EFFECT OF NPK BLENDED FERTILIZER APPLICATION ON SOIL PHYSICO-CHEMICAL PROPERTIES, GROWTH, PHYSIOLOGY AND YIELD OFTWO FINGER MILLET (*Eleusine coracana L. Gaertn.*) VARIETIES GROWN IN ACIDIC SOILS OF KAKAMEGA WESTERN KENYA.

BY

DENNIS SIMIYU WAMALWA

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DECLARATION

Declaration by the Candidate.

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Dennis Simiyu Wamalwa

MSC/SC/00145/2014.

Declaration by supervisors:

This thesis has been submitted for examination with our approval as the university supervisors.

Sign...Date……………….................................

Prof. Godfrey Wafula Netondo

Department of Botany,

School of Physical and Biological Sciences,

Maseno University

Sign...Date..

Dr. Phoebe Anyango Sikuku

Department of Botany,

School of Physical and Biological Sciences,

Maseno University

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DEDICATION

This work is dedicated to my parents Mrs. Annah Simiyu and the late Mr. Vincent Simiyu because their love has kept me going.

ABSTRACT

Finger millet is one of the most important cereal crops in Kenya. It is staple food rich in minerals and vitamins required for good health. Finger millet is a hardy crop compared to other cereals and it is for this reason that its currently being promoted in efforts to address food security. Western Kenya soils are acidic and soil acidity is a serious problem that affects crop productivity in the region. County governments of Kakamega, Bungoma, Vihiga, Busia and Trans-Nzoia are promoting soil application of NPK blended fertilizer (10%N, 26%P, 10%K_2O, 4%S, 8%CaO, 4%MgO and traces of B, Zn, Mo, Cu and Mn) to ameliorate the soil acidity. However, it is not known how the fertilizer affects soil, plant growth, physiology and crop yield. The main objective of the study was to investigate the effect of NPK blended fertilizer application on the soil physio-chemical properties, growth, physiology and yield of finger millet in acidic soils of Kakamega. Experiments were conducted at the crop and livestock research field of Kenya Agricultural and Livestock Research Organization(KALRO) Kakamega station. Experiments were conducted during the short (October-January) and long (March-August) rain seasons of 2015 and 2016 respectively. A Randomized Complete Block Design, involving application of 0,25,50,75 and 100 kg per acre of NPK blended fertilizer as the treatments. Two equal split application were done. Selected finger millet varieties; P-224 and Gulu-E which were sourced from KALRO. The varieties are commonly grown in Western Kenya and are known to be early maturing and drought resistant.. Data was collected on soil pH, soil Aluminium, Calcium and Magnesium, finger length, finger width, plant height, days to 50% flowering, productive tillers, grain yield, chlorophyll content index and plant tissue nitrogen, phosphorus, potassium, magnesium, calcium were collected. Data was subjected to Analysis of Variance using GenStat statistical package version 15.1and means separated at 5% probability level where significant differences($P \leq 0.05$) were observed using the LSD test. Application of NPK blended fertilizer significantly reduced the amount of soil aluminium for both season with the highest reduction recorded under the highest rate. The soil pH, soil calcium and soil magnesium significantly ($P \leq 0.05$) increased linearly with increasing fertilizer rates. The application of NPK blended fertilizer significantly increased the plant height, finger length and finger width of both varieties. At the 75 kg/acre rate the leaves showed significantly highest total chlorophyll content in both varieties with the highest (29.17 umol) under variety P-224. The control showed the lowest physiological activities in terms of chlorophyll content, calcium, magnesium, nitrogen, phosphorus and potassium. Period to 50% flowering were significantly reduced due to application of NPK blended fertilizer where Gulu-E had 80 days at the highest rate while P-224 had 81 days on the same rate. At 50 kg/acre, the number of days to physiological maturity were significantly ($P \leq 0.05$) reduced under both varieties where Gulu-E took 107 days to mature. The number of productive tillers were significantly increased with increasing NPK blended fertilizer application rate especially under Gulu-E variety with a high number of 42 productive tillers per plot. The grain yield was significantly increased by application of NPK blended fertilizer with the peak observed at the 75 kg/acre rate for both varieties but Gulu-E outperformed P-224, therefore Gulu-E may be recommended to farmers due to its increased yield of 1.55 ton/ha. Farmers may also improve finger millet yield and enhance their incomes while sustaining their soil fertility by using NPK blended fertilizer. The study concluded that application rate of 75 kg/acre of NPK fertilizer leads to the highest grain yield potential of finger millet varieties and positive liming effects that may ultimately reduce acidity of soils in the western Kenya region.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic absorption Spectroscopy
ANOVA	Analysis of Variance
Al	Aluminium
AOAC	Association of Analytical Chemists
ARMC	Athi River Mining Company
B	Boron
Ca	Calcium
CAN	Calcium Ammonium Nitrate
CaO	Calcium Oxide
CCI	Chlorophyll Content Index
CCM	Chlorophyll content meter
CEC	Cation Exchange Capacity
CIMMYT	International Maize and Wheat Improvement Centre
Cmol	Cent mole
Cu	Copper
$CuCl_2$	Copper (II) Chloride
DAP	Di Ammonium Phosphate
DAG	Days After Germination
EDTA	Ethylene diamine tetraacetic acid
ENV	Effective Neutralizing Value
H_2SO_4	Sulphuric acid
FAO	Food and Agriculture Organization
Fe	Iron
FYM	Farm Yard Manure
H_2O	Water
KALRO	Kenya Agricultural and Livestock Research Organization
K_2O	Potassium Oxide
KCl	Potassium chloride
$LaCl_2$	Lanthanide Chloride.

Masl	Meters above sea level.
MgO	Magnesium Oxide.
Mn	Manganese
Mo	Molybdenum
Na_2O	Sodium Oxide
NP	Nitrogen Phosphate
NPK	Nitrogen Phosphorus Potassium
P	Phosphorus
pH	Concentration of hydrogen ions.
P_2O_5	Phosphorus (V) Oxide
IBPGR	International Board for Plant Genetic Resources
ICPEAS	Inductively coupled plasma atomic emission spectroscopy.
ICRISAT	International Crops Research Institute for Semi-Arid Tropics
ISFM	Integrated Soil Fertility Management.
Rpm	Rounds per minute
S	Sulphur
SOC	Soil Organic Carbon.
Zn	Zinc.

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CHAPTER ONE

INTRODUCTION

1.1. Background to the study

Finger millet (*Eleusinecoracana* (L.) Gaertn. ssp. *coracana*) originated from the highlands of Ethiopia and is presently mainly grown in eastern and southern Africa (Obilana *et al.*2002).It is an important crop in eastern and southern Africa where small-scale farmers grow it in low input farming systems (Ahmed *et al.,*2000). The crop has food security, nutritional, cultural, medicinal, and economic value with high industrial potential (Suprasanna and Jain 2011). It has been found to adapt better to poor soils, erratic rain and droughts than main food grains like maize and wheat (NRC, 1996). While its production has been declining, there is still a significant demand for the crop and finger millet price has been much higher than other cereals in the past few years (Oerke *et al*.,2012). Interestingly, new food products made from finger millet are also becoming popular among younger people, including noodles, pasta, vermicelli, snacks, and different bakery products (Thilakarathna and Raizada, 2015). The crop contains high nutritional value especially to pregnant women and children for weaning and its seeds can be stored for more than five years due to low vulnerability to insect damage. It provides food security for poor farmers (Rurinda *et al*., 2014).

The potential yield of finger millet in Kenya remains largely low. For instance, millets were grown on 65,000 hectares in 2000 with an average yield of 1.3 tons/hectare (CGIAR, 2001). Former Western province is known to be the largest producer of finger millet in Kenya with production rates of 0.5 ton/ha per year (Takan *et al*., 2002).These low yields are largely explained in terms of droughts and depleted nutrients in soils such as phosphorus, among other reasons. Thus the farmland soils in Western Kenya, mainly the Acrisols (Utisols) and Ferrassols

(Oxisols) are highly weathered, with widespread N and P deficiencies. Significant increase in soil nitrogen, phosphorus, potassium and pH has been reported in combined application of the inorganic fertilizers, farm yard manure (FYM) and lime over control (Eresha *et al.*,2016), despite positive effects of FYM on NPK availability in the soil under finger millet-maize cropping system in Karnataka whose soils are acidic, similar to the ones in western Kenya, it is not known how NPK blended fertilizer influences finger millet production and soil available NPK in acidic soils of Kakamega Kenya.

Prasad (2009) reported increase in yield and grain protein content in finger millet due to N fertilizer application rates of up to 40 kg N ha^{-1} in Andhra Pradesh, India. However increased yields through application of nitrogen alone deplete soils of the other nutrients because higher yields take up greater amounts of other plant nutrients mainly phosphorus and potassium, hence the need for using a fertilizer that will not promote negative effects (Prasad 2009). NPK blended fertilizer has a combination of macro nutrients and micronutrients,(10%N, 26%P_2O_5, 10%K_2O, 4%S, 8%CaO, 4%MgO and traces of B, Zn, Mo, Cu and Mn), it is however not known whether it will give similar results of increased yields if used in the acidic soils of western Kenya. Furthermore, the rate of application of NPK blended fertilizer on finger millet has not been clearly established. Phosphorus (P) is among the major essential nutrients required by the plants for their normal growth, development and yield (Singh *et al.*,2017). Increased Nitrogen phosphate (NP_2O_5) application rate has been found to hasten the number of days to 50% flowering and number of days to physiological maturity respectively, increased plant height and number of fingers (Singh *et al.*,2017). Despite such positive results; it is yet to be established whether application of an NPK blended fertilizer will give similar results when used under finger millet in acidic soils. Phosphorus deficiency symptoms in plants include severe stunting, thin stems, and erect and dark green leaves. Its deficiency reduces seedling height, tiller number, stem diameter, leaf size, and leaf duration (Fageria *et al.*,2003). Application of NPK + FYM increased millet yield compared to NPK alone. It also increased the number of tillers, ear length, ear weight, grain weight, threshing percent, and number of fingers per ear head (Thilakarathna and Raizada, 2015). The findings of Thilakarathna and Raizada, 2015 could be attributed to the activity of FYM which might have played the role of Magnesium Oxide (MgO) and Calcium Oxide (CaO) of liming to enhance uptake of Phosphorus and other nutrients. However the nutrient content in FYM is not known, bulky and not readily available in required quantities. NPK fertilizer, known to have both macro and micro nutrients has not been tested on the performance of finger millet grown on acidic soils of Kakamega.

Most soils found in the highlands of East of the Rift valley and Western Kenya regions have a pH of 4.5 to 5.0 and high exchangeable Aluminium (III) ions (Buri *et al*., 2005) which restricts the availability of P in the soils. Omenyo *et al.*(2010) concluded that Western Kenya continues to experience food insecurity due to poor crop productivity because of increased soil acidity and consequent phosphorus deficiencies with 0.9 million hectares of land having pH < 5.5. The high soil acidity forms complexes with nutrients such as Phosphorus making them unavailable to the plant.

The NPK blended fertilizer, under trade name "Mavuno fertilizer" as commonly known to locals, has 11 different nutrients (10%N, 26%P_2O_5, 10%K_2O, 4%S, 8%CaO, 4%MgO and traces of B, Zn, Mo, Cu and Mn) is one of the NPK fertilizer currently gaining popularity in the region and can offset P deficiency and improve crop yield (Ne'mery and Gramier, 2007). This NPK blended fertilizer contains liming materials that may contribute to liming effects hence their application in soils can improve availability of phosphorus to plants thus resulting to high yields and improved soil properties (Abuom *et al*., 2014).

The NPK blended fertilizer such as mavuno has been promoted as a panacea to the problem of soil acidity in some counties of Western Kenya. For instance the county government of Kakamega supplied a total of 1,913.60 tonnes of NPK blended fertilizer (Appendix 5) to the farmers during the 2014-2015 growing season (Kakamega County Government, 2016 report). Farmers were advised to apply fertilizer at the rate of 80-100 kg/acre at planting and 50-80 kg/acre at top-dressing for maize as per the manufacturer's recommendation (Kakamega County Government, 2016 report). From the report the rates given were not specific but a range. According to Kakamega County Government, (2016) report, the application of this fertilizer led to increased maize production. However, there is paucity and limited research and documentation of how the NPK blended fertilizer with liming components and micro-nutrients application influences the production of finger millet which is majorly grown under these limiting conditions and hence low yields. The information on the effect of application of this fertilizer on the soil physico-chemical properties such as soil pH, soil Calcium, magnesium and aluminium is also lacking. Furthermore the information on the effects of NPK blended fertilizer application rate on plant nutrient uptake and chlorophyll content index on finger millet crop is not known. Abuli (2014) indicated that chlorophyll content was significantly higher in soya bean planted under DAP fertilizer treatment and lowest in control (no fertilizer application) in Tharaka Nithi and Meru whose soils are acidic. The results in chlorophyll content could have been due to Phosphorus uptake which is crucial in the synthesis of photosynthetic pigments, however it is not known if similar results could be found with applications of NPK blended fertilizer on acidic soils on the finger millet. Soil properties are bound to change with applications of fertilizers to the soil. Omollo *et al.* (2016) reported increased Calcium and decreased aluminium toxicity on application of liming materials; calcium hydroxide, Calcium Oxide, Calcium Carbonate grown under sugarcane crop in acidic soils of Kisumu. Baatuuwie (2015)found that NPK blended fertilizer in combination with manure application on maize, led to increased uptake of plant nutrients including Ca, Mg, and NPK. Finger millet is also grown in similar agro-ecological environment like maize. Therefore, application of NPK blended fertilizer would also improve the productivity. However, the effect of NPK blended fertilizer on the chlorophyll content index and nutrient uptake of the finger millet is unknown. The effect of the same fertilizer on the soil physico-chemical properties are also yet to be determined prompting the current study. Therefore the study was conducted as an effort to improve productivity of finger millet in Western Kenya through application of NPK blended fertilizer.

1.2 Problem Statement

Increasing crop productivity through the dissemination of improved cropping practices remains one of the biggest challenges of this century. The sub- Saharan Africa region, Kenya included, continues to experience food insecurity. This is partly due to soil acidity and nutrient depletion, all of which contribute to poor crop production. In western Kenya, about 0.9 million hectares of cultivated land is acidic with pH <5.5, causing high phosphorus deficiencies in the soil. As a result, production levels of finger millet are markedly low and this study aims at linking importance of NPK blended fertilizer application and the soil environment. The strong soil acidity is associated with high exchangeable aluminium toxicities that forms complexes with Phosphorus hence binding and making it unavailable for plant use (Wekha *et al.*, 2016b). This leads to low yields and poor production of crops in Western Kenya region including finger millet whose average yield are below 0.5 tonnes ha^{-1}per year which is only about 16% of its potential

(Wafula *et al*., 2016). Before this study, it was known that application of NPK blended fertilizer increased yield of maize grown in acidic soils of Kakamega, Western Kenya (Kakamega County Government, (2016) report. However, information on application rates on finger millet crop on nutrient uptake, chlorophyll content index, soil pH, soil Ca, Mg, and Al are yet to be clearly established, prompting this study. Therefore, this study intends to determine how the NPK blended fertilizer application may influence finger millet production in the acidic conditions. Although application of liming on acidic soil is a popular approach to addressing acidic soils problem, little effort has been made to further understand the impact of NPK blended fertilizer on the physiology of various finger millet genotypes to reliably determine utilization of available nutrients in the soils. Despite widespread dissemination of information on adoption of NPK blended fertilizer as a remedy to improve food security and increase income generation by the smallholder farmers through increased yields, there is lack of information on its application rates, effect on growth, physiological and yield components of finger millet. The use of locally available minerals in Kenya mainly micro elements and liming element makes NPK blended fertilizer less expensive than other imported mineral fertilizers. This promotes its availability to small-holder farmers hence improve crop productivity of finger millet through proper research and dissemination of information. These aspects are crucial in the performance of the crop to increase yield which in turn leads to food security and economic growth.

1.3 Objectives

1.3.1 General objective

To investigate the effect of NPK blended fertilizer application on the soil physico-chemical properties, growth , physiology and yield of two finger millet varieties grown in acidic soils of Kakamega, Western Kenya.

1.3.2 Specific objectives

1. To determine the effect of NPK blended fertilizer application rates on soil pH and soil nutrients in the acidic soils of Kakamega, Western Kenya.
2. To investigate the effect of NPK blended fertilizer application rates on growth of two finger millet varieties grown in the acid soils of Kakamega, Western Kenya.
3. To evaluate the effect of NPK blended fertilizer application rates on chlorophyll content and nutrient uptake of two finger millet varieties in acid soils of Kakamega, Western Kenya.
4. To determine the effect of NPK blended fertilizer application rates on yield attributes and grain yield of two finger millet varieties grown in acidic soil of Kakamega, Western Kenya.

1.3.3 Hypotheses

i. Soil pH and soil nutrients in acidic soils of Kakamega, Western Kenya are not influenced by different rates of NPK blended fertilizer application..

ii. NPK blended fertilizer application rates have no effect on the growth of two finger millet varieties grown in the acid soil conditions of Kakamega, Western Kenya.

iii. NPK blended fertilizer application rates does not influence the chlorophyll content and nutrient uptake of two finger millet varieties in acid soils of Kakamega, Western Kenya.

iv. Different rates of NPK blended fertilizer application do not have an effect on days to 50% flowering, days to maturity, productive tillers and grain yield of two finger millet varieties grown in acidic soil conditions of Kakamega, western Kenya.

1.3.4 Justification of the study

Several approaches have been used to manage soil acidity including use of soil amendments that counteract the effects of soil acidity such as compost manure or using crops that are tolerant to strong soil acidity. However, these materials are too bulky, vary in quality and mostly not available in adequate amounts required or not accessible to the farmers. NPK blended fertilizer will directly help farmers to reduce on the bulkiness and improve on quality compared to other amendment options available in alleviating soil acidity as well as the cost. Therefore information generated from this study will be useful in the determination of application rate that will lead to proper nutrient utilization for positive soil chemical properties that will enhance plant growth and improved yield of finger millet. The study also aims at establishing the correct application rate of NPK blended fertilizer on finger millet to realize improved crop yields by ensuring creating a conducive soil environment for the crop and provision of specific nutrients required by the plant. The positive impact of NPK blended fertilizer on the yield of finger millet will prompt proper alignment of county government institutions to promote and make the fertilizer more available to farmers and even draft policies that will ensure increased access and availability of the fertilizer at subsidized prices to the farmers. The extension services will also be able to realistically disseminate the actual impact of the fertilizer in the enhancement of yields through reduced acidity, improved soil quality and increased grain yields which in turn can address the minimal profit margins experienced by farmers and increase food supply and generate more income.

CHAPTER TWO

LITERATURE REVIEW

2.1.Finger Millet background

2.1.1 Botany and Ecology

Finger millet [Family Poaceae (Gramineae)], ranks fourth in importance among millets in the world after sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum*) and foxtail millet (*Setaria italic*). Finger millet is among the most cultivated millets and belongs to the genus *Eleusine*, in the Chloridae subfamily. It is the only crop species in the genus *Eleusine* that comprises nine species, eight of which are predominantly wild African grasses (Wani, 2015). Finger millet is an annual plant growing 40-130cm tall and matures in 2½ - 6 months (Watson and Dallwitz, 1992) with profuse tillers. The tillers have ear heads with a 2-8 finger like spikes. The spikelets in spike are arranged closely on both sides of a slender rachis. The spikelet are crowded into two overlapping rows on the outsides of the spike. Each spikelet has 4-5 flowers and may take about 7 days to complete flowering. Flowering takes place simultaneously in all fingers. It is 97 to 99% self-pollinating, and takes between 2.5 to 6 months to mature (Opole *et al*., 2013). The crop possesses good drought tolerance characters but is highly sensitive to frost (Real *et al*., 2014).

2.1.2 Crop requirements

Singh *et al*. (2017) outlined the finger millet growth requirements. It is a short to medium day length plant with optimal photoperiod of 12-hours and grows well under moderate rainfall (500-1,000mm with optimum of 900mm), well distributed during the growing season without prolonged droughts, but with good distribution, it can tolerate rainfall as low as 130mm (Singh *et* *al*. 2017). Finger millet does not tolerate flooding. It grows best where average maximum temperatures exceed 27°C and average minimum do not fall below 18°C, but can grow in temperatures up to 35°C. Dry weather is required for drying the grain at harvest as the crop is harvested at physiological maturity to avoid shattering on drying in the fields. Most of the world's finger millet is grown at intermediate elevations between 500 and 2,400 meters above sea level (masl), but it can grow from sea-level to over 2,400masl. These growth conditions describe typical tropical environments and hence the crop is expected to perform well in East Africa where, unfortunately, yields are dismally low (Neves, 2011). In Africa the crop is usually grown at between 1,000 and 2,000masl and in Nepal up to 2,400masl, (Dagnachew *et al*., 2014). Finger millet can grow on a variety of soils, but does well on well-drained silt loam soils - reddish brown earth, calcic red yellow latasols and sandy regosols (Singh *et al.* 2017). The crop requires a well-prepared seedbed because of its small seed size, and inability to stand weed competition. It is mostly hand weeded to remove *Eleusine indica* and *E. africana* which are hard to distinguish from finger millet at vegetative stages (Neves, 2011). Finger millet seedlings are slow growing and require a weed free environment for 45 days to develop vigorous plants. Planting in rows facilitates weeding.

2.1.3 The origin and distribution of finger millet

Finger millet is thought to have originated from Uganda or neighboring Ethiopian highlands where wide diversity of the genus *Eleusine* exists (Neves, 2011). *Eleusine* species occupy diverse habitats, ranging from open, dry places to under-covers of forests from sea level to highlands and finger millet is grown extensively in the semi-arid regions of Africa and India (Onziga, 2015). Cytogenetical, morphological, flavonoid chemistry, and chloroplast and ribosomal DNA evidence indicates that finger millet evolved directly from the wild tetraploid *E.*

coracana subsp. *africana*, an annual weed common in Africa (Reddy *et al*., 2008). It has x = 9 and 4x= 36 chromosomes with genome composition AABB (Dagnachew *et al*., 2014).

