



Research article

Finger millet (*Eleusine coracana* L.) grain yield and yield components as influenced by phosphorus application and variety in Western Kenya

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Abstract: Finger millet is one of the potential cereal crops that can contribute to the efforts of realization of food security in the Sub-Saharan Africa. However, scientific information available with regards to improving soil phosphorus supply and identification of P efficient varieties for the crops potential yield is limited. In order to investigate the effects of P levels on yield components and grain yield On-station field experiments were conducted in two sites of western Kenya during the long and short rain seasons of 2015. The experiment was laid out in a Randomized Complete Block Design in factorial arrangement with four levels of P (0, 12.5, 25 and 37.5 kg P₂O₅ ha⁻¹ and three finger millet varieties (U-15, P-224 and a local check-Ikhulule) and the treatments replicated three times. The increase of phosphorus levels significantly (P≤0.05) increased the grain yield over the control up to 25 kg P₂O₅ ha⁻¹ during the long rain seasons and 25 kg P₂O₅ ha⁻¹ during the short rain seasons in both sites. Interactions at P≤0.05 were revealed on the grain yield where improved variety P-224 at 25 kg P₂O₅ ha⁻¹ produced the highest grain yield of 4.74 t.ha⁻¹ in Alupe and 4.77 t.ha⁻¹ in Kakamega and the consistent results suggest that the combination is highly recommended. Therefore the use of judicious and proper rates of P fertilizers can markedly increase the grain yield of finger millet in western Kenya.

Keywords: Finger millet - Potential cereal - Food security - Phosphorus supply - Judicious.

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INTRODUCTION

Finger millet (*Eleusine coracana* L. Geartn) belongs to family Poaceae and is one of the most important food cereals in the Sub-Saharan Africa. Indigenous to the highlands of Uganda and Ethiopia, finger millet is widely produced by small scale landholders and consumed locally (Adugna *et al.* 2011). The crop possesses greater impact on the poor in Africa through the provision of food security and economic growth. Its grains can be stored for several years in local storage conditions without damage by insect pests and this cushion against vulnerability to unpredictable famine and drought. It is well adapted to heat, drought and poor soil stress that prevail in marginal and degraded soils (Okalebo *et al.* 1990) and has a relatively better nutritional value with high calcium content as well as crucial amino acids that are deficient in most cereals. These attributes plus its high market value compared to other cereals makes finger millet one of the salient crops among resource poor communities living in food insecure areas (NRC 1996). The cultivation of the crop covers around 65,000 ha in Kenya with an average yield of 1 t.ha⁻¹ which is below the potential as observed in other parts of the world like in India where between 5–6 kg.ha⁻¹ were realized under ideal irrigated conditions (Oduori 2005, NRC 1996).

One of the main problems faced by the farmers is inherent low soil P and degradation due to continued cultivation. Notwithstanding the importance of finger millet, the research attention given to the crop has been

limited and the information is scarce on the P management of the crop. Phosphorus is an essential nutrient for the life of plants whereby without adequate supply plants cannot reach their maximum yield. Adoption of proper agronomic management practices to existing varieties can lead to achieving potential yields. Therefore, it is necessary to know the optimum dose of the P fertilizer to be applied for maximum yields without compromising the environment. Thus, the present study was conducted to determine the effect of phosphorus fertilizer rates on the yield components and grain yield of finger millet in the western region of Kenya where most of the crop is grown.

MATERIALS AND METHODS

Study area

Two On-station experiments were conducted in the crops research stations in Kakamega and Busia Counties. The Kenya Agricultural and Livestock Research Organization (KALRO)-Kakamega lies on Longitude 4°45'0" E and Latitude 0°16'60" N with an elevation of 1523 metres above sea level. The soils were predominantly sandy loam (53.55% sand, 32.18% silt and 14.27% clay). The Kenya Agricultural and Livestock Research Organization (KALRO)-Alupe lies within latitude 0°30' N and Longitude 34°07'50" E with an elevation of 1157 metres above sea level. The soils were sandy loam with 47.57% sand, 35.76% silt/loam and 16.67% clay. The two sites have two growing seasons in a calendar year between March and August termed the long rain season and between September and December which is termed the short rain season. The experiment was carried out in the two seasons of 2015.

