higher Calcium content (Figure 4.22).

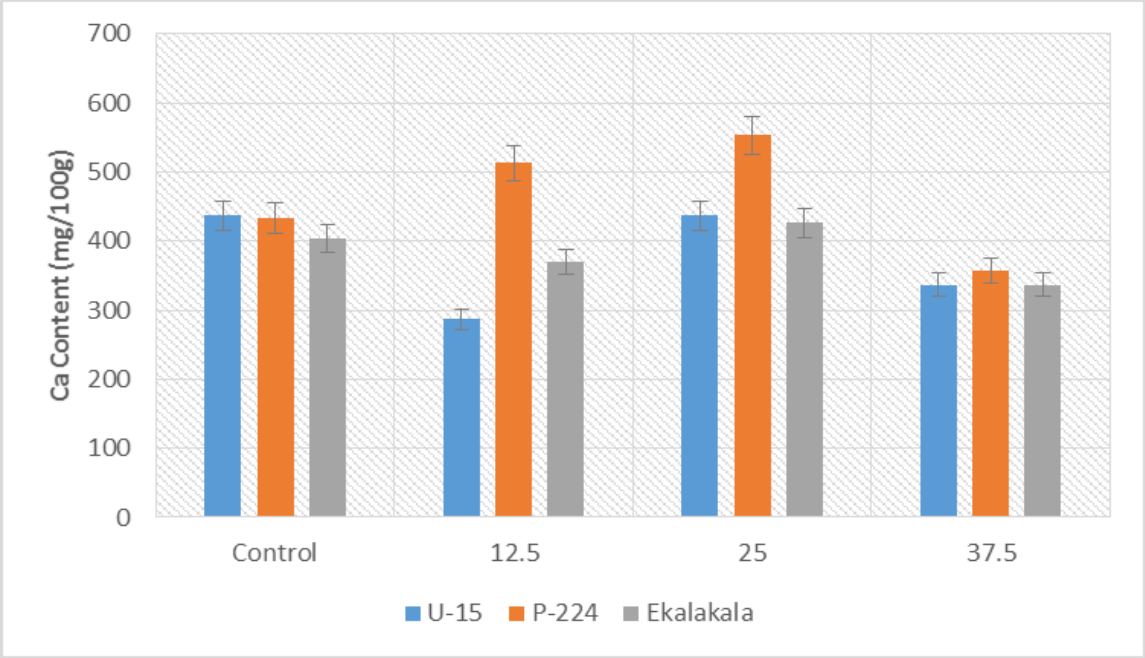

Figure 4.22. Calcium grain content as effected by different phosphorus fertilizer levels and variety

The results on the amount of calcium in finger millet do not concur with those by Kadkol and Swaminathan (1954), who reported that the calcium content of finger millet ranged between 0.25 and 0.30 per cent, which are much lower compared to those of this study which ranged between 0.35 and 0.48 per cent.

4.3.5 Magnesium

Significantly higher amounts of magnesium in the finger millet grains were recorded on the P treatments in Kakamega during the short rain season with 37.5 kg ha^{-1} P_2O_5 and 25.0 kg ha^{-1} P_2O_5. This might be due to the supplemented P which led to increased uptake of magnesium that in turn positively influenced the quantity of Mg nutrient in the grains. An increase on the Mg nutrient content at Kakamega correlated positively with P rates up to 25.0 kg ha^{-1} P_2O_5 where further increase had no effect. During the long rains at Alupe, significant differences were not observed but Magnesium content increased with increasing

Phosphorus application during the long rains (Figure 4.23). This shows that phosphorus can only be beneficial in the transfer of Mg and formation of Mg in the grains of finger millet to an optimal P level where increase beyond becomes constant or negative. There were varietal differences observed but very inconsistent for different seasons in the different locations.

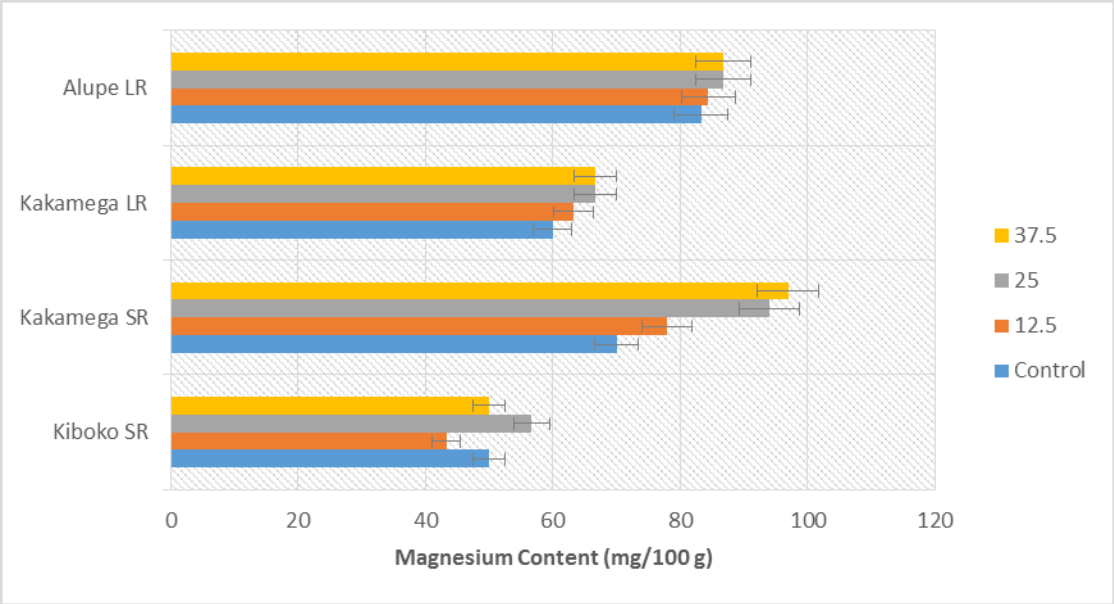

Figure 4.23. Magnesium grain content as effected by different phosphorus levels

4.3.6 Iron

The increase of phosphate rates significantly increased the iron nutrient content in the grains of finger millet in Kakamega during the long rain season as shown in Figure 4.24. The highest phosphorus rate on variety P-224 had the overall highest amount of iron while 12.5 kg ha^{-1} P_2O_5 had the highest content in the U-15 variety and the control indicated the lowest amount of grain iron content in P-224.

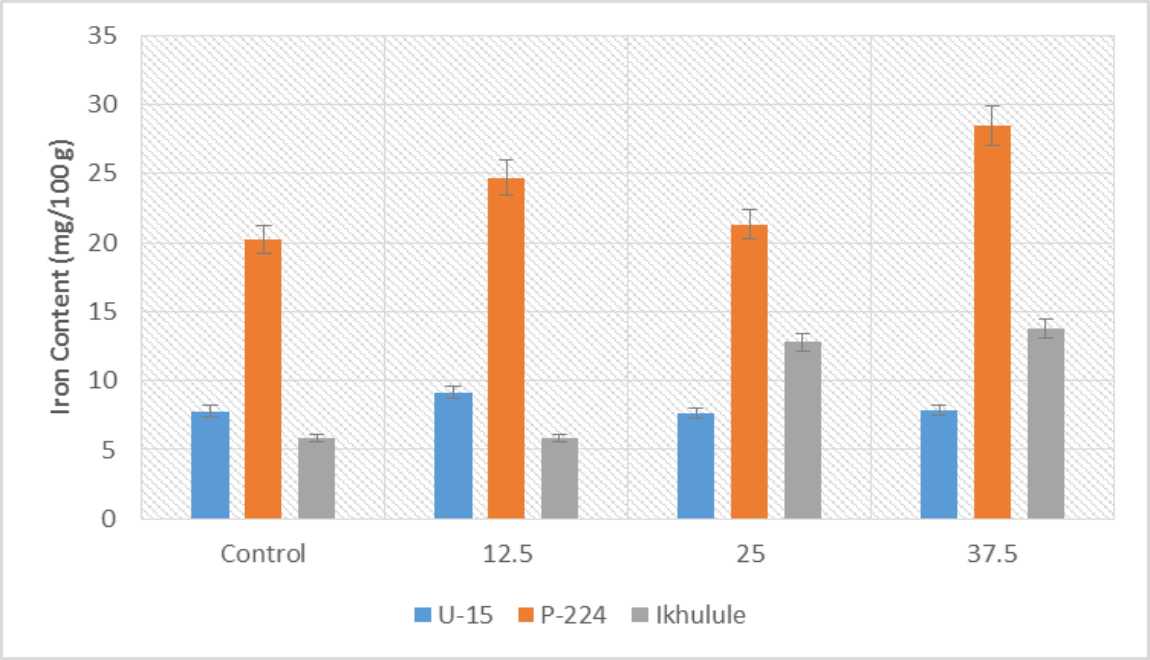

Figure 4.24. Varietal and phosphate rates differences on the iron content in Kakamega during the long rains

The findings showed higher amounts of iron in the P-224 variety grains compared to those report by Rao (1994) that in selected varieties of finger millet for malting where the iron content was around 8.4 mg/100g.

4.3.7 Copper

The amount of copper in the grain indicated significant differences due to application of phosphate rates in all the sites. The application of phosphorus led to an increase of copper in Kakamega for both seasons as shown on Figure 4.25 below. In Alupe the trend was quite different where at 25.0 kg ha^{-1} P_2O_5 the highest amount of copper was achieved while in Kiboko the application of phosphorus led to a decline in the amount of copper in the grains of finger millet during the long rain season, while no significant differences between the treatments were observed in the short rain season.

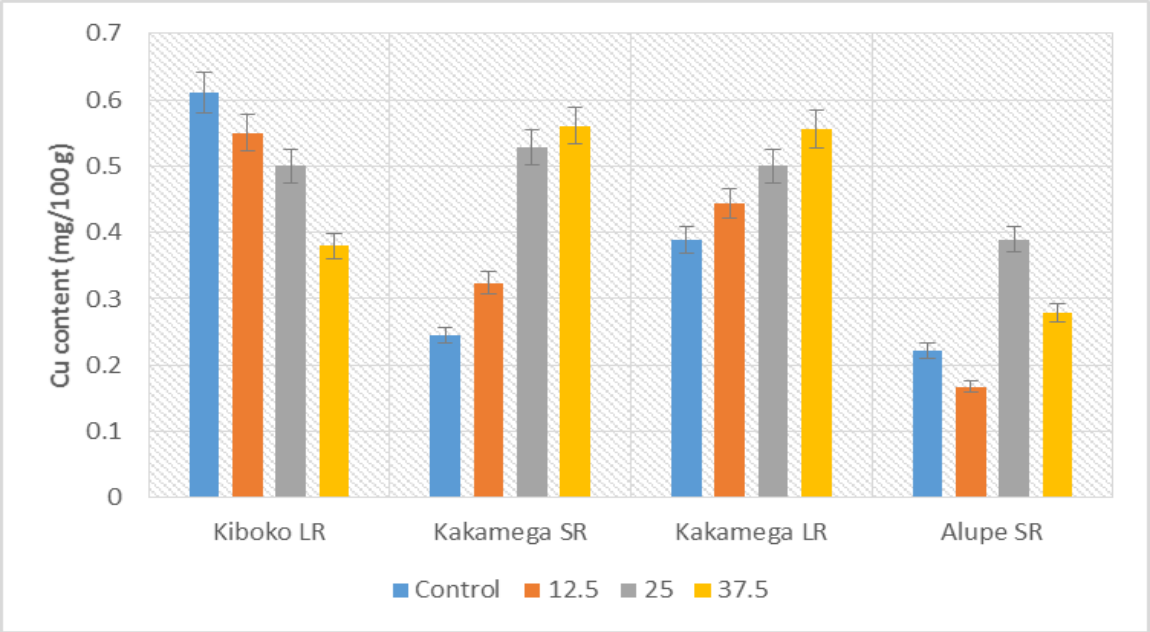

Figure 4.25. Phosphorus levels influence on the grain copper content in the three study sites

4.3.8 Manganese

The manganese contents in the grain of finger millet differed significantly due to phosphorus application but inconsistent throughout the locations and seasons (Table 4.11).

Table 4.11. Influence of phosphorus fertilizer levels on the grain manganese content (mg/100 g) at Kiboko, Kakamega and Alupe during the short and long rain seasons

Kg ha^{-1} P_2O_5	**Kiboko**		**Kakamega**		**Alupe**	
	2014 SR	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	**2015 LR**
Control	15.63a	12.83c	21.42c	18.03d	29.68b	64.00b
12.5	10.93c	13.53b	26.93ab	20.17a	30.40a	57.04d
25.0	11.44b	13.43b	28.01a	18.37c	29.57b	62.43c
37.5	11.56b	14.17a	24.31b	18.67b	28.24c	65.77a
L.S.D$_{0.05}$	0.37	1.80	2.45	0.29	0.14	0.02
CV %	8.6	1.7	2.3	1.6	0.5	0.9

†Values with the same letters within the column are not significantly different

The inconsistency was majorly due to its high mobility rate in the soil and thus influenced the uptake without direct restrictions by the phosphate fertilizer rates. It is only in Kiboko during the long rain season and Kakamega during the short rain season whereby as P rates

increased so did the manganese content and significantly differed from the control which had the lowest quantity. Varietal differences were observed on the manganese nutrient content with the local variety consistently containing the highest in Kakamega (26.3 mg/100g in the short rain and 20.5 mg/100g in the long rain) and Alupe (30.5 mg/100g in the short rain and 63.8 mg/100g in the long rain) while U-15 showed the lowest. Interactions were revealed but with inconsistent patterns which were majorly due to differences in respect to the weather patterns and soil properties.

4.3.9 Zinc

Phosphate fertilizer application had positive influence on the zinc nutrient content of finger millet (Table 4.12). Increase in P rates upto 25.0 kg ha^{-1} P_2O_5 directly impacted on the zinc nutritive component with a drop observed afterwards in Kakamega and Alupe during the long rain seasons due to the excessive phosphorus that probably inhibited accumulation and translocation of zinc in the grain filling phase. Similar reports by Ogembo (2015) was highlighted that, interaction of the excess phosphorus with labile available micronutrients, particularly Zinc and Copper, usually make them unavailable for plant use.

