Research Application Summary

Characterisation of selected sorghum genotypes in Zambia for field traits and aluminium tolerance

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Abstract

Sorghum (*Sorghum bicolor* L.) is a major crop of the hotter and drier regions of the tropics and subtropics grown by resource poor farmers for their subsistence. It can also be cultivated in marginal lands and areas of high rainfall characterized by low pH soils high in aluminum (Al). The overall objective of this study was to characterize selected sorghum genotypes for Al tolerance. The specific objectives were to determine performance of selected sorghum genotypes grown in Al prone environments, establish the relationship between yield components and overall yield and develop a selection criterion for Al tolerance in sorghum. Twenty sorghum genotypes (previously identified) were evaluated at three sites with high soil Al levels. Significant differences (P=0.05) were observed for seven of the nine parameters that were measured and/or derived. Interactions were significant for plant height and grain yield. The entries were significantly different for all the measured and derived parameters except for plant count, pest score and agronomic score. Significant differences were observed for location on days to 50% flowering, plant height, pest score, sundried head weight and grain yield. Associations between the measured and/or derived parameters and grain yield were significant. The direct path effects were low except for head weight which had a significant contribution of 1.4. Direct contributions on yield by other parameters were less than 0.1. Plant height, pest score and agronomic score had significant indirect effects of 0.7, 0.7 and 0.5 respectively via head weight. Selection of head weight and head harvest index would contribute effectively to high yielding sorghum genotypes in low pH soil with high Al. The superior genotypes recommended for Al tolerance are entries 11, 16, 17 and 20.

Key words: Aluminium tolerance, aluminium toxicity, *Sorghum bicolor,* Zambia

Résumé

Le sorgho (*Sorghum bicolor* L.) est une principale culture des régions chaudes et sèches des régions tropicales et subtropicales, cultivée par les agriculteurs pauvres en ressources pour leur subsistance. Il peut aussi être cultivé sur des terres marginales et les zones de fortes précipitations, caractérisées par des sols à faible pH et à niveaux élevés en aluminium (Al). L'objectif général de cette étude était de caractériser les génotypes sélectionnés de sorgho pour la tolérance en Al. Les objectifs spécifiques étaient de déterminer la performance des génotypes sélectionnés de sorgho cultivé dans des environnements sujets à l'Al, d'établir la relation entre les composantes du rendement et le rendement global et de développer un critère de sélection pour la tolérance en Al dans le sorgho. Vingt génotypes de sorgho (préalablement identifiés) ont été évalués dans trois sites ayant des niveaux élevés d'Al dans le sol. Des différences significatives (P = 0,05) ont été observées pour sept des neuf paramètres qui ont été mesurés et / ou dérivés. Les interactions étaient significatives pour la hauteur des plantes et le rendement en grains. Les entrées étaient significativement différentes pour tous les paramètres mesurés et dérivés, sauf pour le dénombrement de plantes, le score des ravageurs et le score agronomique. Des différences significatives ont été observées pour la localisation des jours à 50% de floraison, la hauteur des plantes, le score des ravageurs, le poids de la tête séchée et le rendement en grains. Les associations entre les paramètres mesurés et / ou dérivés et le rendement en grains étaient significatives. Les effets des allées directs étaient faibles, sauf pour le poids de la tête qui a eu une contribution significative de 1,4. Les contributions directes sur le rendement par d'autres paramètres étaient inférieures à 0,1. La hauteur de la plante, le score des ravageurs et le score agronomique ont eu des effets significatifs indirects de 0,7, 0,7 et 0,5 respectivement par le poids de la tête. Le choix du poids de la tête et l'indice de récolte de la tête contribueraient efficacement aux génotypes de sorgho à haut rendement dans le sol à faible pH avec Al élevé. Les génotypes supérieurs recommandés pour la tolérance en Al sont les entrées 11, 16, 17 et 20.