Experimental design and treatments

The experiments were laid out in Randomized Complete Block Design in factorial arrangement with two factor sets of four levels of P (P_0 =Control, P_1 =12.5 kg.ha⁻¹ P₂O₅, P_2 =25 kg.ha⁻¹ P₂O₅ and P_3 =37.5 kg.ha⁻¹ P₂O₅) and three varieties (U-15, P-224 and Ikhulule). Ikhulule was the local check variety and no phosphorus applied for the control. Each treatment was replicated three times while the other cultural practices were kept constant with a blanket application of N (50 kg.ha⁻¹ N) at four weeks after emergence.

Land management and cultural operations

Analysis of composite surface soil samples collected from the experimental fields indicated the soils were moderately acidic (pH in 1:2.5 soil: water ratio of 5.45 in Alupe and 5.60 in Kakamega). The top soils were moderately low in Total N (0.12% in Alupe and 0.18% in Kakamega), high in organic carbon (2.26% in Alupe and 3.40% in Kakamega), low in Olsen extractable P (6 ppm in Alupe and 5 ppm in Kakamega), and moderate in available K contents (0.30% in Alupe and 0.75% in Kakamega).

Land preparation was done prior to the onset of rains during both seasons. Planting was done by hand drilling seeds obtained from ICRISAT in rows spaced 40 cm between rows and later thinned after four weeks between plants to an intra-row spacing of 10 cm. Phosphorus fertilizer was applied wholly by hand drilling at planting according to the treatments as Triple Superphosphate (TSP). All other agronomic operations were done as recommended for the crop. Harvesting on the net plot was done when the fingers had achieved 90% brown color.

Data collection and analysis

The finger length of the longest spike from at least five main tillers from each plot was measured and the average recorded. The finger width was measured across the center of the longest five spikes from each plot and the average recorded. The number of grains per spikelets was counted at dough stage after removing five spikelets from the middle portion of the rachis of five main tillers in each plot and the average recorded. The number of panicles per finger was counted at dough stage on the main ears of five plants and the average recorded. The grain yield from the net plot of every experimental unit (3 m²) was weighed on a Tronix Avery digital scale at 13% moisture content and extrapolated to yield per hectare.

Analysis of variance (ANOVA) was carried out for the grain yield data collected following statistical procedures appropriate for the design using SAS computer software. Whenever significant differences between treatments were observed, the means were separated using Fisher's Protected LSD at 5% probability. Regression analysis was carried out to estimate the relationship between the grain yields as influenced by the applied phosphorus fertilizer.

RESULTS AND DISCUSSION

Influence of phosphorus and variety on yield and yield components

Phosphorus did not have a significant role on the finger length and width in both sites for both seasons (Table 1). However, numerically the control had the shortest fingers in Kakamega for both seasons and in Alupe during the long rain season. The varieties had significant differences ($P \leq 0.05$) for both seasons in Kakamega and Alupe where P-224 had the longest fingers (spikes). Similarly, the widest fingers were observed on variety P-224 in both sites for both seasons. The interaction between phosphorus application levels and variety was only revealed on the finger width in Kakamega during the long rain season where P-224 at $12.5 \text{ kg} \cdot \text{ha}^{-1} \text{ P}_2\text{O}_5$ had the widest fingers with 1.189 cm.

Table 1. The influence of phosphorus and variety on the finger length and width (cm) in Alupe and Kakamega.

Fertilizer Level	Finger Length (cm)				Finger Width (cm)			
	Kakamega		Alupe		Kakamega		Alupe	
	2015 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
0	6.7a	5.3a	7.9a	7.7a	1.00a	1.05a	1.20a	1.10a
12.5	6.8a	5.7a	7.7a	8.0a	0.98a	1.06a	1.11a	1.09a
25.0	6.8a	5.9a	8.3a	8.1a	0.99a	1.02a	1.1a	1.10a
37.5	6.7a	5.8a	7.8a	8.2a	0.98a	1.03a	1.09a	1.08a
F pr.	0.928	0.211	0.671	0.175	0.836	0.71	0.427	0.856
LSD (0.05)	0.650	0.750	0.993	0.504	0.061	0.058	0.155	0.046
Variety								
U-15	6.6b	5.5b	8.4a	8.2b	0.94b	0.98b	1.12b	1.01b
P-224	7.3a	6.4a	8.5a	9.0a	1.04a	1.10a	1.18a	1.15a
Ikhulule	6.3b	5.1b	6.89b	6.9c	0.99b	1.04b	1.08c	1.11a
F pr.	0.003	$\leq .001$	0.001	$\leq .001$	0.003	0.002	0.036	$\leq .001$
LSD (0.05)	0.560	0.685	0.860	0.437	0.053	7.300	0.035	0.040
CV%	9.8	10	12.8	6.4	6.3	7.3	14.1	4.3
Interaction								
P × V	NS	NS	NS	NS	NS	*	NS	NS

