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Effect of NPK Blended Fertilizer Rates on Growth and Yield Attributes of Finger Millet Varieties Grown in Acidic Soil of Western Kenya

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Authors' contributions

Author DSW designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors DSW, GN and PS reviewed the study design and all drafts of the manuscript. Author DSW managed the analyses of the study. Author DSW managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Finger millet (*Eleusine coracana* L) is the staple food among the population of Africa and Asia that supplies a major portion of calories and protein and has a wide range of adaptability to abiotic and biotic stresses and therefore it is for this reason that it is being popularized to curb food insecurity and climate change. 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. Therefore, an experiment was conducted at Kenya Agricultural and Livestock Research Organization (KALRO) Kakamega crops field station for two seasons in 2015 and 2016 to evaluate the influence of NPK blended fertilizer rates on growth and yield components of finger millet under acidic conditions. 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) making it unique to this acidic soil conditions. The design was randomized complete block design, with 0,25,50,75,100 kg application rates per acre of NPK blended fertilizer as the treatments applied in two equal split application and two finger millet

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varieties (P-224 and Gulu-E). The period to 50% flowering was significantly reduced due to the 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 during the long rainy season. At 50 kg/acre, the number of days to physiological maturity were significantly reduced under both varieties where Gulu-E took 107 days to mature during the long rainy season. The number of productive tillers was 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 for both seasons. The study concludes that application rate of 75 kg/acre of NPK blended fertilizer leads to the highest grain yield potential of finger millet and has great liming effects that ultimately reduces the acidity of soils in the western Kenya region.

Keywords: Finger millet; NPK blended; grain yield; productive tillers.

1. INTRODUCTION

Finger millet (*Eleusine coracana* L. Gaertn) 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 [1]. It is a short to medium day length plant with an optimal photoperiod of 12-hours and grows well under moderate rainfall (500-1,000mm with an optimum of 900mm), well distributed during the growing season without prolonged droughts, but with good distribution, it can easily tolerate rainfall as low as 130 mm. 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 [2] which restricts the availability of P in the soils. [3] 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 potential yield of finger millet in Kenya remains largely unknown. For instance, millets were grown on 65,000 hectares in 2000 with an average yield of 1.3 tons/hectare [4]. The 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 [5]. 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 was observed in combined application of the inorganic fertilizers, farm yard manure (FYM) and lime over control [6], 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 in acidic soils of Kakamega Kenya.[7] reported an 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 the 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. NPK blended fertilizer has a combination of macronutrients 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 gives 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 [8]. 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 [8]. 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. Studies by [9] revealed that finger length and width was correlated positively and significantly with monoammonium phosphate fertilizer application and thus with a number of panicles per m^2, number of spikelets per panicle, dry matter yield, plant height and grain yield of rice. [10] Showed that the number of days required to flower varied between 85-100 and increased yields among NP_20_5 fertilizer rates, with the control taking 100 days and 85 days in the applied plots. 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 [11]. The number of productive tillers can increase with fertilizer application on crop plants [12]. Reported on the influence of fertilizers such, where they found that phosphorus had a significant impact on various crops growth attributes they are a paradox for the yield enhancing factors.

The NPK blended fertilizer, under the trade name “Mavuno fertilizer” is one of the NPK fertilizer currently gaining popularity in the region and can offset P deficiency and improve crop yield [13]. The fertilizer has shown some results under maize crop. For instance, the county government of Kakamega supplied a total of 1,913.60 tonnes of NPK blended fertilizer to the farmers during the 2014-2015 growing season [14]. Farmers were recommended 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 [14]. From the report the rates given were not specific but a range. According to [14] 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. Finger millet is also grown in a similar agro-ecological environment like maize. Therefore, application of NPK blended fertilizer would also improve the productivity.

Though finger millet is valued by traditional farmers as a low fertilizer input crop, under these conditions, it suffers from low yields [15]. 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 [16]. 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 [16] thus prompting the current study on the effect of NPK blended fertilizer on growth and yield of finger millet.