Mots clés: Tolérance en aluminium, toxicité en aluminium, *Sorghum bicolor*, Zambie

Background

The future of sorghum (*Sorghum bicolor)* production in Zambia is threatened by low productivity resulting from cultivation in low pH soils. Small scale farmers who grow sorghum in region III use unimproved varieties which have low yield potential, and are tall and nonresponsive to improved management

(MACO, 2002). In order to increase production levels of sorghum in acidic soils of Zambia a number of strategies need to be adapted. Application of agricultural lime to soils having low pH of less than 5 is one way of restoring soil fertility. However, liming is often not economic or practical because of the slow movement of lime especially in the deeper layers of sub soils. Developing cultivars with improved tolerance to acid soil stress offers an alternative solution to address the problem of low yields in sorghum. The study aimed at identifying important plant characteristics under Aluminium (Al) stress to be used in developing an objective basis of selecting for Al tolerance in sorghum.

Literature Summary

Sorghum is relatively undeveloped and has a remarkable array of untapped variability in grain type, plant type, adaptability and productive capacity. It probably has more undeveloped and underutilized genetic potential than any other major food crop (Lost Crops of Africa, 1996). Certain sorghum varieties have been reported to tolerate high aluminum concentrations found in acidic soils (Mohammadi *et al.*, 2003). However, most sorghum cultivars are not tolerant to high concentrations of Al because sorghum improvement programmes have been conducted at locations with near neutral pH soil. Aluminum (Al) phytotoxicity is one of the biggest agronomic problems in acid soils. Aluminium (Al) is a major constituent of most soils but only when it moves into soluble or exchangeable form can it affect plants. Exchangeable aluminum values may be high in soils with pH below 5.5 but may occur at pH values as high as 6.0 in heavy textured soils (Matsumoto *et al.*, 2001).

The main symptom of Al toxicity is the rapid inhibition of root growth, which may translate to a reduction in vigour and crop yields (Kochian *et al.*, 2005). Shoot growth is also inhibited due to limiting supply of water and nutrients. Aluminium (Al) mainly affects plants by inhibiting radical growth which can be seen in the primary and lateral root apexes, which become thick and turn brownish-gray (Rout *et al.*, 2001).

Species in tropical areas are very resistant to Al stress and some of these species can accumulate high concentrations of Al in the leaves, greater than 1% of their dry weight. However, certain plants referred to as Al accumulators such as tea may contain over ten times more Al without any injury. The Al content in these plants can reach as high as 30 mg per gram of dry mass in older leaves (Matsumoto *et al.*, 2001). By contrast, cereals like *Secale cereale*, *Zea mays*, *Hordeum vulgare*, *Triticum aestivum*, x *Triticosecale*, *Sorghum bicolor* and *Avena sativa* do not accumulate high concentrations of Al internally but rather use the Al exclusion mechanism through organic acid exudation (Caniato *et al*., 2007). This may be one of the most widely used mechanisms by most of the species studied. Nevertheless, important differences are manifested in some of the features of these mechanisms in each species, including the nature of the inducibility by Al, the organic acids released, and whether al-induced gene action plays a role in tolerance (Kochian, 2001). Field screening for Al tolerance would be the best approximate for selecting Al-tolerant plants. In practice, however, reliable ranking of tolerance in the field screening is difficult because the Al concentration in soil may not be uniform and because environmental factors interact with soil Al to mask the expression of Al tolerance (Naserian *et al*., 2007). Screening by using the growth response to Al added to the soil in pots at in a greenhouse (referred to as growth-response method hereafter) may be superior in this respect.

Study Description

Twenty advanced sorghum lines/entries obtained from Zambia Agricultural Research Institute under the sorghum breeding programme were used (Table 1). The experiment was conducted

Table 1. List of sorghum genotypes evaluated in the 2008/2009 growing season

Genotype no.	Genotype name
1	SDS 89426
2	PRGC/E#69414
3	ICSV 1089BF
4	MACIA*DORADO
5	ZSV-18
6	ZSV-30
7	ZSV-31
8	SDS 4378-1-1-1
9	SDS 1023-10-2-4-1-3-2
10	SDS 876-3432(OT)8-2-1
11	[SDS3845×SDS4548]F6-10-2
12	[SDS3845×SDS4548]F6-10-3-2
13	[SDS2690-2×M91057]8-2-1-1
14	SDS 2690-2-3-5-1
15	KSV-7
16	KSV-10
17	KSV-4
18	SDS 4380-S7
19	ZSV-12
20	WP-13

in the aluminium toxicity prone areas of Masaiti, Mpongwe and Mansa in region III. The Randomised Complete Block Design (RCBD) was used with three replications at each site. Each entry was sown in four rows (each 4 m long) per plot with an inter row spacing of 75 cm. After thinning an intra row spacing of 50 cm was left between the plants. The total area per plot was 12 m^2 and 200 kg ha^{-1} of Compound D fertilizer (10N: 20P: 10K: 10S) was applied at time of planting to each plot. Urea (46% N) was applied a month after planting at the rate of 100 kg ha^{-1} to each plot. The crop was ready for harvesting after six months from the time of planting.

