

Phosphorus Efficiency among Selected Sorghum (*Sorghum Bicolor L. Moench*) Lines and Segregating Families

Kassim K. Maritim
Department of Biological Sciences,
Moi University, P.O. Box. 1125- 30100 Eldoret.
E: Mail Mkassim2004@Yahoo.Co m

Beatrice A. Were
Department of Biological Sciences,
Moi University, P.O. Box. 1125- 30100 Eldoret.

Samuel Gudu
Moi University,
P.O. Box. 3900 30100 Eldoret.

Augustino O. Onkware
Department of Biological Sciences,
Moi University, P.O. Box. 1125- 30100 Eldoret.

Emily J. Too
Department of Biological Sciences,
Moi University, P.O. Box. 1125- 30100 Eldoret

Abstract

Sorghum (Sorghum bicolor (L.) Moench) is an important food security crop in Kenya but its production is limited by low available soil phosphorus (P) amongst other factors. This is because its cultivation is mainly carried out by resource limited peasant farmers in marginal agricultural areas that are characterized by soils with very low P levels. This study was carried out to evaluate Kenyan sorghums that are tolerant to low P levels. A P efficient sorghum line, MCSR L6 was crossed with a P inefficient but P responsive line, MCSR N64. The resultant F₁ seed was selfed to produce F₂ seed that was used in the current study. Six F₂ segregating families were characterized for P efficiency in the field with low available P (3 mg of P/kg of soil). MCSR L6 yielded better than MCSR N64, under low available P, but showed poor response to P application in the field. The F₂ sorghum families segregated in terms of days to 50 % flowering, plant height, leaf number per plant, tiller number and grain yield. Based on grain yield, the six sorghum families were classified into four groups; efficient and responsive to P, inefficient and responsive to P, efficient and non-responsive to P, and inefficient and non-responsive to P. The results indicate that the F₂ progeny show genetic variability for P efficiency and responsiveness to additional P, implying that these two traits were successfully transferred from the parents to the progenies.

Keywords: *Sorghum Bicolour, Phosphorus Efficiency, Segregating Families*

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the second most important cereal crop after maize in sub-Saharan Africa (Zidenga, 2004). In Kenya, sorghum is an important food security crop which is grown principally in the often drought-prone, marginal agricultural areas of Eastern, Nyanza and Coastal provinces (EPZA, 2005).

The soils where sorghum is cultivated, especially in Western Kenya, have very low available phosphorus (P) (Okalebo *et al.*, 2004). Available P levels in these soils range from 2 -5 mg/kg soil; which is far below the 10-15 mg/kg required for optimal crop production. Therefore low P availability in the soil is among the primary factors limiting sorghum production in most regions of Kenya.

Application of inorganic phosphate fertilizers is the traditional way of increasing crop production in soils with low P (Zhul *et al.*, 2001). Phosphorus is a macronutrient whose availability has profound consequences for plant growth and physiology (Abel *et al.*, 2002) and is required by plants in large doses. The use of large doses of P fertilizers is normally too expensive for the small scale -farmers who dominate the sorghum cultivation. Moreover, utilization of P fertilizers by crops is often very low, ranging from 10 to 30 % in the year applied, due to the high P fixing capacity of acid soils (Zhul *et al.*, 2001). There is need to reduce sorghum production costs by deployment and adoption of low input technology. One of the approaches is the deployment and adoption of P-efficient sorghum varieties.

Genetic potential for P efficiency has been reported in several crops including wheat (Zhul *et al.*, 2001), rice (Ahmad *et al.*, 2000), cowpeas (Krasilnikoff *et al.*, 2003), maize (Corrales *et al.*, 2007) and sorghum (Schaffert *et al.*, 2001). The Moi University Sorghum Research Team screened a large collection of local Kenyan accessions for P efficiency and identified highly P efficient accessions. The accessions were selfed and further tested to develop stable inbred lines, and MCSR L6, which is P efficient, was among the lines that were developed. MCSR L6 was then crossed with a P inefficient but locally adapted

farmer preferred line, MCSR N64. In this study F₂ sorghum families from the cross were screened for P efficiency at Segi in Siaya district where soil P level is about 3 mg/kg of soil.