2. MATERIALS AND METHODS

2.1 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 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; 1585 masl) in the western part of Kenya and the current study was conducted during short and long rainy seasons of 2015 and 2016 respectively.

2.2 Experimental Design and Management Practices

The study adopted the Randomized Complete Block Design (RCBD), replicated three times with five treatments. The treatments included five levels of NPK blended fertilizer (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 experimental unit measured 2 m x 1.7 m (3.4 m^2) with a 2 m pathway between blocks and a 1 m pathway between plots where blocks measured 18 m x 1.7 m (30.6 m^2) translating to an experimental field of 18m x 13.1m (235.8 m^2). The finger millet varieties were P-224 and Gulu-E where the former was an improved variety while the latter was the local variety check.

Soil samples were taken on the plots at a depth of 0 – 30 cm before planting then after harvesting to monitor the change in soil chemical properties. The seeds were planted with 30 cm spacing between rows and later thinned after four weeks to a 10cm 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 the Kenya Agricultural and

Livestock Research Organization, Kakamega. The seeds were drilled in each line. 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 [17] to have plants with 10 cm gap between each individual plant.

2.3 Data Collection

Data on finger width, finger length and plant height was collected randomly from ten tagged plants selected within the plots according to the [18], descriptors for finger millet. 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 and tabulated into days for days to maturity. Productive tillers which beared mature ears were identified, counted and recorded at 50 % plot maturity from each variety per treatment. 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 every other day until at constant seed weight was maintained using a top load balance when the moisture content was 12.5% according to the [18].

2.4 Data Analysis

Data was analyzed using analysis of variance (ANOVA) using GenStat statistical software Version 15.1 to test treatment effect at 0.05% level of significance. The means were separated using the Fischer's Protected LSD test where significant differences between treatments were observed.

3. RESULTS AND DISCUSSION

3.1 Plant Height

The application of NPK blended fertilizer significantly ($P<0.05$) increased the plant height of both varieties in both seasons at dough stage as shown in Figs. 1 and 2. The varieties differed significantly for both seasons with P-224 being superior compared to Gulu-E in respect to height. During the short rainy season, both varieties significantly showed the highest plant height in the applied plots compared to the control. At 50 kg/acre Gulu-E elicited the tallest finger millet plants (42.85 cm) while at the highest rate P-224 showed the tallest crop at 46.32 cm as shown on Fig. 2. During the long rainy season, the highest rate showed the tallest finger millet plants of 63.2 cm and 65.8 cm for Gulu-E and P-224 respectively at the 50 kg/acre rate. In both seasons, the control showed the lowest plant growth in terms of plant height under both varieties. Both varieties significantly showed the highest plant height in the applied plots compared to the control. A polynomial increase was observed with increasing NPK blended fertilizer rates peaking at 50 kg/acre rate followed by a sharp decline thereafter on the Gulu-E variety during the short rains season (Fig. 1). For P-224, there was a linear increase in the plant height with increasing rates up to the highest rate. The results obtained could be due to rapid growth as a result of increased P due to reduced acidity by the fertilizer. Increased nutrients uptake such as Magnesium ions promoted soil aeration, root respiration and increased soil microbes that enhanced nutrient availability to the plant hence leading to increased growth. Optimum potassium and Boron ions which promoted cell division at the apices could have also contributed to the increased plant height in the NPK blended fertilizer applied plots. The decline in results of short rains might be due to limited moisture in the soils to enhance solubility of nutrients. The results are similar to that of [8].

The observed significant performance in growth and yield parameters with application of NPK blended could be attributed to the essential nutrient elements contained in NPK blended fertilizer that is associated with increased photosynthetic efficiency. NPK Blended application which significantly affected the plant height supports the findings of [19]. 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 pH to a level required by finger millet for efficient and increased uptake of nutrients form the soil.