Table 4.12. Influence of phosphorus fertilizer levels and variety on the grain zinc content at Kiboko, Kakamega and Alupe during the short and long rain seasons

Kg ha^{-1} P_2O_5	**Zinc (mg/100g)**					
	Kiboko		**Kakamega**		**Alupe**	
	2014 SR	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	**2015 LR**
Control	1.63ab	2.83b	3.14d	3.00c	2.94c	1.60c
12.5	1.93a	3.53a	3.35c	3.22b	3.01c	1.87bc
25.0	1.44b	3.43a	3.65b	3.28a	3.11b	2.50a
37.5	1.56b	4.17a	3.87a	3.06c	3.73a	2.10b
$LSD_{0.05}$	0.373	1.8	0.054	0.066	0.046	0.179
Variety						
U-15	1.25c	2.98a	2.95c	3.09b	3.34b	1.11c
P-224	1.29b	2.29b	3.21b	3.50a	2.80c	1.70b
L. Variety	1.54a	3.05a	3.54a	2.83c	3.45a	3.25a
PR×V	**	***	**	***	**	***

†Values with the same letters within the column are not significantly different

The local varieties had the most zinc nutrient content except in Kakamega during the long rain season where P-224 was superior. Interactions were observed in all the locations but inconsistent through the locations and seasons (Table 4.13). The findings on the increase of grain zinc content with increasing phosphorus are in tandem with those reported by Loneragan *et al.* (1979) that P application increased the total zinc content accumulation in millet grain of up to 28% due to dilution effect caused by growth promotion.

4.4 Nitrogen Uptake and accumulation

Significant differences ($P \leq 0.05$) were observed on the total nitrogen uptake for both seasons in Alupe, while at Kiboko and Kakamega no significant differences were observed on nitrogen uptake due to differential levels of P application as shown in Table 4.13. During the short rain season in Alupe, the increase in phosphorus rates led to an increase of the total uptake of N in the plants. The highest rate of 37.5 kg ha^{-1} P_2O_5 had the highest total uptake with 1057 kg N ha^{-1} while the control had the least with 705 kg N ha^{-1}.

Table 4.13. Nitrogen uptake on P treatments and varieties in Kiboko, Kakamega and Alupe

Kg ha^{-1} P_2O_5	**Nitrogen Uptake (kg N Ha^{-1})**					
	Kiboko		**Kakamega**		**Alupe**	
	2014 SR	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	**2015 LR**
Control	489a	228a	629a	1293a	705c	452b
12.5	467a	216a	525a	1217a	778b	492b
25.0	485a	237a	582a	1131a	780b	503ab
37.5	487a	249a	527a	1252a	1057a	593a
$LSD_{0.05}$	NS	NS	NS	NS	91.4	94.6
Variety						
U-15	522a	238a	460b	1049b	842a	454c
P-224	477a	229a	582ab	1180b	845a	552b
L. Variety	447a	231a	655a	1440a	802a	592a
$LSD_{0.05}$	NS	NS	136.1	205.4	NS	39.5
PR×V	NS	NS	NS	NS	NS	*

†Values with the same letters within the column are not significantly different

The greater N-uptake with the application of only P is a factor to be considered in finger millet cultivation plans. The effects of fertilization at planting may continue to harvest as attested by higher N content, which declines with P application, therefore, if the uptake of higher amounts of N in P-fertilized stands continues through time, this could reduce soil N stocks in the soils, particularly under poor soil characteristic of peasant farmers. The higher N extraction at harvest could affect the sustainability of soil productivity, and this may, necessitate the need to carry out longer term experiments in order to study the changes in soil nutrient stocks as affected by P fertilization.

Phosphate rates influenced the total nitrogen uptake in finger millet with applied plots being significantly superior to the control. Phosphorus leads to elongation of meristematic tissues and since it is a major constituent of ADP and ATP-the energy currency in metabolic activities in plants, it led to greater photosynthetic rates which increased dry matter production that accumulated more nitrogen. The present trend on the increase in nitrogen uptake with increasing levels of P is in line with reports by Tomar *et al.* (1997) and Mishra and Giri (2004) who found that the increase in total uptake of N and P with nitrogen and phosphorus fertilization could be attributed to the fact that added P increased their availability to plants due to priming effect which in turn might have resulted in profuse shoot and root growth and activating greater absorption of nitrogen from the soil. Furthermore, it is well established that if symbiotic N_2-fixation then the N contents in plant parts are improved if phosphorus fertilization is improved through fertilization or even by biological means. These findings are in confirmation to the earlier reports of Tarafdar *et al.* (1995); Singh *et al.* (2004); Han *et al.* (2006); and Yadav *et al.* (2009). However, a different pattern was observed during the long rains season where increase in P rates led to

a drop in the nitrogen uptake in plants. Phosphorus deficiency restricts activity of meristematic sinks of plants and leads to a demand for assimilates in growth that are responsible for the reduction of source activity and partitioning of photo-assimilates. There are however no reports in favour of direct effect of P-deficiency on a storage sink. Highest nitrogen nutrient uptakes observed in Kakamega during the long rain was mainly due to the high availability of N in the respective study soils and also because of the high mineralization of organic N (Table 4.14). The beneficial effects on nutrient uptake could also be related to the improvement in soil physical properties which was also reported by Nambiar and Abrol (1989).

Ikhulule had the highest nitrogen uptake during the long rain season in Alupe and during both seasons in Kakamega (Table 4.13). This was probably due to its developed rooting system and vigorous vegetative growth that enhanced N uptake and accumulation of N in the plant. There were no significant differences between varieties in Kiboko during both seasons, partly due to the limited amount of N in the soils and the crops had the same high demand characteristics in acquiring the limited soluble N in the soil and that supplemented in topdressing. Recent research studies have demonstrated varietal differences in P efficiency as reported for rice (Sahrawat *et al.,* 2000), maize (Horst, 2000), legume cover crops (Vanlauwe *et al.,* 2000b), and several other crops of the tropical regions (Johansen *et al.,* 1991). Variety U-15 with P rates interactions were superior to that of varieties P-224 and Ekalakala at Kiboko while the local variety Ikhulule was superior to the other two varieties at Alupe and Kakamega.This might indicate that albeit the phosphate rates, the varieties were genetically superior at specific environmental conditions in facilitating efficientthe uptake and partitioning of N to the plant parts. In all the sites for both seasons

it was observed that the most uptake of N was to the grain while the least to the roots. This was probably due to the plants switching mechanism where most N was used for reproduction at the expense of vegetative growth especially at advanced stage of physiological maturity when they were sampled. These genotypic variations could also be due to the efficiency in acquisition of P and N from the rhizosphere, nitrogen use efficiency and phosphorus use efficiency as well as the internal mobilization of N in all parts of plant. Such variations could be explained mainly by the diversity of the finger millet genotypes which is highly influenced by the environmental conditions. Also, organic compounds secreted by the different varietal roots stimulated microbial activity in the rhizosphere, which might have also influenced the P availability which is related to N uptake since it is the source of ATP (Vanlauwe *et al.,* 2000b). Phosphorus and Nitrogen acquisition plays an important role for crop adaptation to low P and N soils and a higher internal P and N use efficiency could help to limit soil nutrient mining, especially in low-input farming conditions and this has been exhibited by varieties like U-15.

4.5 Nitrogen partitioning

The partitioning of nitrogen in finger millet varieties was different across the phosphate rates at all sites. The local varieties was observed to have the poorest partitioning of N to the grains as compared to the improved varieties U-15 and P-224 in all the sites (Figure 4.26). Ikhulule had 23% of N in the grains while Ekalakala had 31% compared to 39% and 43% of P-224 and U-15, respectively.

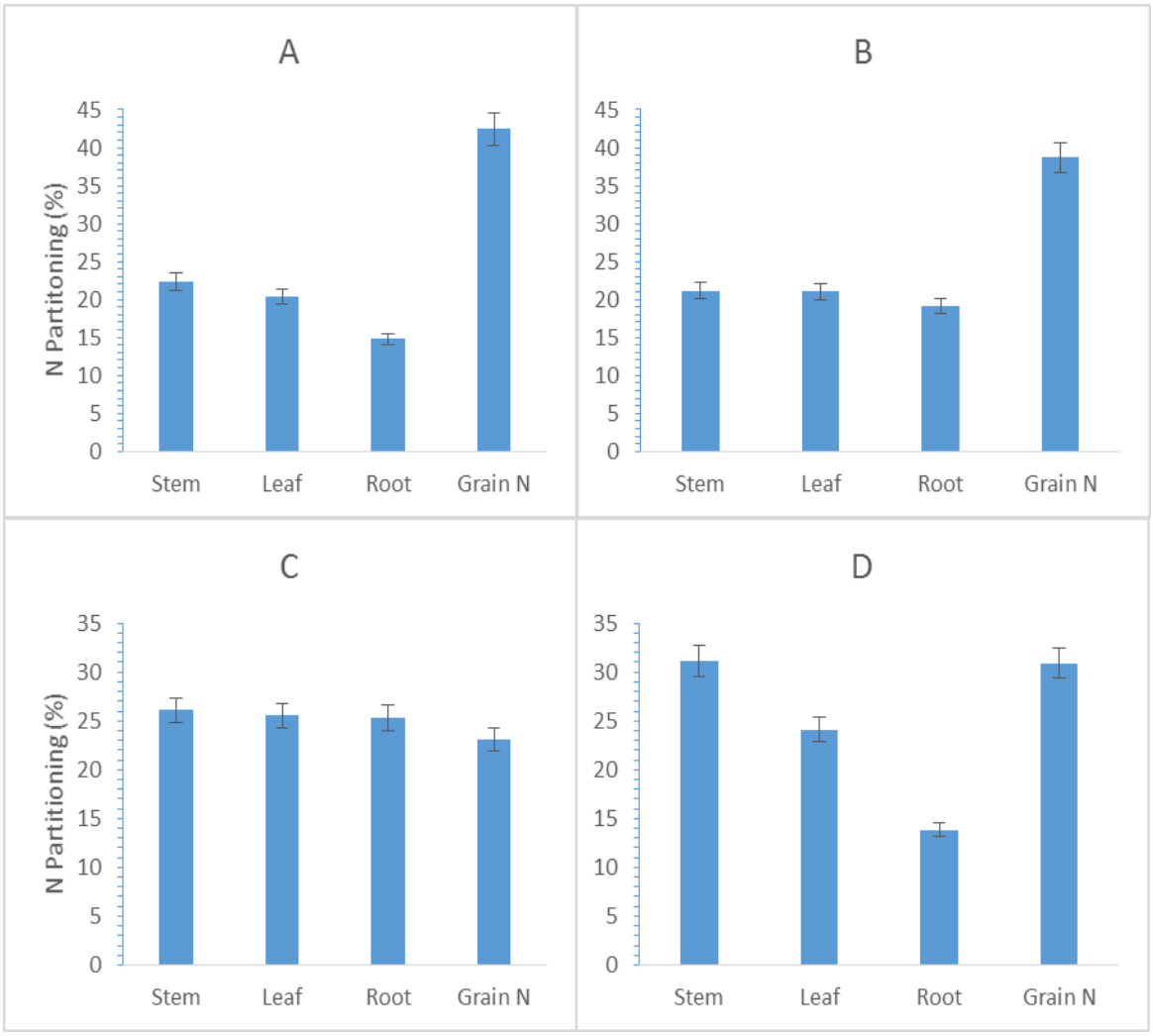

Figure 4.26. Mean nitrogen partitioning in U-15 (A), P-224 (B), Ikhulule (C) and Ekalakala (B) in the study sites

The amount of nitrogen partitioned to the roots were significantly different ($P \leq 0.05$) in Alupe for both seasons and in Kakamega due to phosphate fertilizer application (Figure 4.27). Nitrogen uptake increased linearly with increased phosphorus rates during the short and long rain and short rain seasons at Alupe site.

