Sorghum Genetic Resources with Contrasting Phosphorus Efficiency

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INTRODUCTION

The complex of acidity in tropical soils includes low pH, toxic levels of Al, low availability associated with high adsorption of phosphorus (P), and a generalized low level of plant nutrients. This soil acidity complex often creates a chemical barrier to root growth and development, decreasing root contact with soil nutrients and water, resulting in even greater water and nutrient stress. Forty-eight percent of the potentially arable land of the world is acidic. Sixty-four percent of the agriculture land of tropical South America, 32% of the land of tropical Asia, and 10% of the land in Central America, the Caribbean and Mexico are acidic. The acid savannas or "Cerrado" of Brazil covers an area of 205 million hectares of which 175 million are in central Brazil. Approximately 112 million hectares are considered adequate for agriculture production.

The strategy of eliminating the production constraints of low fertility in acid soils with both liming practices and corrective applications of P is limited technically with respect to correcting the acidity of the subsoil and economically with the high rates of P fertilizer required due to the high P fixing capacity of the soil. A combination of soil management practices, liming in association with corrective levels of P, and use of crop cultivars developed for these low pH conditions is a solution encountered for sustainable crop production in acid soils. Plants that can develop root systems in this chemical barrier explore a greater volume of soil, increasing the supply of soil nutrients and water.

Nutrient use efficiency in plants is driven by soil capacity to supply and the plant's ability to acquire. Plant parameters that are largely responsible for nutrient uptake efficiency are: alteration of the environment in the soil rhizosphere, acquisition from the environment, nutrient movement across roots and delivery to xylem, nutrient distribution within plants, and growth and metabolic efficiency. All of these factors and their interactions with the environment are under genetic control. The identification and understanding of the alteration of the rhizosphere environment, mechanisms of acquisition and utilization of P can facilitate the genetic manipulation of these parameters. There are no known plant traits in the cereals that can identify plants that might have high P utilization efficiency. To achieve any progress in this area, there is a need to first identify genotypes that differ in their ability to acquire P efficiently and that respond differently to applied P. The objective of this research has been to identify genetic resources of sorghum both efficient and inefficient in P utilization and responsive and non-responsive to applied P.

METHODOLOGY FOR SCREENING FOR PHOSPHORUS EFFICIENCY

Thirty-six sorghum lines (Table 1) were evaluated for P efficiency and responsiveness at the National Maize and Sorghum Research Center (CNPMS) of Embrapa during the 1995/96 and 1996/97 growing seasons at Sete Lagoas, MG, Brazil. The experiment was conducted on a Dark Red Latosol (Oxisol) soil under savanna vegetation at 5 and 18 ppm P (Mehlich-1 extractor). The soil was limed to raise the pH to a

Table 1. Average grain production of 36 sorghum lines at two P levels in Year 1.

