__Original Research Article__

Phosphorus Influence on Plant Tissue Nitrogen Contents and Yield Attributes of Finger Millet varieties in Semi-Arid Region of Kenya

ABSTRACT

The experiment was conducted with the aim of evaluating the effect of differential levels of P on finger millet accumulation of N and yield components. On-station experiments were conducted at the KALRO-Kiboko crops research station in Makueni County during the short and long rains of 2014 and 2015 respectively. There were 4 levels of P (0, 12.5, 25 and 37.5 kg ha^{-1} P_2O_5) and three varieties (U-15, P-224 and Ekalakala). Ekalakala is the local check while 0 kg/ha P_2O_5 was the control. The trial was laid out in a randomized complete block design and fitted in factorial arrangement with three replicates given a total of 36 plots. Soil sampling was at a depth of 0-30 cm on all the plots and analytical results showed moderately available P but very low N, organic carbon and zinc. Significant differences *(P=.05)* were observed between the phosphate levels on the nitrogen contents in plant parts with the control showing the lowest N accumulation of 4.95% and 4.90% for the short and long rains respectively while the 25 kg ha^{-1} P_2O_5 rate had the highest with 5.66% in the short rains and 5.14% in the long rains. The stem contained the highest nitrogen content while the roots had the lowest. Phosphate rates did not have significant influence on the yield components except the finger width while the varieties varied significantly *(P=.05)* on the productive tillers, panicle number, grains per spikelet and the harvest index. Variety U-15 had the highest yield for both seasons with a maximum of 3410 kg ha^{-1} for the short rains. The newly released variety (U-15) responded well to moderate P supplemented at 25 kg ha^{-1} P_2O_5 thus can efficiently utilize N in soils with low N like in Makueni and is highly recommended. The optimal P for the yield and N accumulation was 25 kg ha^{-1} P_2O_5 and beyond this point the P would not be translated to profitable yield but a loss to the farmer in the short run.

Keywords: Finger millet; available P; N accumulation; grains per spikelet.

1. INTRODUCTION

Finger millet *(Eleusine coracana)* is the most important small millet grown in eastern and southern Africa and it serves as a subsistence and food security crop that is especially important for its nutrition and resilience to harsh weather conditions. Of all major cereals, this crop is one of the most nutritious [1] especially in calcium. It is a food crop in traditionally low input cereal-based farming systems in Africa, and is of particular importance in upland areas of Eastern Africa. While developing countries in Asia still produce the majority of the world's millets, Africa is becoming the hub of production [2]. In Kenya, the crop is mainly produced in the part of the country west of the Rift Valley and it is cultivated on around 65 000 ha yr^{-1} [1]. However, the yields of finger millet on farmers' fields are generally low, just about 15-16 % of their potential maximum in Kenya [3]. Soil infertility is one of the major constraints to finger millet production throughout much of the Sub-Saharan Africa.

An understanding of the internal and external P efficiencies of modern finger millet varieties is very important in selection of varieties adaptable to P deficient and moderate P conditions. Phosphorus deficiency has been identified as one of the most limiting soil nutrient after nitrogen due to soil erosion, continuous cultivation and fast reversion of soluble P where P fertilization is of fundamental importance in replenishing, enhancing and maintaining soil fertility [4]. Achievement of higher efficacy and efficiency of P mineral fertilization is possible through searching for and improving the methods of assessment of plant nutritional status as well as aiming at optimization of fertilizer use. Knowledge on factual needs of plants concerning balancing of mineral nutrients and utilization efficiency is an important aspect of reducing agricultural negative effects on environment through improper P fertilization.

Nutrient limitation of ecosystems is typically determined by fertilization experiments, with increased biomass or growth rates taken as evidence of limitation [5, 6]. A less direct index of nutrient limitation is foliar nutrient concentration, which is predicted to increase in response to addition of the limiting nutrient, although the positive relationship between biomass and foliar nutrients is not necessarily a linear one. This index is reasonable given that foliar nutrient concentrations (expressed either as N concentration, P concentration, or a ratio of N-to-P) reflect soil nutrient concentrations [7, 8]). Foliar N and P concentrations also relate to the functioning of plants, as comparisons across agro-ecologies have shown that they are correlated with physiological traits such as photosynthesis and dark respiration, and leaf properties that affect resource capture such as specific leaf area and leaf lifespan [9].