The objective of the study was to evaluate the F₂ segregating sorghum families in the field under low P to determine whether P efficiency was successfully transferred from parent MCSR L6 to the progenies.

Materials and Methods

The field experiment was carried out at Segi in Siaya district of Nyanza province, which is located 34° 15' E, 0° 15' N, at an altitude of 1300 meters. It has a mean annual rainfall of 800 to 1200 mm and the mean temperature is about 24°C (National Geographic Society, 1996-2010). The soil is acidic (pH 5.1); with low available soil P of 3 mg/kg of soil.

Sorghum Seed

The sorghum seed from inbred lines, MCSR N64 and MCSR L6 that contrast in tolerance to low available P in the soil and F₂ seed were used. The sorghum lines were developed from local Kenyan accessions through 6 cycles of selfing and selection, and were provided for the study by the Moi University Sorghum Research Team. MCSR N64, which is P inefficient, received pollen from the P efficient line MCSR L6. The F₁ seeds were sowed and plants selfed during the 2007 short rains season to obtain F₂ seed. The F₂ seed was grouped into six families; seed from each F₁ plant formed a family. The F₂ seeds were planted out and selfed in the field to obtain F_{2:3} seed. The F_{2:3} seed from each family was further grouped as either P efficient or inefficient based on grain yield of individual plants planted under low P.

Field Evaluation

The experiment was carried out under a P-deficient soil (3 mg/kg) and was laid out in a split plot design with four replications; phosphorus levels comprised the main plots and sorghum accessions being the sub-plots. The phosphorus levels were low P (no P application) and adequate P (90 kg P₂O₅ ha⁻¹). The F₂ seed and the parentals were sowed in sub-plots of 2 m rows with a spacing of 60 cm between rows and 20 cm within rows and seedlings were thinned to a single plant per hill when they reached six-leaf stage. All the sub-plots were supplied with nitrogen in form of calcium ammonium nitrate fertilizer at planting and as side dressing 6 weeks after planting to a total of 39 kg of N /ha. Recommended insecticides and fungicides were used to control pests and diseases.

Scoring of phenotypic characters was done on the middle rows with outer rows being considered guard rows. Ten plants per row in the middle rows were randomly selected for evaluation and tagged just before flowering. A total of 40 plants per sorghum family under each P level were evaluated. The morphological characters evaluated included days to 50 % flowering; leaf number, tiller number, panicle length, panicle width and total plant height at maturity; and seed weight after threshing.

Classification of the F₂ sorghum families in terms of P efficiency and responsiveness to P was done. Sorghum families with grain yields above the trial mean under low P level were classified as P efficient and those with relative response to P above mean relative response were classified as P responsive (Schaffert et al., 2001). The sorghum families were classified into four groups; efficient and responsive to P (ER), inefficient and responsive to P (IR), efficient and non -responsive to P (EN), and inefficient and non-responsive to P (IN).

Data Analysis

The data was subjected to analysis of variance (ANOVA) and mean separation was done using Duncan's multiple range test using SPSS[®] software (SPSS Inc. Chicago, USA). A probability equal to or less than 0.05 (P ≤ 0.05) was considered to be statistically significant.

Results

The F₂ segregating sorghum families and the parents showed significant variations the morphological traits in the field (Table 1). There were significant differences (P < 0.05) among the sorghum accessions and between P treatments in days to 50 % flowering, but the interaction of P level x genotype was non-significant. Both parents MCSR N64 and MCSR L6 showed no significant differences in 50 % flowering under low P. However, under adequate P, MCSR N64 flowered earlier than parent MCSR L6. Most of the F₂ sorghum families flowered later than either parent both under low P and adequate P. Among the F₂ sorghum families, family 6 flowered early (86 d and 82 d) under both low P

and adequate P respectively. Within each sorghum family and parental line, plants grown under low available soil P tended to flowered later than those supplied with adequate P.