3.2 Finger Width

A linear significant increase on the finger width was observed in the finger millet varieties for both seasons due to application of NPK blended fertilizer (Fig. 3). During the short rains season, the highest NPK blended rate 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. For the long rains season the thinnest fingers were observed on P-224 variety in the control treatment with 0.7 cm while the widest was in the highest rate of NPK blended of the same 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 Fig. 3.

The response of crops to phosphorus which is 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 phosphor us is largely due to its root distribution relative to phosphorus location in the soil [20] that was made available by the liming effect of the blended NPK thus the increase in the finger width. The results obtained were due enhanced synthesis of amino acids, chlorophyll and better

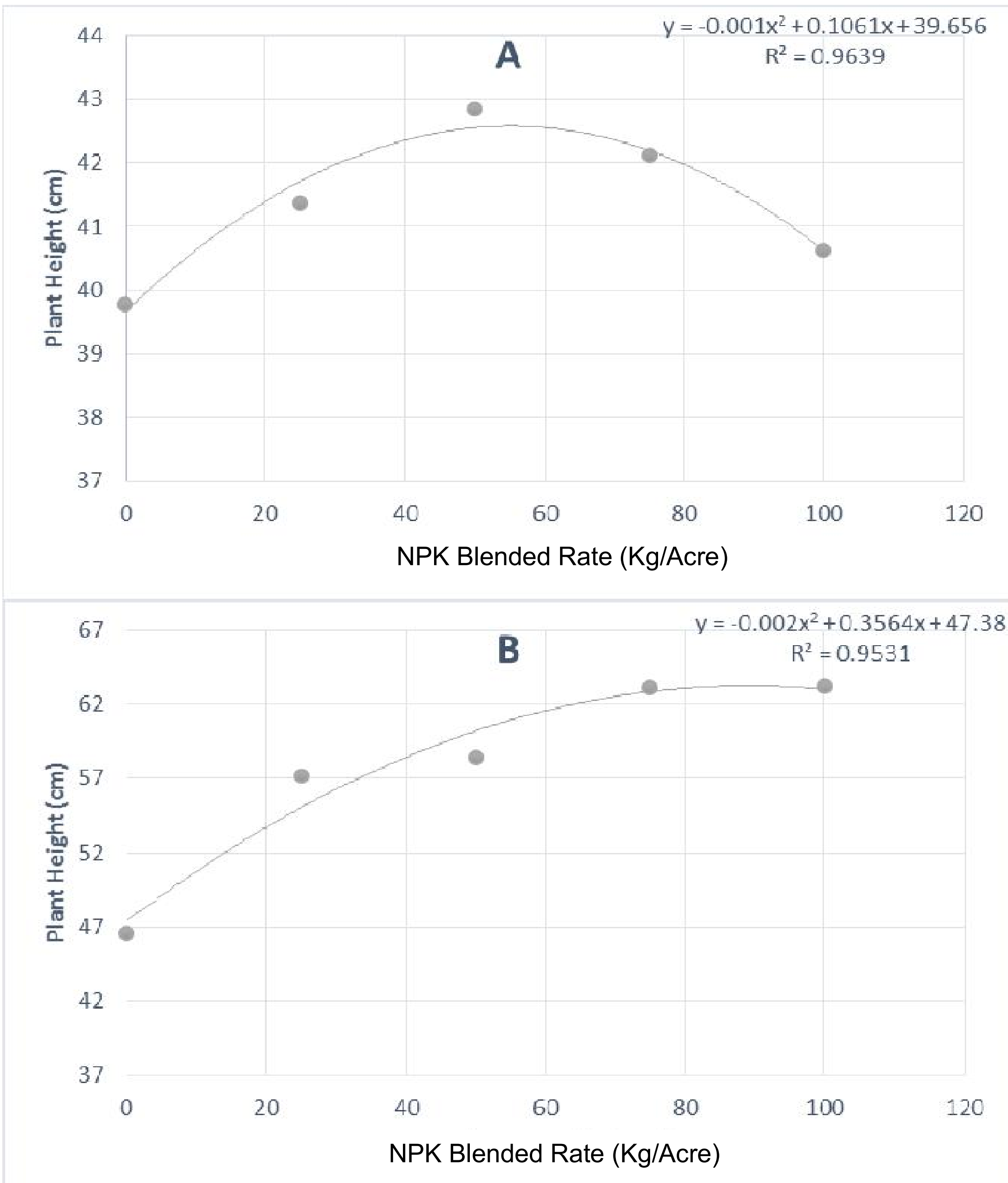

Fig. 1. The plant height respond of Gulu-E variety to NPK blended rates at Kakamega during the short rains season (A) and long rains season (B)