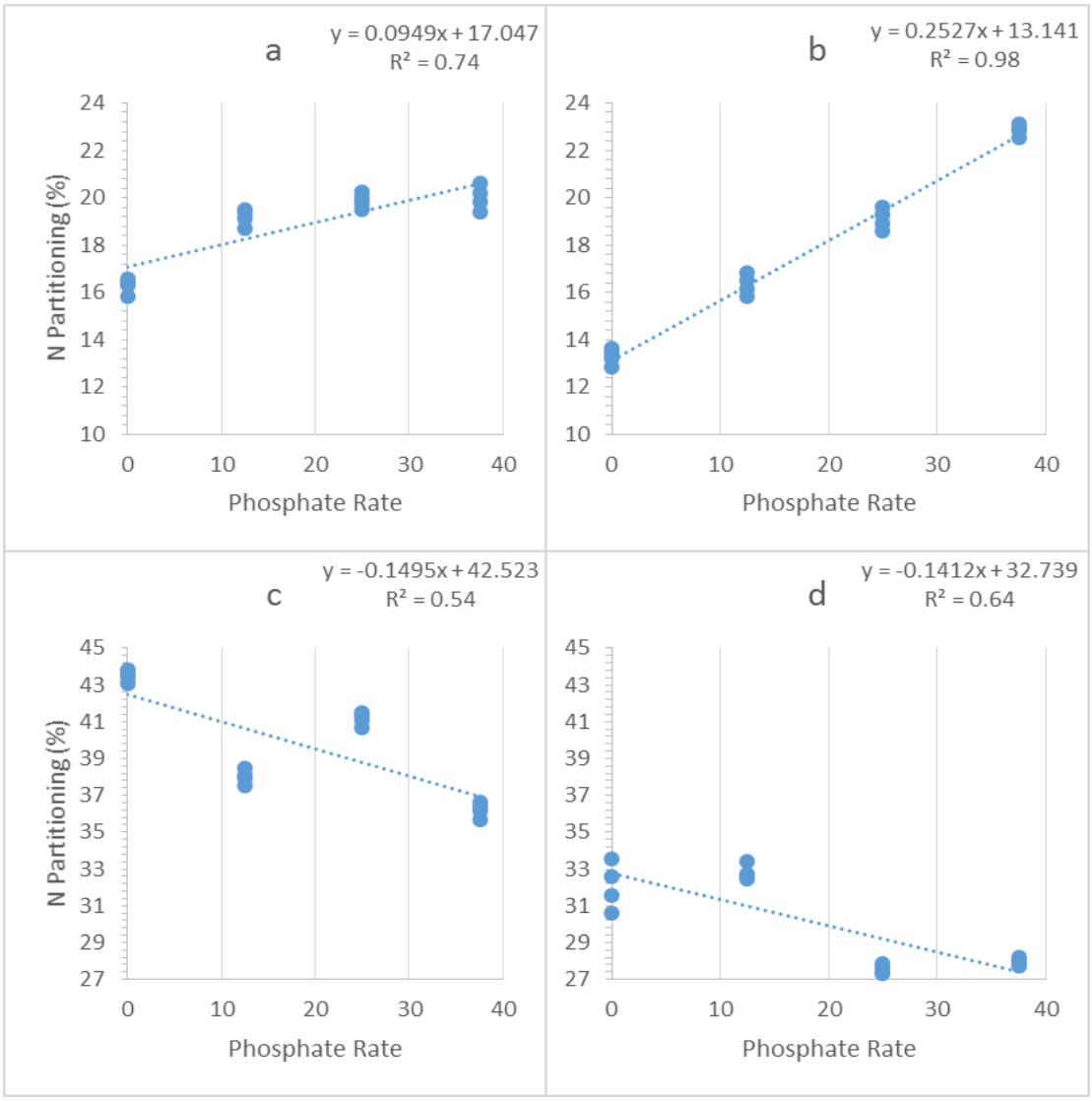

Figure 4.27. Nitrogen partitioning percentage as a linear function of the applied phosphorus in the root during the short (a) and long (b) rain seasons, and in the grain during the short (c) and long (d) rain seasons

The low concentration of N in the roots indicates the reduced uptake at the grain filling stage up to maturity when the sampling was done. There was likely to have been a higher and rapid soil exploration of N uptake by the roots from seedling to tillering stage then reduced thereafter due to more partitioning of more N to the reproductive parts of the crop. Earlier reports have indicated that the energy generated during photosynthesis and carbohydrate metabolism is stored in phosphate compounds and used later for growth and

reproduction (Ayub *et al.*, 2002). Nitrogen is readily translocated within the plants moving from older to younger tissues as the plant forms cells and develops roots, stems and leaves (Ali *et al.*, 2002). Ikhulule showed the highest amount of N accumulation in the roots in the Western Kenya sites because of its root growth architecture which is fast and vigorous colonization of the rhizosphere thus leading to maximum uptake of N compared to the other varieties. It was also observed that the variety showed the highest vegetative biomass at physiological maturity due to its capability to capture most N up the plant prompting increased vegetative growth.

The stem nitrogen contents showed significant differences among the P treatments with highest observed on the 12.5 kg ha^{-1} P_2O_5 application rate for both seasons in Alupe and Kakamega. There were no significant differences on the amount of N in the different P levels in Kiboko due to the optimal availability of P in the soils and additional P did not have significant influence. The lowest amount of N accumulation as shown in Figure 4.28 was observed on the 25.0 kg ha^{-1} P_2O_5 and 37.5 kg ha^{-1} P_2O_5 application rates where elevated P amounts led to reduction of N accumulation probably due to the limiting of other micronutrients by excessive phosphorus.

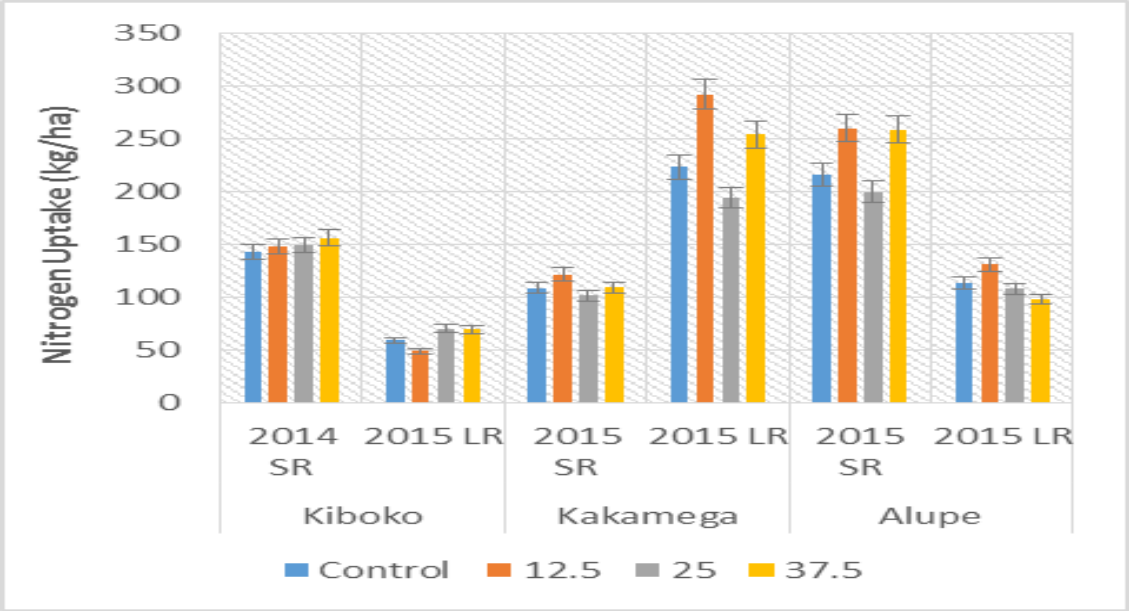

Figure 4.28. Effect of phosphate rates on the N uptake in finger millet stem

Decrease of N concentration in vegetative parts with ontogenic development of individual plants have also been demonstrated and reported in rice (Yang *et al.*, 2007). Varietal differences were not observed though the local check in western Kenya showed the highest uptake in the stem of the finger millet crop. This was due to its large stem girth which enhances higher accumulation of N.

The amount of N partitioned to the leaves at the physiological maturity increased significantly with increased P levels in Alupe during the short rain season where the highest was observed on the highest rate of 37.5 kg ha^{-1} P_2O_5. The long rains season showed a peak at 12.5 kg ha^{-1} P_2O_5 and a sharp drop followed thereafter.

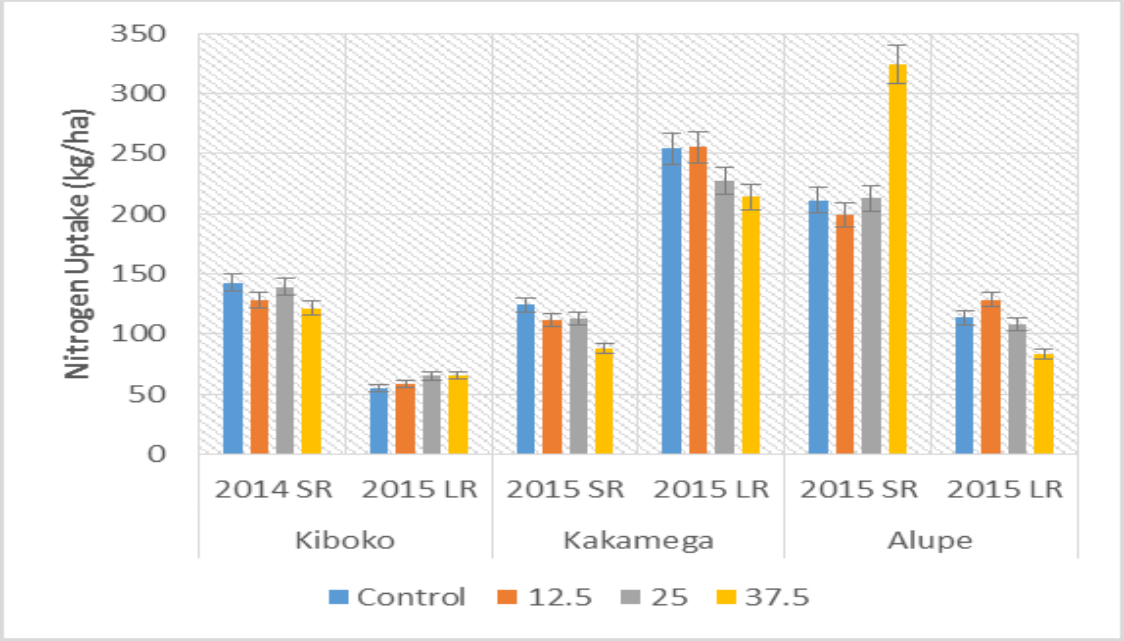

Figure 4.29. Effect of phosphate rates on the uptake of N in leaves of finger millet

It has also been found that fertilization with P did not increase N-concentration in plantation leaves but increased N-accumulation per hectare four-fold because of increased growth (Xu *et al.*, 2002). Chiera *et al.* (2002) reported that sub-optimal supply of phosphorus limits cell division at the meristematic apex of the shoot restricting development of newly developed leaves. In general, P-fertilization ameliorated leaf N content and presumably the photosynthetic capacity of the leaves of finger millet. Same findings were reported by Kirschbaum *et al.* (1992). Improved variety U-15 did indicate significantly the highest N uptake in the leaves in Kiboko during the short rains season with a mean of 162.9 kg N ha^{-1} while the local variety had the least with a mean of 107.8 kg N ha^{-1}. The same trend was observed during the long rains and it is due to the superiority of the variety in adaptation in the semi-arid conditions that increases N assimilation to the leaves that in turn increases the photosynthetic rate of the crop. The reverse was observed in Kakamega and Alupe where the local variety Ikhulule was

superior. The interaction between P-224 variety with 12.5 kg ha^{-1} P_2O_5 application rate showed significantly the highest amount of N in the leaves during the long rains season in Alupe and the same trend observed in Kakamega during the same period. In Kiboko, the interaction between U-15 and 12.5 kg ha^{-1} P_2O_5 application rate] had the highest amount of N in the leaves with a mean of 171.6 kg N ha^{-1}.

Application of P influenced the partitioning of N in the grains of finger millet at all sites for both seasons except in Kiboko during the short rains. As much as most N was partitioned to the grains, the application of different rates of P did not show any significant trend on influencing the amount of N uptake per hectare as shown on Figure 4.30 with a decrease shown with increasing P rates for Alupe (Figure 4.27).

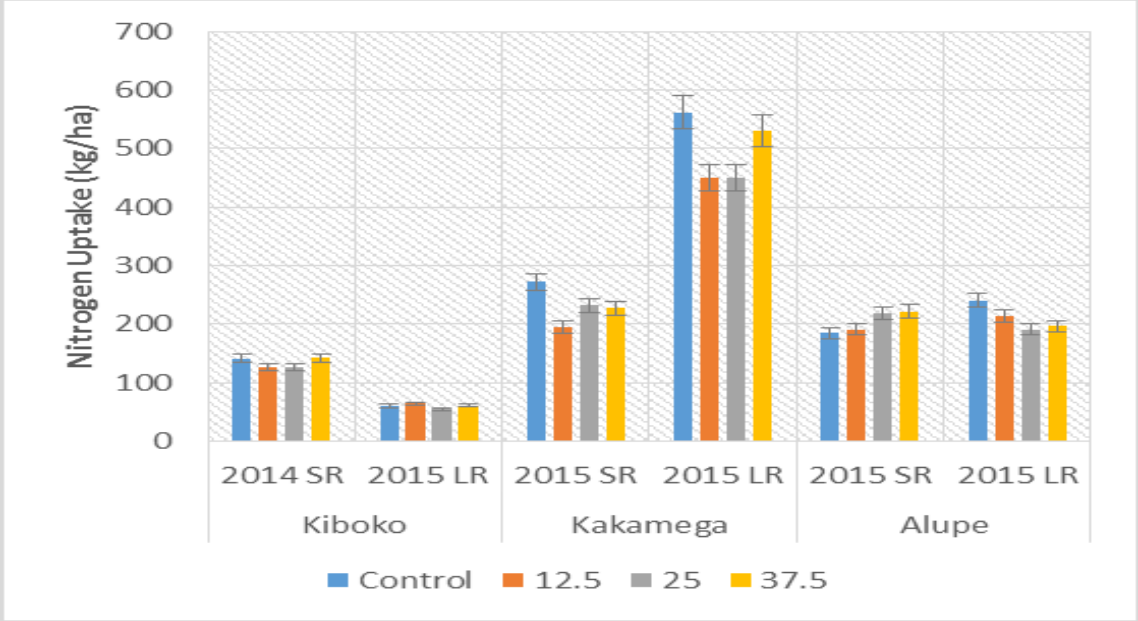

Figure 4.30. Finger millet grain nutrient uptake response to phosphate rates

It has been found that P-deficiency encouraged partitioning of N and P into the grains at the cost of autotrophic organs such as leaves and the stem (Pieters *et al.,* 2001). The

nutrient content of specific organs in the plant depends on their sink strength for that particular nutrient (Jakobsen, 1985). The grain contained highest N indicating they are strong sinks for N in finger millet. On the other hand, significant differences were observed between varieties in Kakamega for both seasons and during the long rains season in Kiboko where the local varieties were superior. Ikhulule had the greatest amount of N taken up and partitioned to the grains for both seasons in Kakamega and same for Ekalakala in Kiboko. No consistent trend was observed on interactions which were otherwise revealed with P-224 and 37.5 kg ha^{-1} P_2O_5 having the highest N uptake in Kakamega while in Kiboko U-15 and 12.5 kg ha^{-1} P_2O_5 had the highest uptake of N in the grains.