Soil samples were collected at each of the three sites and these were tested for pH and Al levels. Parameters that were recorded included days to 50% flowering, plant height (cm), plant count, sun dried head weight, moisture content, head harvest index, grain yield, Agronomic score (1 for best to 5 for worst), disease score (1 for most resistant to 5 for most susceptible) and pest score (1 for least damaged to 5 for most damaged). Analysis of variance (ANOVA) was used to detect statistical differences among different levels of parameters of interest using GenStat Release 7.22. Means were separated using Duncan's Multiple Range Test (DMRT). The conventional path analysis based on the method developed by Dewey and Lu (1959) was used to partition the correlations. MSTAT-C statistical software (MSU, 1988) was used to obtain the correlation coefficients and standard partial regression coefficients. The standard partial regression coefficients from multiple regressions were used as path coefficients and the indirect effects were determined by multiplying the correlation by the respective path coefficients (Ssango *et al*., 2004).

Research Application

Field performance of genotypes grown in locations with low pH. The genotypes performed differently over the three locations for variables measured. Plants in the field experiment grew similarly in terms of agronomic score, except for plant height. Locations, genotypes and their interactions were significant for grain yield. The average yield levels observed were 2.6 tons ha^{-1} at Mpongwe and 1.5 tons ha^{-1} at Mansa (Table 2). The differences among the genotypes for grain yield could be ascribed to inherent genetic differences among the genotypes tested. Grain yield is related to maturity with late maturing genotypes generally yielding more than the early ones. This is related to the length of assimilate synthesis period, that later maturing genotypes produce more biomass and

Table 2. Means of parameters measured and/or derived from twenty sorghum genotypes evaluated at three locations during the 2008/2009 growing season in Zambia.

Genotypes		Days to 50% flowering (No.)	Plant count (No.)	Plant height (m)	Disease score	Pest score	Agronomic score	Sun dried head weight (tons/ha)	Head harvest index	Grain yield (tons/ha)
1		81abc	47a	1.3defg	1.6a	1.4a	1.7a	4.7a	0.6ab	3.0ab
2		78bc	43a	1.9ab	1.7a	1.6a	1.9a	2.9bcdef	0.6ab	2.0abcde
3		84abc	40a	1.5cde	1.9a	1.6a	1.9a	2.3def	0.5b	1.4cde
4		78bc	46a	0.9hi	1.6a	1.4a	1.7a	2.2def	0.6ab	1.4cde
5		81abc	44a	1.4def	1.7a	1.5a	1.7a	2.7bcdef	0.7a	2.1abcde
6		77bc	52a	1.8abc	1.4a	1.5a	1.7a	4.1abc	0.7a	3.2a
7		84abc	38a	1.6bcdi	1.5a	1.4a	1.8a	2.9bcdef	0.6ab	2.2abcde
8		90a	39a	1.2efghi	1.6a	1.6a	1.9a	4.3ab	0.6ab	3.1ab
9		82abc	39a	1.2efghi	1.7a	1.5a	1.7a	2.7bcdef	0.6ab	1.9bcde
10		79bc	39a	1.3defg	1.8a	1.5a	1.9a	1.8ef	0.6ab	1.2de
11		86ab	37a	1.5cde	1.7a	1.5a	2.0a	3.6abcd	0.6ab	2.6abc
12		82abc	43a	1.8abc	1.8a	1.4a	1.8a	2.7bcdef	0.7a	2.2abcde
13		85abc	37a	0.9i	1.7a	1.4a	1.8a	2.3def	0.6ab	1.6cde
14		79bc	41a	1.3defgh	1.7a	1.6a	1.9a	1.6f	0.6ab	1.0e
15		86ab	36a	1.1fghi	1.7a	1.6a	1.7a	2.4def	0.6ab	1.4cde
16		77bc	47a	1.9ab	1.7a	1.5a	1.8a	3.0bcdef	0.6ab	2.3abcd
17		76c	50a	2.0a	1.6a	1.4a	1.8a	3.5abcde	0.6ab	2.5abcd
18		83abc	45a	1.3defg	1.8a	1.6a	2.1a	2.5cdef	0.6ab	1.6cde
19		78bc	43a	1.0ghi	1.8a	1.4a	1.5a	2.3def	0.5b	1.4cde
20		79bc	43a	1.7abcd	1.7a	1.5a	1.8a	3.8abcd	0.7a	3.1ab
Grand mean		81	41	1.4	1.7	1.5	1.8	2.9	0.6	2.1
Location	Mansa	84	42	1.4	1.6	1.5	1.8	2.2	0.6	1.5
	Masaiti	88	39	1.1	1.8	1.7	1.9	-		-
	Mpongwe	73	42	1.8	1.7	1.4	1.8	3.7	0.6	2.6