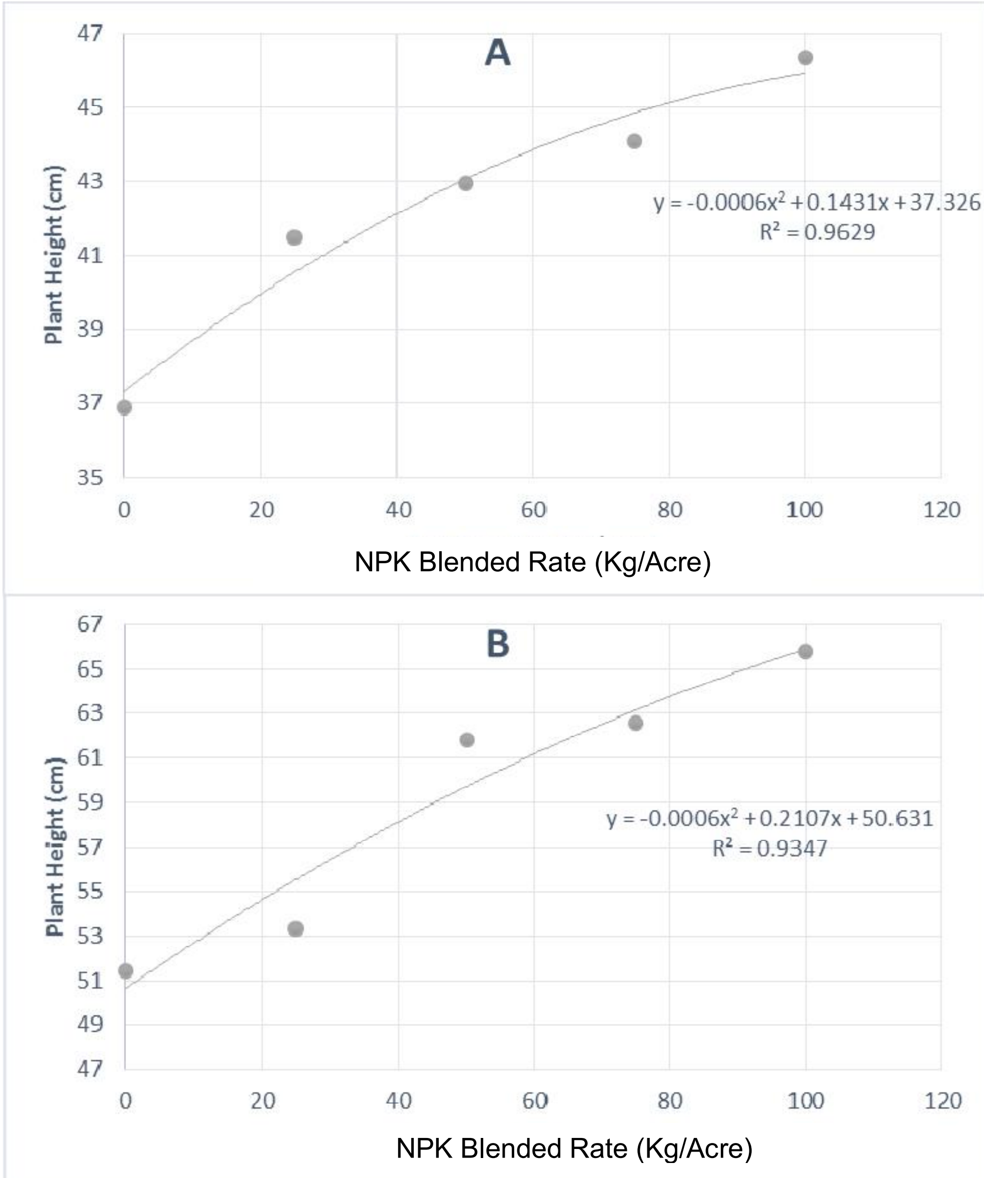

Fig. 2. The plant height respond of P-224 variety to NPK blended rates at Kakamega during the short rains season (A) and long rains season (B)

carbohydrate transformation hence widening the fingers. Potassium and Boron ions present in NPK blended might have promoted cell division leading to widening of the fingers. These results corresponds to those of [9].

3.3 Finger Length

Significant differences (P<0.05) were observed on the finger length of finger millet varieties in the two seasons. The longest fingers of Gulu-E were observed on the 50 kg/acre rate for both seasons. Significant differences (P<0.05) were observed on the finger length of finger millet varieties where Gulu-E showed a conclusive polynomial trend with increasing NPK blended fertilizer rates while P-224 had a linear increase with increasing NPK blended fertilizer rate (Fig. 4) while the longest fingers of Gulu-E were observed on the 50 kg/acre rate. The control had the shortest fingers with a mean of 6 cm for both varieties. 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 during the long rainy season. The results obtained were due enhanced synthesis of amino acids, chlorophyll and better carbohydrate transformation hence widening the fingers. Potassium and Boron ions present in NPK blended might have promoted cell division leading to widening of the fingers. These results corresponds to those of [9].

3.4 Days to 50% Flowering and Days to Maturity

The application of NPK blended fertilizer significantly influenced the period to 50% flowering of finger millet varieties (Table 1). Gulu-E under the control showed the longest period of 96 days during the short rains season with the shortest recorded at the 75 kg/acre rate with a mean of 84 days. During the long rains season the control on variety Gulu-E had the longest period to 50% flowering with a mean of 88 days while the 75 kg/acre rate on variety P-224 had the shortest with a mean of 81 days which was insignificantly different from the 100 kg/acre rate which had a mean of 81.7 days. Variety P-224 did not show a consistent pattern during the same period of the crops growing period. An averagely lesser days with a maximum of 88 days on the control under Gulu-E were observed in the following trial but with the same trend among treatments.

