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Inheritance of acid-soil tolerance in sorghum (*Sorghum bicolor*) grown on an Ultisol

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Key words: agronomic traits, Al-toxicity tolerance, number of roots, tropical acid soil

Abstract

Inheritance of acid-soil tolerance (generally considered Al-toxicity tolerance) in sorghum [*Sorghum bicolor* (L.) Moench] is not clear. Forty F₁ sorghum hybrids and their 14 parents were grown two seasons in the field at relatively high (67 and 71%) and low (43 and 42%) Al saturations on an acid Ultisol in Colombia, South America to evaluate the effects of acid soil on agronomic component traits and to better understand inheritance of acid-soil tolerance of sorghum. For plants grown at the high Al saturation levels, hybrids from acid-soil tolerant [AS-T] × acid soil-sensitive [AS-S] crosses were as tolerant as hybrids from AS-T × AS-T crosses which were as tolerant as their AS-T parents. Hybrids from AS-S × AS-S crosses were all sensitive to the acid-soil stress conditions. General combining ability (GCA) and specific combining ability (SCA) effects were significant for acid-soil tolerance, and GCA effects were more important than SCA effects. Significant GCA and SCA effects were detected for grain yield and number of roots at the low Al saturation level. Additive genetic effects in these genotypes were important for acid-soil tolerance rating, grain yield, and number of roots at the high Al saturation level.

Introduction

Extensive genetic variability has been reported for tolerance to acid-soil stress conditions (considered to be primarily Al toxicity) and other mineral toxicities/deficiencies associated with sorghum [*Sorghum bicolor* (L.) Moench] grown on acid soils (Bastos, 1982; Boye-Goni and Marcarian, 1985; Duncan 1981, 1983; Duncan *et al.*, 1983a, b; Flores and Gourley, 1987; Flores *et al.*, 1986; Furlani and Clark, 1981; Furlani *et al.*, 1983; Gourley, 1987). However, relatively little information is available on the inheritance of Al tolerance in sorghum. Genetic information is needed for plant breeders to effectively improve sorghum germplasm for adaptation to acid soils. Several inheritance studies on sorghum tolerance to Al have been conducted in nutrient solutions

(Bastos, 1982; Boye-Goni and Marcarian, 1985; Furlani and Bastos, 1986; Furlani *et al.*, 1983). However, results from plants grown in nutrient solutions must be validated in field experiments since most acid soils are deficient in various nutrients as well as having toxic levels of elements like Al and Mn (Sanchez and Salinas, 1981).

Plant responses to toxic levels of Al are genetically controlled (Devine, 1982; Duvick *et al.*, 1981; Rhue, 1979). Aluminum tolerance in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) grown in nutrient solutions was controlled by one or more dominant genes (Reid, 1969; Rhue, 1979). Aluminum tolerance in maize (*Zea mays* L.) was reported to be controlled by dominant genes with multiple alleles (Rhue, 1979). Additive gene effects contri-

buted most to the genetic variation of maize grown in nutrient solutions (Magnavaca *et al.*, 1987). In this latter study, dominance effects accounted for only half as much variation as did additive effects.

Pitta *et al.* (1979) suggested that a small number of genes with dominant effects controlled acid-soil tolerance in sorghum. This concept was based on the evaluation of hybrid progenies and their parents grown on an acid soil in the field. Aluminum tolerance in sorghum hybrids grown in nutrient solution expressed dominance, and no maternal or cytoplasmic effects were detected (Fulani *et al.*, 1983). Recent studies on F₁, F₂, and F₃ populations from crosses involving Al tolerant (SC283) and Al sensitive (TX415) sorghum parents grown in nutrient solution indicated that Al tolerance was dominant and controlled by a single gene pair (Furlani and Bastos, 1986). These authors also found that minor genes and genetic modifiers interacted with the major gene pair in the expression of Al tolerance. Bastos (1982) evaluated F₂ and F₃ sorghum populations from Al-tolerant × Al-tolerant and Al-tolerant × Al-sensitive crosses, and concluded that the inheritance of Al tolerance in sorghum was complex and that three or more genes were involved. Furlani (1981) reported that inheritance of aluminum tolerance in sorghum was complex, and the type of genetic mechanism controlling Al tolerance depended on the germplasm used. Variation in Al tolerance of sorghum hybrids from different crosses involving Al-tolerant and Al-sensitive parents has also been noted (Borgnovi *et al.*, 1987). Similar observations of acid-soil tolerance were noted for field-grown sorghum (Gourley, 1987).

