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Finger Millet (*Eleusine coracana*) Fodder Yield Potential and Nutritive Value under Different Levels of Phosphorus in Rainfed Conditions

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Authors' contributions

This work was carried out in collaboration between all authors. Authors WNW, MS and HO designed the study. Authors WNW and JGO reviewed the study design and all drafts of the manuscript. Author NK managed the analyses of the study. Author WNW managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Scarcity of fodder is the major limiting factor for increasing livestock production in Kenya. With rising energy costs and declining water levels in the semi-arid tropics and sub-tropics, crops that use less water like finger millet could become an alternate fodder crop. The fodder potential of three finger millet varieties (U-15, P-224 and a local check) were evaluated under four P fertilizer levels (0, 12.5, 25 and 37.5 kg ha^{-1} P_2O_5) at three sites in Kenya for two cropping seasons. The trials were laid in randomized complete block design in factorial arrangement and replicated three times. A maximum of 28,189 kg ha^{-1} fresh stover yield was realized in the 25 kg ha^{-1} P_2O_5 treatment and consequently 11,616 kg ha^{-1} dry stover yield. The 25 kg ha^{-1} rate elicited the highest fresh

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stover yield at Kakamega and Alupe for both seasons while at Kiboko a linear increase was observed on the stover yield with increasing rates where the highest rate had more than 15% yield compared to the control. The varieties also showed significant differences in all the sites with the local variety, Ikhulule, showing the highest fresh and dry stover yield at Kakamega and Alupe peaking at 28,852 and 12,826 kg ha^{-1} fresh and dry stover yields respectively. Interactions between variety and phosphorus rates were revealed on the crude protein content of the finger millet stover. At Kiboko, the highest crude protein (11.0%) on varieties P-224 and U-15 was exhibited at the highest rate while on the local variety, Ekalakala, the highest protein (10.9%) was realized at the 25 kg ha^{-1} P_2O_5. At Kakamega and Alupe, the highest protein was observed on the local variety, Ikhulule at 12.5 kg ha^{-1} P_2O_5 rate with variety P-224 and U-15 showing the highest at the 25 and 37.5 kg ha^{-1} P_2O_5 respectively. Therefore, finger millet can provide a unique opportunity to improve the availability of fodder to smallholder livestock farmers.

Keywords: Finger millet; fodder; stover; crude protein; smallholder.

1. INTRODUCTION

Finger millet (*Eleusine coracana* (L.) Gaertn) is a staple food crop grown by subsistence farmers in the semi-arid tropics and sub-tropics of the world under rainfed conditions [1]. The name is derived from the seed-head, which has the shape of human fingers. It is highly valued by local farmers for its ability to grow in adverse agro-climatic conditions, where cereal crops such as maize (*Zea mays*), wheat (*Triticum spp*.) and rice (*Oryza sativa*) fail and has been noted to tolerate wide variety of soils. Finger millet has the potential to produce a fairly high grain and forage yield with fewer use of inputs if good crop husbandry is to be followed [2]. The emerging global warming scenario has made finger millet a good potential crop to be used for multiple purposes. The skyrocketing population and scarcity of agricultural water with each passing year has necessitated the inclusion of drought and heat resistant crops like this in cropping patterns. But it is a matter of grave concern that it continues to remain underutilized despite numerous benefits and advantages [3]. While grains are used for human consumption, the crop residues are an excellent source of dry matter for livestock especially in dry seasons. Major crops, especially cereals, produce large quantities of stem and leaf in addition to their saleable product, which is usually seed. The straw or stover is usually over half the harvestable vegetation of the crop. Such coarse roughages cannot be eaten by humans, but they can be transformed into economic products by livestock [4]. Stover of finger millet are often called 'by-product' of grain production even though it is increasingly important and as a result, plant breeders, agronomists, economists and animal nutritionists have to pay more attention than before to the total value of the crop, i.e. whole plant value in which both stover and grain play a part [5]. The change of land use from grazing to cereal production does not usually reduce the amount of roughage available for livestock, as the amount of stover will be as great as or more than the natural herbage previously on offer. The proportion of stover, to grain varies from crop to crop and according to yield level (very low grain yields have a higher proportion of straw - the ratio is infinite when a crop fails through drought) but is usually slightly over half the harvestable biomass [6].