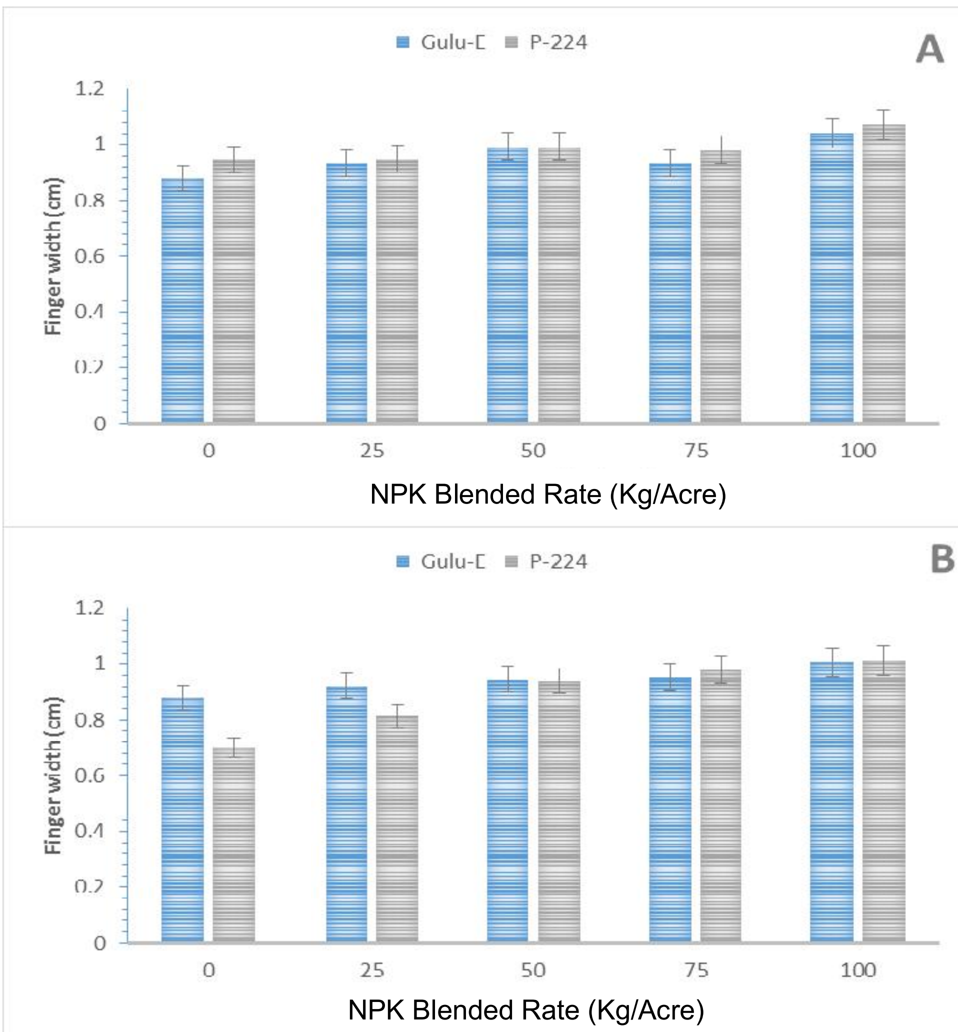

Fig. 3. The finger width of the two varieties during the short rains season (A) and long rains season (B) at Kakamega due to NPK blended fertilizer application. Error bars indicate the LSD at P≤0.05