Note: Means within a column followed by different letter (s) are significantly different at $P \leq 0.05$. LR=Long rain season; SR=Short rain season; **=Significant at $P \leq 0.05$; NS=Not significant at $P \leq 0.05$

Table 2. Effect of phosphorus levels on the number of fingers per panicle and grains per spikelet in Alupe and Kakamega.

Fertilizer Level	Fingers per panicle				Grains per spikelet			
	Kakamega		Alupe		Kakamega		Alupe	
	2015 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR	2015 SR	2015 LR
0	6a	7b	7b	7c	8a	7b	7a	7a
12.5	6a	7b	8a	9a	8a	8a	7a	7a
25	6a	8a	8a	8b	8a	8a	7a	7a
37.5	6a	8a	8a	9a	8a	7b	7a	7a
F pr.	0.834	0.043	0.022	0.003	0.51	0.007	0.799	0.128
LSD (0.05)	0.500	0.842	0.558	0.531	1.000	0.543	0.544	0.576
Variety								
U-15	7a	8a	8a	9a	8a	7b	6b	6b
P-224	7a	7b	8a	8b	8a	8a	7a	7a
Ikhulule	6b	7b	7b	8b	8a	7b	6b	6b
F pr.	0.036	0.002	$\leq .001$	0.005	0.497	0.037	$\leq .001$	0.004
LSD (0.05)	0.500	0.448	0.483	0.460	0.800	0.541	0.471	0.499
CV%	9	14.4	7.3	6.6	12.2	7.4	8.4	9
Interaction								
P × V	NS	NS	NS	NS	NS	NS	NS	NS

Note: Means within a column followed by different letter (s) are significantly different at $P \leq 0.05$. LR=Long rain season; SR=Short rain season; **=Significant at $P \leq 0.05$; NS=Not significant at $P \leq 0.05$

Application of phosphorus fertilizer led to increased number of fingers per panicle for both seasons in Alupe and Kakamega during the long rain season compared to the control (Table 2). The highest number of fingers per panicle was observed during the long rain season in Kakamega with a mean of nine fingers per panicle (head). The number of grains in a spikelet only showed significant differences ($P \leq 0.05$) during the long rain season in Kakamega where the 12.5 and 25.0 $\text{kg} \cdot \text{ha}^{-1} \text{ P}_2\text{O}_5$ treatments had the highest while the control and the highest rate

had the lowest as shown in table 2. The number of fingers per panicle and grains per spikelet varied significantly ($P \leq 0.05$) among the varieties in both sites for both seasons. U-15 showed the highest number of fingers per panicle in both sites for both seasons while P-224 had the highest number of grains per spikelet for both seasons across the sites.

Interactive effect of phosphorus and variety on grain yield

The interaction between variety and phosphorus fertilizer exerted significant influence ($P \leq 0.05$) on the grain yield for both seasons in both sites (Fig. 1). In Alupe during the long rain season, improved variety P-224 at a phosphate rate of $25 \text{ kg} \cdot \text{ha}^{-1} \text{ P}_2\text{O}_5$ had significantly ($P \leq 0.05$) the highest yield of $4.738 \text{ t} \cdot \text{ha}^{-1}$ while the local variety Ikhulule with the highest rate had the lowest grain yield of $2.993 \text{ t} \cdot \text{ha}^{-1}$. At $12.5 \text{ kg} \cdot \text{ha}^{-1} \text{ P}_2\text{O}_5$, the local variety Ikhulule showed the highest grain yield of $4.549 \text{ t} \cdot \text{ha}^{-1}$. Variety U-15 had the highest grain yield on the $25 \text{ kg} \cdot \text{ha}^{-1} \text{ P}_2\text{O}_5$ rate of $4.172 \text{ t} \cdot \text{ha}^{-1}$. The lowest grain yield in the improved varieties was observed on the control. The same pattern shown in the long rain season of the highest yielding combination was observed in the short rain season with $3.695 \text{ t} \cdot \text{ha}^{-1}$. The grain yield was however generally lower compared to the long rain season (Fig. 1). Variety U-15 showed the highest grain yield on the $25 \text{ kg} \cdot \text{ha}^{-1} \text{ P}_2\text{O}_5$ rate while the local variety Ikhulule had the highest grain yield on the two highest rates. The lowest grain yield among the varieties was observed on the control.