Finger millet was introduced to South Asia from its center of origin by sea probably in the third millennium B.C., especially India where it has gained importance and is called “ragi” (Hilu *et al*., 1979). The crop is cultivated in diverse eco-geographical areas where *Eleusine* displays high variability in vegetative, floral and seed morphology (Dramadri *et al*., 2012). Hilu and De Wet, (1976) identified three eco-geographical races: (i) African highland race cultivated in East African highlands, (ii) lowland race grown in the lowlands of Africa and South India, and (iii) Indian race with its centre of distribution in Northeast India. The African highland race is the most primitive and is the precursor of the lowland race (Onziga, 2015), which was subsequently introduced to southern India that developed into a secondary center of diversity, resulting in the Indian race. Hilu and De Wet (1976) believe natural selection was significant in finger millet evolution, with artificial selection restricted within the limits of adaptation of the races to their environments. Archaeological evidence indicates finger millet was a staple crop of the southern Africa region before maize introduction, and today it is found in eastern and southern Africa and is the principal cereal grain in Uganda (especially in northern and western regions), and also found in Zambia and Mozambique (NRC, 1996).

Finger millet production is increasing in Asia and India's yields have increased 50% since 1955 and Nepal’s land under the crop is expanding at 8% per year (NRC, 1996). The growth requirements and the location of center of origin and diversity in East Africa paint a promising future for the improvement of the crop, as the genetic variation needed for breeding should be readily available and growth conditions are what the crop is adapted to, hence yield and production should be expanded in this region as well (NRC, 1996).

2.1.4 Finger Millet Varieties in Kenya

From the local and world germplasm collections, finger millet varieties have been improved over the years. Among the medium maturing varieties, P224, Gulu-E, Serere and KA-2 have shown a yield potential of more than 2 ton/ha under good management. The varieties are recommended for medium potential areas at an altitude above 1500 metres above sea level. Other improved varieties with good yield potential include IE 1010, EKR-227 and P283, which are recommended for the lower midland areas (Ogecha, 1997). The international Crops Research Institute for Semi-arid Tropics (ICRISAT) has also released KNE-479 and KNE-1034 genotypes, which can endure the harsh conditions of semi-arid areas such as Machakos County (specifically the Katangi area) (Shibairo *et al*., 2014). A preliminary survey at the KALRO-Kibos revealed that improved high yielding varieties such as Okhale-1 and U-15 have also been released into the market (Ogecha, 1997). By using improved varieties and better agronomic practices, the yields can improve greatly. Giving small scale farmers access to higher yielding finger millet varieties can contribute to economic development and poverty alleviation in Kenya. Farmers who adopt the improved varieties will not only have increased production that can be sold, they also can share the seeds with other farmers. Ekalakala is a local variety that although with a lower yield potential is early maturing and drought tolerant and is recommended for the drier areas along the lake shores, (Ogecha, 1997).

2.1.5 Nutritional importance

Millets are staple foods that supply a major portion of calories and protein to large segments of populations in the semi-arid tropical regions of Africa and Asia. Finger millet (*Eleusine coracana* (L.) *Gaertn*.) is the primary food source for millions of people in tropical dry land regions. It also has nutritional qualities superior to that of rice and is at par with wheat (Latha *et al.,* 2005).

2.1.6 Finger millet production

The crop can be cultivated in diverse eco-geographical areas worldwide and displays high genetic variability indicating that it can be improved through breeding. The crop has wide adaptability, probably because it is a C_4 plant. The C_4 photosynthetic system is most efficient at photosynthesis in hot and sunny conditions. In Africa, smallholder farmers grow finger millet with area allocated to the crop varying from country to country. In Eastern Africa, finger millet is produced in Uganda, Kenya, Tanzania, Rwanda, Burundi and Ethiopia (Obilana *et al*., 2002). Kenya and Uganda are among the leading producers of finger millet in Africa and the rest of the world. It occupies 2.28, ton/ha of the total area covered by cereal production and accounts for 4% of total cereal yield annually (Assefa, 2012). Finger millet is drought tolerant, disease resistant, effective in suppressing weed growth, and able to grow on marginal lands with poor soil fertility (Thilakarathna and Raizada, 2015). Finger millet varieties are primarily grouped into two types based on crop duration: early maturity (90–100 days) and late maturity (110–120 days). Though finger millet is valued by traditional farmers as a low fertilizer input crop, under these conditions, it suffers from low yields (Reynolds *et al.*, 2015). Most of the soils in the semi-arid tropics, where finger millet is grown, are deficient in macronutrients and micronutrients, mainly due to continuous cropping, low use of mineral fertilizer, poor recycling of crop residues, and low rates of organic matter application which can limit yield potential (Thilakarathna and Raizada, 2015). Therefore, it is important to optimize nutrient management practices and other related factors affecting finger millet cultivation in order to attain better yields under the comparatively marginal local growing conditions. Unfortunately, compared to the major cereal crops, the recommendations available for nutrient management in finger millet are scarce, limiting the ability of agricultural extension officers to assist subsistence farmers (Thilakarathna and Raizada, 2015).

2.2 Influence of fertilizer on plant growth features of finger millet

The fertilizer formulation nitrogen: Phosphate: potassium (NPK) is known to be important for early establishment of finger millet (Mohamed, 2015). Rurinda *et al*. (2014) found that finger millet emergence was low without NPK fertilizer or with manure compared to fertilization with either NP fertilizer or manure and fertilizer, this suggests that manure application alone may not be beneficial to finger millet, perhaps because the nutrients are not readily available to seedling. Therefore for better finger millet establishment, there is need to supply starter NPK mineral fertilizers (Mohamed, 2015). There is a range of NPK fertilizers but the NPK blended fertilizer appears to be better due to its mineral composition. NPK blended (10%N, 26%P_2O_5, 10%K_2O, 4%S, 8%CaO, 4%MgO and traces of B, Zn, Mo, Cu and Mn) has both macro and micro nutrients.

Increase of phosphorus levels significantly ($P \leq 0.05$) increased the grain yield over the control up to 25 kg P_2O_5 ha^{-1} during the long rain seasons and 25 kg P_2O_5 ha^{-1} during the short rain seasons in both Alupe and Kakamega under finger millet crop (Wekha *et al*.,2016a). Although application of phosphorus led to increased yields, it is not known whether application of NPK blended fertilizer could lead to similar results.

Studies concerning N management in finger millet are mainly focused on the amount of N applied, timing of application, and varietal responses to N. The application of Inorganic N fertilizer at the time of planting stimulates better crop emergence especially in N deficient soil (Rurinda *et al.*,2014). Phosphorus is an essential macro element necessary for growth and development of plants. Phosphorus is among the major essential nutrients required by the plants for their normal growth, development and yield (Singh *et al.*,2007). Among the most significant functions of plants on which P has an important effect are reproduction, photosynthesis, nitrogen fixation, crop maturation (flowering and fruiting including seed formation), root development (particularly of the lateral and fibrous rootlets), strength of straw in cereal crops thus helping to prevent lodging and finally, quality and quantity of products (Brady and Weil, 2002). Phosphorus deficiency symptoms in plants include severe stunting, thin stems, and erect and dark green leaves. Its deficiency reduces seedling height, tiller number, stem diameter, leaf size, and leaf duration (Fageria *et al.*,2003). Plants deficient in phosphorus is stunted and in contrast to those lacking nitrogen, are often dark green in color. Besides these, maturity is often delayed compared to plants containing abundant phosphate. Adequate phosphorus enhances many aspects of plant physiology like fundamental process of photosynthesis, flowering, seed formation and maturation (Brady and Weil, 2002). Rice maturity can be delayed by as much as 10–12 days by P deficiency (Fageria *et al*., 2003).

Excess N may delay plant maturity and cause the plant to be more susceptible to diseases and insect pests. It also makes high shoot-to-root ratios while abundant P hastens maturity and in contrast to excess N, it increases root growth relative to shoot growth (Brady and Weil, 2002). Nitrogen promotes P uptake by plants by increasing top and root growth, altering plant metabolism and increasing the solubility and availability of P. Increased yields through application of nitrogen alone deplete soils of the other nutrients because higher yields take up greater amounts of other plant nutrients mainly phosphorus and potassium. This negative effects of nitrogen fertilizer could be solved through application of an NPK blended fertilizer, though its effects on nutrient balancing and uptake is not known.

Omollo *et al.* (2016) reported increased Calcium and decreased aluminium toxicity on application of liming materials Ca $(OH)_2$,CaO, $CaCO_3$. Since NPK blended fertilizer has this liming material it can be of significant importance if incorporated in the growing of finger millet where little research has been conducted.

2.2.1. Plant height

Fertilizer application increases the plant height of crop plants. Lemessa (2016) observed significant increase in plant height with each increment of NP_20_5 rates from the control to the highest rate on finger millet crop in North west Ethiopia. This was attributed to the fact that both nutrients (N and P) are involved in vital plant functions and contributed to enhanced growth in the plant. Such increment of plant height along with increase of NP_20_5 rate might be related to the effect of nitrogen which promotes vegetative growth as other growth factors are in conjunction with it, and N also promotes P uptake hence promoting the growth.

Application of P fertilizer gradually increased plant height, stem diameter, number of leaves per plant, leaf area per plant and fodder yield (Roy and Khandaker, 2010). The possible reason for increase in the height in the plots applied with P over the control may be due to the increase in the uptake efficiency of crop nutrients particularly that increase plant height more in the plots applied with P. The findings are in agreement with those of Khalil *et al*. (2010) who reported significant increase in maize heights with P application over the control.

Omenyo *et al.* (2010) reported that the NPK fertilizer (mavuno fertilizer) application had greater effects on the height of maize plant compared to lime from Homa hills in an experiment conducted in Siaya and North Kakamega. Average height statured plants are preferred for grain target contrary to tall statured plants preferred in fodder (Gowda *et al.*, 2007). Research by

Oluwatoyinbo *et al*., 2005, reported significant increase in the plant height on application of both lime and phosphorus fertilizers. However, it is not known whether similar results could be realized if NPK blended fertilizer is used on finger millet crop grown in acidic soil conditions.

2.2.2. Days to flowering

Lemessa, (2016) showed that the number of days required to flower varied between 85-100among NP_20_5 fertilizer rates, with the control taking 100 days and 85 days in the applied plots. Similarly, a delay in flowering in barley in comparison between applied plots and control has been reported (Mesfin and Zemach, 2015). Thus nitrogen fertilizer considerably influences duration of the pre-an thesis period and spike in barley. From the foregoing, fertilizer application appear to produce positive results. It is however, not clear whether application of NPK blended fertilizer can reduce number of days to flowering when applied to finger millet crop on acidic soils.

2.2.3 Days to maturity

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 plant. In a study by Wafula *et al.* (2016) on finger millet in Western Kenya it was found that application of P significantly reduced the period to maturity compared to the control. Yosef Tabar (2012) reported that phosphorus is important for plant growth and promotes root development, tillering, and early flowering and performs other functions like metabolic activities particularly in the synthesis of protein. 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 (Anella *et al.*, 2004). Boron increases pollen grain germination and fruit setting for peach cultivars, (Filipe *et al*., 2017). A number of organic and inorganic compounds affect in vitro germination, and boron is one of the most important elements (Nogueira *et al.*, 2016).

Wekha *et al.* (2016c) found that phosphorus plays an important part in many physiological processes that occur within a developing and maturing plant, it is involved in enzymatic reactions in the plant and it also hastens the ripening of fruits thus counteracting the effect of excess nitrogen application to the soil. However, the delay of physiological maturity may be due to insufficient amount of essential elements under unfertilized treatment conditions. Studies by (Lombi *et al.* 2004) revealed that finger millet length and width was correlated positively and significantly with fertilizer application and thus with number of panicles per m^2, number of spikelets per panicle, dry matter yield, plant height and grain yield of rice.

Longest finger millet length can be utilized in millet farming to increase finger size which in turn increases the grain yield as it acts as a positive factor for increasing yield. The length of finger millet has direct association with grain yield (Upadhyaya *et al.,* 2008). Agromorphological features are indicative parameters in the selection of the varieties that lead to high yields in crops such as finger millets (Upadhyaya *et al.*, 2008).

2.3.1. Effects of fertilizer on the physiology of finger millet.

2.3.2. Effects of soil acidity on Chlorophyll Content Index

Acidity affects the physiology of plants due to deficiency and toxicity of some nutrient. Reyes-Díaz *et al.* (2010) found that in sorghum cultivars total chlorophyll is substantially decreased with increased acidity. Leaf age and physiological state are important determinants of the chlorophyll content. These factors will affect the chlorophyll content index (CCI). For instance CCI is commonly promoted to measure leaf nitrogen content as an indicator of plant nutrient status. This is because much of the plant nitrogen is bound up in chlorophyll and other photosynthetic compounds (Bhandari *et al*., 2017). Researches have shown significantly high CCI in finger millet planted under synthetic fertilizer treatment, than under manure and lowest in one with no fertilizer application (Nyongesa, 2014). This could be due to nutrient variation in manure as compared to synthetic fertilizer. Lime has been promoted to lower acidity in the soil. However, lime from Homa has been shown to lack micro nutrients such as the trace element Mn which is required by plants for photosynthesis and for enzymes in controlling plant hormones (Osawa and Matsumoto, 2001). Abuli, (2014), showed that chlorophyll content was significantly higher in soya beans planted under DAP fertilizer treatment and lowest in control treatment (no fertilizer application).

2.3.3. Effects of fertilizer on nutrient uptake

NPK blended fertilizer has both macro and micro nutrients (10%N, 26%P_2O_5, 10%K_2O, 4%S, 8%CaO, 4%MgO and traces of B, Zn, Mo, Cu and Mn) essential for crop growth. Phosphorus has an influence on root development, hence can increase belowground biomass for carbon sequestration. This is particularly important in Western Kenya where farmers remove crop residues from agricultural fields for feeding livestock and domestic energy supply, making below ground biomass the main contributor to soil organic matter and carbon (Bellarby *et al.*, 2008). Improved carbon levels associated with P availability would promote P use efficiency and soil productivity (Tittonell *et al.*, 2008). Changing land use and management practices to sequester C in soils can have additional environmental benefits. The rate of soil carbon sequestration through the adoption of recommended management practices on degraded soils ranges from 100 kg ha^{-1} per year in warm and dry regions to 1,500 kg ha^{-1} $year^{-1}$ in cool and temperate regions (Nyambega *et al*., 2014). Soil and crop management technologies that increase soil organic carbon (SOC) levels among others include integrated nutrient management which balances nutrient application with judicious use of inorganic fertilizers. Baatuuwie (2015)found that mavuno fertilizer, an NPK blended fertilizer in combination with manure application in maize, led to increased uptake of plant nutrients including Ca, Mg, and NPK. This could have been as a result of liming activities that increased uptake of the above nutrients. Despite the positive results, there is lack of information on how application of NPK blended fertilizer will have when used under finger millet crop in acidic soils.

2.3.4. Soil Management

The use of inorganic fertilizers is indispensable in alleviating nutrient constraints and is central in integrated soil fertility management (ISFM) practices for improved crop production. Inorganic fertilizers have a high concentration of nutrients that are rapidly available for plant uptake and they can be formulated to supply the appropriate ratio of nutrients to meet plant growth requirements. Today, a wide range of inorganic fertilizers are required to maintain soil fertility and sustainable agricultural systems. Farmers are aware that without inorganic fertilizers the productivity of their crops and pastures will drop and soil nutrient levels will decline rapidly (Sibusisiwe, 2013).

In Western Kenya, about 0.9 million hectares of land are acidic with pH < 5.5 causing high phosphorus deficiencies. As a result, production levels of cereals and legumes are markedly low. Several approaches have been used to manage soil acidity. These include use of soil amendments that counteract the effects of soil acidity. Liming is one of the interventions recommended to ameliorate such soils. Lime materials applied as calcium hydroxide $Ca(OH)_2$, calcium oxide (CaO) or calcium carbonate ($CaCO_3$) have been found to effectively neutralize soil acidity by raising the pH of acidic soils, providing Ca^{2+} and decreasing aluminium toxicity hence stimulating crop growth. Several liming materials such as crushed limestone ($CaCO_3$), dolomitic lime ($CaMgCO_3$), slaked lime ($Ca(OH)_2$), quick lime (CaO) etc., can be used to reduce soil acidity. Research by Regina and Regina (2010) found that liming with farm yard showed significant increase in soil pH, soil calcium and soil magnesium and reduction in soil aluminium in acidic soils. They can be used either singly or in combined form. Studies have shown that apart from reducing the acidity of the soil by counteracting the effects of excess H^+ and Al^{3+}, liming also has several other benefits including, its ability to reduce the toxicity effects of some micro elements by lowering their concentrations while increasing the availability of plant nutrients such as Ca, P, Mo, and Mg in the soil and reducing the solubility and leaching of heavy metals (Fageria and Baligar, 2008). Crops absorb most of these nutrient elements particularly Ca, P, and Mg in substantial amounts and therefore by increasing their amounts in soil crop yields can be significantly improved. Application of lime is, however, affected by factors such as quality of the liming material, soil texture, soil fertility, crop rotation, conservation tillage, crop species and the use of organic manure (Fageria and Baligar, 2008). Osundwa *et al.*(2013)conducted an experiment on improving fertility of some acidic and impoverished soils in western Kenya by liming. The study revealed a concomitant increase in pH, Ca^{2+} and Mg^{2+} contents and a decrease in Al^{3+} concentration of the soil. This altogether resulted in an increase in plant height and crop yield. The apparent reason was the increase in pH and the availability of other essential plant nutrient elements.

The effect of aluminium toxicity in the soil solution causes most of the problems associated with acidic soils. In most soils of Western Kenya, phosphorus is one of the nutrients (after nitrogen) reported to limit crop production as its availability is very low. Several studies have also shown that when Al is in abundance, P is fixed as aluminium phosphate which is insoluble, hence making it unavailable for plant uptake (Patel, 2016). This is largely because soils in this region have naturally low P reserves and the little which is applied is easily fixed due to prevalence of higher levels of Aluminum and Iron oxides that form complexes with P (Nyambega*et al*., 2014). These soils have a greater ability to fix phosphate because of their characteristically high Fe and Al content, which causes considerable immobilization of any fertilizer P applied to these soils. Therefore, regular P fertilizer applications are required to maintain an adequate supply of plant available P (McLaughlin *et al*., 2011).

Two fundamental factors are associated with acid soil infertility; nutrient deficiencies such as P, Ca and Mg, and the presence of phytotoxic substances such as soluble Al and Mn. In the soil, plants absorb nutrients mainly in soluble forms.

2.3.5. Soil Acidity

Acidic soils develop as a consequence of excessive leaching of basic cations, mainly Ca, Mg and K in climatic conditions characterized by excessive rainfall and continuous use of acidifying fertilizer, (Kanyanjua *et al*., 2002). From literature and other sources, soil acidity can be effectively neutralized by either liming or application of FYM. Calcium and Mg can be sourced from dolomitic limestones while P can be sourced from readily soluble sources (including superphosphates) or slowly soluble such as rock phosphates (Pearce and Sumner, 1997). In low pH conditions, there is usually high concentration of Al^{3+} in the soil solution that binds with orthophosphate ions forming insoluble compounds resulting in low levels of extractable P. Excessive Al^{3+} concentrations cause low yields of non-acidic tolerant crops (Pearce and Sumner, 1997).

2.4.1. The influence of NPK blended fertilizer on yield and yield parameters

2.4.2. Productive tillers

The number of productive tillers can increase with fertilizer application on crop plants. The influence of fertilizers such as phosphorus on the number of productive tillers have shown a significant impact on various cereal crops. These growth attributes are a paradox to yield enhancing factors. Khan *et al.* (2010) reported on the influence of fertilizers such as phosphatic, where they found that phosphorus had significant impact on various crops growth attributes. They also suggested that application of phosphatic fertilizers should be at early growth stages for enhancing crop productivity as per their potential. Sisie and Mirshekari, (2011) reported increased tiller development and root growth in wheat on phosphorus application. Jamwal and Bhagat, (2004) reported that basal application of the recommended dose of DAP produced significantly higher number of effective tillers in the crop. The highest numbers of effective tillers (6.06) were reported at the highest rate of (61.5/69 NP_20_5 kg ha^{-1} for variety *Baruda*, significantly, the least number of effective tillers (3.43) were recorded at the control (0/0) for variety *Debatsie* (Lemesse, 2016)

2.4.3. Grain yield

Diminishing land sizes and decline in inherent soil fertility in western Kenya have not only resulted in negative nutrient balances in most small-holder farming systems but also preferential application of fertilizers on the other hand has also led to development of fertility gradients on smallholder farms (Sibusisiwe, 2013). Farmers continue to apply blanket fertilizer recommendations leading to variations in crop yields within a single farm (Tittonell *et al*., 2008). Yields of between 3.8-4.0 t ha^{-1} have been observed in yield trials in Kenya (Oduori and Kanyenji, 2005) while in Uganda 1.8 t ha^{-1} is regarded as average and yields from trials range between 1-4 t ha^{-1} while in Tanzania, local varieties grown are low yielding but selected varieties yield between 1-2.5 t ha^{-1}in yield trials (Chambo, 1993). In a report by Ahmad *et al*. (2000) finger millet grain yields increased from 0.87 to 1.30 t ha^{-1} with increasing P rates. They further stated 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. The NP_20_5 rate of 41/46 kg ha^{-1}gave significantly the highest grain yield (3540 kg ha^{-1}) On the other hand, the lowest grain yield of 1010 kg $ha^{-1}$was recorded due variety *Tadesse* with 0/0 NP_20_5 application (Lemesse, 2016).