Finger millet has high genetic diversity [10]. All finger millet varieties do not respond to nutrients in the same manner. Genotypic variability among different finger millet cultivars has been reported for responsiveness to N and P [11]. Gupta *et al*. [12] evaluated the N use efficiency (ratio of grain yield to N supply) and N utilization efficiency (ratio of grain yield to total N uptake) of three finger millet genotypes under different N inputs and found that there was genotypic variability among the finger millet genotypes' responses to different N inputs, wherein some varieties were highly responsive to N. Therefore, the understanding of the existence in genetic variability in finger millet genotypic response to nutrients prompted the need to study yield and N accumulation responses to P among different varieties in marginal Kiboko, of lower area in Eastern Kenya.

2. MATERIALS AND METHODS

2.1. Site description

The experiment was conducted during the 2014 short and 2015 long rains season at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Kenya Agricultural and Livestock Research Organization (KALRO)-Kiboko Crops Research Station where the previous crop planted was pigeon pea. The station is in Kiboko Location, Makueni County. It lies within longitudes 37°38" East, latitudes 2°16" South and at an elevation of 975 m above sea level. The soils are classified as Acri-Rhodic Ferrassols [13] composed of sand (43.08%), silt (33.91%) and clay (23.01%) with an average pH unit of 8.9. Mean available P was found to be moderate while nitrogen, organic carbon and zinc were extremely low as shown in Table 1. The station received a total of 441 and 286.3 mm rainfall during the short and long rains seasons respectively. The mean maximum and minimum temperature for the short and long rains were 31.8℃ and 17.9℃, and 29.7℃ a nd 15.7℃ respectively with mean precipitation of 83.3% and 85% potential evaporation during the short and long rains respectively.

Table 1: Physiochemical properties of experimental site in Kiboko

Physical properties		
Sand %	43.08	
Silt %	33.91	
Clay %	23.01	
Chemical properties	Short Rains	Long Rains
Soil pH	8.55	9.25
Available N %	0.03	0.03
Organic Carbon %	0.24	0.26
Extractable P ppm	13.25	15.5
Potassium me%	0.49	1.53
Calcium me%	4.37	10.7
Magnesium me%	2.95	3.26
Manganese me%	0.26	0.14
Copper ppm	2.38	2.51
Iron ppm	25.2	44.2

Zinc ppm	1.45	2.86
Sodium me%	0.47	1.05
Electrical Conductivity mS/cm	0.47	0.27

2.2. Experimental design, treatments and data collection

The experiment was laid out in a Randomized Complete Block Design in a factorial arrangement and replicated three times. That is, 4 P rates (0, 12.5, 25 and 37.5 kg ha^{-1} P_2O_5) × 3 varieties (U-15, P-224 and Ekalakala) × 3 replicates (total of 36 treatments). Where Ekalakala was the local check and 0 kg ha^{-1} P_2O_5 was the absolute control. Phosphate fertilizer was measured according to the treatment and divided per row and hand applied as whole during planting as triple superphosphate. Seeds were drilled in the rows and thinned four weeks after planting to a spacing of 10 cm between plants and 50 cm between rows giving a total of 205 plants per plot. The experimental units measured 4 m long and 2 m wide with a 2 m pathway which also separated the plots. Recommended cultural practices were applied throughout the crop growth as per crop demands. The crop was harvested at physiological maturity when 90% browning of the heads was observed. The three middle rows were harvested on a net area of $3m^2$. Data was collected on the number of productive tillers, finger width, finger length, grains per spikelet, number of panicles harvested and the grain yield according to the IBPGR [14]. The harvest index was calculated as ratio of the grain to biological yield.