consequently higher grain yield (Ganesamurthy *et al.*, 2004). In the current study the yields of the genotypes were not all related to the maturity dates, except for genotypes 8 and 11 , which were among the late maturing ones and also high yielding. Among the early maturing genotypes that only 4 and 19 had high yields. Grain yield of the genotypes thus was not simply determined, rather a number of factors inherent to the genotypes contributed to the yield levels observed. Yield is known to be a complex trait (Singh, 2005) determined by several factors among which the current study may not have measured.

Head parameters derived from the field experiment indicated that locations and entries has a significant effect. Genotypes 1, 6, 8, 11 and 20 were the highest yielding in addition to producing the highest sundried head weight. Evidently the yielding ability of the entries could be directly related to these head parameters. Grain yield in sorghum has been reported to be highly correlated to these parameters (Ojo *et al.*, 2006). This result was similar to what Mutegwa *et al.* (1999) found in their study on sorghum yield components and witch weed in which head weight was positively and highly correlated to grain yield. The head HI data suggest that while some entries partitioned more assimilates to the head, they were not partitioned at the same rate between the grain and the supportive structures. Entries 1, 6 and 20 are the only ones that had high head HI and high grain yield. The other entries, 8 and 11, attained the high yields through other mechanisms, possibly seed size or others.

Positive correlations were observed between parameters and yield. Head weight had a significant ($P<0.001$) direct contribution of 1.4 towards yield. Plant height, pest score and agronomic score had significant indirect effects of 0.7, 0.7 and 0.5, respectively via head weight. It was therefore concluded that head weight and head harvest index contributed highly directly to yield and can be used as selection criteria.

Root reaction to aluminum levels. An increase in aluminium concentration resulted in the reduction of root length with sharp mean reduction between 0 mg L^{-1} (17.5 cm) and 4 mg L^{-1} (16.2 cm).There was a steady decline between 12 mg L^{-1} (6.0 cm) and 20 mg L^{-1} (4.4 cm). The genotypes were affected differently by aluminium concentration. There was a reduction, at different rates in root length from concentration 0 through 4, 8, 12 and 16 to 20 mg L^{-1}. For example the root length for entry 8 reduced as the Al concentration increased from 0 mg L^{-1} through to 20 mg L^{-1} by 58%, 34%, 26%, 0.0% and 27% compared to entry 10 whose root length reduced by 41%, 67%, 0.0%, 30% and 4% (Table 3). Similar variation in the reduction rates of root length were observed among the rest of the entries. Root reaction was measured through root length, number of lateral roots, root weight, root biomass and shoot biomass. Root length and root biomass are the best indicators for reaction to aluminum concentrations as they represent the ultimate product of growth and development of roots (Nguyen *et al*., 2003; Kochian *et al*., 2005). The results obtained showed that Al toxicity inhibited root growth as the concentration increased with the least effect at 4ppm and the most severe effect at 20ppm across all entries. These results were consistent with those obtained by Kochian *et al.* (2005), Munyinda *et al.* (2008) and Rangel *et al.* (2007) on similar studies of barley, wheat and beans, which showed that an increase in the Al toxicity lead to a reduction in root growth. Further analysis of the twenty genotypes tested revealed three classes (tolerant, intermediate and susceptible). Genotype 11 was the most tolerant followed

Table 3. Root length means (cm) for the 20 sorghum genotypes evaluated for their reaction to varying Al concentrations in the laboratory at University of Zambia in 2009.