The objectives of this study were to determine inheritance of acid-soil tolerance in sorghum, and to evaluate the effects of acid soil on several hybrids and their parents.

Materials and methods

Ten restorer lines and four male sterile lines (Table 1) were crossed to make 40 hybrids, and each of the parents and hybrids were grown two seasons (Season A = February to June 1986 and Season B = September 1986 to January 1987) on

an acid Ultisol (clayey, oxidic, isohyperthermic, Typic Palehumult) at Quilichao, Colombia, South America. Both the hybrids and parents were grown at high (67% for Season A and 71% for Season B) and low (43% for Season A and 42% for Season B) Al saturation levels, and evaluated for agronomic component and acid-soil tolerance traits.

The chemical properties of the soil are given in Table 2. Nitrogen was applied in a band 30 days after planting at 100 kg N ha⁻¹ as urea. Weeds were controlled with atrazine (2-chloro-4-ethylamine-6-isopropylamine-s-triazine) at 1.0 kg a.i. ha⁻¹. Hand hoeing was used as needed to control additional weeds during the study.

The sorghum lines were grown in a randomized complete block design with three replications. Parents were randomized separately from hybrids to avoid possible competition effects resulting from differences in height of parents and hybrids. Plots consisted of 2 rows, 3 m long, with 0.60 m between rows. The experimental unit was two 2 m row segments with uniform plant density in each plot. Plots were over planted and thinned to 9 cm between plants (200,000 plants ha⁻¹).

The number of days to flowering (50% bloom) was determined for each entry during the growth

Table 1. Sorghum parental genotypes and their acid soil reactions when grown during Seasons A and B on an Ultisol at Quilichao, Colombia

Season A	Acid soil reaction ^a	Season B	Acid soil reaction ^a
Male			
IS 7151	T	IS 9945	T
IS 8933	T	IS 7100	T
IS 3522	T	IS 9636	T
IS 8577	T	IS 9938	T
IS 8931	T	IS 9826	T
3DX57/1/1/910	T	M-35585	T
IS 2765	T	3DX57/1/1/910	T
IS 9636	T	PPQ-2	T
SC 326-6	I	SC 326-6	I
TX 430	S	TX 430	S
Female			
IS 7173C	T	IS 1309C	T
IS 12685C	T	B-Yellow PI	S
Wheatland Der	S	Wheatland Der	S
TX 623	S	TX 623	S

^a T-Tolerant, I-Intermediate, S-Sensitive.

Table 2. Chemical properties of acid Ultisol in Colombia, South America for the growth of sorghum hybrids and parents in the A and B season of 1986

Property/Element	Unit	Season A		Season B	
		Al stress		Al stress	
		High	Low	High	Low
Al saturation*	%	71	42	66.8	43.4
Organic matter	%	6.5	6.5	5.6	5.7
pH (1 soil: 1 water)		4.3	4.7	4.3	4.4
Exchangeable elements					
Al	cmol(+) kg ⁻¹	4.00	2.45	3.50	2.50
Ca	cmol(+) kg ⁻¹	1.11	2.97	1.25	2.78
Mg	cmol(+) kg ⁻¹	0.34	0.28	0.34	0.33
K	cmol(+) kg ⁻¹	0.16	0.21	0.15	0.15
P	μg g ⁻¹	5.4	14.0	6.6	9.8
Mn	μg g ⁻¹	—	—	78	89
Fe	μg g ⁻¹	26	20	13	10
Zn	μg g ⁻¹	2.1	1.8	1.7	2.1

$$* \text{ Percent Al saturation} = \frac{\text{Al cmol(+) kg}^{-1}}{(\text{Al} + \text{Ca} + \text{Mg} + \text{K cmol(+) kg}^{-1})} \times 100$$