Significant differences among various varieties for number of productive tillers per plant has been noticed in previous studies (Shemahonge, 2013), where he concluded that 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. The more the productive tillers the high will be the yield of the crop. Lime application increased maize yield above the control (Margenot *et al.,* 2017). Fertilizer that contain calcium, Nitrogen and Phosphorus like NPK blended fertilizer gave higher yield compared to lime alone (Muthaura 2015). Grain yield is always the ultimate target in most agricultural production. High grain yield production increases the overall yield per plant (Bhandari *et al.,* 2017). Superior varieties could be effectively and efficiently used in the finger millet farming to increase yield hence solve problems of food security in the region. Plants grow in acidic soils have undeveloped root system and exhibit a variety of nutrient deficiency symptoms leading to decreased yields (Shamsi *et al.,* 2007). Application of DAP and manure has given good results in yields of finger millet, however it is yet to be known if better results will be obtained if NPK blended fertilizer is used instead of DAP and manure. Kovačević and Rastija (2010) observed increased yield in maize and barley upon application of dolomite which contains some components present in the NPK blended fertilizer lead to increased maize and barley yield. It is likely that application of NPK blended fertilizer which contains more nutrients than dolomite could even give better yields in finger millet.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The study was conducted as an on-station experiment at the Kenya Agricultural and Livestock Research Organization (KALRO) field station located in the upper medium (UM) ecological zone in Kakamega County in Western Kenya which borders Vihiga County to the South, Siaya County to the west, Bungoma County to the North and Nandi County to the east. The station lies on the latitude of (00^{o} 16' N; 34^{o} 45' E; 1585masl) in Western part Kenya. The soils at Kakamega are Dystro-mollic Nitisol with soil pH of 5.5. The station receives 1971mm of rainfall annually with an average temperature of 20.4°C. The study was conducted during the short rain (SR) season of 2015 which started in October to February and the 2016 long rains (LR) season which started in March to August 2016. The study was carried out in two seasons to confirm the reliability of the results. The rainfall pattern is evenly distributed year round with March and July receiving heavy rains of 273 mm while December and February receiving light rains of 61 mm. The temperature ranged from 18℃ to 29℃. February and November were the hottest months of the year with other months having relatively similar temperatures. The station had an average relative humidity of 67%.

Figure 3.1. Map of Kenya and the Study site, Kakamega County and KALRO: Source, Google maps.

3.2 Experimental design and field management

The experimental field was cleared, ploughed and harrowed to a fine tilth and laid out as a Randomized Complete Block Design (RCBD), replicated three times with five treatments. The treatments included five levels of NPK blended fertilizer of 0, 25, 50, 75 and 100 kg per acre applied in two equal splits, one at planting and another at four weeks after emergence. The rates were in reference to the recommended application rate of 80 kg/acre. The experimental unit measured 2m x 1.7m (3.4 m^2). Five experimental units having five randomized treatments of fertilizer application made up the block. The 2 m pathway between blocks and a 1 m pathway between plots were created giving block measurement of 18 m x 1.7 m (30.6 m^2) translating to an experimental field of 18m x 13.1m (235.8 m^2) from three replicates (Appendix 3 and 4). Soil samples were taken on the plots at a depth of 0–30 cm before planting then after harvesting to monitor the soil chemical properties. The seeds were planted with 30 cm spacing between rows and later thinned after four weeks to a 10 intra-row spacing. In each plot three rows of each of the two varieties (P-224 and Gulu-E) were planted. The varieties were obtained from KALRO, Kakamega since they are the commonly grown in the region, and are known to be early maturing and drought resistant. The seeds were drilled in each line with calibration from an acre toper the plot size and weighed using a digital scale. The first weeding was done 14 days after germination (DAG) and the second weeding 14 days after the first weeding. To ensure enough space for the individual plants thinning of the rows was done during the first weeding (Handschuch and Wollni, 2016) to have plants with10 cm gap between each individual plant. Data was collected randomly from 10 tagged plants selected within the plots according to the International Board for Plant Genetic Resources (IBPGR, 1985) descriptors for finger millet.

Plate1 The experimental plot measuring 18 metres by 13.1 metres at Kakamega site. (Source, Photo taken by researcher).

3.3 Data Collection

3.3.1 Determination of physio-chemical properties

Six soil samples per plot were taken from the depth of 0-30 cm using Elderman auger in a zig-zag pattern to minimize biasness. The collected samples were air-dried for 72 hours and passed through 2 mm sieve to remove large particles and debris and taken to the laboratory for analysis of soil pH and concentrations of Ca, Mg and Al ions before planting and after harvesting according to the Association of Analytical Chemists (AOAC) (2007) methods and procedures.

3.3.1.1 Determination of soil pH

Twenty five ml of distilled water was added to 10 g air-dried sample in a 50 ml beaker. Temperature readings were taken as outlined by Rayment and Lyons (2011) procedure. The mixture was stirred at regular intervals for 30 minutes. The pH meter electrode was washed with distilled water. The contact switch of pH meter was opened, after 5 minutes, the temperature knob was adjusted to room temperature. The electrode was rinsed with water and pH dial was adjusted with a standard pH solution followed by another acid or alkaline one. The electrode was rinsed with distilled water, then with the soil suspension after stirring. The pH value of the soil suspension was read and recorded using pH meter (pH-100 Digital controller, India).

3.3.1.2 Determination of calcium content

Rayment and Lyons (2011) procedure was used in determining the calcium content where ten mililitres of soil saturation extract was pipetted into a 25+0-mL Erlenmeyer flask. It was diluted to 20 mililitres with deionized water, and 3 mL of 2 M sodium hydroxide solution added and 50 mg ammonium purpurate indicator. The resultant mixture was titrated with 0.01 M EDTA. The color changed from red to purple. Near the end point, EDTA was added one drop every 10 seconds since the colour change was not instantaneous. The blank containing all reagents but no soil was ran, and treated in exactly the same way as the samples; and the blank titration reading subtracted from the readings for all samples. The calculation of the calcium content was done as according to Rayment and Lyons(2011).

$$\text{Ca (meq/L)} = \frac{(V - B) \times N \times R \times 1000}{Wt}$$

Where: V = Volume of EDTA titrated for the sample (mL)

B = Blank titration volume (mL)

R = Ratio between total volume of the extract and extract volume used for titration.

N = Normality of EDTA solution.

Wt= Weight of air-dry soil (g)

3.3.1.3 Determination of magnesium content

The procedure by the AOAC (2007) was used to determine the Mg content where 10ml of soil saturation extract was pipetted into a 250-mL flask, then diluted to 20 mL with deionized water then 3 ml buffer solution was added and a five drops of eriochrome black indicator. The sample was then titrated with 0.01 M EDTA (Ethylenediamine tetraacetic acid) until the color changed from red to blue. The magnesium content was calculated according to the formula of the AOAC (2007), as shown below.

$$\text{Ca + Mg (meq/L)} = - \frac{(V - B) \times N \times R \times 1000}{Wt}$$

$$\text{Mg (meq/L)} = \text{Ca + Mg (meq/L)} - \text{Ca (meq/L}$$

Where: V = Volume of EDTA titrated for the sample (mL)

B = Blank titration volume (mL)

R = Ratio between total volume of the extract and extract volume used for titration.

N = Normality of EDTA solution.

Wt= Weight of air-dry soil (g)

3.3.1.4 Determination of aluminium content

To evaluate the potential release of Al, the procedure outlined by the AOAC (2007) was followed where successive extractions of Al were carried out in each sample. This was performed in duplicate by adding 5 g of soil in 50 mL plastic centrifuge tubes with 50 mL of chloride salt extractants (i.e. 1 M KCl, 0.33 M $LaCl_3$ and 0.5 M $CuCl_2$). Sample suspensions with 1 M KCl were shaken for 1 h, while those of 0.5M $CuCl_2$ and 0.33 M $LaCl_3$ were shaken for30 minutes using a reciprocal shaker. Samples were then centrifuged at 2500 rpm for10 min and filtered using a Whatman no. 42 filter paper. The entrained solution left after centrifugation was corrected by weighing the tube and adding sufficient amount of the extractant for each sample to bring the volume of solution back to 50 mL. This extraction procedure was performed on each soil sample for five successive extractions. Aluminium in the extracts was measured by atomic absorption spectrophotometry at 530nm. Cumulative Al released in the soil was computed by taking the total amount of Al released after five extractions. Al in the soil solution was determined by the inductively coupled plasma atomic emission spectroscopy (ICPEAS). The amount of Al measured by the ICPEAS was regarded as total aluminium in the solution

3.3.2 Determination of the growth parameters

The finger length, finger width and plant height were measured from 10 tagged plants, 5 from each variety randomly selected from each treatment following the International Board for Plant Genetic Resources (IBPGR, 1985) plant descriptor for finger millet.

3.3.2.1 Measurement of finger millet length

The finger millet length was measured using a standard ruler from the base to the tip of the longest spike (finger) on the primary tiller at dough stage following procedure by International Board for Plant Genetic Resources (IBPGR, 1985) plant descriptor for finger millet.

Plate 2 Plant height measurement on the tagged plants. (Source, Photo taken by the researcher)

3.3.2.2 Measurement of finger millet width

The finger millet width was measured using a meter rule across the centre of the longest finger on the primary tiller at dough stage following procedure by International Board for Plant Genetic Resources (IBPGR, 1985) plant descriptor for finger millet.

3.3.2.3. Measurement of plant height

The plant height was measured using a standard ruler from the stem base to the top node where the leaves segregate. Plant height was measured after every two weeks after thinning was done (4^{th} week after planting) up to the dough stage following procedure by International Board for Plant Genetic Resources (IBPGR, 1985) plant descriptor for finger millet.

3.3.3. Determination of Physiological parameters

3.3.3.1. Measurement of chlorophyll content Index

The chlorophyll content index (CCI) was measured from the second leaf from the apex of five plants from each variety per treatment at random points along the 5 cm section using an Opti-Sciences CCM-200 spectrophotometer, (Opti- Sciences Inc., Hudson, USA). The CCM-200 spectrophotometer was calibrated with a blank chamber prior to each series of measurements, as per the manufacturer instructions. Measurements were taken at 50% plot maturity according to the procedure and methods of Hoel and Solhaug (1998).

3.3.3.2. Determination of mineral nutrient elements in leaves.

All chemical reagents used were AR-grade.

3.3.3.2.1Measurement of nitrogen content

Motsara and Roy (2008) procedure was used to determine nitrogen at physiological maturity. Plant sample of 0.5gram were wet digested in di-acid mixture, then placed in a Kjeldahl flask. A 0.7g of copper sulphate and 1.5g of potassium sulphate was added, followed by 30ml of 0.05M H_2SO_4. The solution was boiled for 10 minutes until it was clear and then further digested for 15 minutes by adding 30 ml of 0.05M H_2SO_4. The flask was cooled before adding 50 ml of deionized water and transferred to a distilling flask. Twenty three milliliters of hydrochloric acid

(0.1M HCl) was placed accurately in a receiving conical flask. Three drops of methyl red indicator was then added and then tap water was run through the condenser. Thirty milliliters of 35% NaOH was added in the distilling flask and heated for 15 minutes. Excess acid in the distillate was titrated with 0.1M NaOH. The same quantity of 0.1M HCl acid in a receiving conical flask was used to make a blank for reagents.

Nitrogen content in plant tissue (N%) was calculated according to Motsara and Roy (2008) as follows:

$$N\,\% = \frac{\{(V1M1 - V2M2) - (V3M1 - V4M2)\}}{W} \times df \quad \text{where}$$

V1 – milliliters of HCL acid put in receiving flask for samples.
V2 – milliliters of NaOH used in titration
V3 – milliliters of HCL acid put in receiving flask for blank
V4 – milliliters of NaOH used in titrating blank
M1 – molarity of HCL acid
M2 – molarity of NaOH
W – weight of sample taken
df - dilution factor of sample

3.3.3.2.2Measurement of phosphorous content

Motsara and Roy (2008) procedure was used to determine phosphorus content where plant sample of 0.5g was wet-digested in di-acid and then made up to 100ml volume. Five milliliters out of this 100ml was put in a 50ml volumetric flask, then standard phosphate solution added. Standard solution was formed by dissolving 0.2915g of analytical-grade KH_2PO_4 and further diluted to 1 litre for the solution to contain 50µg P/ml. Ten milliliters of vanadomolybdate reagent was added to the volumetric flask. The content of the flask was made up to 50ml with deionized water, then shaken thoroughly, and stored for 10 minutes. The resultant solution was read on a spectrophotometer (Model UV-2600, Shimadzu-Japan). Measuring of the concentrations of Phosphorus was then done on atomic absorption spectrophotometer. This procedure was adopted from (Motsara and Roy, 2008). The absorbance range of 0.0 to 0.15 (Appendix 6) was used to determine the P concentration from the standard curve and calculation done as follows:

P content (µg) in 1g of sample= *C* x *df*; where;

C = concentration of P (µg/ml) as read from the standard curve;

df= dilution factor (1000).

3.3.3.2.3 Measurement of potassium content

Potassium content was measured at plant harvest from five plants for each variety per treatment using an atomic emission spectrophotometer (Model 969, UNICAM, Cambridge, UK) based on the procedure of Motsara and Roy, (2008). Plant samples of 0.5g were made up to 100ml volume after it was digested in di-acid. Five mililitres of this volume was put in 50ml volumetric flask and 10ml and KC1 (AR-grade) solution reagent added, KC1 was prepared by dissolving 1.908g of KC1 in 1 litre of distilled water for it to contain 1mg K/M. The content in the flask was made up to volume with deionized water, shaken thoroughly, and kept for 10 minutes. The absorbance of the solution was measured on a spectrophotometer. The absorbance range of 0.0 to 1.0 (Appendix 7) was used to determine the K content from the standard curve. Content of K for the particular absorbance observed for the sample was determined as below;

K content (µg) in a sample = *C* x *df*; where;

C – concentration of K (µg/ml) as read from the standard curve;

df – dilution factor,

3.3.3.2.4 Measurement of magnesium content

Motsara and Roy (2008) procedure was used to determine Mg content at plant harvest from five plants from each variety per treatment. Plant sample of 0.5 g was wet digested in a di-acid, and the volume was made up to 100 ml with distilled water. Five millilitres of this solution was put in 50 ml volumetric flask and 10 ml of Mg standard solution reagent was added, which had been formed by dissolving 10.141 g of $MgSO_2 .7H_2O$ in 250 ml of distilled water and made to 1 litre volume to give 1000µm Mg/Ml of solution. Lastly 10 ml of this solution was added to 100 ml of distilled water to obtain 10 µm Mg/ml. The absorbance of the final solution was measured on a spectrophotometer (Model UV-2600, Shimadzu-Japan). The absorbance range of 0.0 to 0.6 (Appendix 8) was used to determine the Mg content from the standard curve. The content of Mg for the particular absorbance was determined as below;

Mg content in µm in 1 g of sample = C x df. Where; C = concentration of Mg (µm/ml) as read from the standard curve; df = Dilution factor.

3.3.3.2.5 Measurement of calcium content

According to the procedure of Motsara and Roy (2008) plant samples of 0.5 g at harvest from five plants from each variety per treatment was wet digested in a di-acid and the volume was made up to 100 ml. Five mililitres of the volume was put in a 50 ml volumetric flask and 10 ml of Calcium standard solution reagent prepared by adding 0.2247 g of standard $CaCO_3$ in to 5 ml of de-ionized water then 10 ml of HCl was added to ensure complete dissolution of $CaCO_3$. This was then diluted to 1 litre with deionized water to give Calcium solution of 100 µm Ca/ml. The content in the volumetric flask was made up to volume with the deionized water. The absorbance of the final solution developed was measured on a spectrophotometer (Model UV-2600, Shimadzu-Japan). The absorbance range of 0.0 to 1.6 (Appendix 9) was used to determine the Calcium content from the standard curve. Content of calcium for the particular absorbance that was observed for the sample was determined according to Motsara and Roy, (2008) as shown follows;

Calcium content in µm in 1 g of sample = C x df

Where; C = concentration of Ca (µm/ml) as read from the standard curve;

df = Dilution factor.

3.3.4 Determination of yield parameters

3.3.4.1 Days to 50% flowering

The calendar dates were recorded from the date of sowing to the date when ears had emerged from 50% of the main tillers of each variety per treatment through visual observation by counting the number of plants that had flowered following procedures by International Board of plant Genetics Resources (IBPGR, 1985) plant descriptor procedures .

3.3.4.2 Days to 50% maturity

The calendar dates were recorded from the date of sowing to the date when 50% of the main tillers of each variety per treatment had mature ears through visual observation following (IBPGR, 1985) plant descriptor procedures.

3.3.4.3. Number of productive tillers

Productive tillers which bore mature ears were identified, counted and recorded at 50 % plot maturity from each variety per treatment following (IBPGR, 1985) plant descriptor procedures. .

3.3.4.4. Grain yield per plot (g)

The panicles from each head from the two middle rows of each variety per treatment were thrashed and the seed was kept in a dry place and seed weight taken daily until constant seed weight was maintained using a top load balance when the moisture content was 12.5% according to the IBPGR (1985).

3.3.5 Data analysis

The data collected was subjected to analysis of variance (ANOVA) using GenStat statistical package version 15.1. Means were separated by Least Significant Difference (LSD) test at 0.05 probability level where significant differences were observed. Regression analysis was used to estimate the relationship between grain yield against soil aluminium and chlorophyll content index.

CHAPTER FOUR

RESULTS

Overview.

The results presented are for the long rain season of 2016 since there was no significant differences between the results for the two seasons. The research was carried in two seasons in order to confirm reliability of the results obtained and minimize biasness resulting from seasonal changes. The results for short rain season, 2015 are at the appendix 10.

4.1.1. Soil physico-chemical properties

4.1.2. Soil pH

The application of NPK blended fertilizer increased the soil pH significantly compared to the control under the two finger millet varieties (Figure 4.1). The soil pH at the beginning of the experiment was 5.74 units (Table 4.1) and significant changes were observed at the end of the experiment on the NPK blended fertilizer applied plots. Higher pH was recorded in the treatments of 25, 50 and 100 kg/acre under Gulu-E compared to P-224. However 100 kg/acre had the highest pH of all and significantly($P \leq 0.05$) different from the other treatments. At 100 kg/acre, soil pH under Gulu-E showed significant differences compared to P-224. The soil pH increased with increasing NPK blended rates under both varieties. The highest increase was realized on the highest rate of fertilizer application.

Table 4.1: Initial soil chemical properties before planting the finger millet varieties under varying levels of NPK blended fertilizer at Kenya Agricultural and livestock Research Organization (KALRO) Kakamega in the year 2016.Each value represents the mean of three replications.

Component	Content
Soil pH	5.74
Soil Aluminium Cmol/kg	2.10
Soil Calcium me%	2.35
Soil Magnesium me%	1.15

The highest point was realized at the 100 kg/acre rate on Gulu-E variety with pH 6.44 units. The control had the least significant influence on the soil pH compared to the treated plots.

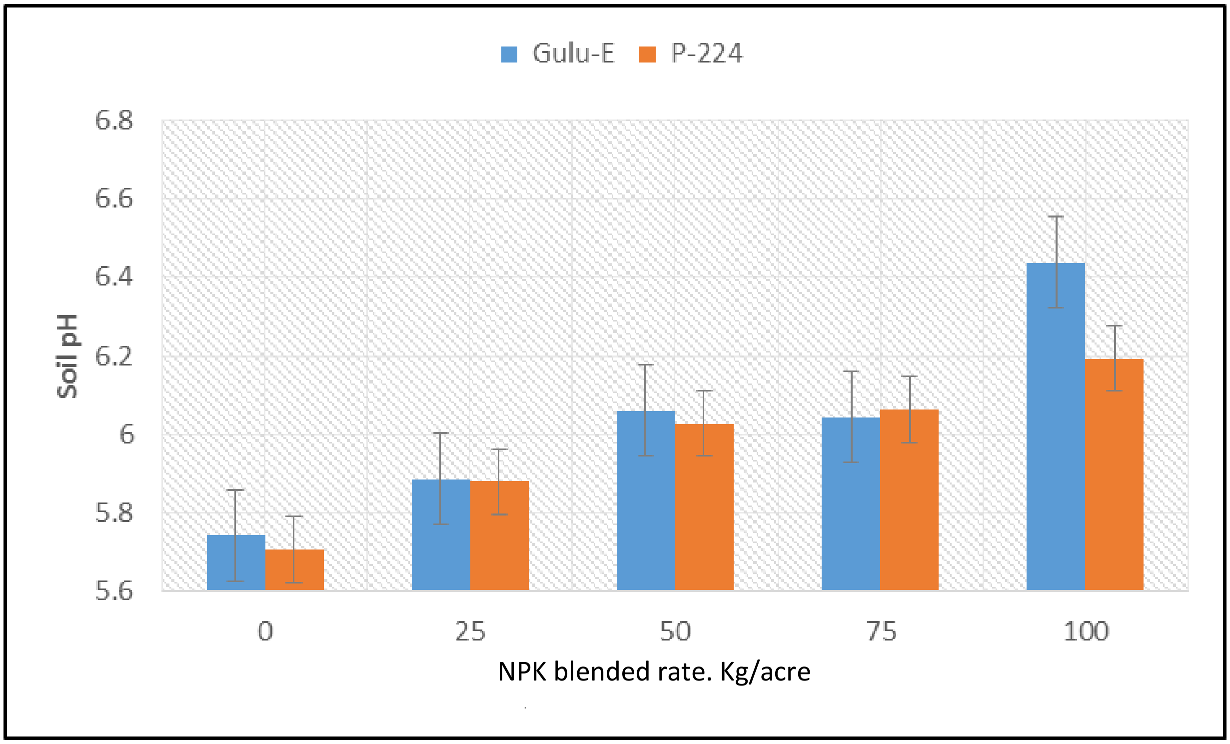

Figure 4.1. The soil pH at harvesting as influenced by application of NPK blended fertilizer treatments at Kakamega under Gulu-E and P-224 finger millet varieties. Each point represents the mean of three replications. Error bars indicate the SE at P<0.05.