4.6 Soil chemical properties balances

The initial soil analysis showed adequate available P in Kiboko at an average of 13 ppm during the short rains and 15 ppm during the long rains as well as all the other elements except for N, organic C and Zn which were low at 0.032%, 0.24% and 1.45 mg/kg respectively during the short rains and 0.03%, 0.26% and 2.85 mg/kg, respectively during the long rains, the pH was strong alkaline with an average of 8.6 during the short rains and a mean of 9.3 during the long rains in Kiboko (Table 4.14).

The initial soil analysis in western Kenya showed low available P according to the scale by Okalebo *et al.* (1992) and Marx *et al.* (2011). Like at Kiboko, the soil mineral N were low as shown in Table 4.14.

Table 4.14. Soil chemical properties in Kiboko, Kakamega and Alupe prior to the start of the experiment

	Kiboko		Alupe		Kakamega	
	SR	**LR**	**SR**	**LR**	**SR**	**LR**
Soil pH	8.6	9.3	4.9	6.0	5.2	5.7
Nitrogen %	0.03	0.03	0.22	0.08	0.35	0.10
Total O. Carbon %	0.24	0.26	2.26	0.74	3.40	0.96
Phosphorus ppm	13	15	6	10	10	5
Potassium me%	0.56	1.54	0.25	0.34	0.5	1
Calcium me%	5.1	10.70	2.4	2.8	5.7	2.7
Magnesium me %	3.2	3.26	2.69	1.79	1.39	1.29
Manganese me%	0.27	0.14	1.11	0.74	0.73	0.16
Copper ppm	2.57	2.51	9.27	10.7	12.6	16.71
Iron ppm	28.5	44.16	39.9	41.5	55.1	59.3
Zinc ppm	1.45	2.85	4.19	5	9.38	9.99
Sodium me%	0.56	1.05	0.22	0.1	0.28	0.24
Elect. Cond. mS/cm	0.48	0.27	*	*	*	*
Exchangeable Acidity	*	*	0.3	0.3	0.3	0.3

It has been established that plants absorb P either as HPO_4^{2}or $H_2PO_4^{1-}$ ions. However, the concentration of soluble orthophosphates is found to be low in most soils, only around 1 mg kg^{-1} or lower and thus must be replenished from other sources to meet the plant phosphorus needs (Richardson *et al.,* 2009). P is supplemented through different industrial fertilizer formulations to counterbalance the stated nutritional deficiency experienced in crops. Still, only a small fraction of these chemical fertilizers can be used efficiently by plants, with the remaining portion being rapidly converted into insoluble complexes in the rhizosphere, without expected impacts on agricultural yield (Fernández *et al*., 2012). Due to sustainable agricultural needs in the current era it is vital to restrict fertilizer use in order

to improve the energetic balance of the ecosystem. This will allow the transformation, mobilization and solubilization of phosphorus from the limited pool and subsequent uptake by plants to achieve the crops genetic potential (Hinsinger *et al*., 2011).

4.6.1 Soil pH

The application of phosphate fertilizers under finger millet led to a decrease in the rhizosphere soil pH in all the sites in both seasons (Figure 4.31). Acidity was least enhanced on the control at all sites while 37.5 kg ha^{-1} P_2O_5 application rate had the greatest net decrease in Kakamega and Kiboko during the long rains. The highest net change was observed in Kiboko during the long rains cropping season where the pH dropped from a mean of 9.2 to 8.0. . This was probably due to phosphoric acid in the phosphate fertilizer which had an acidifying effect on the soil rhizosphere whereby it releases H^+ ions progressively to the soil and acidifying the soil surrounding the band. When the phosphate fertilizer was applied, it reacted with moisture to form phosphoric acid which progressively released hydrogen ions to the soil leading to an acidifying effect in the rhizosphere.

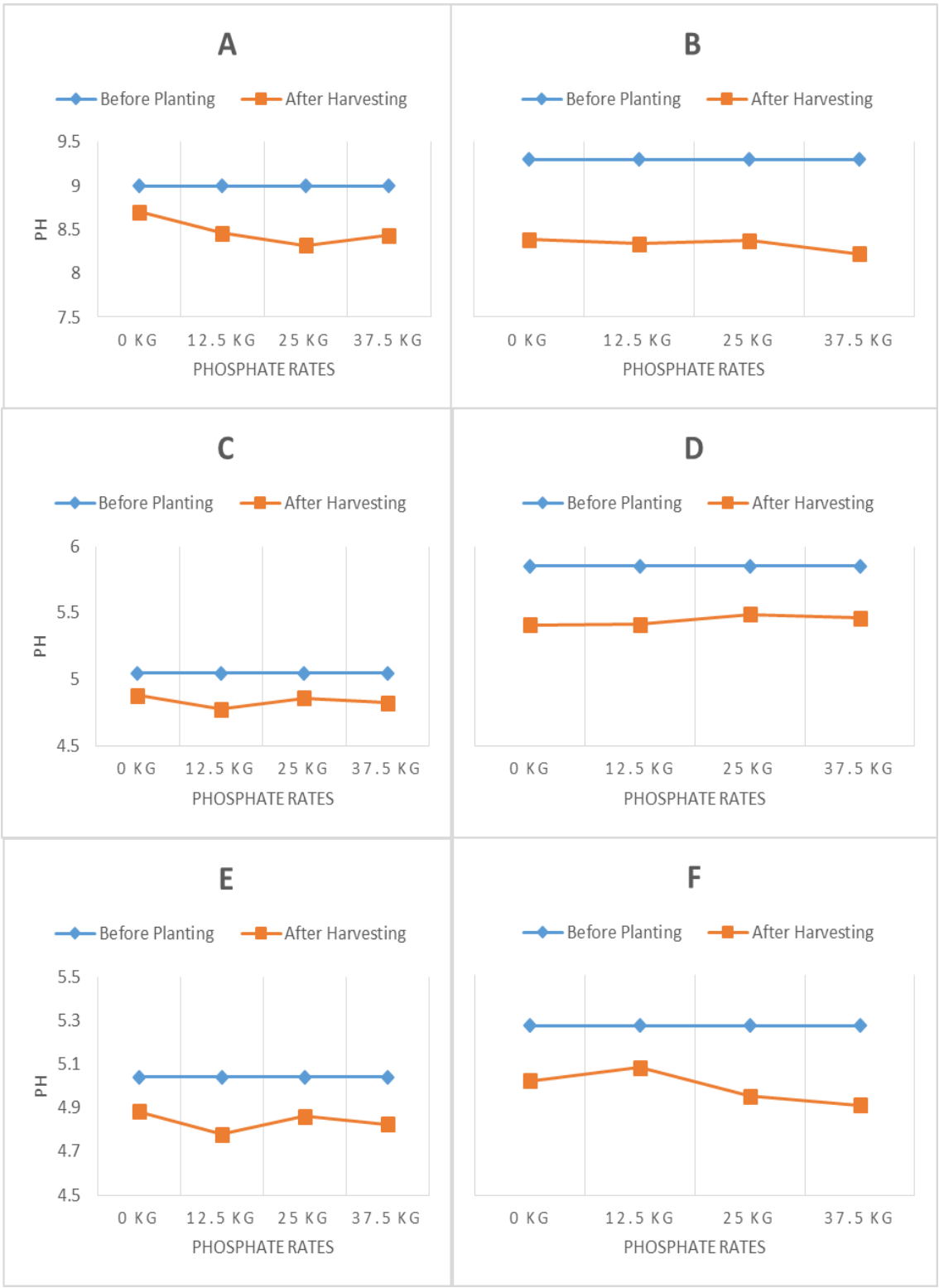

Figure 4.31. Effect of phosphate rates on the soil pH net change in Kiboko short (A) and long rains (B), Alupe short (C) and long (D) rains, and Kakamega short (E) and long (F) seasons.

A decrease in pH with increasing P fertilization has been highlighted in a previous report (James and van Israel, 2001) and was attributed to the acidity of P containing fertilizers. These results also concur with the findings of Tisdale *et al.* (1990) who reported that phosphoric acid released from dissolving phosphate fertilizers such as triple superphosphate and Mono-ammonium phosphate temporarily acidify localized zones at the site of application. They also found that TSP could lower the pH to as low as a mean of 1.5 while MAP could decrease pH to approximately a mean of 3.5. Their acidity has however been found to be rapidly neutralized, but the acidic reaction products may remain to influence the soil properties indicating the need for liming especially for such acid soils as an agronomic practice.

Soils with acid minerals contain certain levels of soluble exchangeable aluminum and iron as observed in Kakamega and Alupe. Therefore the more acid the soil has the more concentrated the aluminum and iron. Fixation of phosphate is much greater below a soil pH of 5.0. In addition to soluble and exchangeable Al and Fe, clay soils are sources of iron and aluminum that are capable of reacting with phosphate ions. In alkaline soils high calcium activity as observed in Kiboko encourages the formation of dicalcium phosphate. As much as dicalcium phosphate solubility is greater than that of iron and aluminum phosphates, it is high enough to supply plants with phosphate as observed in Kiboko (Wekha *et al*., 2016). A decrease on the control was also observed and this is probably due to the application of the blanket top-dress of Urea. This was ascribed by Abreha (2013) who noted that application of N fertilizers aggravated soil acidity through the activity of soil microorganisms that convert ammonia cations into nitrates with subsequent releases of H^+ cations as a byproduct and NO_3^- leaching. Lungu and Dynoodt (2008) also reported that

application of ammonium based fertilizers such as ammonium sulfate, ammonium nitrate and urea aggravated soil acidity. The increase in soil acidity in turn diminishes P intake by crops and raises the toxic ions concentration in soils and inhibits crop growth that jeopardizes future food security (Johannes, 2013). However contrasting findings were reported by Eduardo *et al.* (2013) who noted that different functional groups, that are part of soil OM pools (e.g., carboxylic groups), can release H^+, thereby creating a more acidic environment.

Varietal influence was not significant on the soil pH where and interactions were observed where each variety with the highest rates had the highest negative change on the soil pH.

4.6.2 Soil Nitrogen

The amount of rhizosphere soil N increased in the soils due to application of P at all sites except at Alupe during the short rains season. Phosphate rates increase led to increased amount of mineral N in Alupe and Kakamega during the long rains (Table 4.15).

Table 4.15. Varietal and phosphate rates influence on the soil mineral nitrogen net change

	Mineral-N Net Change (%)					
Kg ha^{-1}	**Kiboko**		**Kakamega**		**Alupe**	
P_2O_5	**2014 SR**	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	2015 LR
0 kg	0.0139a	0.0465a	0.018c	0.114a	-0.047b	0.0706b
12.5 kg	0.001b	0.0534a	0.115b	0.133a	-0.05b	0.0702b
25.0 kg	0.0049c	0.0467a	0.176a	0.127a	-0.029a	0.0803a
37.5 kg	0.0056d	0.0497a	0.174a	0.127a	-0.07c	0.0853a
$LSD_{0.05}$	0.02	NS	0.020	NS	0.01	0.01
Variety						
U-15	0.0093a	0.0523a	0.07c	0.08c	-0.044a	0.098a
P-224	-0.0066c	0.0448a	0.118b	0.138b	-0.044a	0.075b
L. Variety	0.0008b	0.0500a	0.392a	0.158a	-0.058b	0.057c
$LSD_{0.05}$	0.001	NS	0.02	0.02	0.005	0.009
PR×V	***	***	***	***	***	***

†Values with the same letters within the column are not significantly different

The amount of total and mineral N for Kiboko were inconsistent and no particular pattern could be drawn due to the optimal availability of P in the study soils. Varietal differences were inconsistent on the net change in the soils of western Kenya but in Kiboko Ekalakala led to the highest net increase of soil mineral N for both seasons. The N increase on the control could be due to mineralization of unavailable N forms and organic matter plus residues from previous crop through microbial activity. In Kiboko, it was majorly due to the availability of adequate P in the study soils and hence application of more P did not have major influence on soil mineral N. Microbial growth in the soil requires specific carbon, nitrogen and phosphorus ratios and thus microbial population growth is determined by balances in carbon, nitrogen and phosphorous dynamics and this could be also attributed to the continued mineralization and nitrification process with the addition of the Urea at top dressing. Olsen *et al.* (1962) suggested that the N-P interaction was a result of complex biological, chemical and physical factors functioning in the fertilized zones of rhizosphere. Nitrogen turnover in soils is closely related to carbon as reported by Feng and Li (2002) and therefore as the organic carbon increased so did the N in the soil as observed in Kakamega for both seasons.

4.6.3 Soil organic Carbon

There were significant changes ($P \leq 0.05$) on the amount of rhizosphere soil organic carbon but not with a conclusive trend. This could be due to the decomposition of residual materials in the soils that had different rates effecting the treatments differently (Wekha *et al.*, 2016). There was also an increase on the amount of total organic carbon at all sites except in Alupe during the long rains where a decrease was observed (Table 4.16). This was due to decrease in total N which was observed in the same period that was probably

due to low mineralization of organic matter in the soil. However in Kakamega there was an increase in the total organic carbon as the P rates increased. The control had the lowest increase of 1.61% while 12.5 kg ha^{-1} P_2O_5 treatment had the highest (1.79%) and thereafter a drop was observed. The improved variety U-15 had the highest net increase of the organic carbon in Kakamega during the long rains season with 2.08% whereas the local variety did indicate the lowest

Table 4.16. Varietal and phosphate rates influence on the soil total organic carbon net change

	Total Organic Carbon (%)					
Kg ha^{-1}	**Kiboko**		**Kakamega**		**Alupe**	
P_2O_5	**2014 SR**	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	**2015 LR**
0 kg	0.086a	0.383a	0.966d	1.613c	-0.304a	1.194a
12.5 kg	0.023b	0.390a	1.185c	1.793a	-0.410a	1.147a
25.0 kg	-0.077c	0.357b	1.297b	1.673b	-0.343a	1.160a
37.5 kg	0.0238b	0.39a	1.440a	1.623c	-0.323a	1.146a
$LSD_{0.05}$	0.008	0.013	0.020	0.034	NS	NS
Variety						
U-15	0.054a	0.380b	2.158a	2.078a	-0.279a	1.095b
P-224	-0.033c	0.345c	1.684b	1.887b	-0.363a	1.172a
L. Variety	0.023b	0.415a	1.129c	1.063c	-0.393a	1.218a
$LSD_{0.05}$	0.007	0.023	0.032	0.030	NS	0.057
PR×V	***	***	***	***	***	***

†Values with the same letters within the column are not significantly different

The soil organic carbon is a mixture of plant and animal residues at different stages of decomposition and substances synthesized microbiologically and or chemically from products breakdown (Kimble *et al.,* 2002). The soil inorganic carbon includes the elements of carbon and carbonates. Therefore from the results it shows that phosphorus plays a major role in activation of the inorganic and organic elements in the soil. Increase in the soil organic carbon does enhances soil quality, reduces degradation and erosion, improves

surface water quality, and generally increases soil productivity. Increasing soil organic carbon in agricultural soils through proper management allows carbon sequestration that provides a multitude of environmental benefits.