Soil extracting solutions were 1 N KCl for Al, Ca, and Mg; 1 N NH₄OAc for K; Bray II for P; and 0.005 M DTPA (diethylene triaminepentaacetic acid) for Mn, Fe, and Zn.

periods. Prior to harvest, plant height and visual acid-soil tolerance ratings [1 = normal green color, vigorous appearance, uniform height and maturity, and well-filled panicles; 2 = some yellowing of leaves and drying of leaf tips, small panicles, and less vigorous and developed plants; 3 = severe yellowing and interveinal streaking of leaves, severe drying of leaves, very small panicles and stunted thin plants; and 4 = severely stunted plants, no panicles or dead plants] were made for each entry. Three random plants within each experimental plot were pulled and the soil removed from the roots. Plants were taken to the laboratory for counting number of main and secondary roots. The soil was sufficiently loose in the field to allow easy pulling of plants with no mechanical digging required. The mean of three root counts from each plot was used in the statistical analyses. All panicles from each harvested plot were combined, air dried for a minimum of seven days, threshed, and grain yields determined. Grain yields were calculated at 14% seed moisture.

Analyses of variance and genetic analyses followed the procedures described by Ross *et al.* (1983). Seasons were analyzed individually, as were data from the high and low Al saturation levels, since error variances were heterogeneous.

Data from parents were not included in analyses used to estimate combining ability. As pointed out by Ross *et al.* (1983), statistical treatment of fixed lines to draw inferences about hypothetical populations may not be entirely appropriate. With qualifications, quantitative genetic information can be drawn from such studies that may aid in the improvement of acid-soil tolerance in sorghum.

Results and discussion

The 40 hybrids tested in each season were divided into three types according to acid soil responses of their parents: acid-soil tolerant [AS-T] × AS-T, AS-T × acid-soil sensitive [AS-S], and AS-S × AS-S hybrids (Tables 3 and 4). The AS-T × AS-T and AS-T × AS-S hybrid yields at the high Al saturation levels were statistically similar to yields of their AS-T male parents. Yields of AS-S × AS-S hybrids were low and similar to those of their AS-S parents. When hybrids were grown at the low Al saturation levels, yield differences among types of hybrids were small. The highest yields were obtained from the AS-T × AS-T hybrids and the lowest from AS-S × AS-S hybrids in both

seasons. Yield increases of the AS-T × AS-T and AS-T × AS-S hybrids in season B were lower than those noted in season A.

Hybrids from AS-T × AS-S crosses grown at the high Al saturation levels of both seasons had similar acid-soil tolerance ratings as hybrids from AS-T × AS-T crosses (Tables 3 and 4). Hybrids from AS-S × AS-S crosses grown at the high Al saturation levels were as sensitive to the acid soil as their parents in both seasons. No differences in acid-soil tolerance ratings were obtained when hybrids and parents were grown at the low Al saturation levels.

Number of roots for the AS-T × AS-T and AS-T × AS-S hybrids and AS-T parents were similar, and higher than those for the AS-S × AS-S hybrids and AS-S parents (Tables 3 and 4). Few thin roots devoid of fine branches were noted for the AS-S × AS-S hybrids and AS-S parents.

Number of roots for all types of hybrids and their parents were similar when plants were grown at the low Al saturation levels during both growing seasons (Tables 3 and 4). However, the AS-S parents and AS-S × AS-S hybrids had significantly lower number of roots than the AS-T parents and AS-T × AS-T hybrids, respectively, when grown at the high compared to the low Al saturation levels. Number of roots and acid-soil tolerance ratings were positively correlated ($r = 0.51$). Reductions in root growth and number of roots are primary effects of acid soil problems for sorghum grown on an Ultisol (Flores et al., 1988).