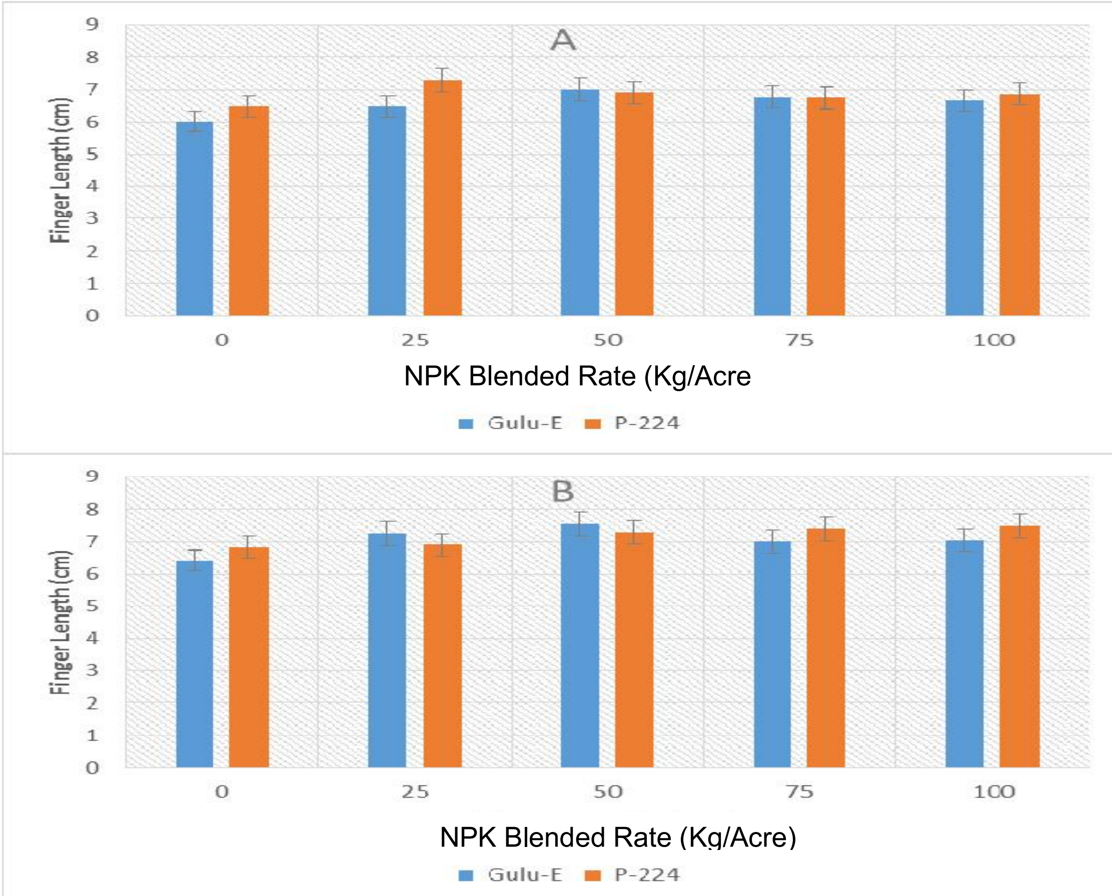

Fig. 4. The influence of NPK blended fertilizer rates on the finger length of finger millet varieties during the long (B) and short (A) rains seasons at Kakamega. Error bars indicate the LSD at P≤0.05.

The 50 kg/acre NPK blended fertilizer rate led to significantly the shortest period to maturation of finger millet varieties (Table 1). The shortest period observed was 107 days under the 50 kg/acre in Gulu-E variety during the long rains season while P-224 took a longer period (118 days) during under the same fertilizer treatment to attain physiological maturity. In the short rains season, variety P-224 at the 75 kg/acre rate the shortest maturation period was recorded with a mean of 109 days while the control of the same variety had the longest period (119.7 days) to physiological maturity. The control had the longest maturation period of finger millet varieties as shown on Table 1. Results on days 50% maturity might have been due to phosphorus availability to the plant that is known to facilitate rapid development of crop to anthesis. NPK blended fertilizer also promoted uptake of Boron and potassium that speeded up fruiting process and pollen grain germination the results are in line to that of [10].Reduction to days to maturity was due to phosphorus, a component of ATP necessary for photosynthesis, protein synthesis, nutrient translocation, respiration and transfer of DNA and RNA that were essential for seed formation and ultimately leading to early maturation. Zinc ions supplied by NPK blended fertilizer promoted growth hormones, starch formation and promotion of seed maturation. At 100 kg/acre days to maturity increased and this could be due to formation of toxic compounds as a result of excess NPK blended fertilizer which might have restricted nutrient uptake by the plants. The results on days to maturity are agree with those of [11].

The significant growth vigour response to fertilizers could be attributed to the fact that finger millet depends on fertilizer phosphorus at

Table 1. 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

Variety	Fertilizer rate	Short rains		Long rain	
		Days to 50% flowering	Days to maturity	Days to 50% flowering	Days to maturity
Gulu-E	0	96.0a	118.3a	88.3a	116.3b
	25	87.7b	116.3b	84.7b	113.7c
	50	88.7b	110.3d	84.3b	106.7e
	75	84.0c	110.3d	84.3b	107.7c
	100	86.7b	113.0c	80.0c	108.3d
P-224	0	86.7b	119.7a	85.7b	118.7a
	25	85.7b	115.0b	85.33b	115.0c
	50	86.0b	110.3d	84.0b	107.7e
	75	88.0b	109.0d	81.7c	109.0d
	100	89.3b	111.0c	81.7c	109.3d
P-Value		0.021	0.009	0.001	0.008
SE		1.122	0.425	1.854	2.237
CV%		2.6	3.8	4.5	5.3