Finger millet stover has been documented to make good fodder and contains up to 61% total digestible nutrients [7]. Millet therefore offers opportunity for development of a thriving livestock industry. Major constraints that have hampered production and utilization of finger millet and its products include limited improved varieties, poor crop management practices, pests and diseases, poor soil fertility, limited commercial utilization and lack of an organized marketing system [8]. Mitigation of these challenges has the potential to increase productivity. Comparison of nutrient composition has shown that the quality of finger millet is relatively higher than that of corn and sorghum in terms of calcium, potassium, and phosphorus levels in their forage [9]. Rice has low crude protein (CP) (around 7 percent); maize, barley and sorghum have intermediate levels (9 to 10 percent CP); and wheat, oats and triticale have the highest levels (around 12 percent CP) [10,11].

Domestic animals continue to make important contributions to global food supply and, as a result, animal feeds have become an increasingly critical component of the integrated food chain. Livestock products account for about

30 percent of the global value of agriculture and 19 percent of the value of food production, and provide 34 percent of protein and 16 percent of the energy consumed in human diets [12]. Meeting consumer demand for more meat, milk and other livestock products is dependent to a major extent on the availability of regular supplies of appropriate, cost-effective and safe animal feeds. Most production systems in the tropic regions are rain-dependent with only limited awareness amongst farmers on using a proper feeding regime and low preparedness for dry periods. Thus, the majority of farmers produce and sell below their potential. Availability of quality fodder is a serious issue, particularly for resource-poor dairy farmers with little or no land for cultivation. The magnitude of this problem naturally varies from farmer to farmer, but it clearly is a sector-wide constraint. High population growth rate, together with the traditional land inheritance norms and poor land policies, have culminated in subdivision of land which exert high pressure on animal feed resources [13]. Availability of grazing land is decreasing due to expansion of cropping to meet the demands for food, urbanization and land use for other activities such as industries. Consequently, the scarcity and low quality feed and fodder resources, in addition to the shortage of water, contribute significantly to low production of milk and meat in these regions [14,15]. Also testing of animal feed or fodder to determine the nutritional value is not a common practice across the sector and as such it still remains difficult to confirm the nutritional value of most crops stover.

Small farmers in rural areas will increasingly depend on crop residues to feed livestock among other feed resources for some time to come [16]. However, for farmers with less land fodder production has to compete with production of food crops. In this case, a well-functioning fodder supply chain combined with provision from the grain would constitute a solution. While the crop is necessarily grown for grain, to mix farm enterprises this way, proper crop management and utilization could help to optimize production. In many cases straw and stover yields from planted crops are low because of repeated harvesting which depletes the soil of nutrients which are usually not replenished coupled with inherently low soil fertility especially N and P. Farmers should, therefore, be educated on the value of fertilizer application for increasing stover production and be advised to practice it either using chemical fertilizers, manure or compost. To improve the quality and quantity of green and dry stover, it is therefore much essential to determine its P fertilizer requirements. The plant nutrition may not only affect the forage production but also improve the quality of forage from a view point of its crude protein contents. Keeping this in view, the present research work was undertaken to assess the influence of different levels of P on the stover yield and quality of three finger millet varieties in different ecological zones in Kenya.

2. MATERIALS AND METHODS

2.1 Study Sites

The On-station experiments were carried out at crops research stations located in Makueni, Kakamega and Busia Counties. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Kenya Agricultural and Livestock Research Organization (KALRO) field station at Kiboko in Makueni County lies within longitudes 37°37' 60 E and latitude 2° 13' 0 S with an elevation of 975 metres above sea level. The Kenya Agricultural and Livestock Research Organization (KALRO) field station in Kakamega County lies within Longitude 4°45'0" E and Latitude 0°16'60" N with an elevation of 1523 metres above sea level. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) field station at Alupe in Busia County lies within latitude 0°30" N and Longitude 34°07'50" E with an elevation of 1157 metres above sea level. The experiment was carried out in two growing seasons of 2015.

2.2 Experimental Design and Data Collection

Three finger millet varieties viz; U-15, P-224 and a local check, where Ikhulule was the local check at Kakamega and Alupe while Ekalakala was used as the local check at Kiboko, were sown under four P levels: 0, 12.5, 25 and 37.5 kg ha^{-1} P_2O_5 in the form of Triple Superphosphate (TSP) where 0 kg ha^{-1} P_2O_5 was the absolute control. The experiments were laid out in a randomized complete block design (RCBD) fitted in factorial arrangement and the treatments were replicated three times. Each experimental plot measured 4 by 2 metres and a 2 m pathway was maintained within each plot. Phosphate fertilizer was applied wholly at the time of sowing through a single hand drill. The crop was sown with single row hand drill on a well prepared seedbed in 50 centimetres apart rows. All other agronomic practices were kept constant and uniform for all the treatments as recommended for the crop.