Genotype	0 mg L^{-1}	4 mg L^{-1}	8 mg L^{-1}	12 mg L^{-1}	16 mg L^{-1}	20 mg L^{-1}	Genotype means
1	14.2cde	12.8cdef	7.3 cdef	3.0 g	4.2 defg	4.3 cdefg	7.6 bcd
2	16.0bcde	20.8ab	7.5 cde	4.7 defg	4.8 bcdef	5.0 bcde	9.8 abcd
3	17.7bcde	12.2 def	4.0 jk	3.8 efg	4.3 def	4.1 cdefgh	7.7 bcd
4	18.5 bcd	14.1 bcdef	5.6 ghij	5.7 cde	4.6 bcdef	4.7 bcdef	8.9 abcd
5	17.1bcde	19.2 abc	10.3 a	5.9 cde	5.9 ab	7.3 a	10.9 abcd
6	13.7 de	13.0 cdef	4.9 hijk	5.9 cde	3.3 fgh	3.6 efgh	7.4 cd
7	13.7 de	15.1 abcde	5.7 ghi	5.4 cdef	2.7 h	3.3 fgh	7.6 bcd
8	19.4 ab	8.2 f	5.4 ghij	4.0 efg	4.0 defgh	2.9 gh	7.3 d
9	14.4 cde	18.5 abcde	2.3 i	2.9 g	2.6 h	3.2 gh	7.3 d
10	20.2 ab	12.0 ef	4.0 jk	4.0 efg	2.8 gh	2.7 h	7.6 bcd
11	20.0 ab	21.9 a	8.8 abc	8.9 ab	5.3 abcd	5.9 b	11.8 a
12	17.8bcde	21.8 a	8.4 bcd	8.1 ab	5.9 abc	5.9 b	11.3 ab
13	14.2 cde	19.1 abcd	6.8 efg	8.4 ab	3.7 efgh	5.3 bcd	9.6 abcd
14	23.6 a	14.5 bcdef	3.5 kl	5.6 cde	3.8 efgh	5.5 bc	9.4 abcd
15	13.2 e	12.7 cdef	7.1defg	8.1 ab	4.8 bcde	5.4 bcd	8.5 abcd
16	18.8 abc	18.5 abcde	9.2 ab	9.6 a	6.7 a	4.0 defgh	11.1 abc
17	20.8 ab	20.0 ab	8.0bcde	8.9 ab	5.4 abcd	4.2 cdefgh	11.2 abc
18	20.7 ab	18.0 abcde	4.2 ijk	6.7 bcd	4.4 def	4.8 bcde	9.8 abcd
19	16.4bcde	12.9 cdef	5.0 hijk	3.3 fg	4.5 bcdef	2.9 gh	7.5 bcd
20	19.4 ab	19.1 abcd	6.4efgh	7.3 abc	4.4 cdef	4.3 cdefg	10.1 abcd
Conc mean	17.5	16.2	6.2	6.0	4.4	4.4	9.1

by genotypes 12 and 17. Genotypes 16, 5, 20, 2, 13, 14, 4 and 15 fell in the intermediate level while genotypes 1, 3, 7, 10, 18 and 19 were moderately susceptible, 6 and 8 were susceptible. Genotype 9 was the most susceptible. This inhibition of root growth can be attributed to Al shock and injury which is more severe as the Al concentration increases. The tolerant genotypes were relatively less severely inhibited by increase in Al toxicity levels and continued to grow relatively longer roots at higher levels of Al concentration.

In this study, an efficient selection criterion for Al tolerance in sorghum that employs deliberate selection of variables that have high and direct effect on yield was developed. This includes variables through which other traits pass indirectly to contribute significantly to high yield. The results obtained suggested that sundried head weight and head harvest index would contribute effectively to high yielding sorghum genotypes in low pH soils with Al toxicity. Based on the results obtained in this study, the superior genotypes recommended for high rainfall areas are entries 11, 17, 16 and 20.