2.3. Soil samples and plant tissue analysis

Soil samples (500 g) were collected from every experimental plot at a depth of 0-30 cm using a soil auger then air-dried in a well-ventilated room for 3 days. The samples were then ground and passed through a 2-mm sieve to obtain 50 g uniform samples from each plot for analysis and storage. The soil pH was determined electrometrically in water as outlined by Okalebo *et al.* [15]. Plant samples from five plants from each experimental unit were collected and separated into roots, stem, leaves and grain from five plants collected from each experimental unit. The samples were weighed and oven-dried to a constant weight at 70℃ for 48 hours. The dried plant materi al was ground using a Crompton Willey mill and passed through a 2-mm sieve to a uniform mass of 8 g for analysis. Soil and plant tissue nitrogen was determined the by Kjeldahl method while organic carbon content was determined using modified Walkley and Black wet oxidation [16]. The analysis of N and organic carbon were done as described by Ryan *et al*. [16]. Extractable potassium was determined by flame photometer [8] whereby a neutral salt solution replaced cations present on the soil exchange complex. Extractable soil nutrients (Ca, Mg, Mn, Cu, Fe, Zn, and Na) were determined by the Diethylenetriamine Pentaacetic Acid (DTPA) method then measured with an AAS [17]. Determination of P involved digestion of soil sample with a strong acid and the dissolution of all insoluble inorganic minerals and organic P forms which followed the procedure described by Olsen and Sommers [18]. For the electrical conductivity, a 5 g sample of soil was placed in a 100 ml disposable plastic cup; 50 ml of deionized water was added. The slurry was shaken on a reciprocating shaker for 45 minutes, and then filtered. Electrical conductivity of the filtrate was then read with a conductivity bridge.

2.4. Data analysis

Data collected was compiled, cleaned and tabulated for statistical analyses. Analysis of variance (ANOVA) was performed using GenStat statistical software version 15.1. Where a significant F-test was observed, the means were separated using Fischer's protected LSD test at 5% probability level.

3. RESULTS AND DISCUSSION

3.1. Nitrogen accumulation

Phosphorus application had significant *(P=.05)* influence on the nitrogen contents of finger millet. The 25 kg ha^{-1} P_2O_5 rate showed the highest total accumulation of nitrogen of 5.66 % during the short rains and

5.49 % during the long rains. The control had the lowest nitrogen content in the plant for both seasons (Table 2). The stem contained the highest nitrogen where all the treatments with phosphorus had higher N contents compared to the control during the short rains season. There was no clear trend in accumulation of N in stems in response to P treatments. The 25 kg ha^{-1} P_2O_5 rate had the highest nitrogen accumulation in the leaves and grains of the crop for both seasons with the control having the lowest except during the short rains on the leaves where the highest rate had the least. Nitrogen contents were enhanced due to the added P which resulted in profuse root development and shoot growth that in turn activated greater absorption of nitrogen from the soil. These results are in conformity with earlier reports [19] in cluster beans. It has been reported that fragile lands such as those in Makueni usually support cropping systems with lower nitrogen contents that also use water less efficiently leading to poor crop yields. It has been reported that as phosphorus rates increase towards the optimum, crop productivity increases but at a decreasing rate, the nitrogen contents typically declines [20]. On the other hand, the roots showed the lowest nitrogen accumulation with the control having the highest during the long rains while no significant differences at *P=.05* were observed between the P treatments in the short rains. This low accumulation of N in the roots might be due to the switching mechanism of the crop to partition N to the reproductive parts at the expense of vegetative ones especially under low soil N conditions. Varietal differences were observed on the nitrogen accumulation in both seasons where U-15 had the highest in all the plant parts.

Table 2. Effect of phosphate rates and varieties on N % concentrations in finger millet plant parts in Kiboko