4.1.3. Soil aluminium

The amount of aluminium in the soil significantly ($P \leq 0.05$) reduced with an increase in the application rates of NPK blended fertilizer as compared to the initial content (Figure 4.2). The initial aluminium content in the soil was 2.10 cmol per kilogram prior to the experiment (Table 4.1) and significant changes were observed after application of the treatments on the initial aluminium content. The content drastically reduced to 1.4 Cmol/kg in the 100 kg/acre under the local variety Gulu-E with marginal differences from P-224. The highest rate elicited the highest reduction of aluminium from 2.10 cmol/kg to 1.4 cmol/kg (Figure 4.2). There was a significant ($P \leq 0.05$) reduction in aluminium content with application of NPK blended fertilizer, however 50 kg/acre and 75 kg/acre were not significantly ($P \leq 0.05$) different in the soil aluminium content. Varietal responses were almost similar, but with slight differences in 25 kg/acre, 50 kg/acre and 100 kg/acre though insignificant. 100 kg/acre was significantly ($P \leq 0.05$) different from other treatments apart from 75 kg/acre for both varietal and treatment wise.

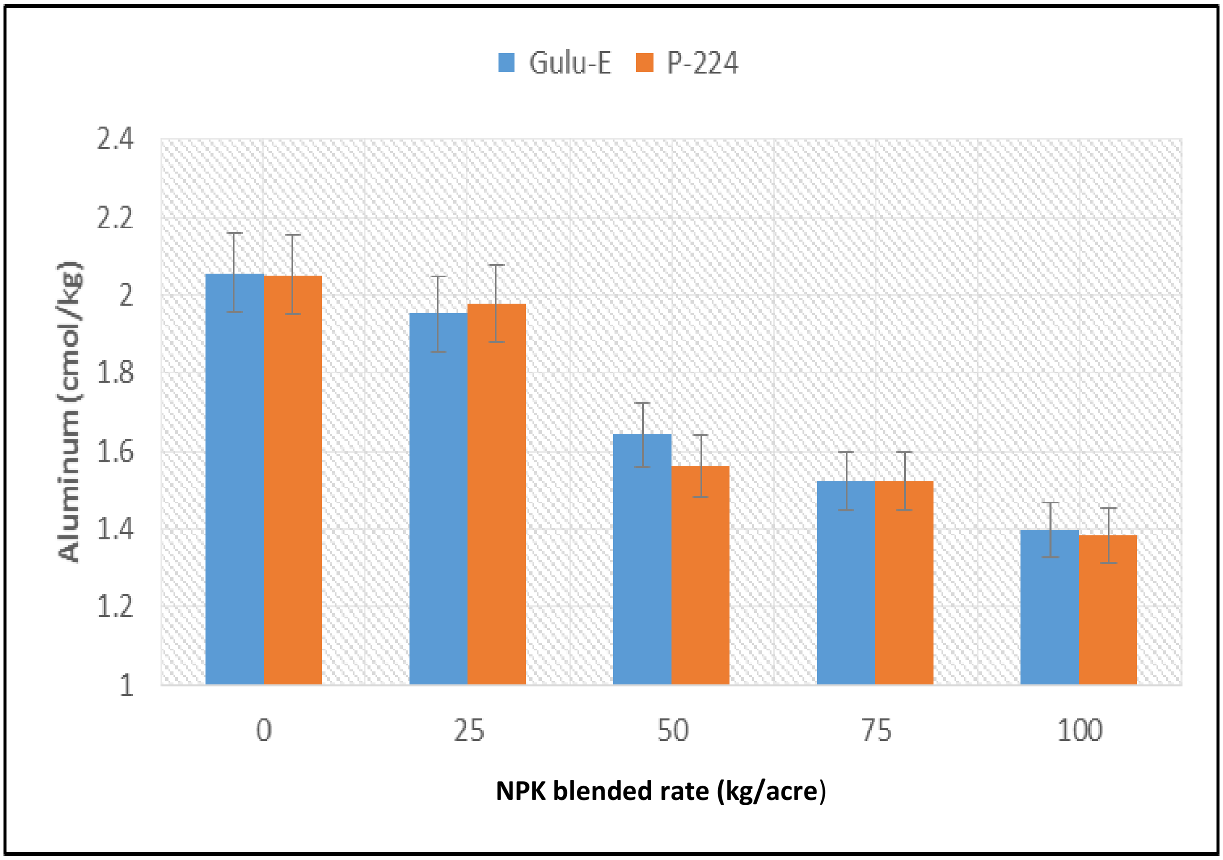

Figure 4.2.The soil aluminium content at harvesting as influenced by application of NPK blended fertilizer treatments at Kakamega under two finger millet varieties (Gulu-E and P-224). Each point represents the mean of three replications. Error bars indicate the SE at P<0.05.

4.1.4. Soil calcium content

The amount of calcium in the soil increased linearly with increase in NPK blended fertilizer rate under the finger millet varieties (Figure 4.3). Before planting, the calcium content was 2.35% (Table 4.1) and the NPK blended rates showed significant influence by changing the initial status of the soil where the highest application rate of 100 kg/acre significantly increased the contents to 3.4%. The calcium content in the soil increased with increasing NPK blended rates with the highest elicited in the 100 kg/acre rate (3.4%) while the 0 kg/acre had the lowest soil calcium content (2.40%). The control had the lowest influence on the calcium balances in the study soils. Calcium content linearly increased steadily and significantly with application of NPK blended fertilizer up to 50 kg/acre. Beyond 50 kg/acre, the calcium content showed a slight increase where there was no significant differences between 50 kg/acre , 75 kg/acre and 100 kg/acre among treatments and varieties.

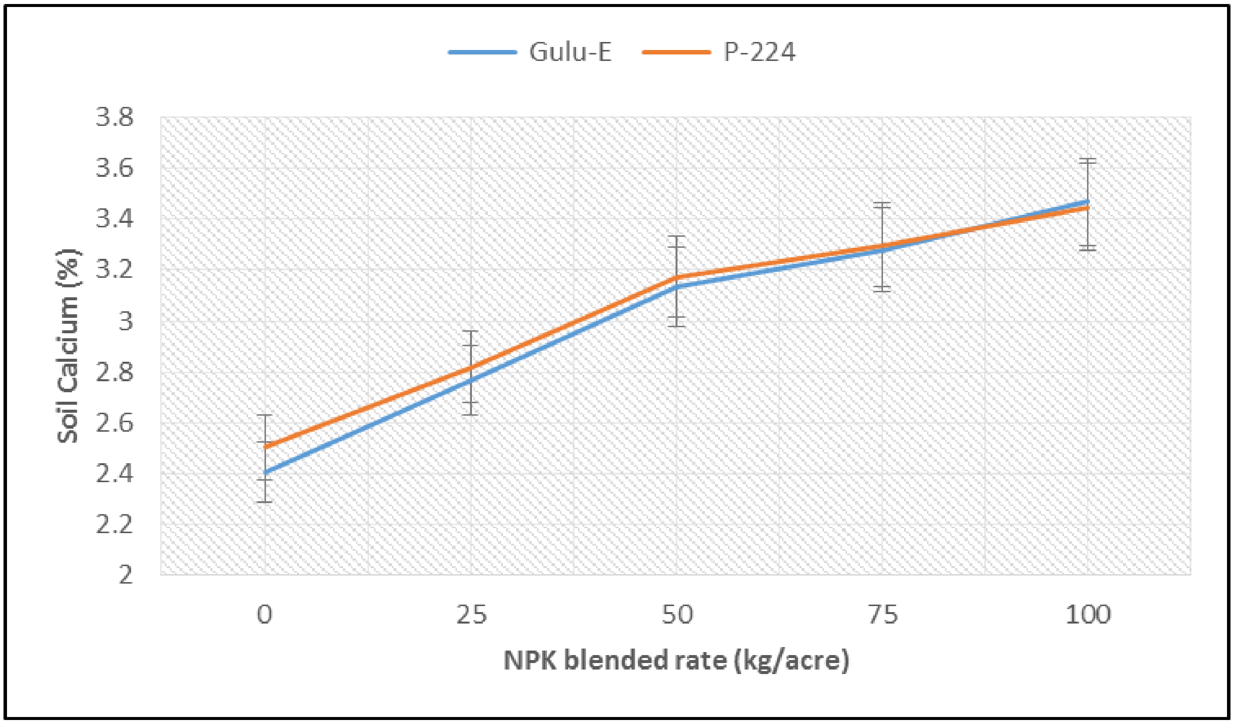

Figure 4.3. The soil calcium content as influenced by application of NPK blended fertilizer treatments at Kakamega for Gulu-E and P-224 finger millet varieties at harvesting. Each point represents the mean of three replications. Error bars indicate the SE at P<0.05.

4.1.5. Soil magnesium content

Magnesium content in the soil increased linearly as the NPK blended fertilizer rate increased under the finger millet varieties (Figure 4.4). Before planting the magnesium amount in the soil was 1.15% (Table 4.1) and the NPK blended fertilizer treatments had a significant influence whereby it significantly increased soil calcium to 2.24% under Gulu-E and 2.3% under P-224 both at the 100 kg/acre rate, which was insignificant to 75 kg/acre for both varieties and treatments. 50 kg/acre significantly increased magnesium content similarly to 75 kg/acre but significantly different from 25 kg/acre.

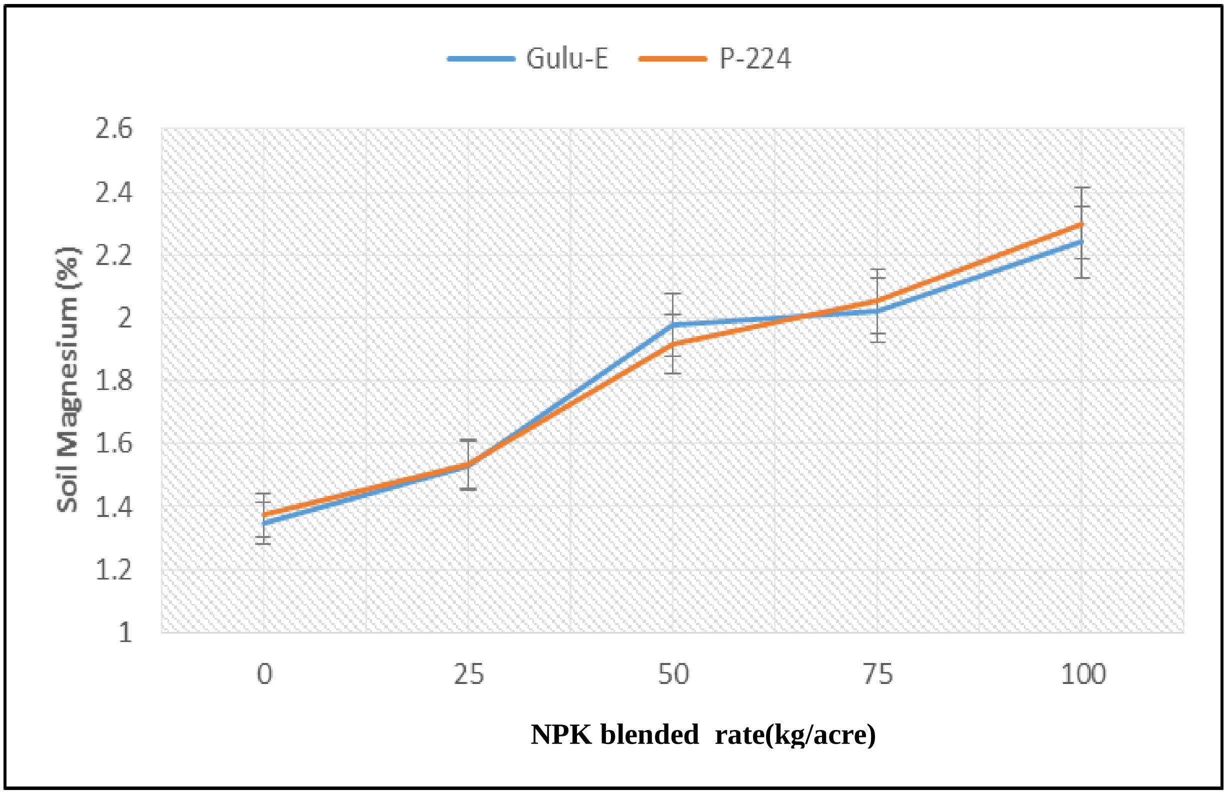

Figure 4.4.The soil magnesium content as influenced by application of NPK fertilizer treatments at Kakamega in two finger millet varieties (Gulu-E and P-224) at harvesting. Each point represents the mean of three replications. Error bars indicate the SE at P<0.05.

4.2 Growth parameters

4.2.1 Plant height

The application of NPK blended fertilizer significantly (P<0.05) increased the plant height of both varieties at dough stage as shown in Figure 4.5. The varieties differed significantly with P-224 being superior compared to Gulu-E in respect to height. At 50 kg/acre and 100 kg/acre the P-224 variety significantly showed a higher plant height in the applied plots compared to the Gulu-E. At 75 kg/acre Gulu-E elicited significantly tallest finger millet plants while at the highest rate

P-224 showed the tallest crop at 65 cm as shown on Figure 4.5. The highest rate (100 kg/acre) showed the tallest finger millet plants of 62 cm and 65 cm for Gulu-E and P-224 respectively. The control showed the lowest plant growth in terms of plant height under both varieties. Both varieties significantly (P≤0.05) showed the highest plant height in the applied plots compared to the control. A linear increase was observed with increasing NPK blended fertilizer rates for both varieties.There was significant (P≤0.05) differences in the plant height at 100kg/acre with finger millet plants showing maximum height. However, there was no significant (P≤0.05) varietal differences between P-224 and Gulu-E at 75 kg/acre and 100 kg/acre.

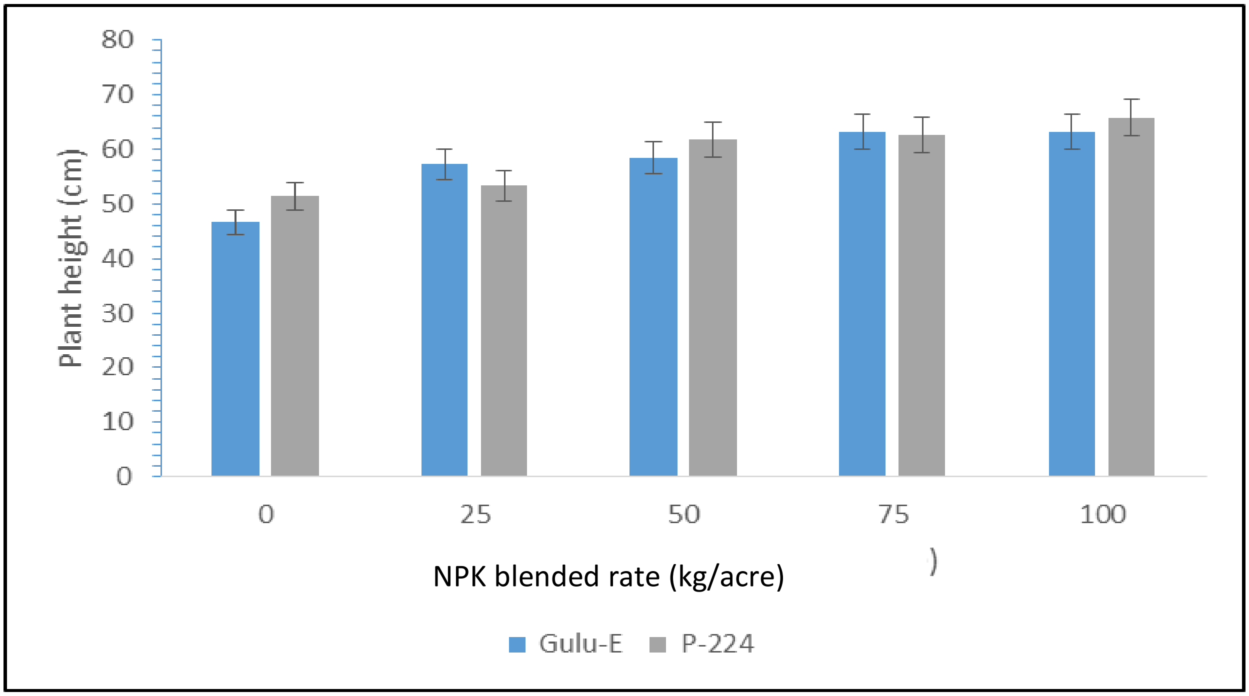

Figure 4.5: The relationship between NPK blended fertilizer rates and the mean plant height at dough stage of finger millet varieties at harvesting. The means of five tagged plants for each variety were used. Each point represents the mean of three replications. Error bars indicate the SE at P<0.05.

Significant differences (P<0.05) were observed on the finger length of Gulu-E finger millet variety at 25 kg/acre and 50 kg/acre but in P-224 variety it was observed at 75 kg/acre and 100 kg/acre. The longest fingers of Gulu-E were observed on the 50 kg/acre rate. Gulu-E showed a conclusive linear trend up to 50 kg/acre treatment, then it decrease with increasing NPK blended fertilizer rates while P-224 had a linear increase with increasing NPK blended fertilizer rate (Figure 4.6) while the longest fingers of Gulu-E were observed on the 50 kg/acre rate, P-224 showed longest at 100 kg/acre but were insignificant. The control had the shortest fingers with 6.4 cm and 7.8 cm for Gulu-E and P-224 respectively. A linear increase was observed on the finger length of P-224 with increasing fertilizer rate peaking on the highest NPK blended fertilizer rate of 100 kg/acre.

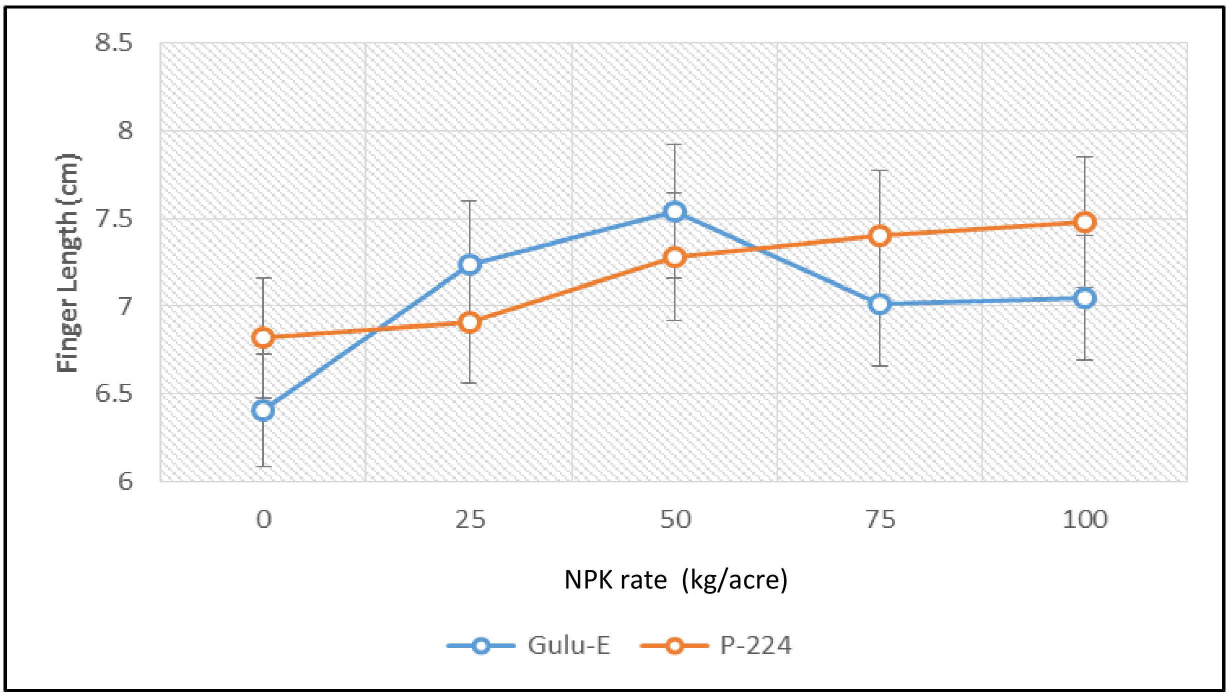

Figure 4.6: The influence of NPK blended fertilizer rates on the finger length. The means of five tagged plants for each variety were used. Each point represents the mean of three replications. Error bars indicate the SE at P<0.05.

4.2.3 Finger width

A linear and significant (P≤0.05) increase on the finger width was observed in the finger millet varieties due to application of NPK blended fertilizer (Figure 4.7). Finger width increased with

NPK blended fertilizer application for both varieties except Gulu-E at 75 kg/acre which slightly dropped with 100 kg/acre being insignificantly different from control and 25 kg/acre. The highest rate of NPK blended elicited the widest fingers (1.07 cm) under the P-224 variety while the lowest (0.88 cm) was observed in the control of Gulu-E variety.

The lowest finger width was recorded on the control under the two varieties. The highest NPK blended fertilizer rate exhibited the widest fingers in the finger millet varieties with a maximum of 1.073 cm under P-224 as shown on Figure 8. Varietal differences were insignificant among the treatments.

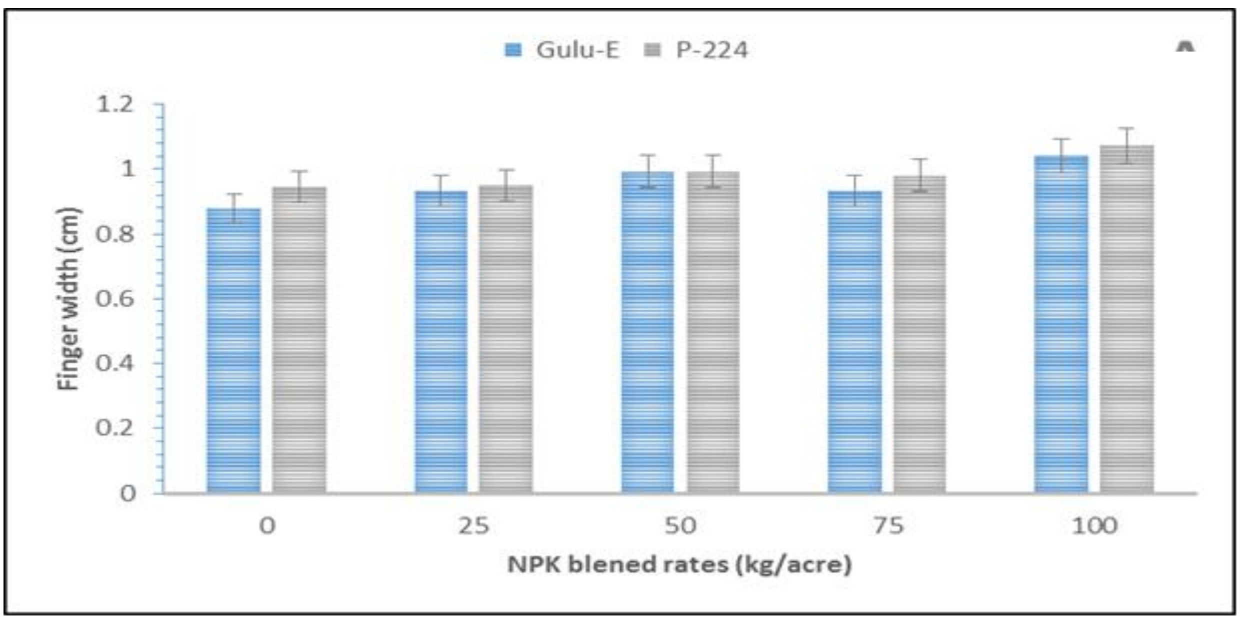

Figure 4.7:The influence of NPK blended fertilizer rates on the finger width of finger millet varieties at Kakamega at harvesting. The means of five tagged plants for each variety were used. Each point represents the mean of three replications. Error bars indicate the SE at P<0.05.