N°	Name	Pedigree	Al T/S*	Grain yield low P A	Grain yield high P B	Relative yield B/A
1	CMSXS 102	BR 001B/Wheatland B	S	2.52	3.02	1.20
2	CMSXS 101	BR 007B	S	2.60	5.01	1.93
3	CMSXS136	SC 283	T	2.70	3.03	1.12
4	BR 012R	(SC748-5XSC326-6)2-1-C-1-C	S	2.88	4.02	1.40
5	SC748-5	SC748-5	S	2.50	3.33	1.33
6	CMSXS110	TX430R	S	2.86	3.93	1.37
7	CMSXS153	156-P-5-2-1	T	2.54	2.95	1.16
8	CMSXS225	(110*153)18-5-1	T	2.95	3.38	1.15
9	CMSXS226	(136*116)30-1-1	T	2.36	3.83	1.62
10	CMSXS227	(136*116)30-1-2	T	2.15	2.78	1.29
11	CMSXS 112	BR 008B /Redlan B	S	3.46	4.33	1.25
12	CMSXS 116	BR 005R/SC326-6 sel	S	3.43	3.70	1.08
13	ATF 01B	B(101*136)16-3-1-1	T	3.11	5.39	1.73
14	ATF 02B	B(101*136)16-3-1-3	T	2.84	4.52	1.59
15	ATF 03B	B(101*136)16-3-1-4	T	3.52	4.88	1.39
16	ATF 04B	B(101*136)16-3-1-5	T	3.18	5.16	1.62
17	ATF 06B	B(101*136)4-1-1-3	S	2.39	1.84	0.77
18	ATF 08B	B(101*136)4-1-2-6	S	2.42	2.34	0.97
19	ATF 14B	B(101*136)4-1-3-11	T	2.42	4.11	1.70
20	ATF 16B	B(101*136)4-1-3-17	S	1.89	2.52	1.33
21	ATF 17B	B(102*136)46-1-1-1	T	3.09	4.21	1.36
22	ATF 19B	B(112*136)16-1-3-3	T	2.44	4.21	1.73
23	ATF 23B	B(112*136)16-1-3-11	T	2.68	3.61	1.35
24	ATF 29B	B(187*136)6-1-2-10	T	2.62	3.61	1.38
25	ATF 30B	B(187*136)6-1-2-11	T	2.62	3.50	1.34
26	ATF 33B	B(DRD*136)42-1-5	T/S	1.83	2.78	1.52
27	ATF 34B	B(DRD*136)42-1-1	T	1.76	3.33	1.89
28	ATF 39B	B(112*136)46-2-2-6	T	2.86	3.29	1.15
29	ATF 40B	B(101*136)14-1-1-11	T	3.33	4.65	1.40
30	ATF 41B	B(102*136)21-1-1-1	T	1.30	2.32	1.78
31	ATF 46B	B(112*136)2-2-2-2	T	2.46	3.67	1.49
32	ATF 49B	B(136*116)2-2-2-1	S	2.42	2.62	1.08
33	ATF 50B	B(136*116)2-2-2-3	S	2.23	2.69	1.21
34	ATF 53B	B(101*136)9-1-1-1	T	2.34	4.45	1.90
35	ATF 54B	B(101*136)9-1-1-3	T	2.64	4.22	1.60
36	ATF 55B	B(136*101)23-1-1-1	T	3.27	5.10	1.56
		Average		2.63	3.68	1.40

** (T) Tolerant or (S) Susceptible to Al toxicity*

range between 5.5 and 6.0. Triple superphosphate was broadcast and incorporated to reach the desired P levels as determined by an incubation curve. N and K were applied based on the soil analysis. This trial was conducted with no additional P added the second year. The experiment was irrigated, but periods of moisture stress probably occurred between irrigation periods. The 36 lines (Table 1) included 12 traditional lines representing both tolerance and susceptibility to Al toxicity and 24 lines derived from crosses between elite B-lines and a source of tolerance to Al toxicity, SC 283 (IS7173C). Twelve lines were susceptible to toxic levels of Al and 24 lines were tolerant. Toxic levels of Al did not occur in the plow layer but were present in the subsoil. Genotypes with above average grain production at the low P level were classified as P efficient and genotypes with above average relative response to P were classified as responsive to P. The 36 entries were classified into four groups; efficient and responsive to P (ER), non-efficient and responsive to P (NR), efficient and not responsive to P (EN), and non-efficient and not responsive to P (NN), according to their field performance for grain yield.

RESULTS AND DISCUSSION

The average grain production of the 36 sorghum lines at the two levels of P in the first year is shown in Table 1. The yields ranged from 1.76 to 3.52 t/ha at low P with a mean of 2.63 t/ha and from 1.84 to 5.39 t/ha at high P with a mean of 3.68 t/ha. The differences between genotypes and P levels for grain yield were highly significant. The interaction between genotypes and P levels was not significant. The CV for grain yield was 21.9%. The relative response to applied P ranged from less than zero to 93% with an average of 41%. The results are graphically depicted in Figures 1 and 2. In Figure 1 average grain yield at low P is plotted against the relative response to additional P. In Figure 2, average grain yield at low P is plotted against grain yield at the high P level. In both graphs, the 36 sorghum lines are divided into four groups; ER, EN, NR, and NN. Tolerance and susceptibility to Al toxicity were not directly related to P efficiency and P responsiveness.