P_2O_5 Rates (kg ha^{-1})	Short Rains					Long Rains				
	Root N%	Stem N%	Leaf N%	Grain %	Total N %	Root N%	Stem N%	Leaf N%	Grain %	Total N %
Control	0.71^{a}	1.53^{b}	1.41^{b}	1.30^{d}	4.95^{b}	1.17^{a}	1.28^{c}	1.17^{c}	1.17^{c}	4.79^{c}
12.5	0.71^{a}	1.65^{a}	1.41^{b}	1.41^{c}	5.18^{b}	1.05^{b}	1.17^{d}	1.40^{a}	1.28^{b}	4.90^{b}
25.0	0.72^{a}	1.65^{a}	1.65^{a}	1.64^{a}	5.66^{a}	1.05^{b}	1.52^{a}	1.40^{a}	1.52^{a}	5.49^{a}
37.5	0.71^{a}	1.65^{a}	1.29^{c}	1.50^{b}	5.15^{b}	1.05^{b}	1.40^{b}	1.28^{b}	1.28^{b}	5.01^{b}
LSD	0.03	0.02	0.01	0.01	0.36	0.04	0.07	0.08	0.08	0.07
Variety										
U-15	0.72^{a}	1.68^{a}	1.77^{a}	1.58^{a}	5.75^{a}	1.14^{a}	1.40^{a}	1.50^{a}	1.50^{a}	4.40^{a}
P-224	0.72^{a}	1.59^{b}	1.33^{b}	1.32^{c}	4.96^{c}	1.14^{a}	1.30^{b}	1.20^{b}	1.40^{b}	3.90^{b}
Ekalakala	0.7^{b}	1.59^{b}	1.24^{c}	1.50^{b}	5.03^{b}	0.96^{b}	1.30^{b}	1.20^{b}	1.00^{c}	3.50^{c}
LSD	0.01	0.05	0.08	0.06	0.30	0.04	0.06	0.07	0.07	0.27
CV%	1.60	1.00	1.00	21.10	5.40	4.10	5.40	6.60	6.20	5.70

Values followed by same letters within the column are not significantly different

These genotypic variations could be due to the efficiency in acquisition of P and N from the rhizosphere, nitrogen use efficiency and phosphorus use efficiency as well as the internal mobilization of N in all parts of plant. Such variations could be explained mainly by the diversity of the finger millet genotypes which is highly influenced by the environmental conditions [21]. Also, organic compounds secreted by the different varietal roots stimulated microbial activity in the rhizosphere, which might also influenced the P availability [22] which is related to N uptake since it is the source of ATP. Phosphorus and Nitrogen acquisition plays an important role for crop adaptation to low P and N soils [22] and a higher internal P and N use efficiency could help to limit soil nutrient mining [23], especially in low-input farming conditions and this has been exhibited by varieties like U-15.

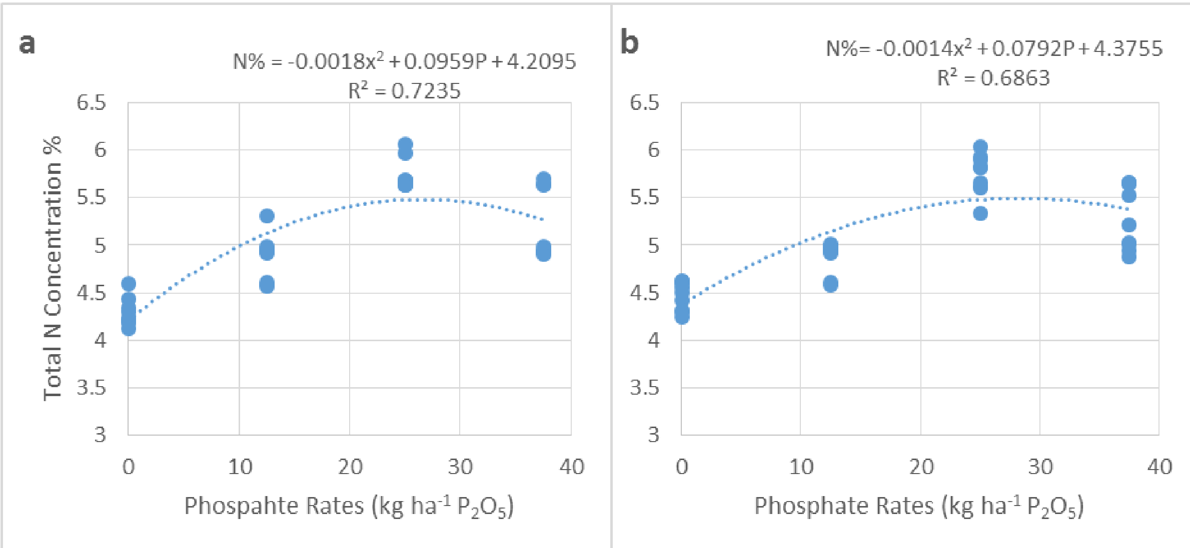

Fig. 1: The influence of phosphate rates on the total nitrogen concentration in finger millet plant for the short rains (a) and long rains (b).