Differences in days to flower were markedly different between AS-T and AS-S parents (Tables 3 and 4), but no pattern was detected for differences in days to flower among the types of hybrids. This was probably because of interactions of different maturity genes in the parental lines. However, the flowering date of parents and hybrids appeared to be delayed when plants were grown at the high compared to the low levels of Al saturation. Delay in flowering and retardation of plant growth and development are typical problems for AS-S sorghum grown on acid soil (Flores et al., 1988).

Plant height of the AS-S × AS-S hybrids was significantly shorter than that for the AS-T × AS-T and AS-T × AS-S hybrids grown at

the high Al saturation level during both seasons (Tables 3 and 4). The differences in plant height among groups of hybrids were likely due to the interaction of genes controlling plant height in sorghum and due to the effect of the high Al saturation level. Although statistical comparisons were not made, AS-S hybrids and parents were generally shorter than were AS-T hybrids and parents at the high compared to the low Al saturation levels. Stunting is a common symptom of plant sensitivity to acid-soil stress conditions.

Differences among male and female lines, an indicator of general combining ability (GCA), in the hybrid group were significant for all traits at the high Al saturation level for both seasons (Table 5). The male × female interactions, an indicator of specific combining ability (SCA), were also significant for all agronomic component traits except grain yield in season A. Parents were significantly different from hybrids for all traits except grain yield in season A. At the high Al saturation levels in both seasons, variations due to GCA were generally larger than those due to SCA, implying major importance of additive gene effects for these traits.

When hybrids were grown at the low Al saturation levels, differences in GCA among males and females were also significant for all agronomic component traits except acid-soil tolerance ratings (Table 6). Male-female interactions were significant for all traits except grain yield, acid-soil tolerance ratings, and number of roots in season A and acid-soil tolerance ratings and plant height in season B. Parents differed significantly from hybrids for all traits except number of roots and acid-soil tolerance ratings in season B. Differences among hybrids and parents for acid-soil tolerance ratings at the low Al saturation levels were not detected. Apparently the stress on plants was not severe enough to show genetic differences among these genotypes.

Agronomic trait data for each hybrid cross and their respective parents are shown in Tables 7-10. Only season B data have been given since trends for both growing seasons were similar. Parents with high GCA or specific combinations of parents for grain yield and acid-soil tolerance can be selected, and may be of immediate usefulness to sorghum breeders using high Al saturation stress conditions. Grain yield, acid-soil toler-

Table 3. Performance of F₁ hybrids from acid-soil tolerant (AS-T) × AS-T, AS-T × acid-soil sensitive (AS-S), and AS-S × AS-S crosses, female and male parents grown at 71% (71-AI) and 42% (42-AI) Al saturation at Quilichao, Colombia during season A

Genotype	Grain yield		Acid-soil tolerance ^c		Number of roots		Flowering		Plant height	
	71-AI	42-AI	71-AI	42-AI	71-AI	42-AI	71-AI	42-AI	71-AI	42-AI
	(kg ha ⁻¹)		(rating)		(number)		(days)		(cm)	
<i>Hybrids</i>										
AS-T × AS-T (18) ^a	3060	5330	1.02	1.0	27	31	67	65	210	244
AS-T × AS-S (20)	2540	4840	1.77	1.0	22	30	72	70	148	200
AS-S × AS-S (2)	110	3370	4.00	1.0	16	28	79	68	55	117
Mean	2230	4510	2.26	1.0	22	30	73	68	138	187
<i>Parents</i>										
AS-T Female (2)	1820	2140	1.17	1.0	19	27	72	71	136	159
Male (9)	3320	4770	1.33	1.0	23	32	77	76	140	168
AS-S Female (2)	830	2170	3.00	1.0	17	29	79	74	62	98
Male (1)	1040	110	4.00	1.0	17	33	82	63	105	109
Mean	1750	2550	2.38	1.0	19	30	78	71	111	134
LSD (0.05) ^b	1270	1940	0.64	NS ^d	6.8	9	4.8	5.8	22	15

^a Numbers in parentheses refer to number of genotypes used to calculate means.

^b LSD values for differences among type of hybrids, among parents and between hybrids and parents.

^c 1 = acid-soil tolerant, 4 = acid-soil sensitive.