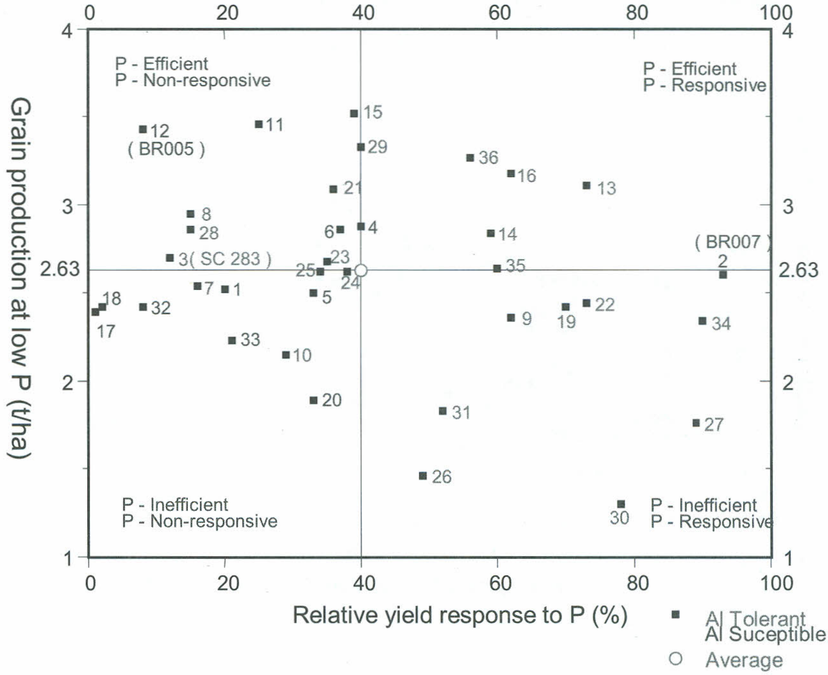

Figure 1. Graphic representation of P efficiency and responsiveness of 36 sorghum lines at two levels of P.

The standard for tolerance to Al toxicity, SC 283, was near average for P efficiency (2.70 t/ha at low P) and not responsive to additional P (12%), whereas the standard for susceptibility to Al toxicity, the commercial male sterile line BR 007B, was near average for P efficiency (2.60 t/ha at low P) and highly responsive to additional P (93%). The Al tolerant line of a P inefficient near-isogenic pair for Al toxicity (ATF 16B and ATF 14B, susceptible and tolerant to Al toxicity respectively) was more responsive to additional P (70%), whereas the Al susceptible line of the pair was less responsive to P (33%). Two Al tolerant near-isogenic recombinant lines, ATF 54B and ATF 53B from the cross between BR 007B and SC 283 were near average for P efficiency and highly responsive to P (60

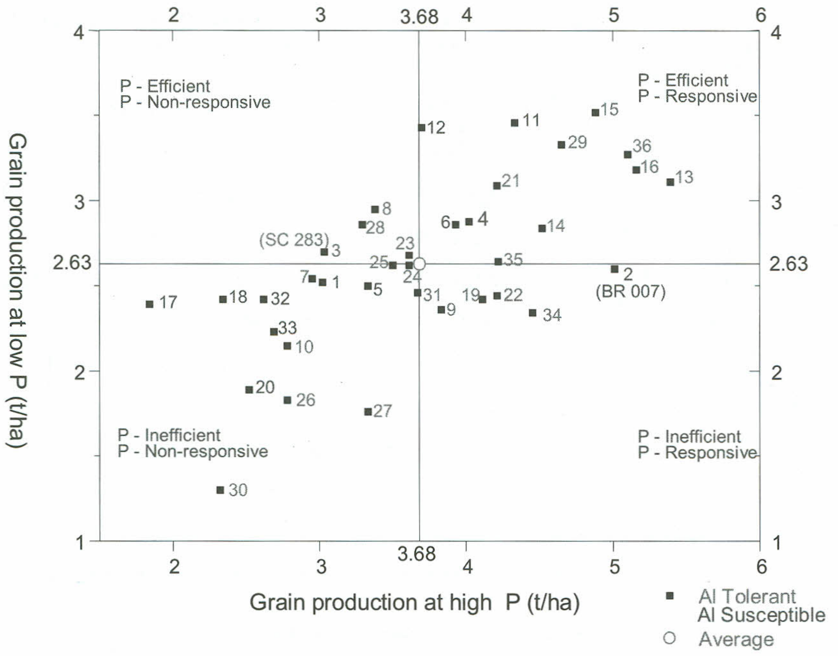

Figure 2. Graphic representation of P efficiency and responsiveness of 36 sorghum lines at two levels of P

and 90% respectively) demonstrating a recombination of Al tolerance and responsiveness to P.