There were significant differences ($P < 0.05$) among the F_2 sorghum families and the parents, and between P treatments in total plant height. Parent MCSR N64 was shorter than parent MCSR L6 under both low P and adequate P. In comparison with the parents, the F_2 sorghum families were taller both under low P and adequate P. However, families 4 and 5 were shorter than parent MCSR L6 under adequate P. Within each sorghum family and parental line, plants grown under low available soil P were shorter than those supplied with adequate P.

Table 1. Effect of P Treatment on 4 Quantitative Traits of F_2 Sorghum Families and the Parents

	<i>Dayto50% flowering</i>		<i>Plant height, cm</i>		<i>Leaf No.</i>		<i>Tiller No.</i>	
	Low P	Adequate P	low P	adequate P	Low P	adequate P	low P	adequate P
MCSR N64	85 ^{ab*}	77 ^c	124.2 ^u	128.0 ^{cu}	8 ^u	8 ^u	0 ^c	1 ^u
MCSR L6	83 ^{du}	82 ^u	157.3 ^{u-u}	179.0 ^{d-c}	8 ^u	9 ^c	0 ^c	1 ^u
Family1	87 ^a	85 ^{du}	202.4 ^{du}	193.0 ^{du}	10 ^{uc}	11 ^u	0 ^c	2 ^a
Family2	87 ^a	86 ^{ad}	172.2 ^{a-d}	198.5 ^{ad}	10 ^{dc}	11 ^d	0 ^c	1 ^b
Family3	87 ^a	82 ^u	182.1 ^{d-c}	217.0 ^d	10 ^{uc}	12 ^d	0 ^c	2 ^a
Family4	87 ^a	86 ^{du}	200.1 ^{du}	176.4 ^{d-u}	10 ^{uc}	12 ^d	0 ^c	1 ^u
Family5	88 ^a	86 ^{du}	183.6 ^{du}	175.6 ^{d-u}	10 ^{uc}	11 ^u	0 ^c	1 ^u
Family6	86 ^{ab}	82 ^b	179.2 ^{a-c}	200.3 ^{ab}	10 ^{bc}	12 ^a	0 ^c	2 ^a

* Means of each trait followed by the same later are not significantly different at $p \leq 0.05$.

The number of leaves per plant differed significantly ($P < 0.05$) among the F_2 sorghum families and their parents, and between P treatments. The F_2 sorghum families had more leaves per plant compared to the parents under both low P and adequate P. Sorghum plants within each family and parental line that were supplied with P had slightly more leaves than those plants under low P. Tillering differed significantly ($P < 0.05$) among the F_2 sorghum families, and was also influenced by P treatment. With adequate P application families 1, 3 and 6 produced more tillers. Also, sorghums grown under adequate P tillered more than those grown under low P.

Table 2: Effect of P Treatment on Grain Yield of F_2 Sorghum Families and the Parents

<i>Accession</i>	<i>Seed weight/plant, g</i>		<i>% P response Class (B/A*100)</i>	
	Low P (A)	Adequate P (B)		
MCSR L6	25.65 ^{u-1}	28.00 ^{u-1}	109	E N
MCSR N64	20.26 ^l	33.18 ^{u-1}	164	I R
Family-1	21.88 ^{el}	38.53 ^{d-u}	176	I R
Family-2	30.13 ^{u-1}	51.70 ^d	171	E R
Family-3	24.81 ^{u-1}	36.82 ^{u-e}	128	I N
Family-4	28.38 ^{cl}	46.82 ^{d-c}	165	E R
Family-5	25.46 ^{u-1}	25.90 ^{u-1}	102	E N
Family-6	25.02 ^{d-l}	50.03 ^{a-d}	200	I R
Trial mean	25.39	38.11	152	

* Means followed by the same later are not significantly different at $p \leq 0.05$.