A quadratic trendline (Fig. 1) revealed that the yield reached the peak (optimal) point with 25 kg ha^{-1} P_2O_5. Beyond this point, there is likelihood of luxury consumption, which may have economic implication to a farmer. Accumulation of nitrogen by the plants was not linear, but rather polynomial and after about 25 kg of P per hectare for both seasons (Fig. 1) the nitrogen contents started to descent. Previous work by Mohidin *et al.* [24] reported peak yield and accumulation on nutrients at 90 mg L^{-1} as opposed to 120 mg L^{-1} with yield reducing at 120 mL^{-1}. Depending the type of soil, P beyond optimal level can have a negative interaction with micronutrients such as Mn and Zn as previously reported [25]. Other findings [26] working with different onion varieties and different rates of N showed concurring results to current work. The results of the authors showed R^2 values of between 0.82-0.91 amongst varieties. Understanding optimal nutrient requirements is important particularly in regards to maintaining safe environment.

The control showed the lowest N because phosphorus deficiency restricts activity of meristematic sink of plants and leads to a demand for assimilates in growth that are responsible for reduction of source activity and partitioning of photo-assimilates [27].

3.2. Yield attributes

Phosphate rates showed significant differences (*P=.05*) on the finger widths with the 25 kg ha^{-1} P_2O_5 rate having the widest spikes for both seasons as shown in Fig. 2. The finger length, harvest indices, threshability, number of harvested panicles and productive tillers were not responsive to applied P and were similar to the control. This was probably due to the availability of P above the critical value of 10 ppm in the study soil and therefore the additional P through phosphate fertilizer did not lead to significant differences.