The average grain production of the 36 sorghum lines at the two levels of P in the second year is shown in Table 2. The yields ranged from 0.66 to 3.12 t/ha at low P with a mean of 1.79 t/ha and from 1.49 to 5.64 t/ha at high P with a mean of 3.51 t/ha. The differences between genotypes and P levels for grain yield were highly significant. The interaction between genotypes and P levels was not significant. The reduction in average yield at low P may have been caused by a reduction of residual P from year one to year two and reducing the level of P to less than 50% 0f the critical level. The standard for tolerance to Al toxicity, SC 283, was above average for P

Table 2. Average grain production of 36 sorghum lines at two P levels in year 2.

N°	Name	Pedigree	Al T/S *	Grain yield low P A	Grain yield high P B	Relative yield B/A
1	CMSXS 102B	BR 001B	S	1.14	2.10	1.84
2	CMSXS 101B	BR 007B	S	1.30	4.40	3.89
3	CMSXS136	SC283	T	2.61	3.54	1.36
4	CMSXS 178	BR 012R	S	1.33	2.73	2.05
5	SC748-5	SC748-5	S	1.82	3.03	1.66
6	CMSXS110	TX430R	S	1.82	2.49	1.37
7	CMSXS153	156-P-5-2-1	T	2.94	5.64	1.92
8	CMSXS225	(110*153) 18-5-1	T	1.82	3.65	2.01
9	CMSXS226	(136*116)30-1-1	T	1.71	2.34	1.37
10	CMSXS227	(136*116)30-1-2	T	1.50	3.04	2.03
11	CMSXS 112B	BR 008B-Redlan B	S	1.20	4.10	3.42
12	CMSXS 116R	BR 005R	S	2.05	3.32	1.62
13	ATF 01B	B(101*136)16-3-1-1	T	1.29	4.86	3.77
14	ATF 02B	B(101*136)16-3-1-3	T	1.35	4.97	3.68
15	ATF 03B	B(101*136)16-3-1-4	T	1.55	4.33	2.79
16	ATF 04B	B(101*136)16-3-1-5	T	1.58	4.68	2.96
17	ATF 06B	B(101*136)4-1-1-3	S	1.84	3.16	1.72
18	ATF 08B	B(101*136)4-1-2-6	S	1.33	2.52	1.89
19	ATF 14B	B(101*136)4-1-3-11	T	2.53	3.15	1.25
20	ATF 16B	B(101*136)4-1-3-17	S	1.72	2.69	1.56
21	ATF 17B	B(102*136)46-1-1-1	T	2.24	4.32	1.93
22	ATF 19B	B(112*136)16-1-3-3	T	2.46	3.89	1.58
23	ATF 23B	B(112*136)16-1-3-11	T	1.58	3.20	2.03
24	ATF 29B	B(187*136)6-1-2-10	T	3.12	3.66	1.17
25	ATF 30B	B(187*136)6-1-2-11	T	1.98	2.80	1.41
26	ATF 33B	B(DRD*136)42-1-2	T/S	1.57	3.13	1.99
27	ATF 34B	B(DRD*136)42-1-1	T	2.19	2.27	1.04
28	ATF 39B	B(112*136)46-2-2-6	T	2.27	3.26	1.44
29	ATF 40B	B(101*136)14-1-1-11	T	2.18	3.72	1.71
30	ATF 41B	B(102*136)21-1-1-1	T	0.66	1.49	2.26
31	ATF 46B	B(112*136)2-2-2-2	T	1.64	4.22	2.57
32	ATF 49B	B(136*116)2-2-2-1	S	2.03	3.69	1.82
33	ATF 50B	B(136*116)2-2-2-3	S	1.84	3.59	1.95
34	ATF 53B	B(101*136)9-1-1-1	T	1.15	3.97	3.45
35	ATF 54B	B(101*136)9-1-1-3	T	1.46	3.74	2.56
36	ATF 55B	B(136*1101)23-1-1-1	T	1.95	4.49	2.30
	Average			1.79	3.51	2.09

efficiency (2.61t/ha at low P) and slightly responsive to additional P (36%), whereas the standard for susceptibility to Al toxicity, the commercial male sterile line BR 007B, was below average for P efficiency (1.30 t/ha at low P) and highly responsive to additional P (289%). The Al tolerant line of a P inefficient near-isogenic pair for Al toxicity (ATF 16B and ATF

Table 3. Grain Yield of Four Sorghum Genotypes Contrasting for Phosphorus Efficiency at Two Levels of Soil Phosphorus - 50% (5ppm) and 100% (10ppm) Phosphorus Critical Level.