^d NS = not significant.

Table 4. Performance of F₁ hybrids from acid-soil tolerant (AS-T) × AS-T, AS-T × acid-soil sensitive (AS-S), and AS-S × AS-S crosses, female and male parents grown at 67% (67-AI) and 43% (43-AI) AI saturation at Quilichao, Colombia during season B

Genotype	Grain yield		Acid-soil tolerance ^c		Number of roots		Flowering		Plant height	
	67-AI	43-AI	67-AI	43-AI	67-AI	43-AI	67-AI	43-AI	67-AI	43-AI
	(kg ha ⁻¹)		(rating)		(number)		(days)		(cm)	
<i>Hybrids</i>										
AS-T × AS-T (9) ^a	3300	4040	1.22	1.0	30	44	80	72	189	228
AS-T × AS-S (28)	3680	3750	1.28	1.0	27	35	72	68	182	214
AS-S × AS-S (3)	330	2930	3.72	1.0	19	34	78	64	82	134
Mean	3340	3760	1.45	1.0	27	37	74	68	176	211
<i>Parents</i>										
AS-T Female (1)	2840	1430	1.0	1.0	23	39	75	69	95	122
Male (9)	3150	3660	1.5	1.0	24	31	77	72	146	172
AS-S Female (3)	230	1820	3.89	1.0	14	31	80	68	60	117
Male (1)	20	2070	4.0	1.0	10	29	85	65	15	108
Mean	2250	3030	2.13	1.0	21	31	78	70	114	152
LSD (0.05) ^b	510	660	0.60	NS ^d	7.5	12	3.2	1.7	17	30

^a Numbers in parentheses refer to number of genotypes used to calculate means.

^b LSD values for differences among type of hybrids, among parents and between hybrids and parents.

^c 1 = acid-soil tolerant, 4 = acid-soil sensitive.

^d NS = not significant.

Table 5. Mean squares and coefficients of variation (c.v.) for grain yield, acid-soil tolerance, number of roots, flowering and plant height of sorghum hybrids and parents grown at 71% and 67% AI saturation in seasons A (A) and B (B), respectively

Source of variation	Degrees of freedom	Grain yield		Acid-soil tolerance		Number of roots		Flowering		Plant height	
		A	B	A	B	A	B	A	B	A	B
Genotypes	53	2,265,694**	6,560,167**	1.90**	2.48**	56.2**	93.4**	85.2**	62.1**	7042**	8141**
Hybrids (H)	39	1,670,515**	5,306,985**	1.48**	1.52**	53.5**	64.8**	64.2**	52.4**	7071*	4997**
Male (M)	9	2,054,855**	15,779,461**	20.32**	5.41*	33.0*	11.3**	37.9**	35.6**	15573**	20294**
Female (F)	3	8,449,520**	1,358,783**	47.05**	0.46*	474.8**	115.3**	520.3**	393.8**	40974**	1164**
M × F	27	789,178**	2,254,849**	1.55*	0.34*	13.6	43.6*	22.3**	19.6**	469**	323**
Parents vs H	1	415,862	38,762,021**	1.20*	14.6**	144.8**	969.1**	1346.9**	589.0**	55513**	124707**
Error A ^a	106	618,353	99,188	0.16	0.14	17.8	21.6	8.79	4.01	182	114
Error B ^a	78	631,895	111,087	0.09	0.08	15.8	22.3	10.3	3.04	180	109
c.v.		29.4	10	25	19.5	18.4	17.8	4.1	2.4	8.4	5.9

*, ** Significant at the $P < 0.05$ and $P < 0.01$, respectively.

^a Error A is residual mean square of analysis including parental lines; Error B is residual mean square of analysis of combining ability excluding parental lines.