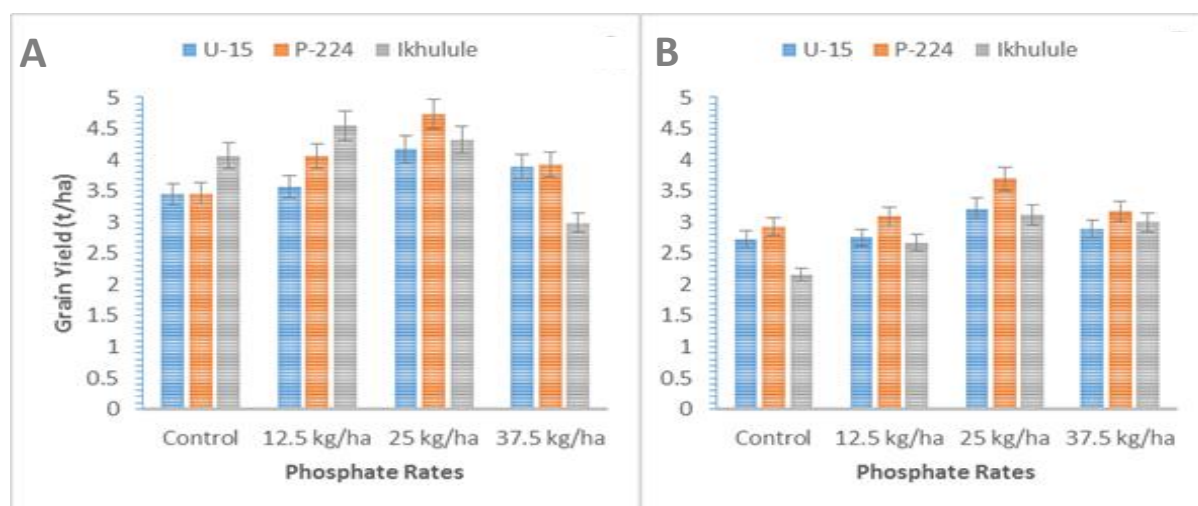


Figure 1. The influence of variety and phosphorus fertilizer on the grain yield of finger millet in Alupe during the long (A) and short (B) rain seasons.

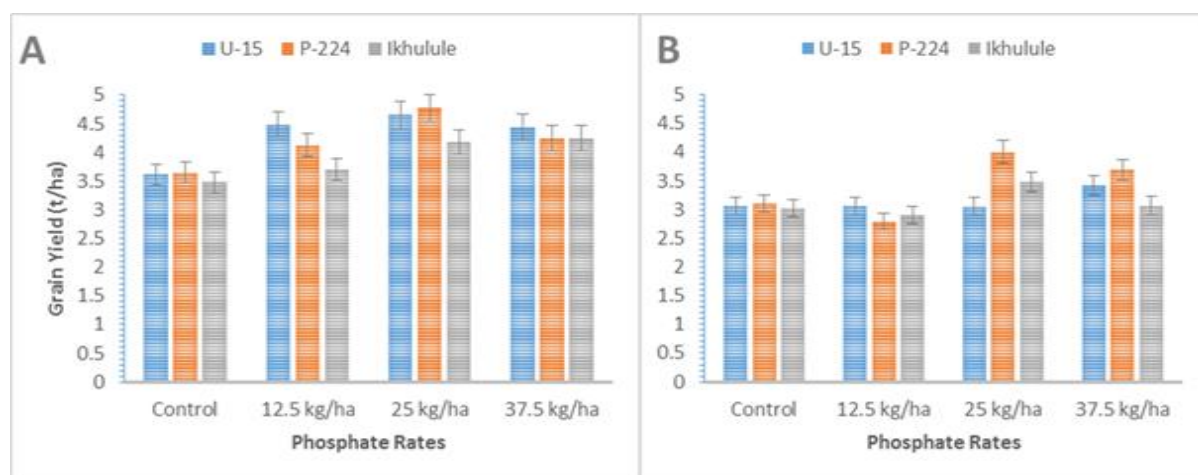


Figure 2. The influence of variety and phosphorus fertilizer on the grain yield of finger millet in Kakamega during the long (A) and short (B) rain seasons.