4.3.1 Physiological components

4.3.2 Chlorophyll content index

The NPK blended fertilizer rate of 75 kg/acre significantly (P≤0.05) increased the total chlorophyll content in the leaves of both varieties as compared to the other treatments during the study. The varieties showed very minimal differences in the chlorophyll content index and was the lowest under the control (Figure4.8) indicating that the two varieties responded to NPK blended fertilizer in the same way. Though insignificant, the 75 kg/acre rate on the P-224 variety showed slightly higher chlorophyll content (29 umol) per unit fresh weight of leaves. At 75 kg/acre both varieties were significantly different from other treatments . However, varietal differences were insignificant among the treatments.

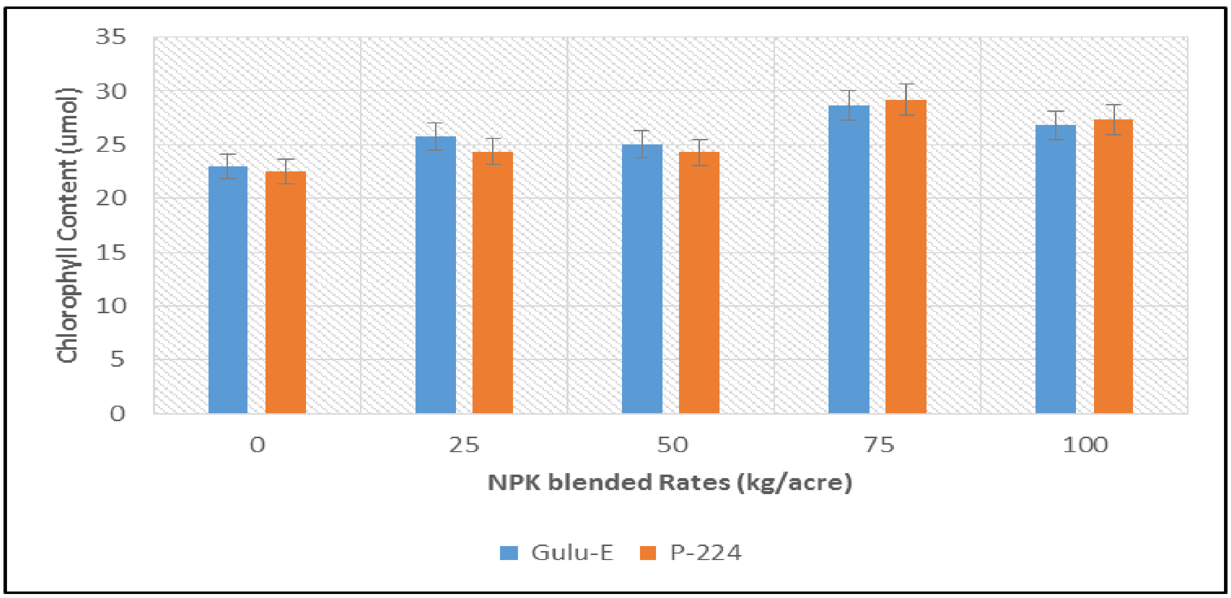

Figure 4.8:The influence of NPK blended fertilizer on the chlorophyll content at harvesting of Gulu-E and P-224 finger millet varieties in acidic soils of Kakamega. Each point represents the mean of three replications. Error bars indicate the SE at P<0.05.

4.3.3 Tissue calcium content

The 75 kg/acre NPK blended rate elicited significantly ($P \leq 0.05$) the highest calcium content in the finger millet plant tissue of both varieties but was insignificant to all other treatments except the control (Table 4.2).

4.3.4 Tissue potassium content

Significant differences at $P \leq 0.05$ were observed between the NPK blended fertilizer treatments on the plant tissue potassium content (Table 4.2). The 75 kg/acre rate showed the highest K content in the plant tissues of finger millet where P-224 had 1057 mg/100 g and Gulu-E had 997 mg/100 g. 75 kg/acre treatment in both varieties were significantly different $P \leq 0.05$ from other treatments.

4.3.5 Tissue magnesium content

Significant differences ($P \leq 0.05$) were observed between the treatments as shown on Table 4.2. Varieties Gulu-E and P-224 elicited the lowest magnesium content in the control. The highest Magnesium tissue content in Gulu-E was observed on the 100 kg/acre NPK rate but insignificant to 25, 50 and 75 kg/acre rates. Variety P-224 showed a different trend where above 50 kg/acre rate had the highest Mg content which was insignificant to control and 25 kg/acre where application of the fertilizer led to a linear increase of Mg content. The control under variety Gulu-E had the lowest Mg content (55 mg/100 g) while that on variety P-224 had only 53mg/100 g. A peak of 70 mg/100 g was recorded on variety Gulu-E in the highest rate of 100 kg/acre.

4.3.6 Tissue nitrogen content

Application of NPK blended fertilizer significantly ($P \leq 0.05$) influenced the nitrogen content in the finger millet tissues (Table 4.2). The highest content was observed on Gulu-E variety on the highest rate whereas the same trend was observed on P-224 variety. A linear increase was observed with increasing NPK blended fertilizer rates peaking at 100 kg/acre with 2200 mg/100 g for Gulu-E variety and 2193 mg/100 g for P-224 variety. In Gulu-E 100 kg/acre was significantly different from other treatments. P-224 showed insignificant differences between 100 and 75 kg/acre treatments (Table 4.2). Varieties showed insignificant differences among the treatments.

4.3.7 Tissue phosphorus content

The phosphorus tissue content was insignificantly influenced by the NPK blended fertilizer treatment. There was no conclusive pattern observed but the control exhibiting the lowest phosphorus content for both varieties. The 100 kg/acre NPK blended rate elicited the highest P tissue content under both varieties with Gulu-E having 358 mg/100 g and P-224 having 357 mg/100 g (Table 4.2).

Table 4.2: The influence of NPK blended fertilizer on the calcium, magnesium, nitrogen, phosphorus and potassium contents at harvesting in Gulu-E and P-224 finger millet varieties at Kakamega. Each point represents the mean of three replications.

Variety	Fertilizer Rate	Calcium mg/100 g	Potassium mg/100 g	Magnesium mg/100 g	Nitrogen mg/100 g	Phosphorus mg/100 g
Gulu-E	0	113b	670b	55b	1778b	335a
	25	119a	847ab	63ab	1920ab	340a
	50	120a	797ab	65a	1877ab	337a
	75	127a	997a	63ab	1940ab	353a
	100	122a	823ab	70a	2200a	358a
P-224	0	110b	713ab	53b	1758b	322a
	25	120a	860ab	60ab	1885ab	330a
	50	120a	757ab	67a	1830ab	340a
	75	126.7a	1057a	67a	2065a	347a
	100	123.3a	793ab	67a	2193a	357a
P-Value		0.044	0.008	0.033	0.036	0.555
LSD		13.3	167.8	10.62	270.7	39.68

Values in columns followed by the same letter do not differ significantly at $P \leq 0.05$.

4.4. Yield components

4.4.1 Days to 50% flowering

The application of NPK blended fertilizer significantly ($P \leq 0.05$) influenced the period to 50% flowering of finger millet varieties (Table 4.3). The control on variety Gulu-E had the longest period to 50% flowering with a mean of 88 days which was significantly different from the rest of the treatments. At 25kg/acre, 50kg/acre and 75kg/acre had no significant difference on Gulu-E variety on the number of days to 50 % flowering. However,100 kg/acre showed significant difference from the rest with an average of 80 days to 50 % flowering on Gulu-E. 75 kg/acre and 100 kg/acre rate on variety P-224 had the shortest with a mean of 81.7 days which were significantly different from 0, 25 and 50 kg/acre kg/acre rate. Variety Gulu-E out performed P-224 on the number of days to 50% flowering (Table 4.3).

Table 4.3: The days to 50% flowering and days to maturity of Gulu-E and P-224 finger millet varieties as influenced by NPK blended fertilizer rates at Kakamega. Each point represents the mean of three replications.

Variety	Fertilizer Rate	Days to 50% Flowering	Days to Maturity
Gulu-E	0	88.3a	116.3b
	25	84.7b	113.7c
	50	84.3b	106.7e
	75	84.3b	107.7e
	100	80.0c	108.3d
P-224	0	85.7b	118.7a
	25	85.3b	115.0c
	50	84.0b	107.7e
	75	81.7c	109.0d
	100	81.7c	109.3d
P-Value		0.001	0.008
LSD		1.63	1.78

Values in columns followed by the same letter do not differ significantly at $P \leq 0.05$

4.4.2 Days to maturity

The 50 kg/acre NPK blended fertilizer rate led to significantly shortest period to maturation for both finger millet varieties and were insignificant (Table 4.3). The longest period observed was 116.3 and 118.7 days under the 0 kg/acre in both Gulu-E and P-224 respectively to attain physiological maturity. An increase in the application above 50 kg/acre of NPK blended fertilizer increased number of days to physiological maturity. Both varieties performed better at 50 kg/acre application. Varietal differences were observed at control and 75 kg/acre treatment with Gulu-E slightly superior to P-224.

4.4.3 Productive tillers

Significant differences $P<0.05$were observed on the number of productive tillers due to NPK blended application in the two varieties. However, the highest number of productive tillers was recorded at the 100 kg/acre of NPK blended fertilizer application and was insignificant to 75 kg/acre on variety Gulu-E and to P-224 at the similar treatments (Table 4.4). Variety Gulu-E responded positively to application of NPK blended fertilizer where 100 kg/acre had the highest number of productive tillers per plot with a mean of 42 compared to P-224 variety though insignificant.

Table 4.4: The number of productive tillers per plot and grain yield (g) per plant at harvesting of Gulu-E and P-224 finger millet varieties as influenced by NPK blended fertilizer rates at Kakamega. Each point represents the mean of three replications.

Variety	Fertilizer Rate	No. of productive Tillers/Plot	Grain Yield (g)/Plant
Gulu-E	0	21.9c	69.0d
	25	24.4bc	107.0b
	50	29.2b	89.7c
	75	42.3a	155.0a
	100	42.4a	140.0a
P-224	0	22.9c	65.3d
	25	32.3b	71.3d
	50	32.4b	101.3b
	75	40.1a	110.3b
	100	41.9a	93c
P-Value		0.043	0.017
LSD		6.11	8.89

Values in columns followed by the same letter do not differ significantly at $P \leq 0.05$

The control had as low as 21.9 and 22.9 total productive tillers per plot for Gulu-E and P-224 varieties respectively which was almost 50% lower than the NPK blended fertilizer treated plots.

4.4.4 Grain yield

The finger millet grain yield significantly increased with application of NPK blended fertilizer with Gulu-E variety showing the highest yield at 75 kg/acre compared to P-224 but insignificant as shown on Table 4.4. Both varieties at 75 kg/acre, Gulu-E had significant higher yield than P-224. The highest grain yield per plant was observed on the 75 kg/acre rate under Gulu-E variety with a mean of 155 g/plant. The same trend was observed on the P-224 variety during the same growing period with a mean of 110.3 grams per plant. The control exhibited the lowest grain yield per plant under both varieties which were insignificant. Gulu-E performed slightly better than P-224 (Table 4.4).

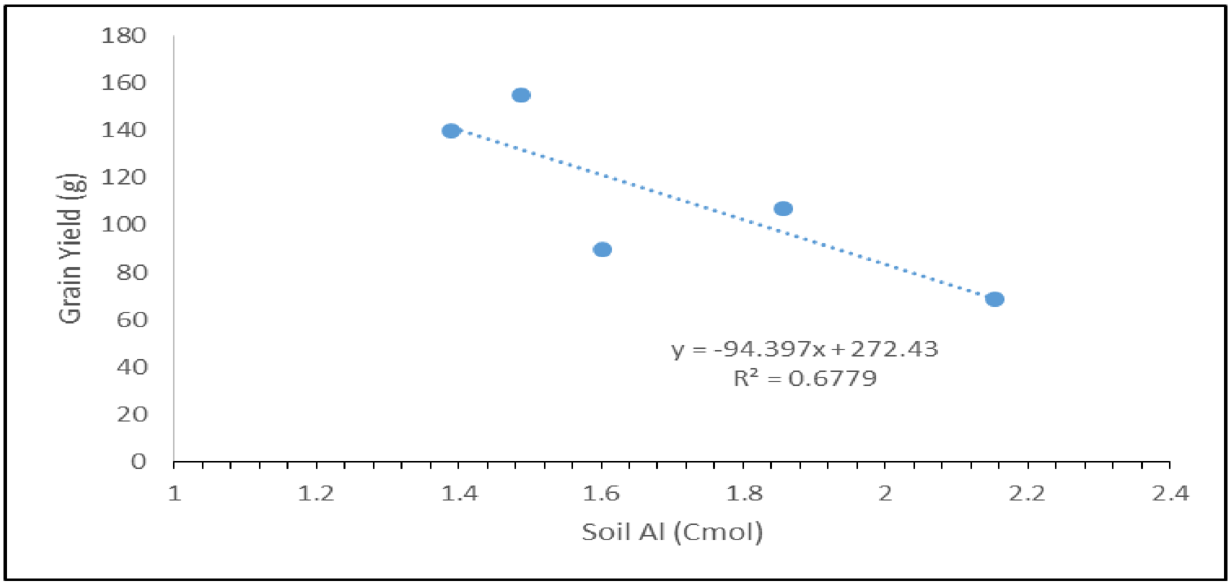

Figure 4.9: Linear relationship between the soil aluminium content and the grain yield of Gulu-E finger millet variety at Kakamega.

The increase in the amount of aluminium in the soil significantly led to a linear decrease in the grain yield (r^2=0.68). At 1.4 Cmol, the grain yield was recorded to be at average of 141 g per plant but there was a drop to 78 g per plant as the amount increased to about 2.2 Cmol (Fig. 4.9).

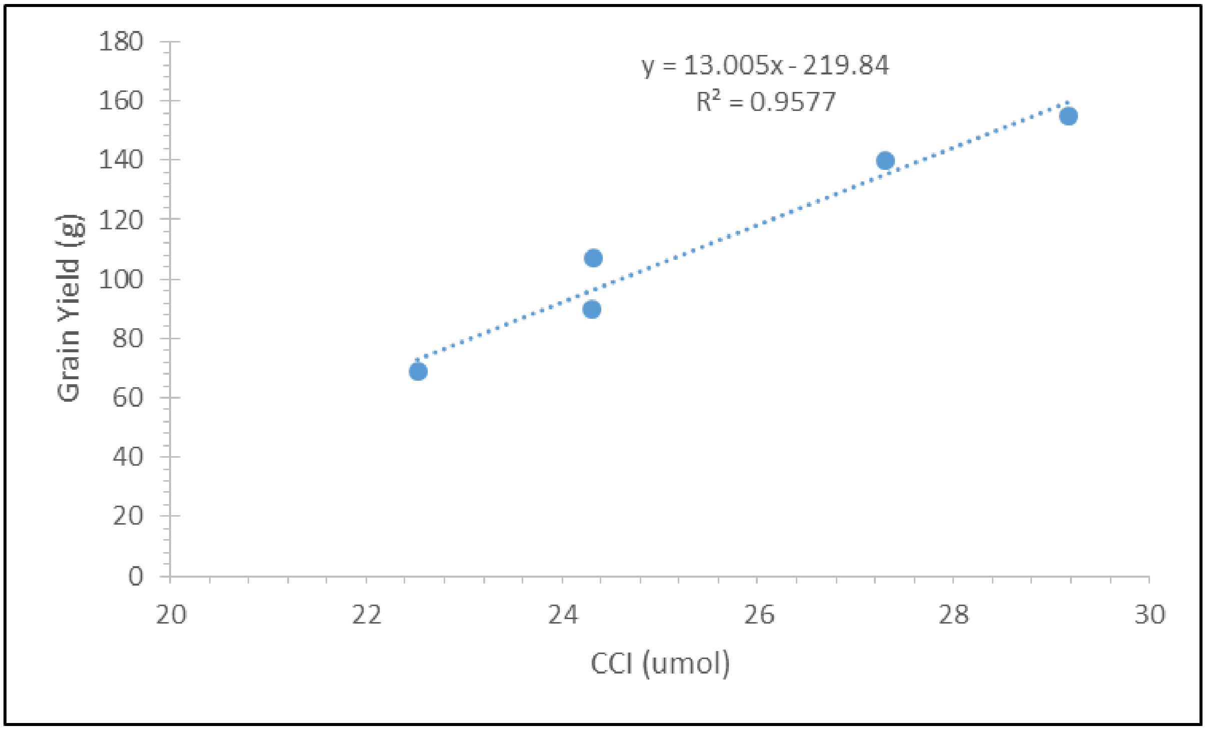

Figure 4.10: Linear relationship between the soil chlorophyll content index and the grain yield of Gulu-E finger millet variety at Kakamega.

There was a linear increase in the finger millet grain yield with increase in the amount of chlorophyll index in the leaves (Fig. 4.10). At 22.5 umol of chlorophyll, the grain yield was recorded to be 69 g per plant but the grain yield increased to 155 g per plant when the level of chlorophyll in the leaves was at 29.17 umol.

CHAPTER FIVE

DISCUSSION

5.1 The influence of NPK blended fertilizer on Soil pH and soil nutrients

5.1.1 Soil pH

The NPK blended fertilizer led to an increase in the soil pH with the highest recorded under variety Gulu-E at the highest rate. The increase could be attributed to its extensive root system that highly activated microbial activities in the soil rhizosphere. The 50kg/acre fertilizer rate increased soil pH in both varieties probably due to the activity of basic oxides present in the NPK blended fertilizer. The findings observed on soil properties after application of the NPK blended fertilizer are in tandem to that of Regina and Regina (2010) who reported increase in soil pH after application of liming with farm yard manure on acidic soils. The CaO and MgO dissolved in water to form calcium hydroxide and magnesium hydroxide which neutralized the acidity in the soils under study. Under moisture levels in the soils the fertilizer dissolves in soils faster where the Ca^{2+} and Mg^{2+} ions attaches to soil particles replacing the acid cations (H^{+}) thus the soil becomes less acidic at 100 kg/acre of NPK blended fertilizer application. Highest pH on Gulu-E may be due to genetic superiority that may have made Gulu-E able to tolerate high levels of aluminium in the soils compared to variety P-224.From the results it is evident that nutrient inputs are limited as the soils were low in pH hence leading to soil acidity. The soil acidity makes some nutrients such as phosphorus unavailable through formation of Al-P complexes and nutrient leaching (Wekha *et al*., 2016b). Therefore, basis that the future development and growth in agricultural production largely depend on enhanced land management technologies.

5.1.2 Exchangeable aluminium

The NPK blended fertilizer significantly reduced the aluminium content in the soil with the lowest recorded in the highest application rate. At the start of the experiment, the amount of exchangeable aluminium in the soil was high as well as that of the control at the end of the experiment compared to those applied with the NPK blended fertilizer therefore relating to the significantly lower grain yield at higher soil aluminium contents compared to the higher yields at lower aluminium content in the soil. This higher exchangeable aluminium content could have been due to low pH hence acidity in the study soils. Aluminium in the soil might have steadily reduced with application of NPK blended fertilizer, as the fertilizer increased the soil pH hence reducing aluminium in the study soils. The results are in agreement with the findings by Omollo *et al*., (2016) who reported reduction of aluminium on application of liming materials Ca $(OH)_2$, CaO, $CaCO_3$. Under acidic conditions Al^{3+} which firmly binds on the soil particles begin to dissolve and enter the solution but as the pH was reversed through application of the NPK blended fertilizer the Al^{3+}were released as the rate increased with the soil becoming less acidic. The effectiveness of the NPK blended fertilizer could also be attributed to the increase of calcium and magnesium quantity released in the soil solution by the fertilizer. The CaO and MgO are basic oxides which dissolve in the water to form Ca(OH) and Mg(OH) which are basic. The alkaline solutions as a result neutralize the acidity in the soil and subsequently reduce the aluminium toxicity in the soils (Regina and Regina 2010). This is in accordance to studies by Conyers *et al.*(2003) and Caries *et al.*(2008) who reported a decrease of exchangeable aluminium following application of fertilizers which had liming effects in acidic soils. The reduction in soil aluminium from 50 kg/acre upwards may have been due to increase in soil pH to above pH of

6.0. At this point soluble aluminium is not likely to be a problem due to its reduction below the lethal levels to plants (Caries *et al.* 2008).