Immediately after harvesting the grains from the net plot of 3 m^2, the fresh fodder yield on the four 3-m-long middle rows, were harvested just above-ground by using cutlasses, weighed with a spring balance and recorded. The material was then sun dried and weighed until a constant weight was observed using a spring balance and the air-dry fodder yield recorded. Ten dried plants from each plot were collected and the total nitrogen N content was determined by the Kjeldahl method and multiplied by the 6.25 factor to give the crude protein content [17].

2.3 Data Analysis

Analysis of variance (ANOVA) was performed using GenStat statistical software Version 15.1 to test treatment effects at 95% confidence level. The means were separated using Fischer's Protected LSD test where significant differences were observed between treatments.

3. RESULTS AND DISCUSSION

3.1 Fresh Stover Yield

The finger millet fresh stover yield varied significantly between the phosphorus treatments in all the study sites (Fig. 1). There was a linear increase in the fresh finger millet residues at Kiboko as the phosphorus fertilizer rate increased while a peak was realized at the 25 kg ha^{-1} P_2O_5 rate at Kakamega and Alupe whereby further increase led to a decline. At Kakamega during the long rain season, the highest finger millet fresh stover yield (28, 189 kg ha^{-1}) was recorded in the 25 kg ha^{-1} P_2O_5 while the control showed the lowest fresh stover yield in all the sites except at Kiboko during the long rain season where the 12.5 kg ha^{-1} P_2O_5 elicited the lowest. This difference between the 12.5 kg ha^{-1} P_2O_5 treatment and the control was however not significantly different as shown in Fig. 1. Phosphorus is one of the highly limited nutrients in farmers' agricultural lands in Africa [18] and therefore the positive increase in the fresh stover yield was due to low P levels in the study soils. The root development of finger millet was enhanced by the applied phosphorus and it positively affected the ability of plant to explore more soil cover and get adequate nutrients that enhanced biomass accumulation. The low stover yield in the control was probably due to the limited supply of P compared to the other treatments leading to low energy support in the plant. This result is supported by another study which found that low biomass accumulation is mainly due to the effect of P deficiency on plant growth [19]. Similarly, another study found that immobility of phosphorus in the soil is one of the reasons for its low availability in Sub-Saharan soils and by supplementing it through phosphates allows the crop roots to grow through the soil to get to the essential nutrients that the plant needs [20]. Yet other studies also found that after two seasons of field study in Western Kenya, P application rates on African Nightshade affected the plant heights, leaf numbers, leaf area and that leaf yields increased with increasing P rate although the differences between 40 kg/ha and 60 kg/ha were not significant at P=.05 [21]. The increase in yield with P fertilization is in line with findings by another author who found that where phosphorus fertilizer was applied the straw yield was higher in wheat crop [22]. They argued that it was due to the role of P in modifying soil and plant environment that is conducive for better growth. The findings are also in agreement with another study where it was found that application of phosphorus fertilizers gradually increased fodder yield of sorghum (*Sorghum bicolor* L. Moench) [23]. Positive correlation between fodder yield of Pangola grass and P fertilizers were also reported in another study by [24]. Further, it was reported that green forage yield increased significantly with increasing levels of phosphatic fertilizers in Lucerne [25] and the total yield of green forage of kallar grass increased with increasing levels of P fertilizer [26]. The results of the present findings contradicts those reported earlier in German grass [27] and in Napier grass [28] where no significant response in biomass yield was observed due to phosphorus application.

Significant differences were observed between the varieties in the fresh stover yield in all the sites except at Kiboko during the short rain season (Fig. 2). At Kakamega and Alupe, the local variety, Ikhulule, had significantly the highest fresh stover yield while variety U-15 had significantly (*P=.05*) the lowest. At Kakamega during the long rain season, Ikhulule showed the highest fresh stover yield (28,852 kg ha^{-1}). At Kiboko, a conclusive trend could not be drawn between the varieties where the local variety, Ekalakala showed the lowest fresh stover yield during the short rain season, though insignificantly different from the others while variety P-224 had significantly the lowest fresh stover yield during the long rain season with the other two varieties showing the highest. The importance of P application was realized on the increase in the biomass in the P applied treatments over the control which could be due to the increase in the uptake efficiency of different finger millet varieties in terms of nutrients that likely contributed to increased plant biomass. These findings are in conformity with those of other scientists [29,30], who found significant increase in biomass of maize varieties with P application over that of the control and significant differences between the varieties on stover yields.