In Kakamega during the long rain season significant interactions ($P \leq 0.05$) between variety and phosphorus fertilizer were observed where variety P-224 showed the highest yield at $25 \text{ kg} \cdot \text{ha}^{-1} \text{ P}_2\text{O}_5$ ($4.770 \text{ t} \cdot \text{ha}^{-1}$) as well as variety U-15 ($4.650 \text{ t} \cdot \text{ha}^{-1}$) which was however insignificantly different from that at $12.5 \text{ kg} \cdot \text{ha}^{-1} \text{ P}_2\text{O}_5$ rate and the highest rate (Fig. 2). The local variety Ikhulule had the highest grain yield at the highest rates of phosphorus

fertilizer as observed in the short rain season in Alupe. Irrespective of the varieties, the lowest grain yield was observed in the control. In the short rain season, the highest grain yield (4.0 t.ha⁻¹) was observed on variety P-224 at the 25 kg.ha⁻¹ P₂O₅ rate while the same variety had the least grain yield on the 12.5 kg.ha⁻¹ P₂O₅ rate and the control. The local variety Ikhulule showed the highest grain yield at the 25 kg.ha⁻¹ P₂O₅ while improved variety U-15 showed the highest grain yield at the highest rate of phosphorus fertilizer (Fig. 2).

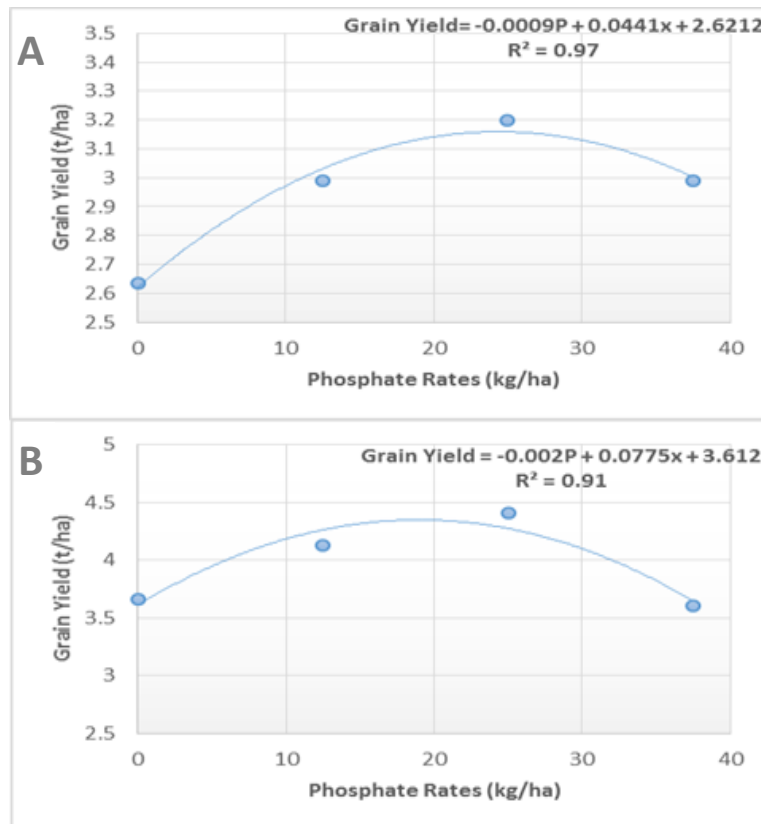


Figure 3. Mean grain yield as a polynomial function of phosphate rates for finger millet during the short (A) and long (B) rain seasons in Alupe.