4.6.4 Soil Phosphorus

Application of phosphate fertilizers led to a significant ($P \leq 0.05$) increase in the amount of phosphorus in the rhizosphere soil at all sites during both seasons (Figure 4.32). The highest net increase in Kiboko was observed on the 12.5 kg ha^{-1} P_2O_5 treatment with a mean of 8.7 ppm and 11.3 ppm during the short and long rains respectively. In western Kenya sites Alupe and Kakamega, the greatest net increase was observed on the 12.5 kg ha^{-1} P_2O_5 and 25.0 kg ha^{-1} P_2O_5 treatments with the highest (5.7 ppm) observed in Alupe during the long rains season on the 25.0 kg ha^{-1} P_2O_5 treatment. The control did indicate the lowest net gain on the soil available P in both sites for both seasons (Figure 4.32). Varietal influence was significant on the soil phosphorus concentration where treatments under U-15 (7.29 ppm) and P-224 had the highest net increase (7.06 ppm) during the short rains in Kiboko while P-224 (4.08 ppm) was highest in Alupe during the short rains and Ikhulule (5.00 ppm) during the long rains and U-15 in Kakamega with 6.25 ppm during the long rains and 4.75 ppm during the long rains. This indicates a greater soil nutrient recycling of P under improved varieties.

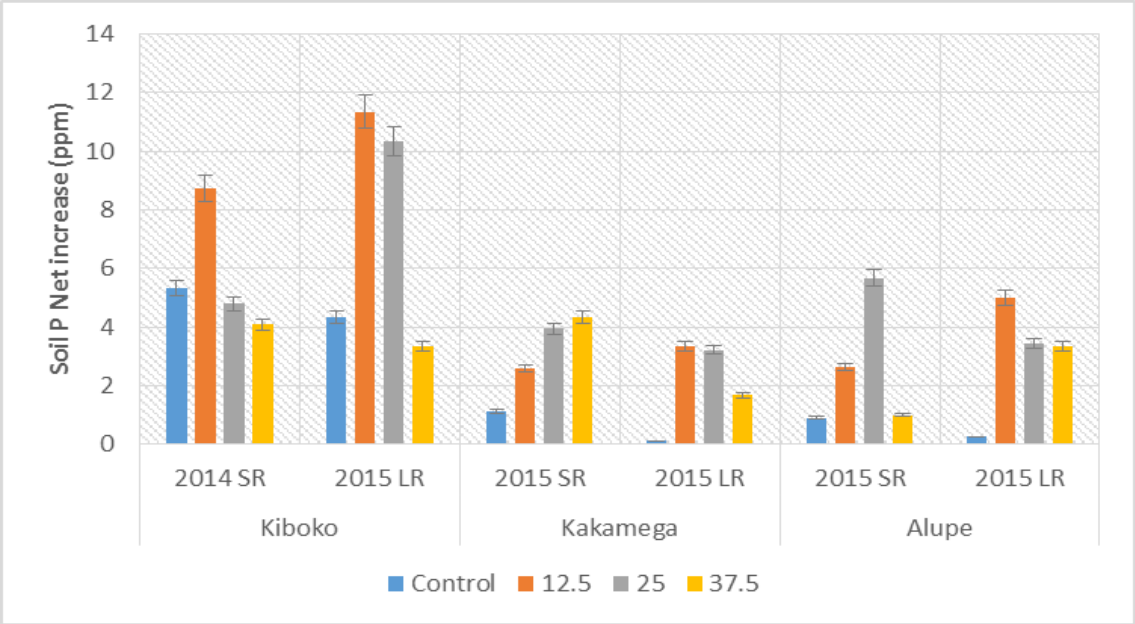

Figure 4.32. Phosphate rates influence on the net change of soil P in the study sites

Kiboko showed the highest net increase during the long rains season due to the low uptake rate of applied P because of low soil moisture which is fundamental in diffusion of P which enhances uptake. Dissolution and diffusion rate of solid phase phosphate to solution phosphate dictated the soil phosphate availability where moisture is of great importance for the transformation. Phosphate added to soil reacted with the solid phase where fixed P was not completely lost because it slowly became available to plants over time depending on soil and the phosphorus compound type. It has been found that fixed P is not entirely lost but it becomes slowly available to crops over several years depending on soil and P compound type. This finding is consistent with those of Troeh and Thompson (1993) who found that phosphorus is held firmly and hence unavailable to plants until the organic material in the soil environment decomposes, and concluded that plant roots and rhizosphere organisms which are found around plant roots excrete phosphatase enzymes

capable of hydrolyzing some organic phosphate compounds, releasing inorganic phosphate for absorption by the plants.

4.6.5 Soil Potassium

The content of K in the rhizosphere soil significantly ($P \leq 0.05$) dropped at all sites in both seasons due to P application. These results agree with the report by Marschner (1995) that potassium is not part of the structure of organic compounds and thus it is rapidly depleted in soil during plants' growing period. The control and the highest P rate had the highest net decrease of K in Kiboko and Alupe for both seasons (Figure 4.33). This might be due to increased root development and vigorous growth that led to higher uptake of K which was not supplemented during the growing period. It has been reported that extremely efficient mechanisms are found in higher plants to take up K at even very low concentrations in the soil solution (Gommers *et al.*, 2005). This creates a gradient in the roots, creating a favorable environment for release of non-exchangeable K forms. This causes a permanent buffering of exchangeable and nonexchangeable K forms that are adsorbed with both low and high bond energy in soils (Kaminski *et al*., 2007).

Treatments under Ekalakala led to the greatest decrease of K in the soil in Kiboko while P-224 had the greatest in Alupe and the local variety, Ikhulule in Kakamega. This was probably due to the root and growth architecture of the varieties which enhanced uptake of K in the study sites.

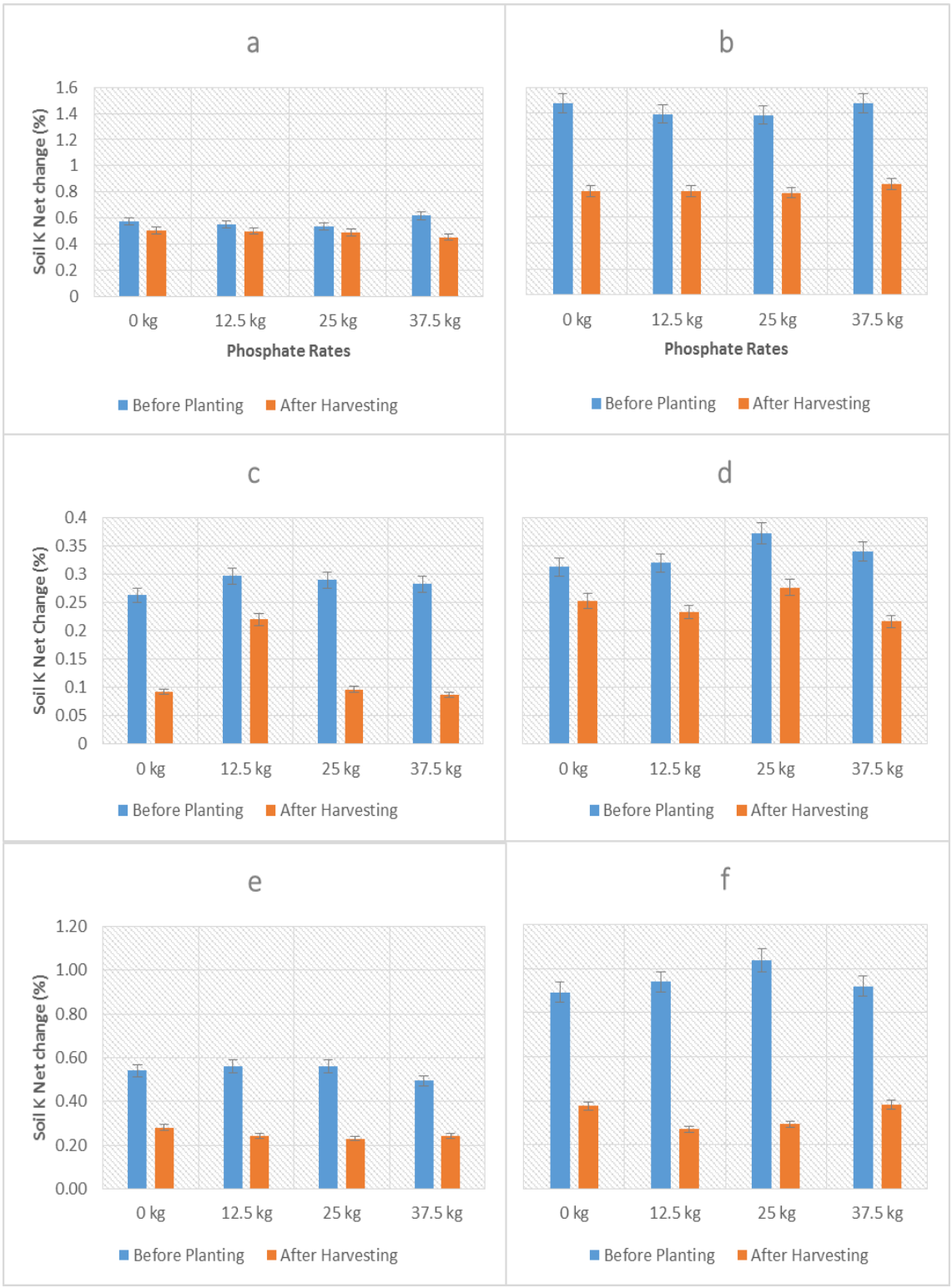

Figure 4.33. Potassium net change due to phosphorus fertilizer rates in Kiboko short (a) and long (b), Alupe short (c) and long (d), and Kakamega short (e) and long (f) rains seasons

4.6.6 Soil Calcium

There were significant differences (P≤0.05) in the net amount of rhizosphere soil Ca at all sites but with inconsistent results (Table 4.17). The control had the least net increase during the short rains season in Kiboko and the highest net decrease was observed during the long rain season. The same pattern was observed in Alupe while in Kakamega the reverse was observed where the control showed the highest soil calcium increase. Varietal influence and interactions did not show a consistent pattern.

Table 4.17. Influence of phosphate fertilizer rates and variety on net soil calcium change

	Calcium (%)					
Kg ha^{-1}	**Kiboko**		**Kakamega**		**Alupe**	
P_2O_5	**2014 SR**	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	**2015 LR**
0 kg	0.96c	-6.43d	0.89d	2.40a	-1.14c	1.40b
12.5 kg	1.71a	-4.23a	1.37c	2.00b	-0.82a	1.47b
25.0 kg	1.44b	-5.36b	2.54a	1.77d	-1.07b	2.40a
37.5 kg	1.64a	-5.76c	2.85b	1.96c	-1.08b	1.13c
$LSD_{0.05}$	0.170	0.158	0.141	0.122	0.063	0.169
Variety						
U-15	2.00c	-5.55b	1.42c	1.55c	-0.96a	1.40b
P-224	1.54b	-6.05a	1.87b	1.90b	-1.14b	2.25a
L. Variety	0.77a	-4.75c	2.72a	2.64a	-0.98b	1.15c
$LSD_{0.05}$	0.147	0.137	0.213	0.106	0.054	0.147
PR×V	***	***	***	***	**	***

†Values with the same letters within the column are not significantly different

The same results as for the current result on the increase of calcium has earlier been reported that Phosphorus (P) application enhances soil calcium by improving the cation exchange capacity and buffering capacity of the soil (Gachene and Kimaru, 2003).

4.6.7 Soil Magnesium

Application of P rates showed significant influence (P≤0.05) on the amount of rhizosphere soil Mg where a net increase was observed in Kiboko with 12.5 kg ha^{-1} P_2O_5 and 37.5 kg

ha^{-1} P_2O_5 treatments showing the highest net increase in the short (0.485%)and long (0.767%) rains seasons respectively. In Alupe there was a net decrease on the soil Mg for both seasons where the 37.5 kg ha^{-1} P_2O_5 treatment had the greatest net decrease (-1.307%) for the long rains season while the 25.0 kg ha^{-1} P_2O_5 treatment had the most net decrease (-0.869%) of Mg during the short rains season. In Kakamega, the 12.5 kg ha^{-1} P_2O_5 treatment elicited the highest increase (0.894% and 0.795%) of soil Mg during the short and long rain seasons respectively. Varietal influence ($P \leq 0.05$) were observed on the soil Mg where Ekalakala had the highest net increase (0.455%) during the short rains while U-15 was the most influential in the net increase (0.812%) during the long rains season in Kiboko. U-15 again showed the greatest influence on the net increase (0.850% in the short rain and 0.755% in the long rain) of Mg in Kakamega. The highest net decrease of soil Mg in Alupe was under the local variety Ikhulule during the short rain (-0.855%) and the lowest under P-224 in the long rain season (-1.325%).

4.6.8 Soil Iron

The amount of iron in the rhizosphere soil drastically reduced in Kiboko during the long rains and Kakamega due to application of phosphate fertilizers with 37.5 kg ha^{-1} P_2O_5 application rate showing the highest iron. During the same period the control had the lowest net decrease in Kiboko. The opposite was observed during the short rain season in Kiboko where an increase was observed with the control showing the lowest increase. The same trend was observed in Alupe where the control had the lowest net increase of iron content in soil for both seasons (Figure 4.34). The P applied treatments had differing quantities without a definite pattern but had greater increase of Fe compared to the control.