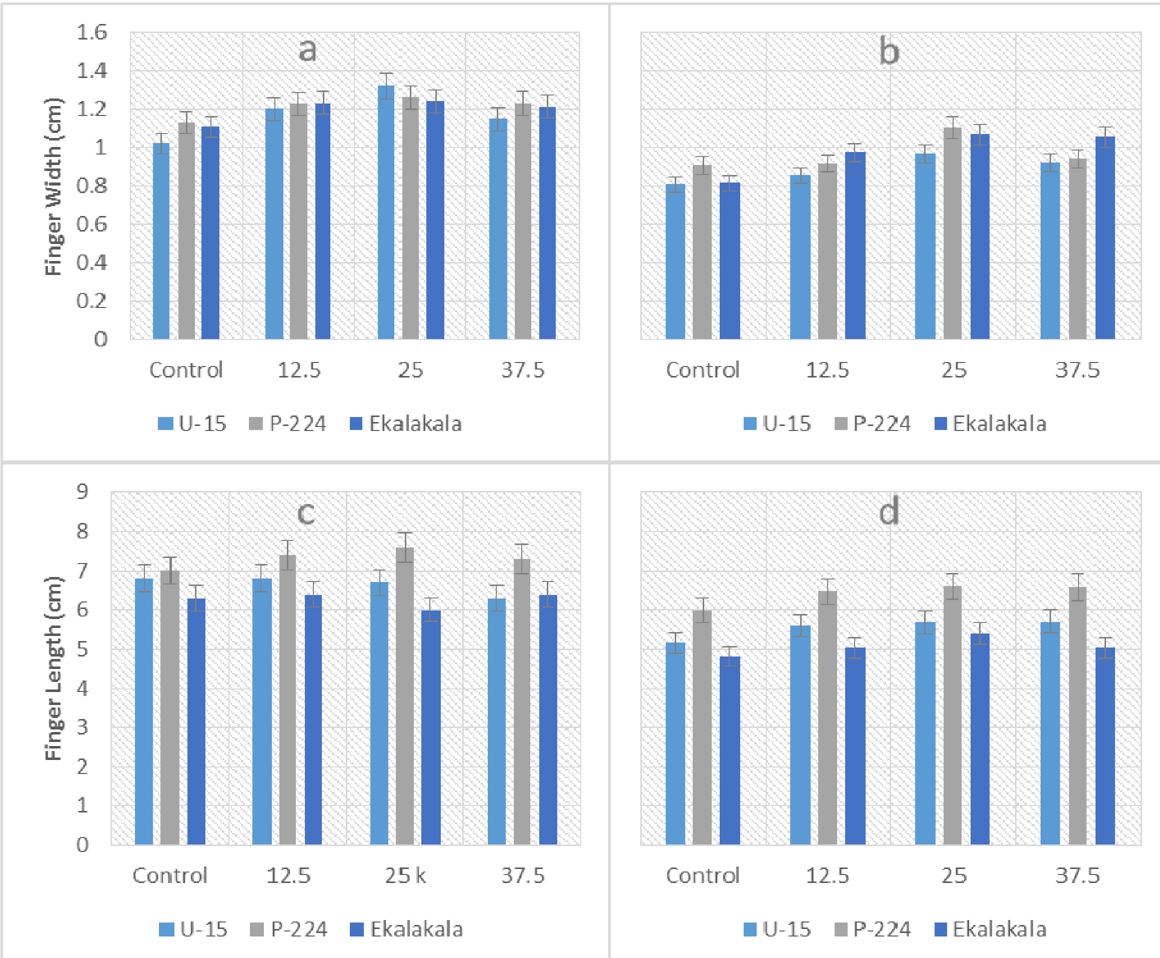

Fig. 2. Influence of phosphate rates on the finger width during the short (a) and long (b) rains season and finger length during the short (c) and long (d) rains seasons

Previous work based on multi location field experiments conducted in Eastern Uganda, Tenywa *et al.* [28] 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. However, Hedge and Gowda [29] reported a reduction in finger millet grain yields from 16.3 to 14.7 kg ha^{-1} P_2O_5 when the P application rate was increased from 30 to 60 kg ha^{-1} P_2O_5. This could be due to negative interactions with micronutrients when applied beyond certain level (depending on soil characteristics). Similar to inorganic N, this result suggests that application of excess P does not improve yield, but rather that application of balanced fertilizer is crucial.

The pattern in yields and yield components in response to P supply is in line with findings reported by Sankar [30] in semi-arid Alfisols. There could be other limiting factors that could limit P uptake and hence these yield components. Various other scientists [31, 32] also reported similar trends which are in agreement with our findings. They concluded that phosphorous had a significant impact on yield attributes of various cereals crops and the yield reduction after peak value a paradox in regards to some yield enhancing factors.

Notably, all the above traits were significantly influenced by varieties for both seasons as shown on Table 3. U-15 had the highest harvest index for both seasons but with the lowest number of grains per spikelet. Significant genotypic variation for traits related to P acquisition and P use efficiency has been observed in various crops. Cereal improvement in the recent decade has been mainly attributed to the increased harvest index. So far this trait has not been fully exploited in finger millet. Among the various factors influencing the harvest index, mineral nutrition is of utmost significance [33]. Reddy [34] on the effect of P on stability of harvest index with two contrasting genotypes of finger millet contradicted this finding, he found that as P level increased from 20 to 80 kg ha^{-1} there was a significant increase in biomass and grain yield but the harvest index and partitioning percentage decreased significantly with increased P levels. This contradiction was probably due to the difference in the available phosphorus values in the study soil and because of the rate where the highest in the study was more than double to that used in the current study.

Table 3. The effect of varieties on the harvest index, threshability, grains per spikelet, panicles and productive tillers during the long and short rains season

Variety	Harvest Index		Threshing %		Grains/ Spikelet		Panicles (3 m^2)		Productive tillers (3 m^2)	
	Short rains	Long rains	Short rains	Long rains	Short rains	Long rains	Short rains	Long rains	Short rains	Long rains
U-15	0.36^{a}	0.41^{a}	65.90^{a}	81.70^{a}	6.20^{b}	6.10^{b}	270.20^{a}	141.00^{ab}	125.00^{a}	38.00^{a}
P-224	0.31^{c}	0.35^{c}	63.00^{b}	72.60^{b}	7.20^{a}	6.80^{a}	238.90^{b}	123.00^{b}	107.00^{b}	19.00^{b}
Ekalakala	0.33^{b}	0.38^{b}	66.50^{a}	79.30^{a}	7.00^{a}	6.80^{a}	246.40^{ab}	149.00^{a}	130.00^{a}	37.00^{a}
L.S.D	0.02	0.02	2.09	3.11	0.45	0.58	25.37	19.70	13.09	6.60
CV (%)	11.50	7.80	7.40	4.70	7.90	10.20	11.90	25.50	19.80	7.40