5.1.3 Soil calcium

The amount of calcium increased with increasing NPK blended rates in both varieties because at low pH the bioavailability of calcium was retarded by high concentration of Al but due to the release of Ca by the fertilizer this was reversed where the exchangeable Ca increased with increasing soil pH. Similarly, an increase in the amount of Ca in the soil with increasing NPK blended fertilizer rates could also be attributed to the fact that calcite contained in the fertilizer which released more Ca in the solution and also the reduced soil acidity that hindered leaching of nutrients, hence making Ca readily available .The findings are in agreement with the results of Omollo *et al*.(2016)who reported increased plant tissue calcium on application of liming materials Ca $(OH)_2$,CaO, $CaCO_3$. The observed increase in Ca and Mg levels were also in agreement with the findings of Fageria and Stone (2004) who reported an increase of Mg and Ca content in acidic soils as a result of fertilizer application enriched with dolomite. The increased calcium above 50 kg/acre might have been due to reduced soil aluminium which in turn increased calcium availability. This was due to reduced calcium leaching as a result of increased soil pH.

5.1.4 Soil magnesium

The application of NPK blended led to increase in soil magnesium because it contained MgO which was released in the soil solution and the basic essential cation deficiency was corrected in the soils. By correcting the soil pH, the deficiency of the exchangeable cations was reversed by making them more available. The magnesium contents in the soils were significantly higher in the NPK blended applied plots compared to the control probably due to the MgO contents in the fertilizer. The increased calcium above 50 kg/acre could be attributed to reduced soil aluminium which in turn increased availability of magnesium in the study soils. The MgO present in the NPK blended fertilizer neutralized the acidity in the soils and this in turn minimized nutrient leaching thereby making them more available for plant uptake.

5.2 The effect of NPK blended fertilizer rates on growth of finger millet

5.2.1 Plant height

The increase in plant height with application of fertilizer may have been occasioned by improved uptake of the nutrients in the fertilizer where by the shortest plants of the two varieties were observed in the control. The liming-induced improvement in the plant height of the crops in the acidic soils through increase in the P availability thus rapid early growth. The increase in height could also be due to optimal magnesium ions in the soils that promoted soil aeration thus root respiration and increased soil microbes to promote nutrient availability to the plant. The liming effects in the NPK blended fertilizer also may have affected both the chemical and microbial transformation of N and P in the soil therefore enhancing the metabolism activity of the plants and this increased rate of growth. The observed significant positive performance in growth parameters with application of fertilizer could be attributed to the essential nutrient elements supplied by NPK blended fertilizer that is associated with increased photosynthetic efficiency. NPK blended fertilizer application which significantly increased the plant height supports the findings of Oluwatoyinbo *et al*. (2005). The results also concur with the findings of Singh *et al.*(2017) who reported increased plant height and number of fingers due to increased NP_2O_5 application rate. The increased performance of NPK blended fertilizer in terms of growth parameters could also be due to nutrient composition and additional calcium (Ca^{2+}) which raised the soil pH to a level required by finger millet for efficient increase uptake of nutrients form the soil. The application of other fertilizer formulation other than NPK blended has led to acidification of the study soils and this may mean that the supplied nutrients might have been fixed by aluminium and manganese complexes due to lack of calcium, a unique element in NPK blended fertilizer (Muthaura, 2015). There were slight differences in varieties, but P-224 was slightly superior than Gulu-E with an outstanding plant height. This shows that P-224 utilized NPK blended nutrients more than Gulu-E, and this could be due to their genetic differences. At 100 kg/acre plant height was more superior but was insignificant to 50 kg/acre and 75kg/acre. This might be due to potassium and boron present in the NPK blended that promotes cell division at apices (Nogueira *et al*, 2016).

5.2.2 Finger millet length

The finger millet length was significantly affected by fertilizer application. The control had the least finger length compared to those applied with NPK blended fertilizer. The numerical increase in the finger length was probably due to the enhanced metabolic processes due to the optimum nutrients supplied by the NPK blended fertilizer. The results are in agreement with those of Lombi *et al.* (2004) which revealed that finger length correlated positively and significantly with fertilizer application on the grain yield of rice. The response of crops to phosphorus and other essential nutrients which are limited under acidic conditions 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 was largely due to its root distribution relative to phosphorus location in the soil (Wekha *et al.*, 2016b) that was made available by the liming effect of the NPK blended which would have probably prevented leaching of the required nutrients hence available for the plant uptake. The significant growth vigour response to fertilizers could be attributed to the fact that finger millet depends on fertilizer rich in phosphorus at its early stages of growth and this might have stimulated root proliferation and acquisition of nutrients like nitrogen, potassium, sulphur, calcium, magnesium, and traces of boron, zinc, molybdenum, copper and manganese for growth that were present in the NPK blended fertilizer thus longer fingers of the crop. Gulu-E peaked at 50kg/acre with long fingers. Above 50kg/acre led to decrease in the finger length. In P-224 finger length increased with increase in NPK blended fertilizer application peaking at 100kg/acre. This could mean that Gulu-E was able to fix and use minimal fertilizer nutrients to achieve higher yields (Table 4.4). This might be due to differences in their genetic make-up.

5.2.3 Finger millet width

There was a steady increase in the finger millet width with application of NPK blended fertilizer while the control had the lowest in both varieties. The positive response of the finger millet varieties on the finger width on application of NPK blended fertilizer was due to the low availability of essential nutrients in the study soils that were supplied optimally by the fertilizer. The results are in agreement with those of Lombi *et al.* (2004) which revealed that finger millet width correlated positively and significantly with fertilizer application on the grain yield of rice. The increase in finger millet width might have been also due to the enhanced synthesis of amino acid, chlorophyll and better carbohydrate transformation which resulted in widening of the fingers.P-224 was more responsive to the NPK blended fertilizer than Gulu-E, peaking at 100kg/acre. However, there was no significant difference among varieties at 50kg/acre and 75 kg/acre. This could have been due to potassium and boron nutrients present in the applied NPK blended fertilizer that may have promoted cell division leading to longer finger millet (Nogueira *et al*, 2016).

5.3 The influence of NPK blended rates on chlorophyll content and mineral contents of two finger millet varieties

5.3.1 Chlorophyll content

The NPK blended fertilizer led to an increase in the chlorophyll content in the finger millet varieties. The increase was attributed to the applied fertilizer which availed the important nutrients such as phosphorus, magnesium and calcium that are important for the synthesis of chlorophyll in the chloroplasts. Since the fertilizer had magnesium, iron, calcium and nitrogen which are components in chlorophyll molecule structure, hence the significant relationship between the NPK blended and chlorophyll content. Nitrogen is a component of the enzymes associated with chlorophyll synthesis and the chlorophyll concentration reflects relative N status in the soil which was greatly enhanced through the NPK blended fertilizer. The results agree with those of Abuli, (2014) which indicated that chlorophyll content was significantly higher in soya bean planted under DAP fertilizer treatment and lowest in control treatment (no fertilizer application) in acidic soils of Tharaka Nithi and Meru. Significant increase of CCI at 75 kg/acre could be attributed to increased magnesium and phosphorus nutrients which are components of chlorophyll molecule. Beyond 75 kg/acre application, CCI declines and this could be due to excess magnesium. Excess magnesium leads to reduced root respiration due to reduced soil aeration hence reduced soil microbes leading to reduced breakdown of organic matter and nutrient availability to plants. Excess magnesium could also lead to production of toxic compounds in plants which end up limiting nutrient uptake by plants.

5.3.2 Tissue calcium

The calcium content was higher in the NPK blended fertilizer treatments compared to the control because the release of Ca to the soil from the fertilizer enhanced uptake by the two varieties. Tissue calcium increased with NPK blended fertilizer application up to 75 kg/acre. There was a decline in the 100 kg/acre application rate. This could be attributed to the increased levels of potassium which antagonistically affects calcium uptake at the highest rate. The results are in agreement with those of Baatuuwie, (2015) who found that NPK blended fertilizer in combination with manure application in maize led to increased calcium uptake by the plant. Results also agree with those of Omollo *et al.*(2016) who reported increased Calcium on application of liming materials Ca $(OH)_2$,CaO, $CaCO_3$. In both varieties, the tissue calcium content was higher at 75kg/acre with 126.7mg/100g.

5.3.3 Tissue potassium

There was a positive increase on the K content in the tissues of finger millet due to application of NPK blended fertilizers. Potassium content increased with up to 75 kg/acre may be due to optimal levels of calcium and nitrogen that enhanced potassium uptake. Excessive calcium and nitrogen above optimum led to drop of potassium levels. These results are in agreement with those of Baatuuwie, (2015) who found that NPK blended fertilizer in combination with manure application in maize, led to increased potassium uptake by the plant.

5.3.4 Tissue magnesium

There was an increase in the amount of magnesium as NPK blended rates were increasing. With reduced soil acidification, increased amounts of Magnesium was released and absorbed by the plant in exchangeable form due to the increase in the variable charge. More magnesium was present in the soil solution and thereby making conducive for uptake hence higher uptake. Higher tissue magnesium levels might have also been due to optimum levels of nitrogen which is synergistic to magnesium. This results are in agreement with those of Baatuuwie, (2015) who found that NPK blended fertilizer in combination with manure application in maize led to increased magnesium uptake by the plant. Variety Gulu-E peaks at the highest rate of 100 kg/acre, on the other hand, P-224 starts peaking at 50 kg/acre, which is insignificant to 75 kg/acre and 100kg/acre.

5.3.5 Tissue nitrogen

Application of NPK blended fertilizer led to an increase in the tissue nitrogen (N). The increase in tissue nitrogen may be attributed to optimal levels of copper and boron nutrients present in the NPK blended fertilizer that could have promoted nitrogen uptake by the finger millet varieties. At low pH both soluble and complexes of aluminium and manganese cations inhibits proper root growth and development (Millaleo *et al*., 2010) apart from other negative effects on nutrient uptake and biochemical reactions in growing crop. These results are in agreement with those of Baatuuwie(2015) who found that NPK blended fertilizer in combination with manure application in maize led to increased nitrogen uptake by the plant. Both varieties P-224 and Gulu-E had highest tissue nitrogen content at 2193 mg/100g and 2200 mg/100g respectively. This may be due to optimum levels of copper and boron nutrients in the soil, (Nogueira *et al*., 2016).

5.3.6 Tissue phosphorus

There was a significant steady increase in the amount of tissue Phosphorus due to the NPK blended fertilizer application. This was because of the Phosphorus component in the fertilizer that may have led to increased uptake of the nutrient and also the increase of the soil pH with increasing NPK blended rates that might have led to the reduction of Fe and Al ion concentration in the soil thereby decreasing the adsorption/precipitation of P thus more uptake and accumulation in the plant tissues. With the variable charges in the soil, the decrease in pH increased the anion exchange capacity and thereby higher retention of P resulting in the release of P for plant uptake.

Acidic soils are usually low in available P and have a high capacity to tie up added P by forming insoluble compounds with iron and aluminium. The solubility of phosphorus ions depends greatly on pH because pH influences both the kind of phosphorus ion present and the concentration of the precipitating ions. According to Cresser *et al*.(1993) the influence of soil pH on phosphorus solubility is one of the reasons for reducing acidity in soils. The application of NPK blended fertilizer could have precipitated Al^{3+} as $Al\ (OH)^3$ which was dominant in the acid soils of the study site, thus increasing plant available P as echoed by Havlin *et al*.(2005).

Plants require a balanced supply of nutrients throughout their development and the split application of the NPK blended ensured this as indicated in the higher tissue contents of N and P as well as the chlorophyll. The nutrient uptake followed the Liebig's law of the minimum where the linear response to mobile nutrients continued with each added increment of nutrient until a certain potential for that growing environment was reached. Generally, the crop accumulated most of its nutrients between flowering and ripening stages. Nutrients supplied by NPK blended fertilizer played a very vital role as far as root growth and development and grain formation and grain filling is concerned. Therefore, low nitrogen uptake early in a plant's growth lowers nutrient quantity for the seed, affecting both yield and quality as recorded under the control. The higher plant tissue nutrient (N, P, K Ca, and Mg) content with combined N and P application at the site could be attributed to the synergistic N enhancement of P uptake. While N is the most limiting nutrient generally in soil has shown that deficiency of soil phosphorus reduces the efficiency of N use by crops (Vanlauwe *et al*., 2011).Under the influence of soil acidity stress, physiological processes including photosynthesis, phosphorous uptake disease resistance and germination are significantly reduced(Were and Ochuodho, 2014; Souza *et al*., 2017). The reduced uptake of the nutrients under study in the plant parts for the control plots is due to the low supply of energy to meet the requirement by plants to take up nutrients from the soil and translocate them through the plant. Increased plant N content could be due to the mineralization of organic N which was found to increase due to NPK blended fertilizer application. There was a positive increase on the phosphorus content in the tissues of finger millet due to application of NPK blended fertilizers. Increased tissue phosphorus might be due to optimum levels of molybdenum, copper and zinc nutrient that synergistically increases phosphorus uptake by plants. No significant differences were observed among all the treatments. However, there was a general increase in tissue phosphorus content across all treatments up to 100 kg/acre. These results are in agreement with those of Baatuuwie (2015) who found that NPK blended fertilizer in combination with manure application in maize, led to increased phosphorus uptake by the plants.

5.4. The influence of NPK blended fertilizer rates on yield components and grain yield of finger millet

5.4.1 Days to 50% flowering

The control on both varieties showed the longest period in attaining 50% flowering of finger millet as compared to the NPK blended fertilizer plots because the fertilizer supplied P as well as ameliorating acidity and thus making P more available thus the rapid development of the crop to anthesis. Low soil pH as observed in the study site of the current experiment may have depressed the activities of many beneficial soil microbes Wekha *et al.*,(2017) such as those that convert unavailable N, P, and S to available mineral forms. Acidic soils give poor crop performance in terms of crop growth and development. This is due to unavailability of P and N resulting from P fixation and slowing down of nitrification rates (Fennel *et al*., 2005). The findings agree with that of Lemessa, (2016) who reported reduced number of days to 50% flowering with application of NP_20_5 rates on varieties of finger millet. Gulu-E took less number of days to flowering at the highest rate of 100 kg/acre. P-224 took one more day at 100 kg/acre. The reduction in the number of days to 50% flowering could be attributed to boron nutrient present in the applied fertilizer that speeded up the fruiting processes and pollen grain germination (Nogueira *et al*., 2016 and Filipe *et al*., 2017).

5.4.2 Days to maturity

The application of NPK blended fertilizer led to faster maturation of the finger millet varieties compared to the control. The findings agree with those of Anella *et al*. (2014) for research conducted in Oklahoma that showed that maturity of wheat was reduced by as much as 4-7 days with fertilizer application .The fertilizer contained P which is the most important restrictive factor in plant growth and development. Phosphorus is a major component of ATP, a molecule that provides energy to plants for photosynthesis, protein synthesis, nutrient translocation, nutrient uptake, respiration and transfer of genetic material DNA and RNA which are essential in formation of seeds and ultimately led to early maturation under the optimal supply of the nutrient through the NPK blended fertilizer. An earlier report by Wekha *et al*. (2016c) corroborate with the findings of this study that phosphorus contained in the fertilizer caused early ripening in plants and decreases grain moisture. The NPK blended fertilizer has been known to reduce soil acidity and therefore improving nutrient uptake by plants. Previous work based on multi location field experiments conducted in Eastern Uganda found 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 under row planting conditions (Wekha *et al*. 2016a). Both varieties matured earlier at 50kg/acre application rate. Application rate above 50kg/acre delayed time to maturity. Therefore, too much nutrients above optimum delays maturity of the finger millet crop. The delay might be due to negative interactions between elements resulting from excess fertilizer application. The early maturation could also be attributed to zinc, a micronutrient present in the NPK blended fertilizer that promotes growth hormones, starch formation and promotion of seed maturation.

5.4.3 Productive tillers

The NPK blended fertilizer significantly increased the number of productive tillers compared to the control in both varieties. Sisie and Mirshekari, (2011) reported that phosphorus was essential for tiller development and root growth in wheat. The NPK blended fertilizer increased formation of tillers because the mechanism is regulated through phytohormonal mechanism where the ratio of cytokinins produced in the root apices and auxins produced in the shoot apices might have had special significances where essential nutrients were made available by the fertilizer. Increased cytokinin production and transport to the shoot enhances aerial tillering where P plays a pivotal role. These 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 fertilizer on wheat crop. This findings also agree with those of Khan *et al.*(2010) who reported increase in the number of productive tillers due to phosphorous applications on various cereal crops. Gulu-E had highest number of productive tillers, 42 tillers at 75 kg/acre and 100kg/acre, whereas P-224 had highest number of tillers at 100kg/acre which were insignificant to 75 kg/acre. Fertilizer utilization was similar in both varieties.

5.4.4 Grain yield

The application of NPK blended fertilizer led to a significant increase in the grain yield of the two finger millet varieties compared to the control. The increase in yield is therefore, attributed to the increased availability of N and P due to NPK blended fertilizer application. Many studies have not quantified the amounts of nutrients to be added in relation to the measured yield improvement in Kenya on finger millet. NPK blended fertilizer is essential for root growth and energy transfer processes in plants. Like root growth and development, grain formation and grain filling was positively affected by macro and micro nutrients supplied by the NPK blended granular fertilizers. For instance, without fertilizer application, both grain formation and grain filling was lowered in control plots. The increase in the grain yield due to increasing NPK blended fertilizer rates is mainly due to the role of optimum P in energy provision for seed formation and grain filling. The results are in line with findings of Ahmad *et al*. (2000), who found that finger millet grain yields increased from 0.87 to 1.30 t ha^{-1} with increasing P rates. Increase in the grain yield could have been due to increased uptake of manganese nutrient an important component in photosynthesis, nitrogen assimilation and metabolism. Gulu-E , at 75kg/acre gave highest yield of 155g but insignificant to 100kg/acre that gave 140g. At 75kg/acre P-224 gave highest yield of 110.3g while 100kg/acre gave 93g. Therefore Gulu-E was superior to P-224 in the yield performance. These results are similar with the findings of Lemasse, (2016) who reported significant highest grain yield due toNP_20_5 application on finger millet varieties.

CHAPTER SIX

CONCLUSION, RECOMMENDATION AND SUGGESTIONS FOR FURTHER RESEARCH

6.1 Conclusion

- The soil aluminium significantly reduced with application of NPK blended fertilizer. This raised the soil pH, soil calcium content and soil magnesium content steadily. The liming effects of the fertilizer were distinctively highlighted from the results of this study with a linear reduction on the grain yield observed with increased aluminium content in the soil.

- Application of NPK blended fertilizer enhanced growth of finger millet. This positively and directly impacted on the final grain yield. The study showed that essential nutrients were deficient in the study site.

- The physiological components (chlorophyll content, calcium, magnesium, potassium, nitrogen and phosphorus) were positively influenced by application of NPK blended fertilizer. It was observed that the increasing chlorophyll content index, there was a positive linear increase on the grain yield per plant of finger millet. The productive tillers increased as NPK blended fertilizer was applied while the days to 50% flowering and days to maturity reduced because P found in the NPK blended fertilizer stimulated rapid growth, flower initiation, fertilization and grain formation.

- The most important characteristic to the farmer, the grain yield was positively responsive to application of fertilizer where the peak was observed at 75 kg/acre. The reduced grain yield at the highest rate was attributed to the reduced absorption of essential nutrients under excess P while the lower rates did not reach the optimal conditions for optimal energy provision to the plants maximum metabolism.

6.2 Recommendations.

It can be recommended from this study that:

1. The NPK blended fertilizer application can positively ameliorate the soils in western Kenya by reducing the acidity, similar to activity of lime and at the same time provide essential nutrients to improve the yields.

2. The highest grain yield of finger millet may be achieved at the 75 kg/acre rate through improved days to 50% flowering, days to maturity, productive tillers which positively and significantly impact on the eventual yield and the rate is therefore recommended.

3. The physiological activities of finger millet are highly improved under application of NPK blended fertilizer at a rate of 75 kg/acre which is recommended as it facilitates positive plant metabolism.

4. Application rate of 75 kg/acre NPK blended fertilizer led to the realization of the highest potential grain yield of Gulu-E finger millet variety through increased crop growth. This corresponds to production rate of 1.55 t/ha compared to 0.5 t/ha as earlier documented.

6.3 Suggestions for further research

The study also found there are some gaps to be investigated:

1. To find out the long-term influence of NPK blended fertilizers on the soil chemical balances and residual effect of P to crops.

2. In this study, it was not clear why there was decline in finger millet length on Gulu-E as opposed to P-224 beyond 50 kg/acre of NPK blended fertilizer application. Further studies should look in to reasons why there was a decrease in finger length of Gulu-E on fertilizer application above 50 kg/acre.

3. The study did not focus on tolerance levels of varieties to acidity, therefore there is need for further studies on how the two varieties tolerate different levels of acidity and the impacts of applied NPK blended to the changes in soil pH.

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APPENDICES

APPENDIX 1: Pictorial field and laboratory procedures. (Photo by researcher).

a). The tagged plants in a plot that were used for sampling procedures.

b). The experimental unit measuring 2 metres by 1.7 metres at the Kakamega site.