No.	Name	Pedigree	Al t/s*	Grain yield low P Y1	Grain yield low p Y2	Ave yield low P	Grain yield high P Y1	Grain yield high P Y2	Ave yield high P	Relative response to P Y1	Relative response to P Y2	Ave response to P	Class
2	CMSXS 101	BR 007B	S	2.60	1.30	1.95	5.01	4.70	4.86	1.93	3.61	2.49	N R
3	CMSXS 136	SC 283	T	2.70	2.61	2.66	3.03	3.54	3.29	1.12	1.36	1.23	E N
9	CMSXS 116	BR 005R	S	3.43	2.05	2.74	3.70	3.32	3.51	1.08	1.62	1.28	E N
12	CMSXS 226	(136*116)30-1-1	T	2.36	1.71	2.04	3.83	2.34	3.09	1.62	1.37	1.51	N R
	Trial average			2.63	1.79	2.21	3.68	3.51	3.60	1.40	2.09		

14B, susceptible and tolerant to Al toxicity respectively) was more responsive to additional P (56%) whereas the Al susceptible line of the pair was less responsive to P (25%). Two Al tolerant near-isogenic recombinant lines, ATF 54B and ATF 53B from the cross between BR 007B and SC 283 were slightly below average for P efficiency and highly responsive to P (245% and 156% respectively) demonstrating a recombination of Al tolerance and responsiveness to P.

The grain yield of four sorghum genotypes contrasting for phosphorus efficiency at two levels of soil phosphorus are compared in Table 3. Classification of the genotypes into the four classes becomes more difficult when using data from both years, but it is clear that BR 007B is highly responsive to P and BR 005R is P efficient at lower levels of P. The classification of SC

Table 4. Average grain production (t/ha) of the parents and 12 progenies derived from the cross of CMSXS 101B and SC283 at two levels of P for two years.

No.	Name	Pedigree	Al t/s*	Grain yield low P y1 (a)	Grain yield low P y2 (c)	Ave yield low P (e)	Grain yield high P y1 (b)	Grain yield high P y2 (d)	Ave yield high P (f)	Rel yield b/a	Rel yield d/c	Ave rel. yield f/e
2	CMSXS 101	BR 007B	S	2.60	1.30	1.95	5.01	4.40	4.70	1.93	3.89	2.41
3	CMSXS136	SC 283	T	2.70	2.61	2.66	3.03	3.54	3.28	1.12	1.36	1.23
13	ATF 01B	B(101*136)16-3-1-1	T	3.11	1.26	2.19	5.39	4.86	5.12	1.73	3.77	2.33
14	ATF 02B	B(101*136)16-3-1-3	T	2.84	1.35	2.10	4.52	4.97	4.74	1.59	3.68	2.57
15	ATF 03B	B(101*136)16-3-1-4	T	3.52	1.55	2.54	4.88	4.33	4.61	1.39	2.79	1.81
16	ATF 04B	B(101*136)16-3-1-5	T	3.18	1.58	2.38	5.16	4.68	4.92	1.62	2.96	2.07
17	ATF 06B	B(101*136)4-1-1-3	S	2.39	1.84	2.11	1.84	3.16	2.50	0.77	1.72	1.18
18	ATF 08B	B(101*136)4-1-2-6	S	2.42	1.33	1.88	2.34	2.52	2.43	0.97	1.89	1.29
19	ATF 14B	B(101*136)4-1-3-11	T	2.42	2.53	2.48	4.11	3.15	3.63	1.70	1.25	1.46
20	ATF 16B	B(101*136)4-1-3-17	S	1.89	1.72	1.80	2.52	2.69	2.61	1.33	2.96	1.45
29	ATF 40B	B(101*136)14-1-1-11	T	3.33	2.18	2.76	4.65	3.72	4.19	1.40	1.71	1.51
34	ATF 53B	B(101*136)9-1-11	T	2.34	1.15	1.74	4.45	3.97	4.21	1.90	3.45	2.41
35	ATF 54B	B(101*136)9-1-1-3	T	2.64	1.46	2.05	4.22	3.74	3.98	1.60	2.56	1.94
36	ATF 55B	B(136*101)23-1-1-1	T	3.27	1.95	2.11	5.10	4.49	4.79	1.56	2.30	2.27
		Average		2.76	1.70	2.16	4.09			1.43		