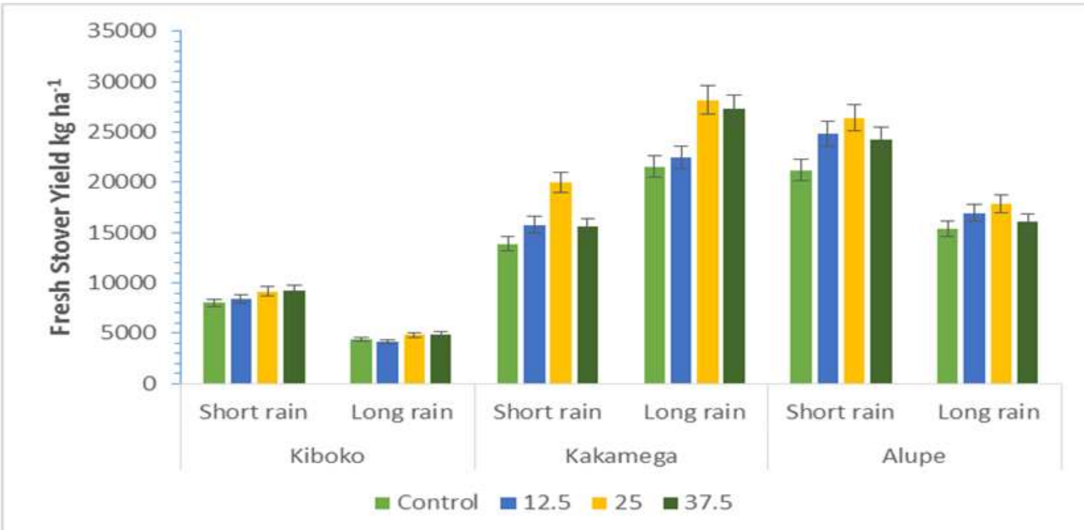

Fig. 1. The fresh stover yield of finger millet as influenced by phosphate rates at Kiboko, Kakamega and Alupe, Kenya for the short and long rain seasons of 2015

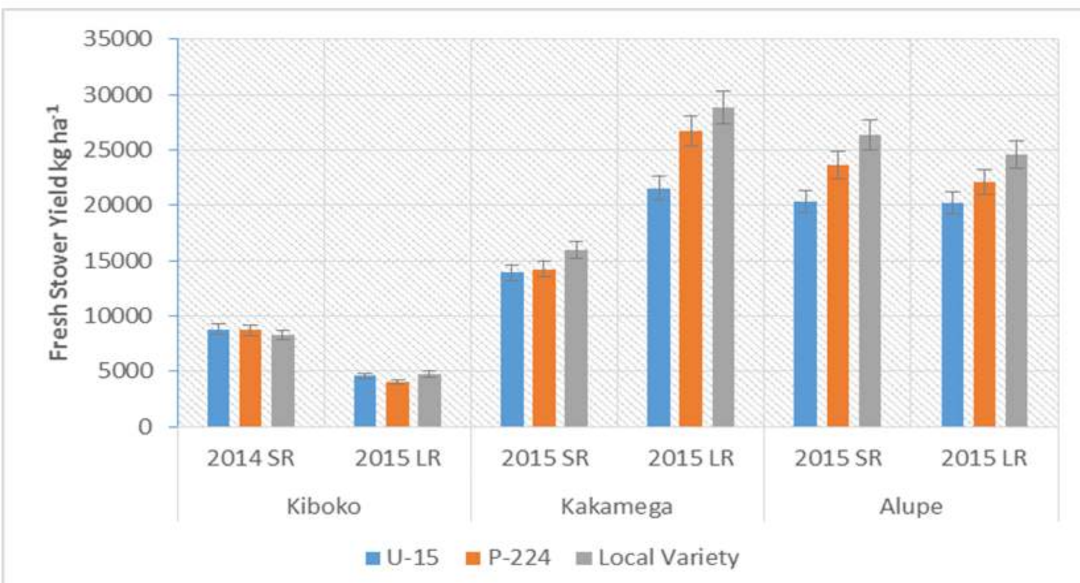

Fig. 2. The varietal influence on the fresh stover yield of finger millet at Kiboko, Kakamega and Alupe, Kenya for the short and long rain seasons of 2015