Values followed by same letters within the column are not significantly different

U-15 and Ekalakala had the greatest threshing ability with the highest of 81.7% observed during the long rains season on U-15. The highest number of grains per spikelet was shown on P-224 and Ekalakala. U-15 and Ekalakala had the highest number of panicles harvested and number of productive tillers on the net plot. The productive tillers accounted for almost 50% of the harvested panicles on U-15 and Ekalakala which directly impacted on the final grain yield. The superiority of U-15 on most of the yield components translated to the highest yield among the varieties for both seasons as shown on Fig. 3. The short rains had a higher mean grain yield compared to the long rains where U-15 revealed 3.41 and 1.94 tonnes per hectare respectively. The performance of U-15 probably indicates the predominance of additive gene effects in controlling these traits in the variety hence the high potential in yielding.

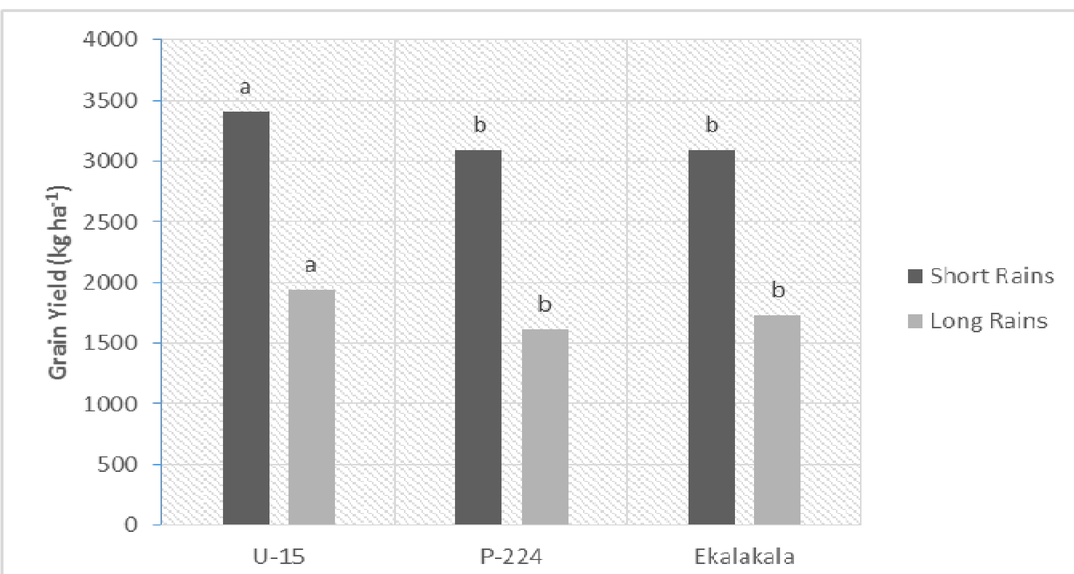

Fig. 3. Varietal effect on the grain yield during the short and long rains seasons

Matsuo *et al.* [35] also found significant differences in grain yield of rice varieties with variable P levels. Path coefficient analysis by Manyasa [36] revealed that productive tillers per plant, grains per spikelet and threshing percent had positive direct genetic effects on grain yield. The same results were also reported by Bezawelataw *et al.* [37].

4. CONCLUSION

Phosphorus had a positive influence on the nitrogen accumulation in the plant parts and total nitrogen uptake of finger millet as well as the finger width for both seasons with the peak observed at 25 kg ha^{-1} P_2O_5. The newly released variety U-15 responded well to the low N in Makueni and yielded the highest (3,410 kg ha^{-1}) which is five times the national average production and is ideal to achieve food security, poverty eradication and economic growth which are topmost set targets for sustainable development goals.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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