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

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 are present in the NPK blended fertilizer. Many studies have not quantified the amounts of nutrients to be added in relation to the measured yield improvement in Kenya on finger millet and therefore NPK blended fertilizer is essential for root growth and energy transfer processes in plants. Application of NPK blended fertilizers is therefore suggested at early growth stages in order to support the lateral growth stages of crops to enhance productivity as per their given potentials [21].

3.5 Productive Tillers

Significant differences were observed on the productive tillers during the short rains due to NPK blended application in the two varieties where the highest number was recorded at 100 kg/acre of Gulu-E which was though not significantly different from that of P-224 at 75 kg/acre as well as that of Gulu-E (Table 2). During the long rains season, the same trend was observed with the control of both varieties showing the lowest mean productive tillers. 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 as shown on Table 2. The control had as low as 22 total productive tillers per plot and almost 50% lower than the NPK blended fertilizer treated plots.

The increase in the number of productive tillers was due to increased uptake of phosphorus ion which is known to promote tillering. The increase in the number of productive tillers in the blended NPK treatments corroborate with findings on tillering by [22] which showed that the number of tillers per plant were more where NPK blended fertilizer was applied compared to no application in the case of wheat crop. The findings are in conformity with studies by [23] who found a significant increase in the number of tillers per plant with the increase of NPK blended level from 0 to 150 mg P kg-1 of soil. Findings are also similar to those of [12].

3.6 Grain Yield

The finger millet grain yield significantly increased with application of NPK blended fertilizer with Gulu-E variety showing superiority compared to P-224 as shown on Table 2. 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. During both growing periods, the control exhibited the lowest grain yield per plant under both varieties. Like root growth and development, grain formation and grain filling was positively affected by macro and micro nutrients supplied by the

Table 2. 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

Variety	Fertilizer rate	Short rains		Long rains	
		No. of productive tillers/plot	Grain yield (g)/plant	No. of productive tillers/plot	Grain yield (g)/plant
Gulu-E	0	25.3b	34.7d	21.9c	69.0d
	25	25.0b	52.7c	24.4c	107.0b
	50	27.7b	67.7b	29.2b	89.7c
	75	36.7a	80.3a	42.3a	155.0a
	100	42.7a	70.3b	42.4a	140.0a
P-224	0	26.3b	44.7d	22.9c	65.3d
	25	40.0a	55.0c	32.3b	71.3d
	50	28.3b	64.3b	32.4b	101.3b
	75	41.3a	78.7a	40.1a	110.3b
	100	34.3a	58.7c	41.9a	93.0c
P-Value		0.047	0.005	0.043	0.017
SE		1.841	4.512	3.854	8.658
CV%		11.2	10.5	8.9	11.3

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

NPK blended granular fertilizers. Results indicate that 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. Increase in grain yield is due to optimum phosphorus, molybdenum, calcium and magnesium that were necessary for photosynthesis, nitrogen assimilation and metabolism. The results are in agreement with [10].

4. CONCLUSION

The study showed that essential nutrients were deficient in the study site especially phosphorus and the soils were predominantly acidic. The finger width was also positively and significantly influenced by the application of fertilizer due to the increased energy supply for grain filling where P is a major component of ATP. 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 might be due to the reduced absorption of other essential nutrients under excess P while the lower rates did not reach the optimal conditions for optimal energy provision to the plant's maximum metabolism. The application rate of 75 kg/acre NPK blended fertilizer will lead to the realization of the highest potential grain yield of finger millet through increased crop growth, improved days to 50% flowering, days to maturity, productive tillers which positively and significantly impacted on the eventual yield and the rate is therefore recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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