3.2 Dry Stover Yield

There was a significant increase in the dry stover yield of finger millet as phosphorus fertilizer increased and peaked at 25 kg ha^{-1} P_2O_5 treatment except at Kiboko during the long rain season where the highest rate (37.5 kg ha^{-1} P_2O_5) showed the highest dry stover yield (Fig. 3). The control exhibited the lowest dry stover yield across the sites compared to the P-applied plots. Soils containing insufficient contents of plant available P not only produced economically lower biomass yields but other inputs particularly N is used less effectively by the plants because of their synergistic interaction [31]. The highest dry stover yield (11,616 kg ha^{-1}) was recorded at Kakamega during the long rain season on the 25 kg ha^{-1} P_2O_5 treatment. The importance of an appropriate nutrient balance in crop production and in the maintenance and enhancement of soil fertility was therefore realized. Similar results were reported in another study in Ethiopia on the effects of mineral P fertilizer on growth components of flooded lowland rice [32] where it was found that fertilizer levels showed significant differences for dry straw yields probably because the applied phosphorus increased microbial activity in the rhizosphere of the plants roots. In another study similar results were reported where application of phosphorus fertilizer increased plant height gradually, stem diameter, number of leaves, leaf area and the total fodder yield in two sorghum cultivars [23].

Varietal differences were significant in all the sites (Fig. 4) where variety P-224 and local variety, Ikhulule showed the highest dry stover yield at Kakamega and Busia while inconsistent variations were observed at Kiboko between the varieties.

During the short rain season at Kiboko, varieties P-224 and Ekalakala exhibited the highest dry stover yield and variety U-15 had the lowest dry stover yield while in the long rain season, variety U-15 had significantly the highest dry stover yield. The findings agree with those by other researchers [33,34] who reported variation in biomass production with variety under different climatic conditions and agro-ecologies in straw yields in rice.

3.3 Stover Crude Protein Content

Interactions between variety and phosphorus rates were revealed on the crude protein contents of the finger millet stover (Table 1). At Kiboko, the highest crude protein (11.0%) on variety U-15 and P-224 was observed at the highest rate while on the local variety, Ekalakala, the highest crude protein (10.9%) was realized at the 25 kg ha^{-1} P_2O_5 rate. At Kakamega and Alupe, the highest crude protein was at the 25 kg ha^{-1} P_2O_5 rate on the local variety, Ikhulule which was however not significantly different from that at the 12.5 kg ha^{-1} P_2O_5 rate. On variety U-15, the highest phosphorus rate led to the highest

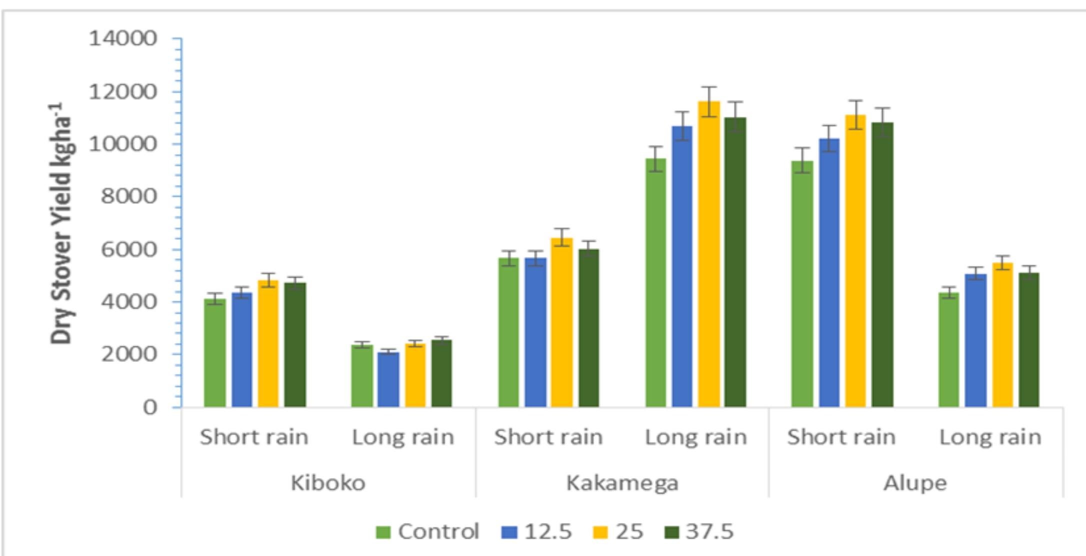

Fig. 3. The dry stover yield of finger millet as influenced by phosphate rates at Kiboko, Kakamega and Alupe, Kenya for the short and long rain seasons of 2015