Interactions were revealed in all sites but without a conclusive pattern due to climatic and soil differences.

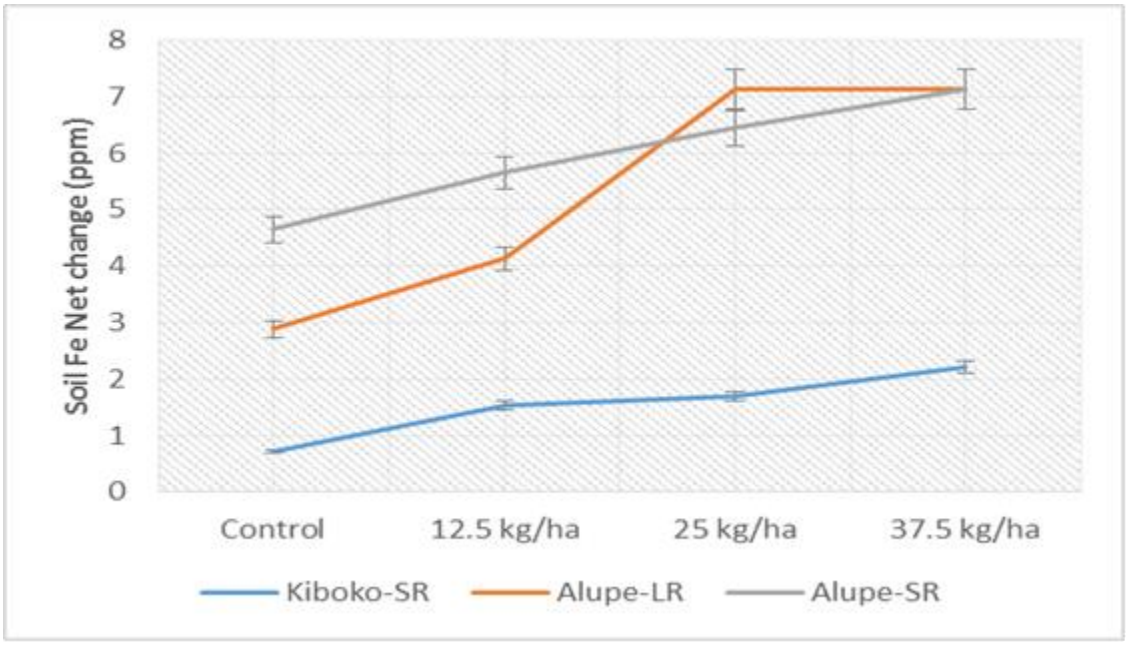

Figure 4.34. Soil change on iron content due to phosphate rates in Alupe and Kiboko

4.6.9 Soil Zinc

Phosphate rates had significant influence ($P \leq 0.05$) on the rhizosphere soil zinc with a decrease observed across the sites. Greatest net decrease was observed with the highest P rate of 37.5 kg ha^{-1} P_2O_5 while the lowest with the control in Kiboko and Kakamega for both seasons and in Alupe during the long rains season (Figure 4.35). As like most of the other nutrients in the soil, interactions were revealed but with inconsistent patterns across sites and seasons with the soil chemical and physical properties plus the weather conditions playing a major role.

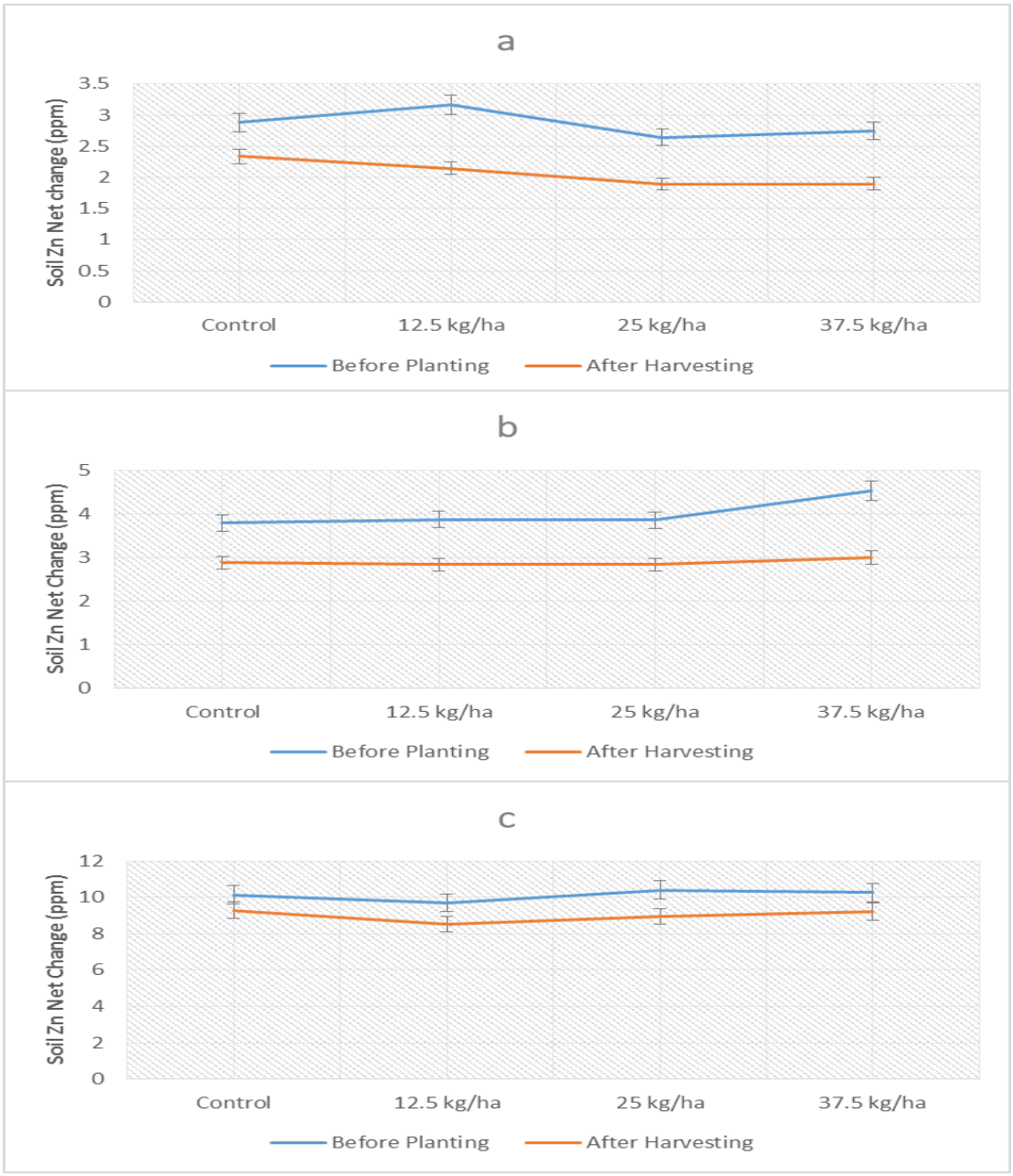

Figure 4.35. Phosphate rates effect on the soil zinc net change in Kiboko (a), Alupe (b) and Kakamega (c) during the long rains season

Zinc concentration decreased with application of phosphorus fertilizer to further confirm that Zn is mobile and its interaction with phosphate reduces its availability. This findings does not support the assertions of Vaněk *et al*. (2005) that Zinc and Cadmium are highly mobile and available in the soil especially under higher P levels.

4.6.10 Soil Sodium

The amount of sodium in the rhizosphere soil changed due to application of phosphate fertilizers whereby it increased during the short rains and decreased during the long rains in Kiboko. Also similar findings were reported in a study by other scientists (Maroeto *et al*., 2007; Rachman *et al*., 2008) on the increase of soil Na that soils under irrigation have higher Na and generally the EC due to experimental units which tend to restrain saline water and mud particularly on the surface layer. The highest positive (0.122%) and negative (-0.329%) change were observed on the 25 kg ha^{-1} P_2O_5 treatment in the short and long rains respectively while the least positive (0.065%) and negative (-0.066%) during the short and long rains respectively was observed on the control in Kiboko. In Alupe and Kakamega the control was on the extreme with highest net increase and decrease however with an inconsistent pattern on the P treatments. P-224 had the most positive influence in Kiboko and Alupe on the soil sodium while U-15 in Kakamega. There was no clear-cut conclusion on the balances due to varieties on sodium probably due to differing weather conditions.

4.6.11 Soil Manganese

The amount of rhizosphere soil Mn was significantly ($P \leq 0.05$) influenced by phosphate fertilizer rates at all sites. In Kiboko the 12.5 kg ha^{-1} P_2O_5 treatment led to the greatest net increase for both seasons with 0.076% during the short rain and 0.28% during the long rain season. As an increase was observed in Kiboko for soil Mn content there was a decrease in the other sites where the control had the most in Alupe (-0.26%) during the long rains cropping season. During the short rains season the control again had the most net decrease on soil Mn (-0.647%). This signifies that P is fundamental in maintaining the balances of

Mn in the rhizosphere and its application therefore probably enhances the availability of Mn in the soil. Varietal influence was observed in all the sites without any conclusive trend.

4.6.12 Soil Copper

Copper in the rhizoshere soil increased with application of phosphate fertilizer except in Kakamega where it decreased. The application rate of 37.5 kg ha^{-1} P_2O_5 showed the highest soil increase in Alupe for the long and short rains season (Figure 4.36). On the other hand, the greatest net drop was observed on the same treatment in Kakamega with inconsistent pattern for both seasons. Differing and inconsistent patterns were observed on the varieties as well as their interactions with phosphate rates.

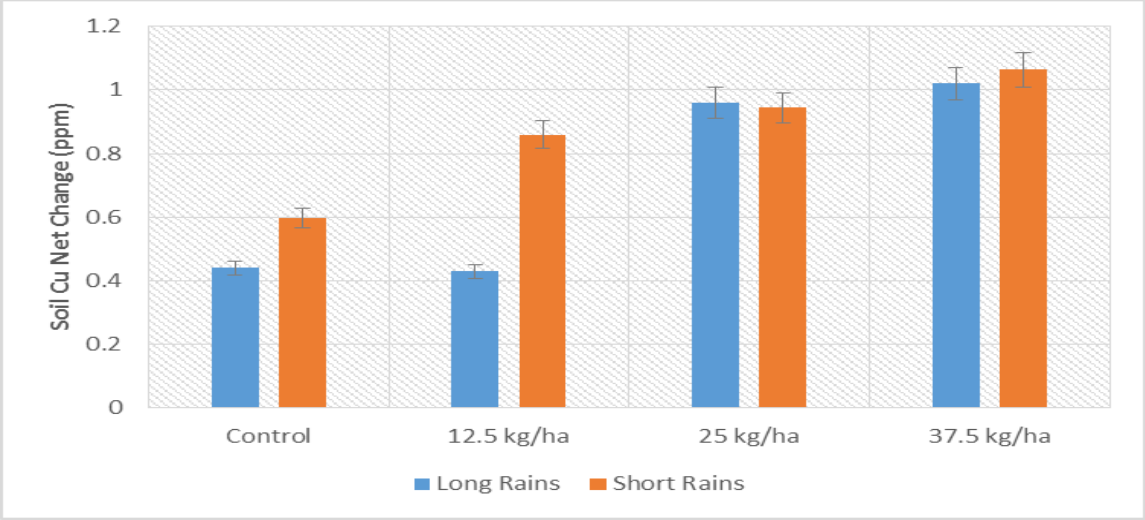

Figure 4.36. Copper soil net change due to phosphorus levels in Alupe during the short and long rains

The increase in copper due to application of phosphorus in this experiment is consistent with the findings of Oyedele *et al.* (2006) who found that applying phosphate fertilizers does increase the amount of heavy metals like Cu in the soils.

4.6.13 Soil Electrical Conductivity

Treatments influenced significantly ($P \leq 0.05$) the electrical conductivity in the rhizosphere soil for both seasons in Kiboko. The control and 25 kg ha^{-1} P_2O_5 treatment had a significantly higher balance of 0.11 mS/cm and 0.1 mS/cm respectively during the short rains while the control had the lowest net gain of 0.56 mS/cm during the long rains where the other treatments were significantly different with 37.5 kg ha^{-1} P_2O_5 showing the highest net gain of 1.03 mS/cm (Figure 4.37). Variety P-224 had the highest gain for the varieties with a net gain of 0.09 mS/cm during the short rains while U-15 had the highest net gain of 0.77 mS/cm during the long rains. The interaction between U-15 and 37.5 kg ha^{-1} P_2O_5 had the greatest increase of 1.28 mS/cm during the long rains.