Table 6. Mean squares and coefficients of variation (c.v.) for grain yield, acid-soil tolerance, number of roots, flowering and plant height of sorghum hybrids and parents grown at 42% and 43% Al saturation in season A (A) and B (B), respectively

Source of variation	Degrees of freedom	Grain yield		Acid-soil tolerance		Number of roots		Flowering		Plant height	
		A	B	A	B	A	B	A	B	A	B
Genotypes	53	5,802,921**	2,988,632**	0	0	59.8**	176.5**	77.6**	314.0**	8505**	7575**
Hybrids (H)	39	37,009,088**	2,133,950**	0	0	56.5**	175.0**	47.5**	28.6**	6890**	6001**
Male (M)	9	6,139,841**	2,074,584**	0	0	73.3*	244.1**	26.0*	32.6**	21051**	22948**
Female (F)	3	16,665,648**	1,676,187**	0	0	144.9**	665.6**	323.2*	195.4**	23740**	4905*
M × F	27	1,459,218	2,204,601**	0	0	41.1	90.8*	24.0**	8.7*	297**	474
Parents vs H	1	47,461,472**	16,520,211**	0	0	16.4	1083.8*	1853.1*	125.5*	125081**	108519**
Error A ^a	106	1,440,301	167,218	0	0	29.9	50.9	12.8	1.16	88.3	345
Error B ^a	78	1,600,449	198,965	0	0	25.6	48.4	14.4	1.09	76.4	361
c.v.		25.7	11.9	0	0	18.0	18.9	5.1	1.5	4.7	9.0

*, ** Significant at the $P < 0.05$ and $P < 0.01$, respectively.

^a Error A is residual mean square of analysis including parental lines; Error B is residual mean square of analysis of combining ability excluding parental lines.

Table 7. Grain yield, acid-soil tolerance, and number of roots of sorghum male and female parental lines and their F₁ hybrids grown at 67% Al saturation on acid Ultisol

Male	Female				Mean	
	IS 1309C	B-Yellow PI	Wheatland Der	TX 623		
Grain yield (kg ha ⁻¹)	(2840)	(540)	(130)	(20)	(880)	
IS 9945	(3760) ⁴	3340	5330	4370	3320	4090
IS 7100	(4140)	3520	3780	6050	5390	4690
IS 9636	(4090)	3380	4760	3340	3160	3660
IS 9938	(4280)	3090	4260	3520	3680	3640
IS 9826	(2790)	3260	4460	3690	4540	3990
M 35585	(1850)	3240	2940	2790	1920	2720
3DX57/1/1/910	(3760)	3310	3020	5420	4110	3960
PPQ-2	(2540)	3690	4860	3000	3530	3770
SC 326-6	(1120)	2840	2500	1310	1680	2090
TX 430	(24)	2310	180	680	130	830
Mean	(2840)	3210	3610	3420	3150	3340
LSD (0.05) ¹ = 270; LSD (0.05) ² = 170; LSD (0.05) ³ = 510						
Acid-soil tolerance ⁵ (rating)	(1.00)	(4.00)	(3.67)	(4.00)	(3.17)	
IS 9945	(2.00)	1.16	1.00	1.00	1.33	1.13
IS 7100	(1.00)	1.16	1.00	1.00	1.00	1.04
IS 9636	(1.33)	1.16	1.00	1.00	1.16	1.08
IS 9938	(1.17)	1.16	1.00	1.33	1.16	1.17
IS 9826	(1.33)	1.16	1.17	1.17	1.00	1.13
M 35585	(2.00)	1.33	1.66	1.66	1.50	1.54
3DX57/1/1/910	(1.17)	1.33	1.00	1.00	1.17	1.13
PPQ-2	(1.67)	1.00	1.17	1.60	1.40	1.31
SC 326-6	(1.83)	1.50	1.83	1.66	2.00	1.75
TX 430	(4.00)	1.83	3.67	3.50	4.00	3.25
Mean	(1.75)	1.26	1.45	1.50	1.57	1.45
LSD (0.05) ¹ = 0.23; LSD (0.05) ² = 0.15; LSD (0.05) ³ = 0.60						
Number of roots	(23)	(16)	(15)	(11)	(16)	
IS 9945	(28)	34	30	25	25	28
IS 7100	(23)	35	25	25	32	29
IS 9636	(24)	28	26	32	24	27
IS 9938	(26)	27	35	27	24	28
IS 9826	(20)	35	25	29	29	30
M 35585	(21)	30	21	22	24	24
3DX57/1/1/910	(30)	28	26	37	30	30
PPQ-2	(20)	26	26	21	27	25
SC 326-6	(25)	24	22	21	24	23
TX 430	(10)	30	19	19	18	21
Mean	(23)	30	25	26	26	27
LSD (0.05) ¹ = 3.8; LSD (0.05) ² = 2.4; LSD (0.05) ³ = 7.5						