** I- P inefficient, E- P efficient, R- P responsive, N- P non-responsive.

The grain yields differed significantly ($P < 0.05$) among the F_2 sorghum families and the parents, and between the P treatments (Table 2). MCSR L6 yielded better than MCSR N64 under low P but in contrast, MCSR N64 yielded better than MCSR L6 under adequate P supply. The F_2 sorghum families showed segregation in grain yield under both low P and adequate P supply. Most F_2 sorghum families yielded better than the P inefficient parent MCSR N64 under low P, with families 2 and 4 yielding even better than the P efficient parent MCSR L6.

When supplied with adequate P, the F_2 sorghum families yielded better than either parent, except for family 5. The yield for all the entries was better when P was applied. MCSR N64 responded better to

P application than MCSR L6. Among the F₂ sorghum families, family 6 showed the highest (200 %) relative response to P supply while family 5 (102 %) showed the lowest relative response to P supply.

The F₂ segregating sorghum families and parents were also grouped in terms of P efficiency under low P and responsiveness to P supply based on their grain yield in the field (Table 2). MCSR L6 and family 5 were grouped as P efficient but non-responsive to P application. Parent MCSR N64 and families 1 and 6 were grouped as P inefficient and responsive to P supply. Families 2 and 4 were P efficient and responsive to P supply, indicating that these families inherited both the P efficiency of MCSR L6 and P responsiveness of MCSR N64. In contrast, Family 3 was grouped as P inefficient and non-responsive to P supply.

Discussion

Parental sorghum lines, MCSR L6 and MCSR N64, and the F₂ sorghum families showed significant morphological differences when grown in the field with or without P application. The F₂ sorghum families showed segregation in days to 50 % flowering, total plant height, leaf number and tillering when compared with the parents. Most of the F₂ sorghum families flowered later, were taller, had more leaves and tillered more than the parental lines. The high yields of the F₂ sorghum families than the parents can be attributed to heterosis; a phenomenon where when inbred lines are crossed, the progeny show an increase in character means for traits that previously suffered a reduction due to inbreeding depression (Falconer, 1989). Regardless of the sorghum family or parental line, sorghum plants grown under low P tended to flower later, were shorter, had fewer leaves and tillered less compared with plants supplied with P fertilizer. According to Camacho *et al.* (2002), morphological variables have been used to express the influence of mineral nutrients on plant growth patterns since vegetative growth responds positively to fertilizer application. Plant height, leaf number (Camacho *et al.*, 2002), tillering and grain yield (Castillon, 2001) are reduced by low available P. However, plant maturation is delayed by low P availability.

The P efficient parent, MCSR L6 had a higher grain yield than the P inefficient parent, MCSR N64 under low P. In contrast, MCSR N64 had a higher grain yield than MCSR L6 with adequate P application. This implies that although MCSR L6 is P efficient, it responds poorly to additional P compared to MCSR N64. Schaffert *et al.* (2001) attributed the poor response of some sorghum genotypes to P application to yield ceiling effect. MCSR N64 seems to be a useful sorghum line in breeding because although it is P inefficient, it responds well to additional P application and can transmit this to the progenies.

Some of the F₂ sorghum families performed even better than the P efficient parent under low P, and better than the P responsive parent when supplied with P. The higher performance in some of the F₂ sorghum families compared to the parents can also be attributed to heterosis of the sorghum families.

The F₂ sorghum families were grouped in terms of P efficiency and response to P supply. Some of the families segregated towards parents MCSR L6 and MCSR N64 by being P efficient and non-responsive to P, and P inefficient and responsive to P respectively. The presence of some F₂ families with characteristics of the parents indicates that the genes for P efficiency and responsiveness to P were successfully transferred from the parents to the progenies.

There were other sorghum families that were P inefficient and non-responsive to P, and P efficient and responsive to P. These sorghum families possessed a recombination of the parental attributes. This indicates that independent assortment for P efficiency and responsiveness to P occurred. The occurrence of recombinants which were both P efficient and responsive to P application is important in development of superior sorghum varieties. Such plants will be able to yield well at low P and even better when supplied with P. According to Corrales *et al.* (2007), high responsive by plants to P fertilizer application is an important characteristic for achieving high crop productivity.