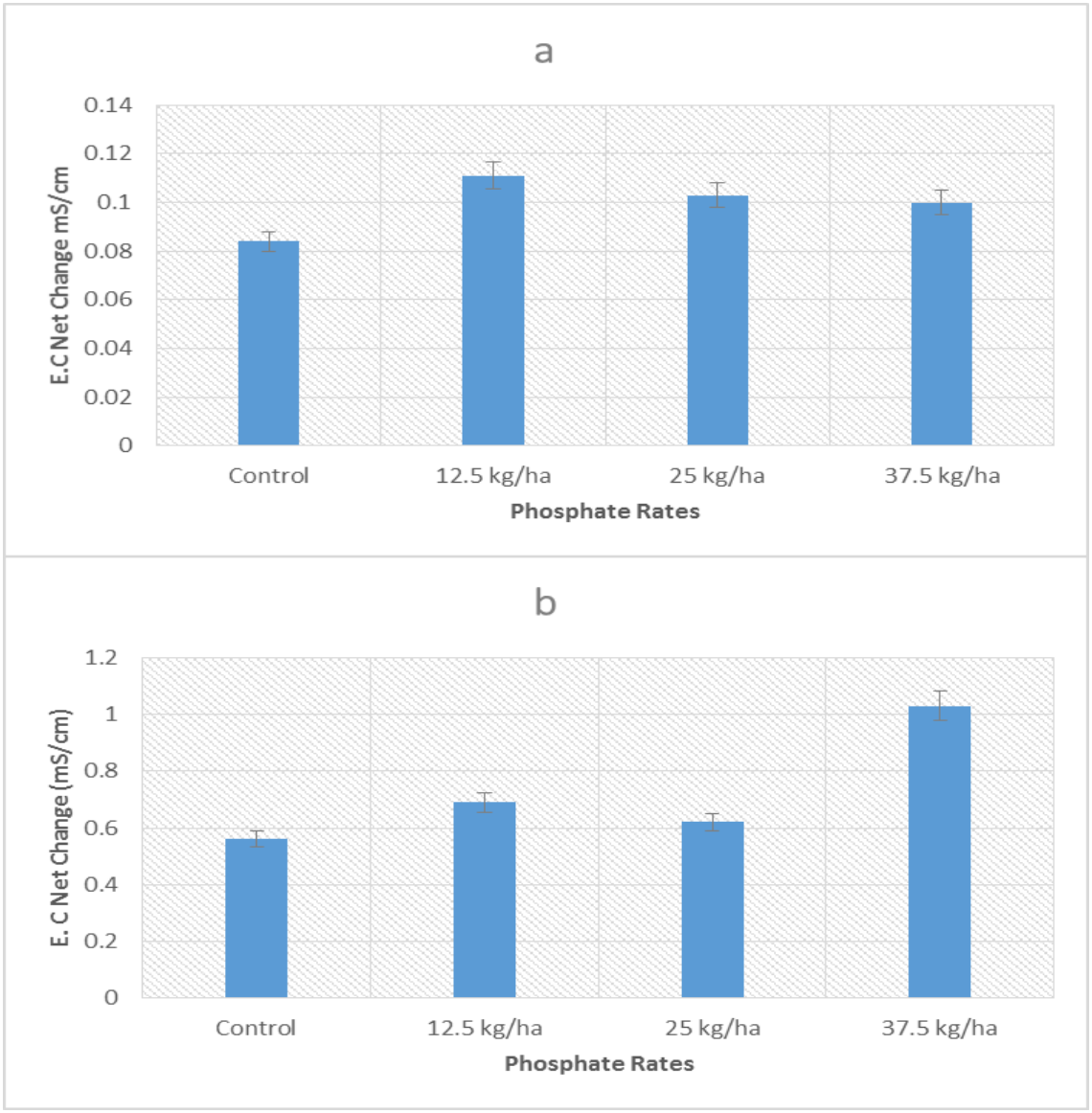

Figure 4.37. Soil electrical conductivity as influenced by phosphate rates in Kiboko short (a) and long (b) rains

The soil solution electrical conductivity (EC) is determined by the ion concentration especially of Na. Therefore the EC might have increased with the level of soil salinity due to irrigation which contained significantly higher amounts of soluble salts and the phosphorus pentoxide contained in the phosphate fertilizer. Similar findings were reported by Wong *et al.* (1999)

4.6.14 Exchangeable Acidity

Application of phosphate fertilizers led to an increase in the soil exchangeable acidity in western Kenya sites for both seasons (Figure 4.38). Increase in P rates led to an increase in the exchangeable acidity capacity with a peak observed at 25.0 kg ha^{-1} P_2O_5 application rate then a drop followed thereafter with further increase while the control did have the lowest net change for both seasons. Varietal differences were observed but without definite trends in both sites and the P influence might have not super ceded that of variety.

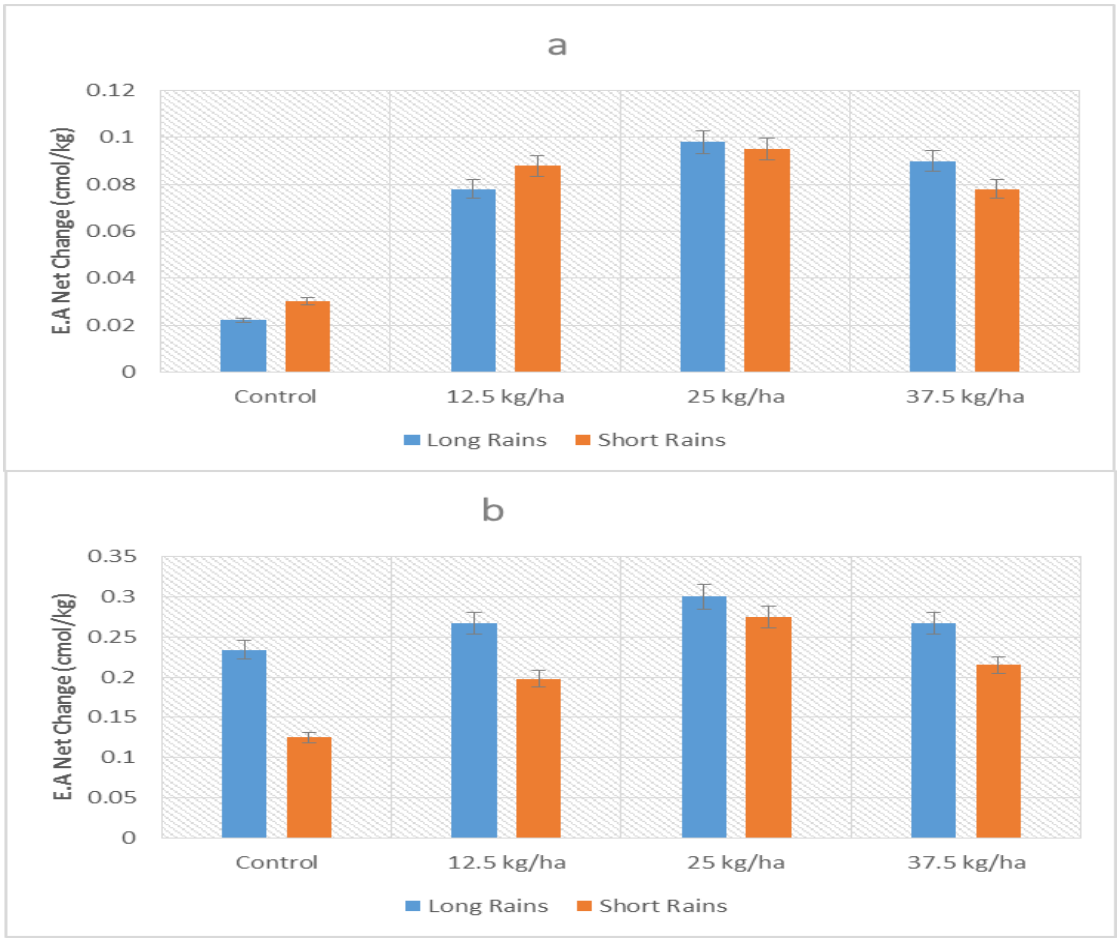

Figure 4.38. Exchangeable acidity dynamics in Alupe (top) and Kakamega (bottom) due to phosphorus fertilizer rates

4.7 Associations between traits

The grain yield was positively and significantly correlated (P<0.001) to the total dry biomass, total fresh biomass, dry panicle biomass, fresh panicle biomass, plant height, productive aerial tillers, productive basal tillers, and the leaf blade length (P<0.01) across the study sites as shown on Table 4.18 below. Low but significant (P<0.001) correlations were observed between the grain yield and the total aerial tillers, total basal tillers, days to 50% flowering, days to maturity and at P<0.05 there was the grains per spikelet, seedling vigor and the threshability percentage.

Table 4.18. Path correlation coefficients for grain yield with positively correlated components across the sites

	Path Coefficients on Grain Yield
Dry Panicle biomass	0.979***
Dry straw biomass	0.8647***
Fresh Panicle biomass	0.9562***
Fresh straw biomass	0.8994***
Leaf blade Length	0.8414**
Productive aerial tillers	0.5639***
Productive basal tillers	0.4549***
Plant height	0.4829**
Total dry biomass	0.9407***
Total fresh biomass	0.9254***
	Path Coefficients on Grain Yield
Total aerial tillers	0.3016***
Total basal tillers	0.3825***
Days to 50% Flowering	0.2526***
Days to Maturity	0.2865***
Grains per Spikelet	0.1672*
Seedling Vigor	0.1592*
Threshing %	0.1706*

†***=significant at P≤0.001, **=significant at P≤0.001, *=significant at P≤0.05

Phosphate fertilizer did directly impact on the total fresh and dry biomass which had high effects on the yield in the P-deficient soils in Kakamega and Alupe. Phosphorus is known to be important in synthesis and part of ATP which is important in energy transfers in the plants and optimal levels do therefore elevate biomass increment. The same results have been reported by Sonnad *et al.* (2008) and Priyadharshini *et al*. (2011). The 25.0 kg ha^{-1} P_2O_5 treatment did indicate the peak on biomass and thus led to highest yields at that point with an increase to 37.5 kg ha^{-1} P_2O_5 being detrimental. The local variety did indicate highest biomass but its low conversion capability on the grain yield was lower compared to P-224 which had as high biomass but with greater nutrient conversion rate on the grain yield.

Table 4.19. Spearman's rank correlation coefficients between seven (7) quantitative traits in Alupe

Long Rains-Alupe								
1000-Grain-weight	1	-						
Finger length	2	-0.2283	-					
Finger per panicle	3	-0.1120	0.3286*	-				
Finger width	4	-0.1458	0.1447	0.2337	-			
Grain yield	5	0.2069	0.1875	0.2679	0.1862	-		
Harvest Index	6	0.2404	0.1747	-0.2463	-0.4251	-0.2585	-	
Leaf Number	7	0.1321	0.5222**	0.3169	0.3169	0.1747	0.2254	-
		1	2	3	4	5	6	7
Short Rains-Alupe								
1000-Grain-weight	1	-						
Finger length	2	-0.2298	-					
Finger per panicle	3	-0.2837	0.5628***	-				
Finger width	4	0.1168	0.2772	0.1546	-			
Grain yield	5	0.1342	0.4301**	0.4336**	0.2393	-		
Harvest Index	6	-0.1074	0.3087*	0.3386*	0.3542*	0.1632*	-	
Leaf Number	7	0.4201	0.2987*	0.2169**	0.0436	0.4823**	-0.34*	-
		1	2	3	4	5	6	7

†***=significant at P≤0.001, **=significant at P≤0.001, *=significant at P≤0.05

Table 4.20. Spearman's rank correlation coefficients between seven (7) quantitative traits in Kakamega

Long Rains-Kakamega								
1000-Grain-weight	1	-						
Finger length	2	-0.2414	-					
Finger per panicle	3	-0.1202	0.231	-				
Finger width	4	-0.0063	0.3417*	-0.337	-			
Grain yield	5	-0.112	0.0399	-0.2944	0.1992	-		
Harvest Index	6	0.0954	0.4469	0.2152**	0.0413	0.105	-	
Leaf Number	7	0.1964	0.243	0.1999	0.1441	0.1006	-0.1906	-
		1	2	3	4	5	6	7
Short Rains-Kakamega								
1000-Grain-weight	1	-						
Finger length	2	0.0743	-					
Finger per panicle	3	-0.0865	0.0149	-				
Finger width	4	-0.1146	0.5056**	0.189	-			
Grain yield	5	0.2647	0.2902*	0.2591	0.1759	-		
Harvest Index	6	0.1521	0.2166	-0.4839	-0.2819	0.1977	-	
Leaf Number	7	0.0018	0.1946	0.5832	0.2802	0.1006	0.3639	-
		1	2	3	4	5	6	7

†***=significant at P≤0.001, **=significant at P≤0.001, *=significant at P≤0.05

Table 4.21. Spearman's rank correlation coefficients between seven (7) quantitative traits in Kiboko

Short Rains-Kiboko								
1000-Grain weight	1	-						
Finger length	2	0.3658*	-					
Finger per panicle	3	-0.4016*	-0.1602	-				
Finger width	4	0.0821	-0.1322	-0.2155	-			
Grain yield	5	0.4046*	0.6581***	0.1077	-0.287	-		
Harvest Index	6	0.4635**	0.502**	-0.1067	-0.2867	0.8242***	-	
Leaf No	7	0.1422	0.2388	0.168	-0.281	0.111*	-0.1082	-
		1	2	3	4	5	6	7
Long Rains-Kiboko								
1000-Grain weight	1	-						
Finger length	2	-0.0725	-					
Finger per panicle	3	-0.1981	0.1998	-				
Finger width	4	0.3084	0.5855***	-0.1523	-			
Grain yield	5	-0.1093	0.1574***	0.6443	-0.1208	-		
Harvest Index	6	0.3424*	0.4216**	0.1475	-0.281	0.4164**	-	
Leaf No	7	0.1104*	0.3881	0.4974	0.1923	0.5626*		-
		1	2	3	4	5	6	7

†***=significant at P≤0.001, **=significant at P≤0.001, *=significant at P≤0.05

The phosphate application also increased the plant height in Kakamega and Alupe where at 25.0 kg ha^{-1} P_2O_5 rate the maximum was observed and as the character has elicited positive correlation with yield (Table 4.20 and 4.21). Similar findings have been reported by Chaudhry *et al*. (2003) in pearl millet. As observed on the biomass P-224 had the tallest plants that highly correlated to grain yield compared to Ikhulule which was equally and even taller but did poorly in partitioning of N to the grain yield and N uptake and concentration on grains which ultimately reduced the grain yield. It was also observed that the finger length was positively correlated with the plant height which directly impacted on the grain yields at all sites. As much as finger length did not directly influence grain yield it interacted positively with plant height which directly impacted on yield. This is a positive indirect association with the yield. This findings collaborate with those by Suyambulingam and Jebarani (1977) who reported positive significant correlations between plant height and finger length and also the number of fingers per panicle. The direct influence of finger length on the yield are in tandem with the report by Bendale *et al*. (2002) and Ganapathy *et al*. (2011).