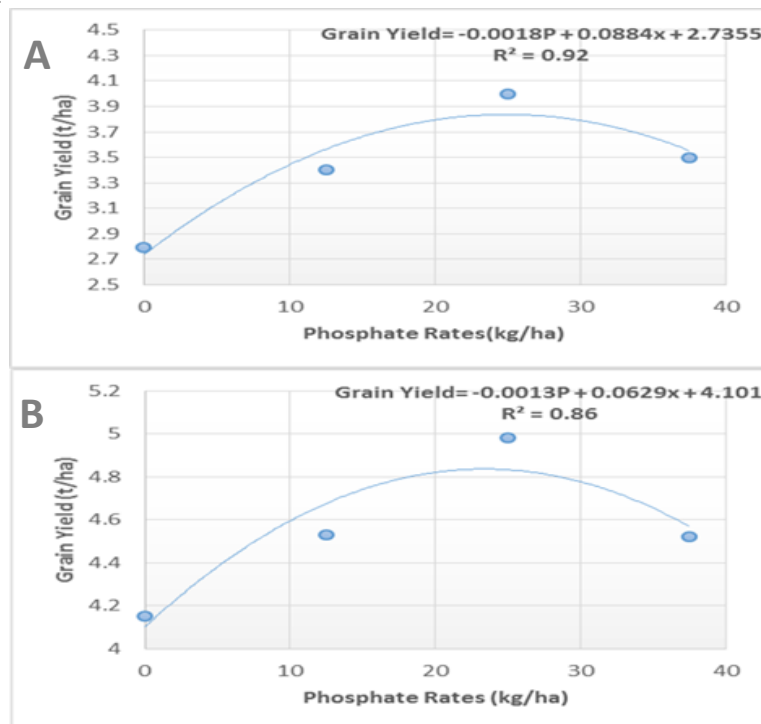


Figure 4. Polynomial regression characterizing the relationship between the grain yield response of finger millet varieties to applied phosphorus fertilizer in Kakamega during the short (A) and long (B) rain seasons.

The influence of phosphorus was significant ($P \leq 0.05$) on the finger millet varieties grain yield for both seasons in the two sites. In Alupe, grain yield significantly increased from 2.6 t.ha⁻¹ on the control to 3.2 t.ha⁻¹ with an increase in the level of phosphorus fertilizer up to 25 kg.ha⁻¹ and started decreasing with further increase as shown in figure 3 during the short rains season. During the long rain season, the increase of phosphorus fertilizer up to 20 kg.ha⁻¹ showed significantly ($P \leq 0.05$) the highest grain yield with a 20.56% increase over the control. During the same period, the highest rate and the control elicited the lowest grain yield (Fig. 3). In Kakamega, a linear trend was observed with the increment of the phosphorus fertilizer dose up to 25 kg.ha⁻¹ and thereafter decreased in the short rain season while in the long rain season an increase of up to 20 kg.ha⁻¹ showed the peak on the grain yield and a drop followed thereafter. The highest yield of 4.0 t.ha⁻¹ was observed during the short rain season and 4.98 t.ha⁻¹ in the long rain season while the control had the lowest grain yield for both seasons (Fig. 4).

DISCUSSION

The numerical increase in the finger length in Kakamega is probably to the enhanced metabolic processes due to optimum phosphorus and lack of reduced metabolic activity. However, the insignificant response to applied P might be due to the optimal availability of N and supplement of Urea during study period which led to the luxurious vegetative growth and induced the hidden P hunger. Similar findings were reported by Dixon (2003) who found that in low soil P, foliar application of P only corrected the deficiencies and maintained higher yields but did not increase the spike length or width of winter wheat due to excessive application and availability of nitrogen. The increase in the number of fingers per panicle was due to the synthesis of amino acid and chlorophyll and better carbohydrates transformation which resulted in better growth and a higher number of panicles which ultimately produced more number of grains per spikelet. These findings were in conformity with that by Parmer (2007) who observed an increase in the number of spikes per head due to an increase of phosphorus up to 100 kg P₂O₅ per hectare of super phosphate in Tuberose Cv. Double. The improved varieties produced higher number of grains per spikelet during the same period due to their ability to respond positively to applied phosphorus through efficient utilization and also due to their genetic potential. Similar spikelet count differences among rice varieties were reported by Obaidullah (2007).