The F₂ sorghum families segregated in both directions in P efficiency and response to P application. Weidong *et al.* (2001) reported that P use efficiency showed continuous variation with segregation in both directions, suggesting polygenic inheritance pattern in wheat. Therefore results of this study suggests that P efficiency and response to P application are under polygenic inheritance. Therefore, further research should be done to have a better understanding of genetic control of both P efficiency and responsiveness to P. This information will be useful in guiding breeding aimed at development of low P tolerant sorghum varieties.

Conclusions

There was genetic variability for P-efficiency and responsiveness to P fertilizer application among the F₂ sorghum families which implied that P-efficiency and responsiveness to P application was successfully transferred from the parents MCSR L6 and MCSR N64 respectively, to the progenies. The occurrence of recombinants with combined attributes of the two parents indicates that P efficiency and responsiveness to P are independently inherited.

Acknowledgments

The financial support for this research was from SIDA -SAREC through the BIOEARN project. The research team under the BIOEARN project who provided sorghum seeds for this study is also gratefully acknowledged.

References

- Abel, S., T icconi, C. A., & Delatorre, C. A. (2002). Phosphate sensing in higher plants. *Physiologia plantarum* 115, 1-8.
- Ahmad, S., Yaseen, M., & Saboor, A. (2000). Genetic variation for phosphorus use in rice at two levels of soil applied phosphorus. *Pakistan Journal of Biological Sciences* 3 (8), 1274-1276
- Camacho, R., Malavolta, E., Guerrero-Alves, J. & Camacho, T . (2002). Vegetative growth of grain sorghum in response to phosphorus nutrition. *Scientia Agricola*, 59: 771-776.
- Castillon, P. (2001). Influence of phosphate fertilization on the nutrition and yield of barley on a soil with low plant - available phosphorus. *Plant and Soil*, 91, 221-229.
- Corales, I., Amenós, M., Poschenrieder, C. & Barceló, J. (2007). Phosphorus efficiency and root exudates in two contrasting tropical maize varieties. *Journal of Plant Nutrition*. 30, 1-14.
- Export Processing Zones Authority -EPZA (2005). Grain production in Kenya. pp. 1 -2.
- Falconer, D. S. (1989). *Introduction to quantitative genetics* (3rd edition). New York, U.S.A: Longman scientific & technical. pp. 283-285.
- Krasilnikoff, G., Gahoonia, G. & Nielsen, N. E. (2002). Variation in phosphorus Uptake Efficiency by Genotypes of Cowpea (*Vigna unguiculata*) due to Differences in Root Hair Length and Induced Rhizosphere Processes. *Plant and Soil* 251, 83-91.
- National Geographic Society, 1996 -2010 report .
- Okalebo, J. A., Gudu, S., Obura, P. A., Othieno, C.O. & Ligeyo, D. O. (2004). *Response of maize genotypes to nitrogen, phosphorus and lime in acid soils of western Kenya*. Presented to the 22nd Annual Conference of the Soil Science Society of East Africa in Nov-Dec. in Arusha, T anzania.
- Schaffert, R. E., Alves, V. M. C., Pitta, G. V. E., Bahia, A. F. C. & Santos, F. G. (2001). Genetic variability in sorghum for P efficiency and responsiveness. *Plant nutrition-Food security and sustainability of agro -ecosystems*. pp. 72-73.
- Weidong, C., Jizeng, J. & Jiyun, J. (2001). Identification and interaction analysis of QT L for Phosphorus use efficiency in wheat seedlings. *Plant nutrition-Food security and sustainability of agro-ecosystems*. pp. 76-77.
- Zidenga, T . (2004). DNA-based methods in sorghum diversity studies and improvement, pp. 1 -3.
- Zhul, Y., Smith, S., Howes, N. & Smith, F. (2001). Phosphorus (P) uptake efficiency of doubled haploid lines of spring wheat derived from parents with different P uptake efficiency. *Plant nutrition-Food security and sustainability of agro-ecosystem*. pp. 70-71.