Fig. 4. The varietal influence on the dry stover yield of finger millet at Kiboko, Kakamega and Alupe, Kenya for the short and long rain seasons of 2015

Table 1. The leaf blade length of finger millet as influenced by phosphate rates and variety in Kakamega and Alupe, Kenya during the short and long rainy season, 2015

Variety	P treatment	Kiboko		Kakamega		Alupe	
		2015 SR	**2015 LR**	**2015 SR**	**2015 LR**	**2015 SR**	**2015 LR**
U-15	Control	8.7b	6.3c	6.4b	6.9b	6.7b	6.9b
	12.5	8.8b	6.5c	6.0c	7.3b	6.7b	6.9b
	25	8.8b	8.8b	8.3ab	7.6b	7.7b	7.2b
	37.5	11.0a	9.4ab	9.1a	9.0a	7.3b	8.3a
P-224	Control	6.6c	8.7b	7.0b	7.1b	6.7b	7.1b
	12.5	6.6c	8.7b	7.1b	7.5b	6.7b	7.9b
	25	8.8b	8.7b	8.1ab	8.7a	8.7a	8.1a
	37.5	10.9a	8.7b	8.3ab	8.9a	8.9a	8.3a
Local variety	Control	8.7b	6.5c	7.9b	8.0b	7.7b	7.9b
	12.5	8.8b	8.7b	8.9a	9.1a	8.9a	8.9a
	25	10.9a	10.9a	9.1a	9.6a	9.9a	8.9a
	37.5	10.9a	10.9a	9.1a	9.1a	9.9a	9.1a
LSD		**1.58**	**1.26**	**0.95**	**0.76**	**1.16**	**1.47**

Values followed by different letters within the column are significantly different at P=.05

crude protein content while on variety P-224, the 25 kg ha^{-1} P_2O_5 rate showed the highest crude protein content. In all the sites, the control showed the lowest crude protein content compared to the finger millet stover from phosphorus treated plots.

Phosphorus leads to elongation of meristematic tissues and since it is a major constituent of ADP and ATP-the energy currency in metabolic activities in plants, it led to greater photosynthetic rates which increased dry matter production that accumulated more nitrogen that influenced directly to the higher crude protein. The present trend on the increase in tissue protein with increasing levels of P is in line as reported by [35,36] that the increase in total uptake of N could be attributed to the fact that added P increased their availability to plants due to priming effect which in turn might have resulted in profuse shoot and root growth and activating greater absorption of nitrogen from the soil. The varietal differences on the crude protein could be due to their genetic efficiency in the utilization of P in the soil. Other recent research studies have also demonstrated varietal differences in P efficiency as reported for rice [37], maize [38], legume cover crops [39], and several other crops of the tropical regions [40].

4. CONCLUSION

Results from this study showed that finger millet stover can be one of the best alternatives to fodder production among smallholder farmers in Kenya. Phosphorus application significantly increased the fresh and dry stover yield of finger millet. The 25 kg ha^{-1} P_2O_5 rate is highly recommended for Kakamega and Alupe while the 37.5 kg ha^{-1} P_2O_5 rate is best for Kiboko especially for the quantity of the stover. The difference in the rates is probably due to the conditions of the different sites where Kiboko is semi-arid, Kakamega is humid and Alupe sub-humid with the latter two having higher soil organic matter that favors higher solubility of P. For the nutritional requirement, the 12.5 kg ha^{-1} P_2O_5 rate under the local variety, Ikhulule is recommended in Kakamega and Alupe while at Kiboko the improved varieties are recommended with the 37.5 kg ha^{-1} P_2O_5 rate. The complementary nutritional characteristics make finger millet a potential crop for fodder especially during the drier seasons in humid regions and for the dryland regions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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