¹ For differences among means of hybrids with common male parents.² For differences among means of hybrids with common female parents.³ For differences among hybrids and parents.⁴ Numbers in parentheses are parental values.⁵ 1 = acid soil tolerant, 2 = acid soil sensitive.

Table 8. Flowering and plant height of sorghum male and female parental lines and their F₁ hybrids grown at 67% AI saturation on acid Ultisol

Male	Female				Mean
	IS 1309C	B-Yellow PI	Wheatland Der	TX 623	
<i>Flowering (days)</i>	(75)	(79)	(85)	(76)	(79)
IS 9945	(78) ⁴	81	71	73	75
IS 7100	(72)	80	71	71	73
IS 9636	(79)	81	72	74	75
IS 9938	(76)	82	71	73	75
IS 9826	(77)	78	71	72	73
M 35585	(82)	74	69	68	71
3DX57/1/1/910	(76)	81	69	70	73
PPQ-2	(74)	78	70	71	73
SC 326-6	(84)	83	71	71	76
TX 430	(85)	75	79	74	77
Mean	(78)	79	71	72	74
LSD (0.05) ¹ = 1.4; LSD (0.05) ² = 0.9; LSD (0.05) ³ = 3.2					
<i>Plant height (cm)</i>	(95)	(83)	(58)	(39)	(69)
IS 9945	(166)	207	212	196	207
IS 7100	(173)	211	197	212	206
IS 9636	(159)	211	203	201	207
IS 9938	(209)	195	197	197	198
IS 9826	(131)	207	189	195	200
M 35585	(133)	191	171	165	175
3DX57/1/1/910	(141)	190	186	197	196
PPQ-2	(119)	169	169	150	165
SC 326-6	(82)	119	112	100	111
TX 430	(15)	133	86	85	95
Mean	(133)	183	172	170	176
LSD (0.05) ¹ = 9; LSD (0.05) ² = 5; LSD (0.05) ³ = 17					

¹ For differences among means of hybrids with common male parents.

² For differences among means of hybrids with common female parents.

³ For differences among hybrids and parents.

⁴ Numbers in parentheses are parental values.

Table 9. Grain yield, acid-soil tolerance, and number of roots of sorghum male and female parental lines and their F₁ hybrids grown at 43% Al saturation on acid Ultisol