**(T)Tolerant or (S) Susceptible to Al toxicity*

283 was more P efficient in the second year and noon responsive to P in both years. The average grain production (t/ha) of the parents and 12 progenies derived from the cross of CMSXS 101B and SC283 at two levels of P for two years are compared in Tables 4. The average grain production (t/ha) of the parents and three families (9 progenies) derived from the cross of CMSXS 101B and SC283 at two levels of P for two years are compared in Table 5. The recovery of genotypes tolerant to Al toxicity and responsive to P and genotypes susceptible to Al toxicity and non-responsive to P strongly suggest that these traits are inherited independently.

Table 5. Average grain production (t/ha) of the parents and three families (9 progenies) derived from the cross of CMSXS 101B and SC283 at two levels of P for two years.

w N°	Name	Pedigree	Al T/S*	Ave yield low P (E)	Ave yield high P (F)	Ave rel. Yield (F/E)
2	CMSXS 101	BR 007B	S	1.95	4.70	2.41
3	CMSXS136	SC 283	T	2.66	3.28	1.23
13	ATF 01B	B(101*136)16-3-1-1	T	2.19	5.12	2.33
14	ATF 02B	B(101*136)16-3-1-3	T	2.10	4.74	2.57
15	ATF 03B	B(101*136)16-3-1-4	T	2.54	4.61	1.81
16	ATF 04B	B(101*136)16-3-1-5	T	2.38	4.92	2.07
		Family 16 Ave. (4)	T	2.30	4.84	2.10
34	ATF 53B	B(101*136)9-1-11	T	1.74	4.21	2.41
35	ATF 54B	B(101*136)9-1-1-3	T	2.05	3.98	1.94
		Family 9 Ave. (2)	T	1.89	4.10	2.18
17	ATF 06B	B(101*136)4-1-1-3	S	2.11	2.50	1.18
18	ATF 08B	B(101*136)4-1-2-6	S	1.88	2.43	1.29
2	ATF 16B	B(101*136)4-1-3-17	S	1.80	2.61	1.45
		Family 4 Ave. (3 S)	S	1.93	2.51	1.35
19	ATF 14B	B(101*136)4-1-3-11	T	2.48	3.63	1.46

**(T)Tolerant or (S) Susceptible to Al toxicity*

CONCLUSIONS

Genetic variability for both P use efficiency and P responsiveness was identified within a set of 36 sorghum line representing both tolerance and susceptibility to Al toxicity. Recombination for these traits was observed in a set of 24 recombinant lines developed for tolerance to Al toxicity. These results indicate that the genetic control of tolerance to Al toxicity and efficiency and responsiveness to P are independent. The next step in understanding the interaction of these traits is to evaluate hybrids involving these traits in varying level of P as well as identifying genetic markers for these traits.

In general the yields for both P treatments were less in the second year, but more so in the low P treatment. This may have been the result of lower P availability in the soil as no P fertilizer was applied in the second year. The line CMSXS 101B had one of the highest responses to added P. The Al tolerant line, CMSXS 136, responded poorly to additional P in both years. This may be because it reaches its yield potential at the low level of P, or that it does not respond to P. These data indicate that these sorghum lines respond differently to P stress in field conditions. The line CMSXS 116 may be described as a P efficient line at low levels of P. The line CMSXS 101B may be described as a P responsive line. The line CMSXS 136 may be P efficient at low levels of P, but is not responsive to additional P. This may be due to a yield ceiling, that is the line is producing at its maximum limit and therefore does not respond to additional P or that it simply does not have a P acquisition mechanism to respond to additional P. Recombinant lines derived from CMSXS 101B x CMSXS 136 were either responsive to P like CMSXS 101B or non-responsive to P like CMSXS 136.