APPENDIX 2: ANOVA TABLES

Analysis of variance

Variate: Soil Al

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0.02094	0.01047	1.81	
Rep.*Units* stratum					
Fertilizer_Treatment	4	1.994647	0.498662	86.15	<.001
Variety	1	0.001613	0.001613	0.28	0.604
Fertilizer_Treatment.Variety	4	0.009487	0.002372	0.41	0.799
Residual	18	0.104193	0.005789		
Total	**29**	**2.13088**			

Variate: Soil Ca

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0.007807	0.003903	0.43	
Rep.*Units* stratum					
Fertilizer_Treatment	4	3.903753	0.975938	106.64	<.001
Variety	1	0.010453	0.010453	1.14	0.299
Fertilizer_Treatment.Variety	4	0.011247	0.002812	0.31	0.869
Residual	18	0.164727	0.009151		
Total	**29**	**4.097987**			

Variate: Soil pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.000327	0.000163	0.02	
Rep.*Units* stratum					
Fertilizer_Treatment	4	0.094913	0.023728	2.91	0.05
Variety	1	0.00972	0.00972	1.19	0.29
Fertilizer_Treatment.Variety	4	0.007247	0.001812	0.22	0.923
Residual	18	0.14694	0.008163		
Total	**29**	**0.259147**			

Variate: Soil Mg

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0.025807	0.012903	1.42	
Rep.*Units* stratum					
Fertilizer_Treatment	4	3.357147	0.839287	92.53	<.001
Variety	1	0.001203	0.001203	0.13	0.72
Fertilizer_Treatment.Variety	4	0.01208	0.00302	0.33	0.852
Residual	18	0.16326	0.00907		
Total	**29**	**3.559497**			

Variate: CCI_umol_Fr_wt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.24	0.12	0.01	
Rep.*Units* stratum					
Fertilizer_Treatment	4	135.09	33.77	2.99	0.047
Variety	1	0.67	0.67	0.06	0.81
Fertilizer_Treatment.Variety					
	4	3.99	1	0.09	0.985
Residual	18	203.58	11.31		
Total	**29**	**343.57**			

Variate: Tissue K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	23167	11583	0.61	
Rep.*Units* stratum					
Fertilizer_Treatment	4	369980	92495	4.83	0.008
Variety	1	653	653	0.03	0.855
Fertilizer_Treatment.Variety					
	4	11580	2895	0.15	0.96
Residual	18	344567	19143		
Total	**29**	**749947**			

Variate: Tissue N_mg_100g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	51332	25666	0.52	
Rep.*Units* stratum					
Fertilizer_Treatment	4	648372	162093	3.25	0.036
Variety	1	83	83	0	0.968
Fertilizer_Treatment.Variety					
	4	29125	7281	0.15	0.962
Residual	18	896785	49821		
Total	**29**	**1625697**			

Variate: Finger Length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.5674	0.2837	1.18	
Rep.*Units* stratum					
Fertilizer_Treatment	4	3.6901	0.9225	3.82	0.02
Variety	1	0.0083	0.0083	0.03	0.855
Fertilizer_Treatment.Variety					
	4	0.9488	0.2372	0.98	0.442
Residual	18	4.3446	0.2414		
Total	**29**	**9.5592**			

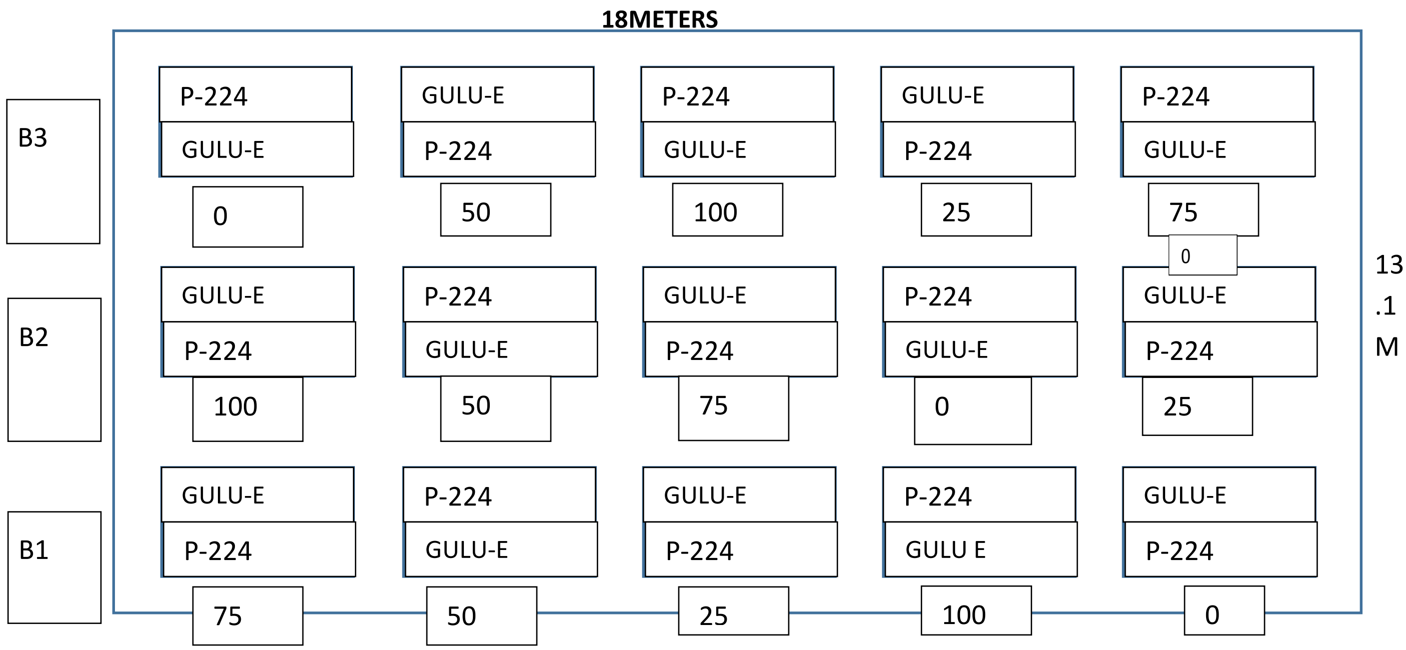
Variate: Finger Width

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.032019	0.016009	6.79	
Rep.*Units* stratum					
Fertilizer_Treatment	4	0.222648	0.055662	23.62	<.001
Variety	1	0.008333	0.008333	3.54	0.076
Fertilizer_Treatment.Variety					
	4	0.040093	0.010023	4.25	0.013
Residual	18	0.042426	0.002357		
Total	**29**	**0.345519**			

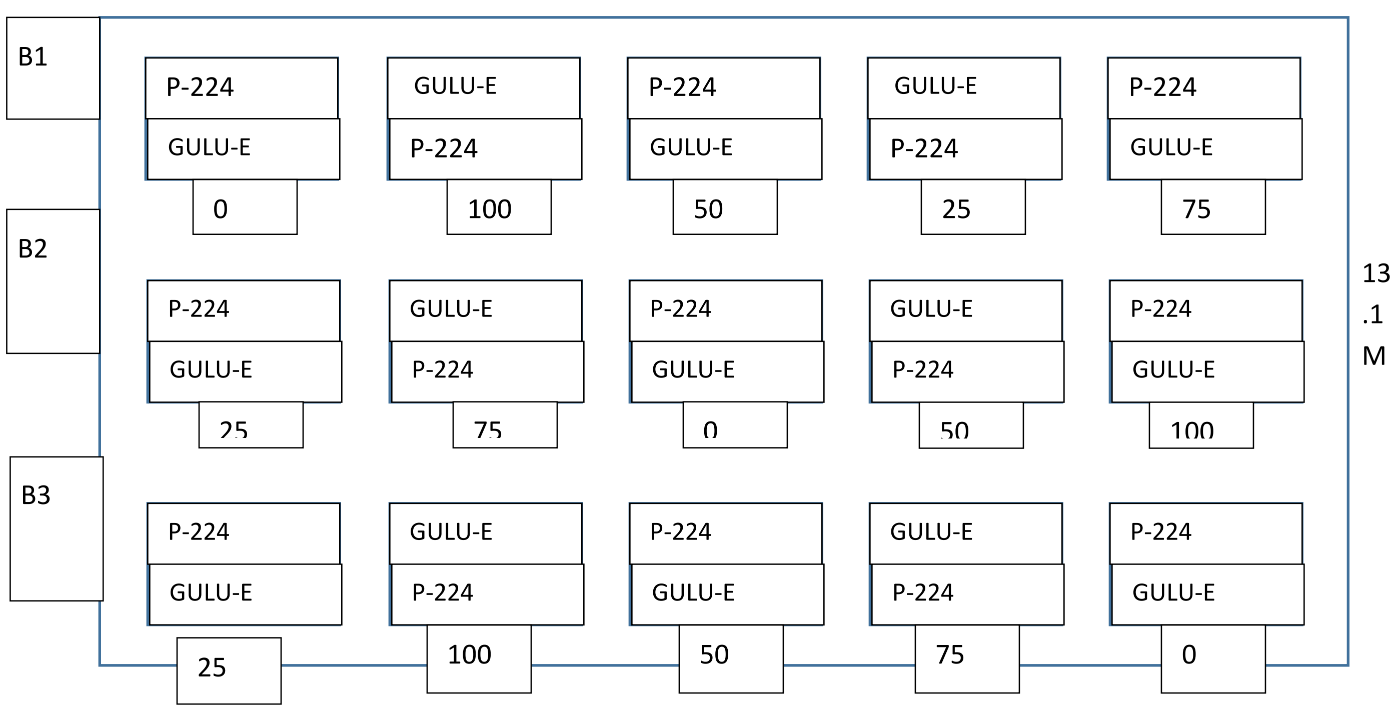
Variate: Plant Height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	39.38	19.69	1.1	
Rep.*Units* stratum					
Fertilizer_Treatment	4	441.52	110.38	6.18	0.003
Variety	1	33.25	33.25	1.86	0.189
Fertilizer_Treatment.Variety					
	4	49.69	12.42	0.7	0.605
Residual	18	321.3	17.85		
Total	**29**	**885.15**			

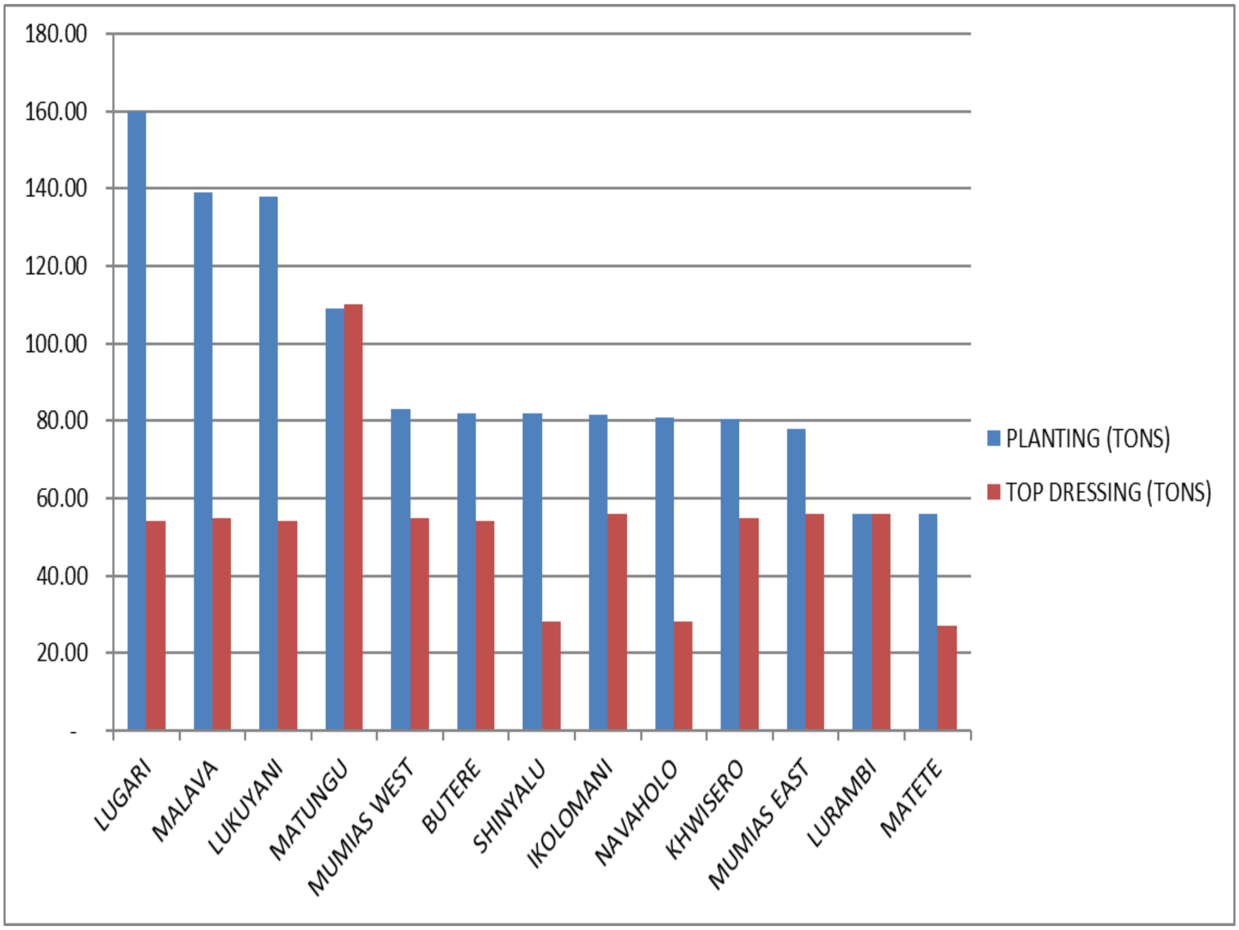
APPENDIX 3: Experimental layout in the field at KALRO-Kakamega station for the short rain season



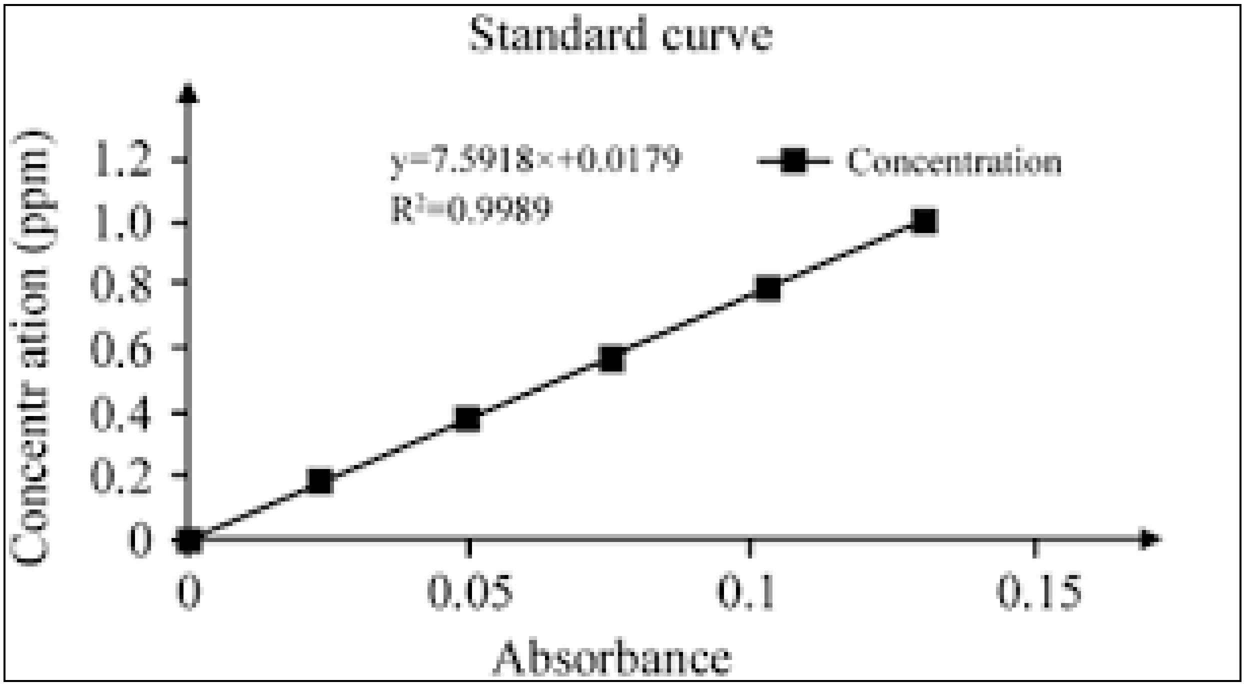
APPENDIX 4: Experimental layout in the field at KALRO-Kakamega station for the long rain season.



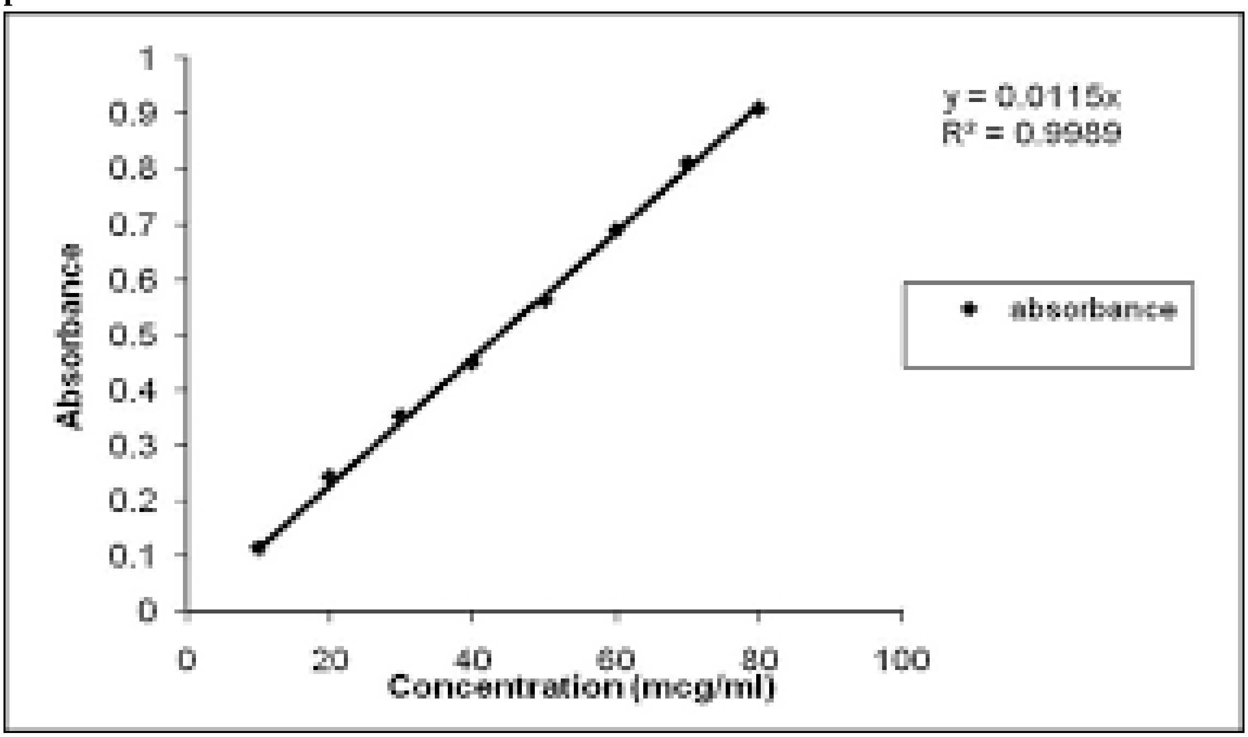
APPENDIX 5: Bar graph presentation of the planting and top dressing NPK (mavuno fertilizer) subsidized fertilizer - county Government of Kakamega by sub-county 2015.



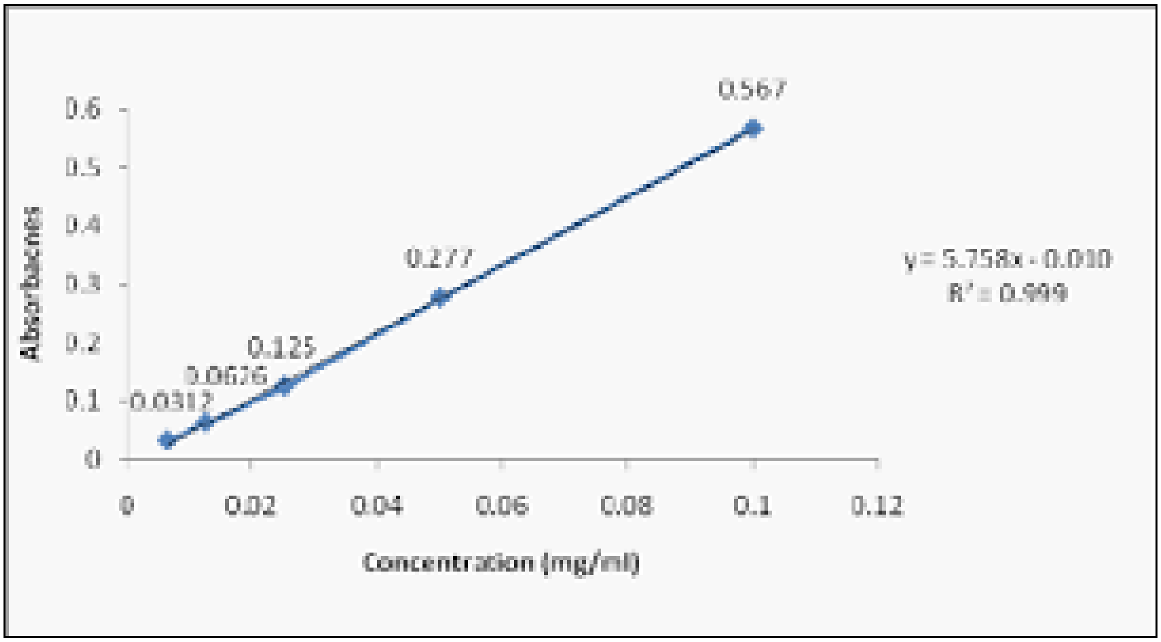
APPENDIX 6: The standard curve in the calibration of plant tissue phosphorus