Male	Female					
	IS 1309C	B-Yellow PI	Wheatland Der	TX 623	Mean	
<i>Grain yield (kg ha⁻¹)</i>	(1430)	(1310)	(2070)	(2070)	(1720)	
IS 9945	(3820) ⁴	3990	4760	3770	3590	4030
IS 7100	(4400)	3970	4980	3540	3840	4090
IS 9636	(3640)	4280	3730	4320	2310	3660
IS 9938	(4020)	3640	3330	4410	3170	3640
IS 9826	(3160)	3540	3450	5800	3850	4160
M 35585	(2890)	4120	3380	3420	3390	3580
3DX57/1/1/910	(4590)	3800	2200	4820	4460	3820
PPQ-2	(4690)	4150	3970	4820	4460	4350
SC 326-6	(1740)	4920	2920	1880	2610	3080
TX 430	(2070)	3900	2970	1880	3830	3170
Mean	(3500)	4030	3570	3880	3550	3760
LSD (0.05) ¹ = 360; LSD (0.05) ² = 230; LSD (0.05) ³ = 660						
<i>Acid-soil tolerance rating⁵</i>	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)
IS 9945	(1.0)	1.0	1.0	1.0	1.0	1.0
IS 7100	(1.0)	1.0	1.0	1.0	1.0	1.0
IS 9636	(1.0)	1.0	1.0	1.0	1.0	1.0
IS 9938	(1.0)	1.0	1.0	1.0	1.0	1.0
IS 9826	(1.0)	1.0	1.0	1.0	1.0	1.0
M 35585	(1.0)	1.0	1.0	1.0	1.0	1.0
3DX57/1/1/910	(1.0)	1.0	1.0	1.0	1.0	1.0
PPQ-2	(1.0)	1.0	1.0	1.0	1.0	1.0
SC 326-6	(1.0)	1.0	1.0	1.0	1.0	1.0
TX 430	(1.0)	1.0	1.0	1.0	1.0	1.0
Mean	(1.0)	1.0	1.0	1.0	1.0	1.0
LSD (0.05) ¹ = NS; LSD (0.05) ² = NS; LSD (0.05) ³ = NS (not significant)						
<i>Number of roots</i>	(39)	(34)	(31)	(27)	(33)	
IS 9945	(28)	48	38	34	56	44
IS 7100	(28)	48	36	34	33	38
IS 9636	(30)	45	36	36	38	39
IS 9938	(35)	48	43	29	30	38
IS 9826	(25)	43	32	34	36	36
M 35585	(27)	37	24	30	31	30
3DX57/1/1/910	(39)	47	34	49	48	44
PPQ-2	(21)	37	28	33	30	32
SC 326-6	(44)	46	34	26	27	33
TX 430	(29)	37	40	26	35	34
Mean	(31)	44	34	33	36	37
LSD (0.05) ¹ = 6; LSD (0.05) ² = 4; LSD (0.05) ³ = 12						

¹ For differences among means of hybrids with common male parents.² For differences among means of hybrids with common female parents.³ For differences among hybrids and parents.⁴ Numbers in parentheses are parental values.⁵ 1 = acid-soil tolerant; 4 = acid-soil sensitive.

Table 10. Flowering and plant height of sorghum male and female parental lines and their F₁ hybrids grown at 43% Al saturation on acid Ultisol

Male	Female				Mean	
	IS 1309C	B-Yellow PI	Wheatland Der	TX 623		
<i>Flowering (days)</i>		(69)	(65)	(69)	(68)	(68)
IS 9945	(73) ⁴	71	68	69	69	69
IS 7100	(69)	73	68	69	68	69
IS 9636	(72)	72	68	69	68	69
IS 9938	(71)	72	67	69	68	69
IS 9826	(71)	71	66	69	68	69
M 35585	(74)	68	63	62	69	65
3DX57/1/1/910	(72)	71	67	68	67	68
PPQ-2	(68)	72	67	68	68	69
SC 326-6	(77)	78	64	68	69	70
TX 430	(65)	70	63	64	64	65
Mean	(71)	72	66	67	68	68
LSD (0.05) ¹ = 0.84; LSD (0.05) ² = 0.53; LSD (0.05) ³ = 1.7						
<i>Plant height (cm)</i>		(122)	(109)	(97)	(145)	(118)
IS 9945	(189)	246	243	241	244	243
IS 7100	(175)	249	228	230	244	238
IS 9636	(187)	254	246	242	265	252
IS 9938	(242)	241	236	231	239	237
IS 9826	(171)	224	229	203	240	224
M 35585	(158)	227	186	174	215	201
3DX57/1/1/910	(158)	256	230	242	250	244
PPQ-2	(147)	230	187	172	204	198
SC 326-6	(123)	123	126	114	130	123
TX 430	(108)	196	131	118	152	149
Mean	(166)	224	204	197	218	211
LSD (0.05) ¹ = 15; LSD (0.05) ² = 10; LSD (0.05) ³ = 30						

¹ For differences among means of hybrids with common male parents.

² For differences among means of hybrids with common female parents.

³ For differences among hybrids and parents.

⁴ Numbers in parentheses are parental values.

ance, and number of roots of AS-S parents were greatly improved in these environments when crossed with an AS-T parent.

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