Phosphate fertilizer did increase the leaf blade length which showed direct positive correlation with the grain yield. This is due to the high capacity to intercept light and thereby increasing the photosynthetic rate. Similar correlations were found by Dewey and Lu (1959). The number of leaves did indicate direct positive correlation with the grain yield but not significantly in Kakamega only which shows the importance of higher leaf number in increasing the nutrients sink source. Therefore this does increase the sink size which in turn elevates plants metabolism that leads to greater yielding. This is in tandem with early reports by Subedi and Budhathoki (1996).

The productive aerial and basal tillers did have direct positive effects on the grain yield across sites due to the doubling ability which increases the number of heads per plant other that the main tiller. This is in accordance with studies by Ravikumar and Seetharam (1993) and Sonnad *et al*. (2008). Phosphorus did indicate increase of both effective tillers and the varieties which directly led to increased grain yields on those with relatively higher numbers.

The application of phosphorus fertilizers at 25.0 kg ha^{-1} P_2O_5 facilitated in reduction of the period to 50% flowering and maturity. It was found that this two variables were positively correlated with the grain yield. Early maturing varieties also assure higher yields. This findings agree with those by Bezawelataw *et al.* (2006).

Threshing percentage directly impact on grain yield in all the sites which reiterates other findings by Bidinger and Mukuru (1995) in pearl millet. The capability of higher removal of grains from their pockets do assure highest grain yields and U-15 did indicate superiority thus elevating its produce and it is an important aspect to breeders to enhance the other variety like P-224 whose conversion rate from dry panicle to grains is lower.

The grain per spikelet prompted the grain yield and this has also been reported by Lule *et al*. (2012) in finger millet and Eldin *et al.* (2012) in sorghum. The number of grains per spikelet were observed to be highest in P-224 which had the highest yield and this coefficient confirms it. The seedling vigor was greatly influenced by phosphate rates in Kakamega and Alupe where P deficiency was observed. It positively correlated with the grain yield directly across sites. Phosphorus triggers vigorous root establishment and

development which in turn increases mineral uptake of other essential nutrients from the soil.

The number of fingers per panicle were directly and positively correlated to the finger length at all sites except in Kiboko which in turn was positively correlated to the grain yield (Table 4.21). This therefore shows an indirect positive influence to the grain yield. This findings agrees with those of Priyadharshini *et al*. (2011) and Ganapathy *et al*. (2011). Therefore varieties with longer and more fingers in this case P-224 are highly encouraged for adoption because of assured higher yields. The harvest index did indicate direct effects on grain yields in Alupe during the short rains and in Kiboko in both seasons. However, indirect influence was observed on grain yield through number of leaves, finger per panicle and finger width. This strongly highlights the need for increased adoption of the improved variety U-15 which had the highest harvest index in all the sites.

Negative correlations were observed on the 1000-grain weight on the finger length, finger width, harvest index and grain yield. This is due to the plants mechanism to use more photo-assimilates at the expense of grain filling leading to low grain weights, hence significantly reducing the total grain yield of finger millet. This was also confirmed by Yan and Wallace (1995).

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

- This study demonstrated that proper phosphorus fertilization would achieve potential production under improved varieties of finger millet. Phosphate fertilizer application significantly ($P \leq 0.05$) increased the stand vigor, plant height, number of leaves, leaf blade length, total aerial tillers, productive aerial tillers and productive basal tillers. The days to 50% flowering and days to maturity were significantly ($P \leq 0.05$) reduced through phosphorous fertilization. All the growth parameters were responsive to varietal differences where P-224 was the tallest variety in Kakamega at dough stage while Ikhulule was tallest at physiological maturity. Interactions were observed on lodging where variety P-224 with P applied combinations had the highest number during the long rain season in Kakamega. The 25.0 kg ha^{-1} P_2O_5 did lead to the highest grain yield in western Kenya with variety P-224 outperforming the other varieties. The protein content, phosphorus content, potassium content, iron content and zinc content in the grains increased with increasing P rates with optimal content observed on the 25.0 kg ha^{-1} P_2O_5.
- Phosphorus application significantly increased the nitrogen uptake where highest total uptake was observed on the highest rate in Alupe.
- Significant differences were observed on N partitioning with the highest observed in the grains and the lowest on the roots with increased P rates leading to a reduction in the partitioning percentage to the grain. Interactions were revealed between variety and phosphate fertilizers with greatest nitrogen uptake observed in

Kakamega during the long rains (1288 kg N ha^{-1}) on the combination between local variety, Ikhulule and 12.5 kg ha^{-1} P_2O_5. Improved varieties U-15 had the highest N-partitioning to the grains with over 43% while Ikhulule had the lowest with 23%.

- The soil pH reduced significantly due to phosphate application in all the sites with the highest rate indicating the most negative balance. The amount of total and available P increased in the soil due to phosphorus fertilizer application in all the sites for both seasons. The P treated plots showed a significant increase in the electrical conductivity for both seasons in Kiboko as the exchangeable acidity was enhanced through phosphate fertilization in Kakamega and Alupe during both seasons.

5.2 RECOMMENDATIONS

- Through the findings from this study, it is recommended that application of 25.0 kg ha^{-1} P_2O_5 will lead to the greatest yields in the western Kenya Counties of Kakamega and Busia. This potential grain yield will be maximized under the improved variety P-224 at Alupe and Kakamega. Small-holder farmers who are majorly characterized with a poor financial resource base can afford using the phosphorus-based fertilizers which assured higher yields (6 times more than the average national yield) at this minimal rate. The rate translates to 22 kg per acre of TSP or DAP, 21 kg per acre of MAP which is only about half a bag and the yields can reach 4.4 tonnes per hectare. The application of phosphorus fertilizer beyond 25.0 kg ha^{-1} P_2O_5 will be detrimental to finger millet grain yield.

- Since the increase in P supply led to further uptake of N, there is need for caution to avoid continuous cultivation of finger millet as this can lead to excessive extraction of N or by striking a balance between P rates and the crops residue management.
- The partitioning of N to the grain under low P application implies more export of nutrients with grains to the market yet the allocation to roots means that this will be recycled back to the soil. There is therefore need to strike a balance between grain quality and by extension nutrient export and nutrient recycle for sustainable productivity of the soil.
- However, due to optimal availability of soil P in Makueni, application of P fertilizer is of no economic importance because it does not guarantee higher net returns from yields and is therefore not favored but U-15 is highly recommended for adoption by farmers due to its higher yield performance and better N and P utilization efficiency.

5.3 FURTHER RESEARCH AND WAY FORWARD

Further studies should be conducted to find out how phosphorus influences the soil pH and soil phosphorus availability in long-term conditions. Acidification impacted positively on availability of P to the plants due to increased Aluminium and Iron ions in acid soils and Calcium ions in alkaline soils where their interaction with phosphorus fertilizers form complex oxides. This will help evaluate how a stable equilibrium between acidification and phosphorus availability in the soil through P fertilizer application can be achieved without counter action.

The nitrogen use efficiency of finger millet is of extreme importance and as much as the N uptake was evaluated in this study there should be pin-point studies on how phosphorus influenced the agronomic, physiological and recovery nitrogen and phosphorus use efficiencies in the plant. Microbial activity make-up is a big constituent of the root environment and quantifying them and their activity is of great relevance to the scientific knowledge pool.

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APPENDICES

APPENDIX 1: Weather Pattern in Kiboko, Kakamega and Alupe

Rainfall was very scarce in Kiboko during the long rains season with only a total of 286.3 mm compared to the short rains that recorded 441 mm (Table 5.1a). In Alupe the long rains had a total of 705.4 mm while the short rains had 845 mm as shown on Table 5.1c and in Kakamega the short rains had a total of 809.3 mm while the long rains had a total of 1245.9 mm as shown on Table 5.1b.

Appendix 1. Monthly rainfall, temperatures and relative humidity for the two cropping seasons of 2014 and 2015 at Kiboko

	T. Rainfall (mm)	Max (°C)	Min (°C)	RH (%)
2014 Short Rains Season				
October	2.5	32.9	18.1	75.1
November	186.5	31	18.7	84.4
December	199.5	29.6	18.4	88.4
January	0	32.1	16.2	82.1
February	52.5	33.5	17.9	86.4
2015 Long rains season				
April	185.6	32.1	18.7	89.2
May	83.2	30	17.2	88.2
June	8.7	29.4	14.9	80.7
July	3.8	28.7	13.9	82.6
August	5	28.3	14.6	84.5

Source: Meteorological Department, Kiboko.

Appendix 2. Monthly rainfall, temperature and relative humidity for the two seasons of 2015 at Alupe

	T. Rainfall (mm)	Max (°C)	Min (°C)	RH (%)
2015 Short Rains Season				
October	101.4	29.1	18.2	77.4
November	215.8	30.4	16.9	78.9
December	114.7	29.6	17.2	77.6
January	49.6	31.2	17.5	76.2
February	88.1	30.8	16.9	77.8
2015 Long rains season				
March	79.3	35.9	18.3	73.6
April	125	30.1	18	76.9
May	125.1	30.6	17.9	76.6
June	125.6	30.8	17.5	77.2
July	125.1	31.1	16.9	77.1
August	125.3	31.3	16.9	77.2

Source: Meteorological Department, Alupe.

Appendix 3. Monthly rainfall, temperatures and relative humidity for the two cropping seasons of 2015 at Kakamega

	T. Rainfall (mm)	Max (°C)	Min (°C)	RH (%)
Short Rains Season				
October	195.6	28.2	14.5	68
November	315.7	27.2	14.4	71
December	132	29.3	14.2	79.2
January	50.4	28.7	15.7	70.2
February	115.6	31.1	15.7	72.2
Long rains season				
April	368.3	28	15.7	76
May	302.5	27.6	15.9	83.3
June	230.8	26.9	15.5	84.9
July	145.5	28.1	14.6	85.2
August	198.8	28.8	14.8	84.9

Source: Meteorological Department, Kakamega.

Appendix 4. Interaction effect on the lodging count in Alupe and Kakamega during the long rains

Variety	**Fertilizer Level (kg ha^{-1} P_2O_5)**	**Kakamega**	**Alupe**
U-15	0	24 b	8 bc
	12.5	16 b	5 c
	25.0	16 b	6 c
	37.5	11b	7 bc
P-224	0	19 b	16 b
	12.5	26 b	35 a
	25.0	26 b	37 a
	37.5	21 b	40 a
Local Check	0	26 b	4 c
	12.5	45 a	5 c
	25.0	47 a	4 c
	37.5	56 a	3 c
L.S.D		**16.96**	**9.89**

†Values with the same letter(s) within the column are not significantly different

Appendix 5. Varietal differences on the number of grains per spikelet in Kiboko, Kakamega and Alupe

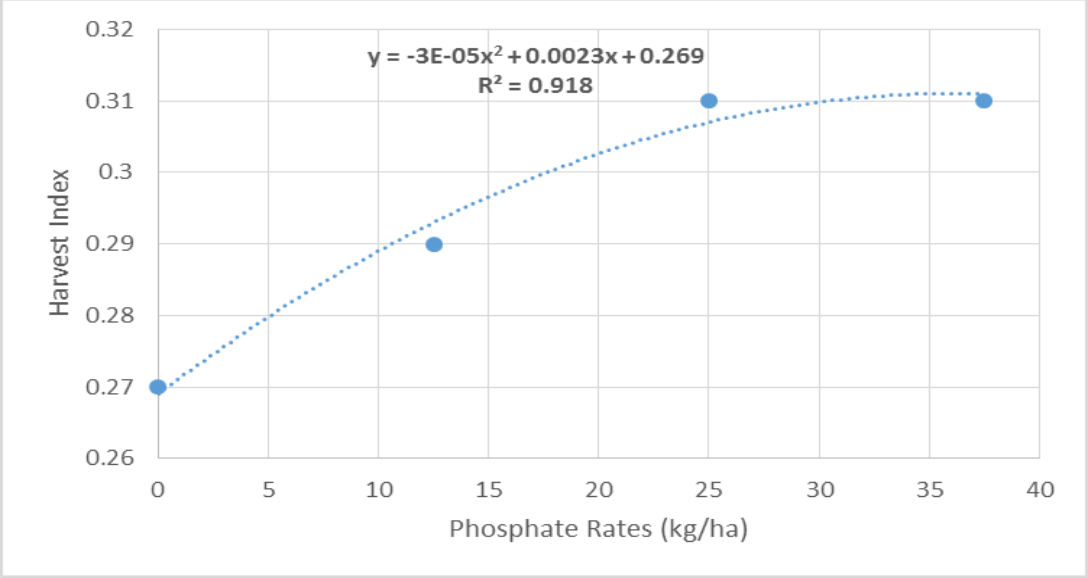
	Kiboko		Kakamega		Alupe	
	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
U-15	6b	6b	8a	8a	6b	6b
P-224	7a	7a	8a	8a	7a	7
L. Check	6b	6b	8a	8a	6b	6b
P-Value	***<.001***	***0.003***	***0.497***	***0.737***	***<.001***	***0.004***

†Values with the same letter(s) within the column are not significantly different

Appendix 6. The influence of phosphorus and variety on the 100-grain mass of finger millet in the study sites

	Kiboko		Kakamega		Alupe	
P Treatments	2014 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
Control	2.3a	2.7a	3.2a	2.6a	3.2a	2.5a
12.5	2.2a	2.7a	3.2a	2.4a	3.2a	2.6a
25	2.3a	2.6a	3.3a	2.3a	3.3a	2.6a
37.5	2.2a	2.6a	3.2a	2.6a	3.2a	2.5a
P-Value	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
Variety						
U-15	2.4a	2.7ab	3.3a	2.3a	3.2b	2.6a
P-224	2.1b	2.5b	3.2a	2.5a	3.3ab	2.4a
Local Check	2.1b	2.9a	3.2a	2.5a	3.5a	2.6a
P-Value	***<.001***	***0.045***	***0.591***	***0.291***	***0.042***	***0.214***

†Values with the same letter(s) within the column are not significantly different



Appendix 7. Phosphate rates influence on the harvest index at Kakamega-long rain season