The positive response of finger millet varieties on the applied P was due to the low available tested P in the study soils. It has also been reported that in many parts of western Kenya P stress is a major limiting nutrient and also the response of other nutrients is usually inhibited under this limitation (Opiyo 2004). Phosphorus efficiency of the identified variety P-224 was probably due to its genetic ability to produce high yield per unit P acquired. Ozturk (2005) reported that the identification of P efficient varieties with great ability to grow and yield in soil with limited phosphorus supply and efficiently use applied P improves the sustainability of crop production. This reduces the production cost for the small holder farmers which is associated with high P applications and minimizes environmental pollution resulting from run-off of excess P fertilizer. The capacity for P uptake has been documented to be affected by several environmentally or genetically controlled factors that differ among varieties (Pearse *et al.* 2006). Pearse *et al.* (2006) also introduced a model that roots in some varieties have a positive effect on P uptake, which enhances P status and efficiency. Different varieties have inherent differences in the maximum growth rate and P uptake which leads them to differ in their productivity (Shen *et al.* 2005). Ren *et al.* (2007) also found that different species of ryegrass with inherent low growth rates accumulated higher levels of phosphorus in their shoots at low P-levels which led to lower grain yields probably due to reduced efficiency of P for grain filling. The difference in P uptake among the genotypes showed the diversity in efficiency with which plants are able to absorb P from soils with varying P availability (Hinsinger 2009). During the short rain season in Kakamega the control had the same grain yield as the 12.5 kg.ha⁻¹ P₂O₅ rate and it is probably due to the availability of phosphorus that was earlier in its organic form. Organic forms of P are found in humus and other organic material (Masinde *et al.* 2009). Phosphorus in organic material is released by a mineralization process involving soil organisms (Shen *et al.* 2005) and thus the increased growth on the control as that of mildly P applied treatment.

The increase in grain yield was probably due to the positive influence of phosphorus in initiation and growth of roots that in turn sped up and increased the uptake of essential elements and moisture from the soil. Supply of optimal phosphorus also ensured that the plants inhibited the formation of excess roots that would have led to the excessive loss of carbon from the plants rooting system and reducing the efficiency in energy production (Shane & Lambers 2005). Several investigators have reported the same findings that either initiation or

inhibition of root formation is linked to internal P concentration, uptake and availability in the soil and significantly influences the productivity of crops (Li & Liang 2005, Shen *et al.* 2005). Alam *et al.* (2003) also reported similar findings that the application of phosphorus fertilizer (SSP) to wheat crop significantly increased the grain yield as well as P-uptake over control. A limited supply of P reduces leaf area and therefore reducing the supply of photosynthates to the grain and subsequently reducing the grain filling. Optimal phosphorus also increased the synthesis of cytokinins which enhanced the flowering process that supported the higher formation of grains. Various scientists (Rehman *et al.* 2006, Yousaf 2004) have also reported that appropriate and balanced phosphorus fertilization on wheat and rice not only caused grain yield enhancement but also had a positive impact on phosphorus and another nutrient uptake by these crops. Finger millet varieties efficiency on the use of available phosphorus might also be due to the plants mechanism to secrete phosphatases which are key drivers of rhizosphere activities that influenced P uptake. These chemical and biological processes in the rhizosphere determine the mobilization and acquisition of soil nutrients, microbial dynamics, and controls nutrient use efficiency of crops, thus profoundly influencing crops productivity (Hinsinger 2009, Richardson *et al.* 2009, Wissuwa *et al.* 2009). Optimal availability of P resulted in an increase of nutrient use efficiency by the provision of adequate energy and an early proliferation of growth attributes which increased the grain yield potential.

CONCLUSION

Application of phosphorus affected positively the productivity of the finger millet varieties in Kakamega and Alupe for both seasons. An increase of more than 20% was observed on the 20 kg.ha⁻¹ P₂O₅ rate during the long rain seasons in both sites and at 25 kg.ha⁻¹ P₂O₅ in the short rain seasons. The maximum yield was achieved under the improved variety in both sites due to its superiority in efficiency in utilizing applied phosphorus fertilizer and superior yield attributes. The application of phosphorus fertilizer beyond 25 kg.ha⁻¹ P₂O₅ was found to be detrimental to finger millet grain yield in the study regions of Kenya.

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