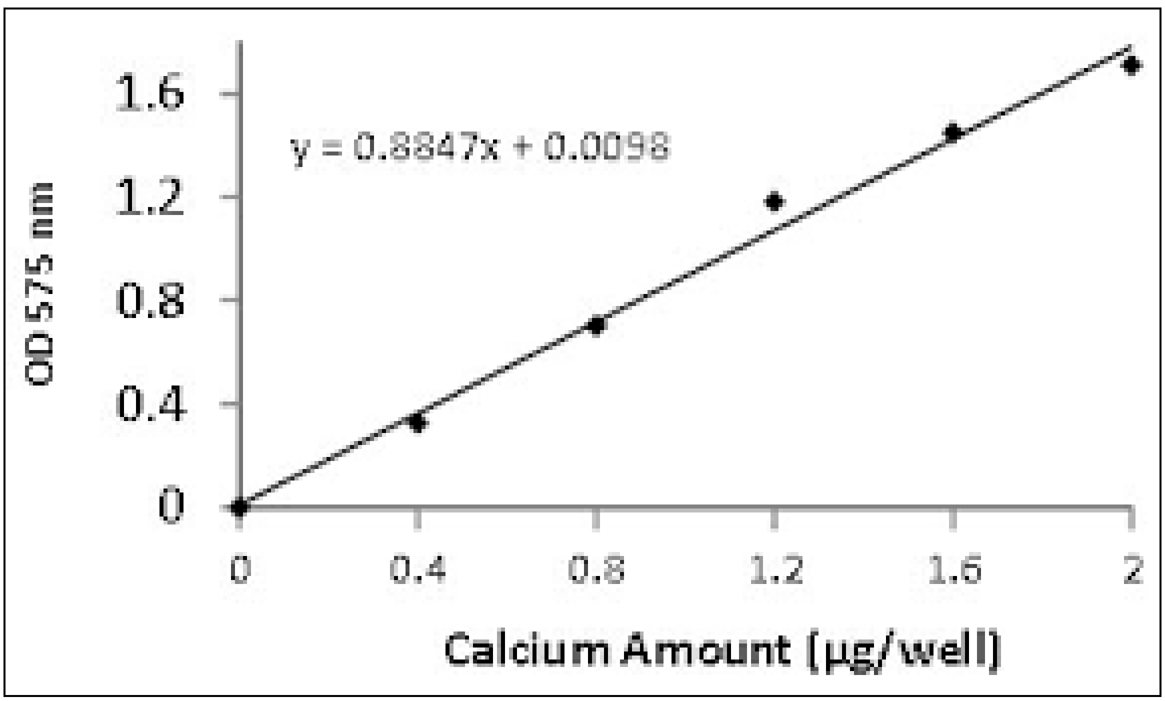
APPENDIX 7: The standard curve in the calibration of plant tissue potassium



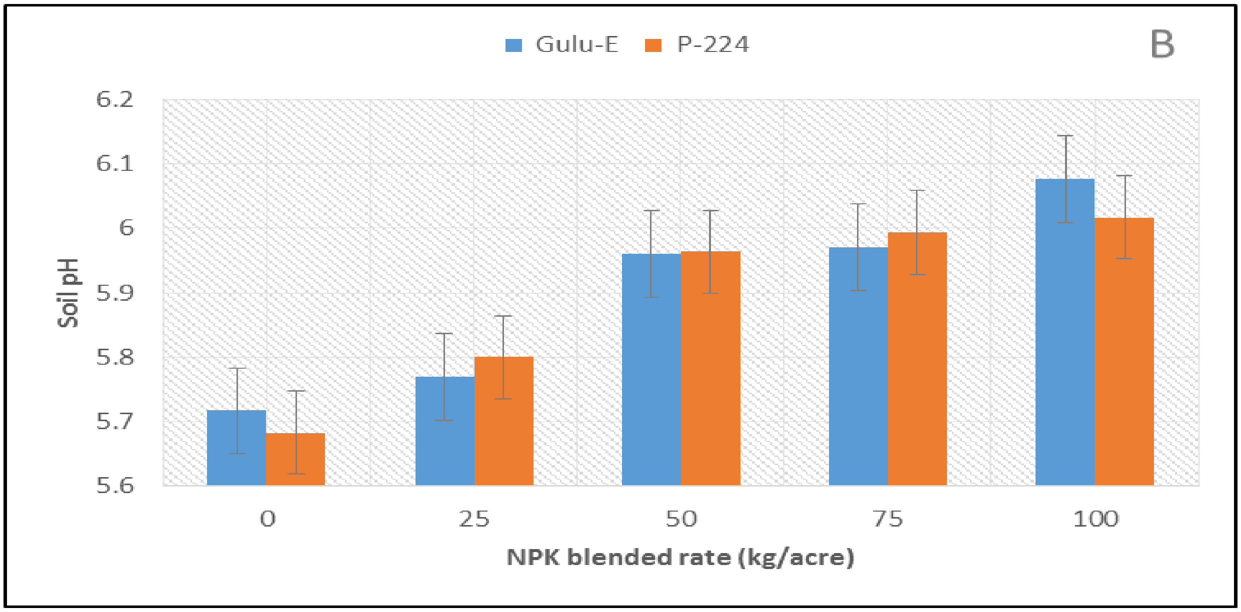
APPENDIX 8: The standard curve in the calibration of plant tissue magnesium



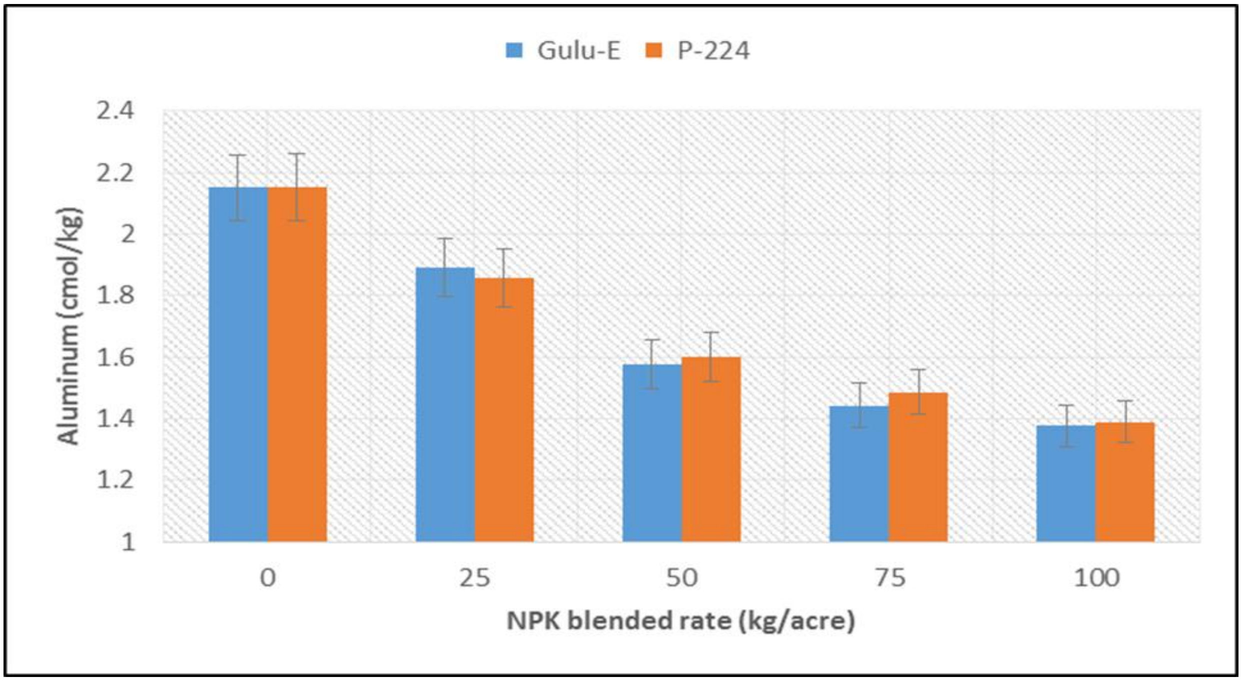
APPENDIX 9: The standard curve in the calibration of plant tissue calcium.



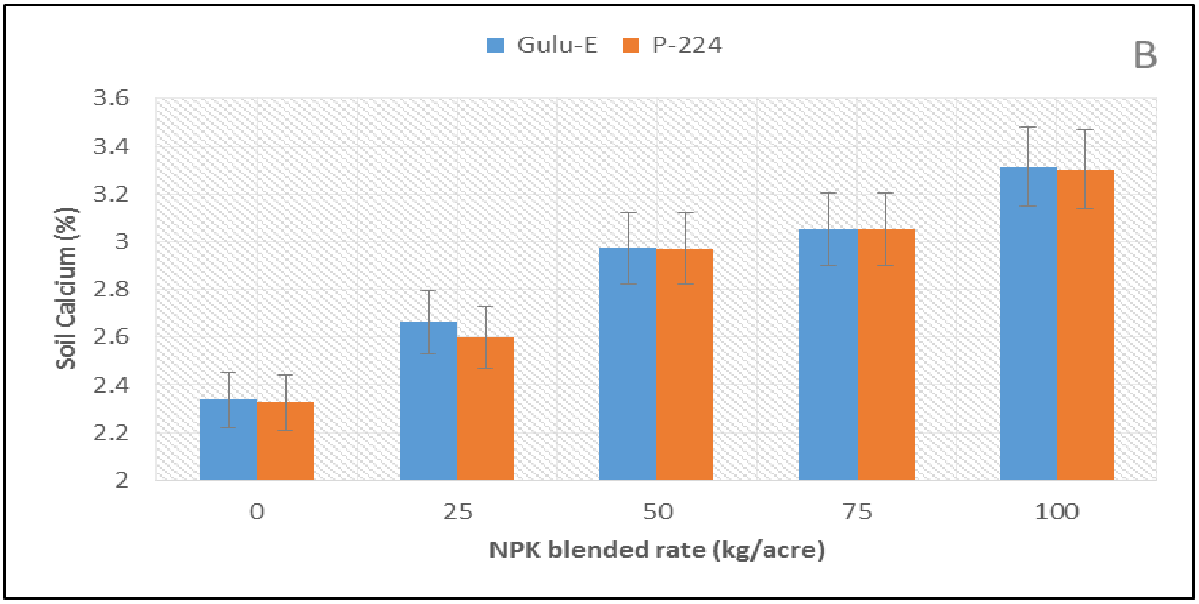
APPENDIX 10 Short rain season results under the influence of NPK blended fertilizer on acidic soils of Kakamega, Western Kenya.



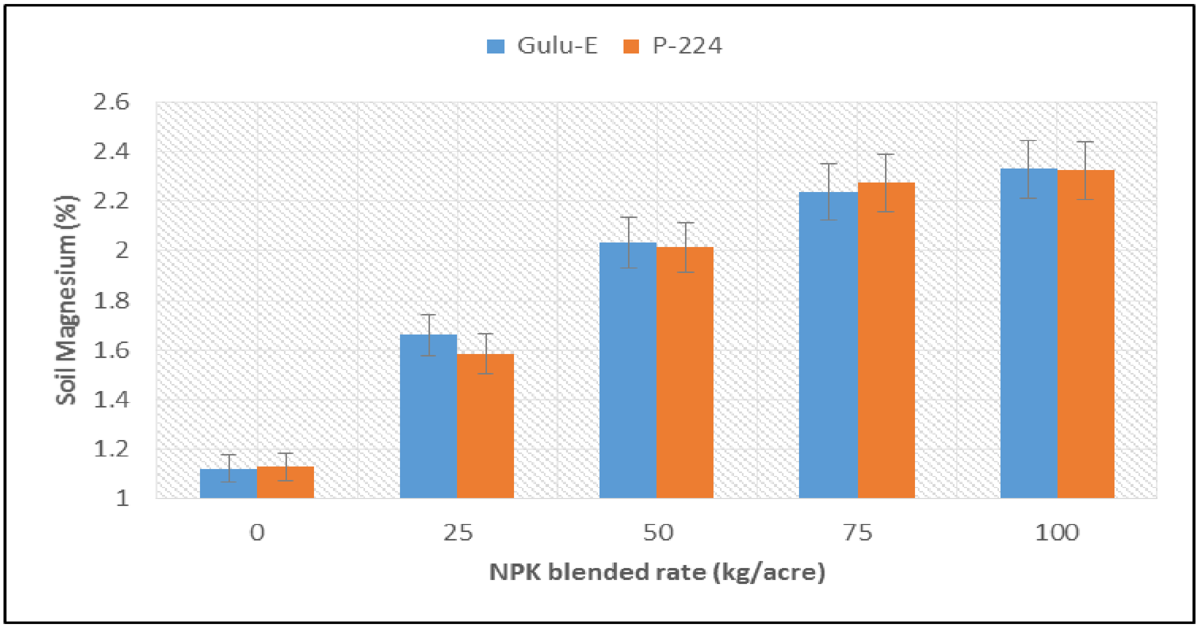
The soil pH at harvesting as influenced by application of NPK blended fertilizer treatments at Kakamega under Gulu-E and P-224 finger millet varieties during the short season of 2015.



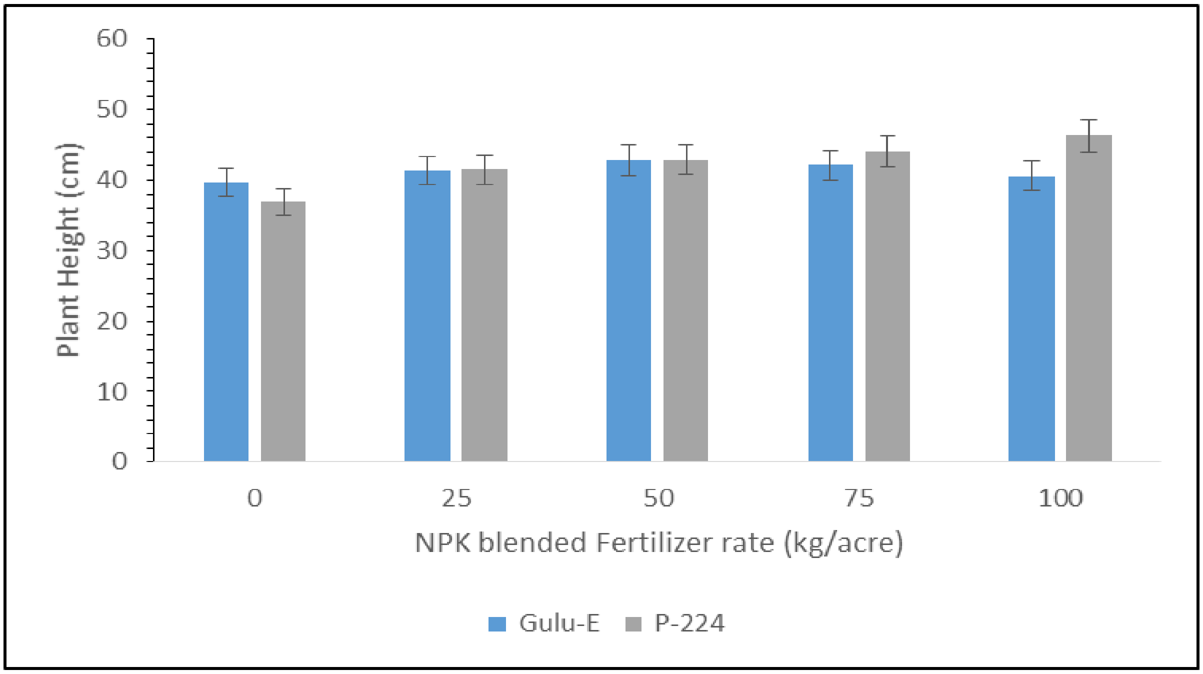
The soil aluminium content at harvesting as influenced by application of NPK blended fertilizer treatments at Kakamega under two finger millet varieties (Gulu-E and P-224) during the short rain season of 2015.



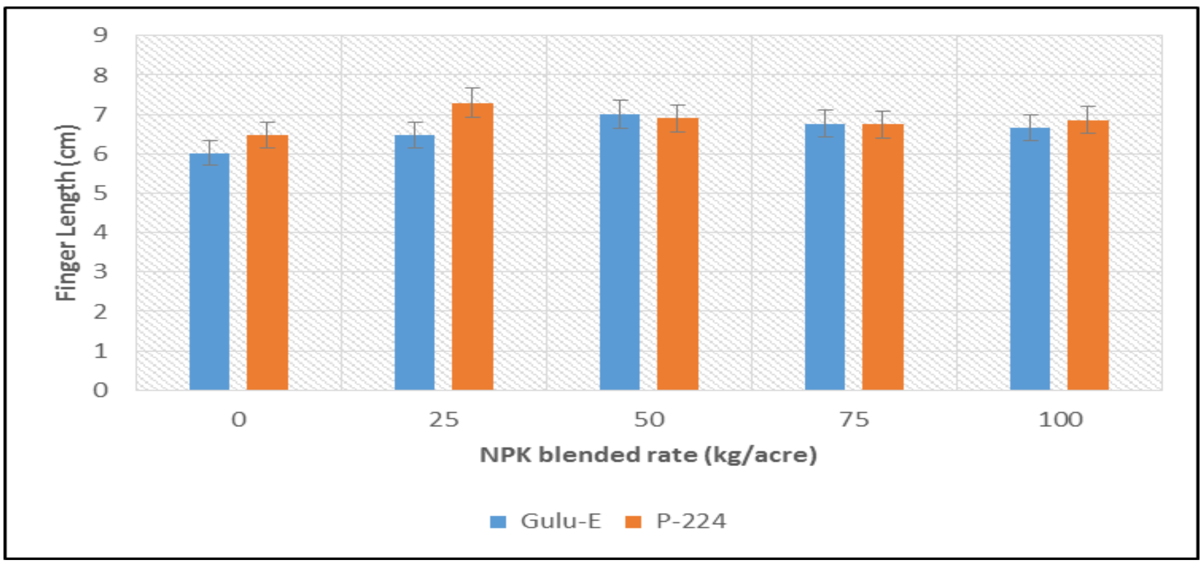
The soil calcium content as influenced by application of NPK blended fertilizer treatments at Kakamega for Gulu-E and P-224 finger millet varieties at harvesting for the short rain season of 2015.



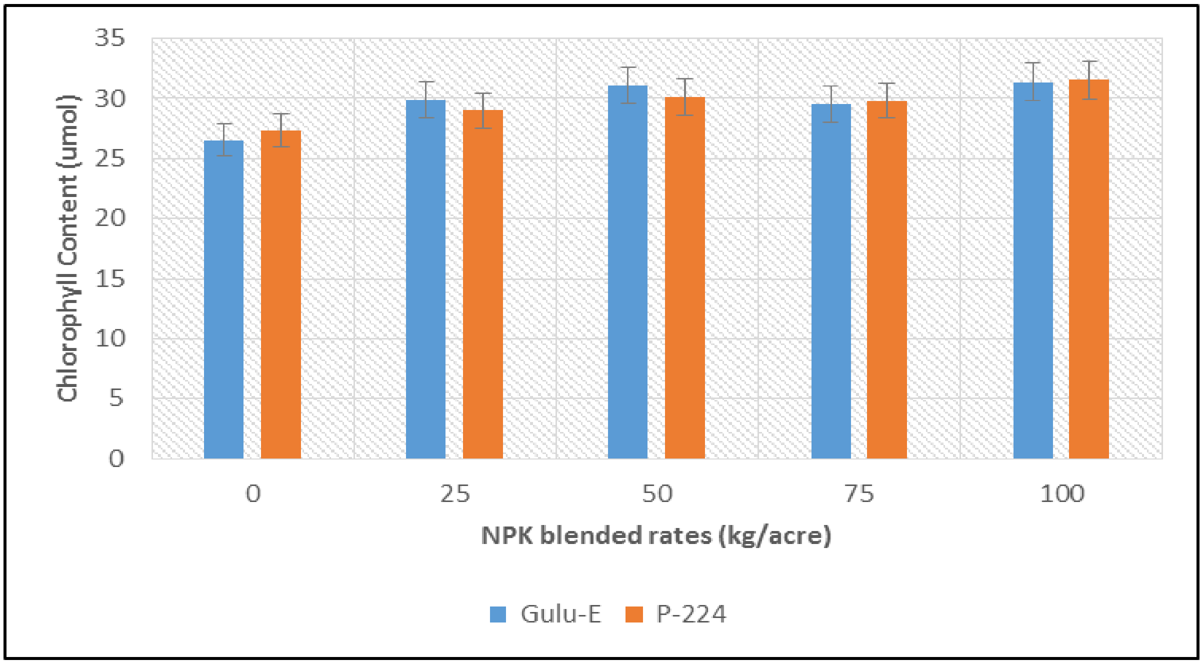
Soil magnesium content as influenced by application of NPK fertilizer treatments at Kakamega in two finger millet varieties (Gulu-E and P-224) at harvesting during the short rain season of 2015.



Mean plant height at dough stage of finger millet varieties at harvesting during the short rains season of 2015.



Finger length of finger millet varieties at Kakamega at harvesting during the short rain season of 2015.



Influence of NPK blended fertilizer on the chlorophyll content at harvesting of Gulu-E and P-224 finger millet varieties in acidic soils of Kakamega during the short rain season of 2015.

Effect of NPK blended fertilizer on the calcium, magnesium, nitrogen, phosphorus and potassium contents at harvesting in Gulu-E and P-224 finger millet varieties at Kakamega during the short rain season of 2015.

Variety	Fertilizer Rate	Calcium mg/100 g	Potassium mg/100 g	Magnesium mg/100 g	Nitrogen mg/100 g	Phosphorus mg/100 g
Gulu-E	0	64.3a	758a	142b	2361b	358b
	25	81a	1012a	152ab	2514a	413ab
	50	71.7a	855a	160a	2595a	459a
	75	71.7a	983a	150ab	2493ab	393ab
	100	75.3a	950a	142ab	2650a	430a
P-224	0	60.3	757a	133b	2463ab	353b
	25	81.3	1027a	163a	2467ab	402ab
	50	73.3a	857a	148ab	2572a	447a
	75	72.0a	1003a	142ab	2468ab	400ab
	100	72.7a	1017a	157a	2598a	389ab
P-Value		0.139	0.223	0.045	0.042	0.003
LSD		14.16	263.6	23.6	254.6	62.59

Values in columns followed by the same letter do not differ significantly at P≤0.05

Days to 50% flowering, days to maturity, number of productive tillers and grain yield of Gulu-E and P-224 finger millet varieties as influenced by NPK blended fertilizer rates at Kakamega during the short rain season of 2015.

Treatment		Days to 50% Flowering	Days to Maturity	Productive Tillers/Plot	Grain Yield (g)/Plot
Gulu-E	0	96.0a	118.3a	25.3b	34.7d
	25	87.7b	116.3b	25.0b	52.7c
	50	88.7b	110.3d	27.7b	67.7b
	75	84.0c	110.3d	36.7a	80.3a
	100	86.7b	113.0c	42.7a	70.3b
P-224	0	86.7b	119.7a	26.3b	44.7d
	25	85.7b	115.0b	40.0a	55.0c
	50	86.0b	110.3d	28.3b	64.3b
	75	88.0b	109.0d	41.3a	78.7a
	100	89.3b	111.0c	34.3a	58.7c
P-Value		0.021	0.009	0.047	0.005