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References

Caniato, F.F., Guimaraes, C.T., Shaffert, R.E., Alves, V.M.C., Kochian, L.V., Borem, A., Klein, P.E. and Magalhaes, J.V. 2007. Genetic diversity for aluminium tolerance in sorghum.*Theor Appl Genet* 114: 863-876.

Dewey, D.R. and Lu, K.H. 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agronomy Journal* 51:515-518.

Ganesamurthy, K. and Seshadri, P. 2004. Genetic variability, character association and path coefficient analysis in Soy bean. *Madra Agric J.* 91 (1-3): 61-65

Kochian, L.V. 2001. Investigating the complexity of Aluminium tolerance mechanisms in cereal crops. 5th international symposium on plant-soil interactions at low pH. 104pp.

Kochian, L.V., Piñferos, M.A. and Hoekenga, O.A. 2005. The physiology, genetics and molecular biology of plant aluminum resistance and toxicity. *Plant Soil* 274:175-195.

Lost Crops of Africa. 1996. National Academy Press. Vol 1. Grains.

Matsumoto, H., Yamamoto, Y. and Rama Devi, S .2001. Aluminum toxicity in acid soils. Plant responses to aluminum. In: M. Prasad (Ed). Metals in the Environment. Marcel Dekker, New York. pp. 289–319.

Ministry of Agriculture and Cooperatives. (MACO). 2002. Sorghum Production Guide. Soils and Crops Research Branch, Zambia.

Mohammadi, S.A., Prasanna, B.M. and Singh, N.N. 2003. Sequential path model for determining interrelationships among grain yield and related characters in maize. *Crop Sci.* 43: 1690–1697.

MSU, 1988. MSTAT-C microcomputer statistical program. Michigan State University, East Lansig, MI.

Munyinda, K., Tembo, L., Lungu, D.M. and Masuwa, J. 2008.Evaluating for aluminium tolerance in sweet sorghum varieties. Cereal Research Communications. UNZA.

Mutegwa, C.S.,Tongoona, P., Mabasa, S., Chivinge, O.A. and Ichishahayo, D. 1999. Path Coefficient Analysis of phenotypic correlations of sorghum [*sorghum bicolar* (L) Moench] yield components and witchweed [*striga asiatica* (L) Kuntze] parameters.17th East African Biennial Weed Science Conference Proceedings. pp.137-143.

Naserian, B., Asadi, A.A., Rahimi, M. and Ardakani, M.R. 2007. Evaluation of wheat cultivar mutants for morphological and yield traits and comparing of yield components under irrigated and rainfed conditions. *Asian J. Plant Sci.* 6:214-224.

Nguyen, B., Brar, D., Bui, B., Nguyen, T., Pham, L. and Nguyen, H. 2003. Identification and mapping of the QTL for aluminum tolerance introgressed from the new source, *Oryza rufipogon* Griff, into indica rice (*Oryza sativa* L.). *Theor Appl Genet* 106: 583-593.

Ojo, D.K., Omikunle, O.A., Oduwaye, O.A., Ajala, M.O. and Ogunbayo, S.A. 2006. Heritability, Character correlation and Path coefficient Analysis among six inbred lines of Maize (*Zea mays* L.). *World Journal of Agricultural Sciences* 2(3): 352-358

Rangel, A.F., Rao, M.I. and Horst, W.J.2007. Spatial aluminium sensitivity of root apices of common bean genotypes with contrasting aluminium resistance. *Journal of Experimental Botany* 58(14): 3895-3904

Rout, G., Samantaray, S. and Das, P. 2001. Alimunium toxicity in plants: A review. *Agronomie* 21:3- 21.

Singh, B.D. 2005. Plant Breeding Principles and Methods.7th Edition. Kalyani Publishers. India.

Ssango, F., Speijer, P.R., Coyne, D.L. and De Waele, D. 2004. Path analysis: A novel approach to determine the contribution of nematode damage to East African Highland banana (*Musa* spp. AAA) yield loss under two crop management practices in Uganda. *Field Crops Research* 90:177–178.