Genetic Variation in *Sorghum bicolor* (L.) Moench for Tolerance to High Levels of Exchangable Aluminum in Acid Soils of Brazil*

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Aluminum toxicity is an important growth limiting factor in many acid soils. The problem in Brazil is particularly serious in strongly acid subsoils that are difficult to lime. Acid subsoils with aluminum at toxic levels reduces root penetration and increases the probability of injury by drought (Foy, 1974a).

The "cerrado" constitutes one of the vegetation types most widely distributed in Brazil occupying more than two million square kilometers concentrated principally in the States of Goiás, Mato Grosso and Minas Gerais (Cruz, 1972). The soils associated with "cerrado" vegetation are generally acid, low in phosphorus and high in toxic aluminum. Mendes (1972) summarized the results of 1,200 soil samples of "cerrado" vegetation types from Minas Gerais, the Federal District, and Goiás analyzed by the soils section of the Agriculture Research Institute of the Central-West (IPEACO) of the Ministry of Agriculture of Brazil. Of

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these samples, 32.5 percent had a pH of less than 4.30 and an additional 66.4 percent had a pH between 4.31 and 5.49. In addition 28.4 percent of the samples had exchangable aluminum levels between zero and 0.50 meg/ 100 g, 17.8 percent between 0.51 and 1.00 meg/100 g, 11.3 percent between 1.01 and 1.50 meg/100 g and 42.5 percent greater than 1.50 meg/ 100 g. Exchangable aluminum less than 0.3 meg/100 g is considered to be low while values greater than 1.00 meg/100 g are considered to be high. Of these same samples 72 percent had phosphorus levels considered to be low or very low. Textural analysis indicated that 88% of the samples were either a sandy loam, clay, sandy clay loam, or clay loam. These soils have a very low water holding capacity. Because of this low water holding capacity and periods of one to two or more weeks without rain commonly occuring even during the rainy season, these soils are considered to be droughty.

These "cerrado" soils frequently have a topography which makes them suitable for mechanized agriculture and are located in geographical areas with adequate infrastructure for intensive agricultural development. The utilization of these soils for economic intensive agriculture requires plant species and varieties which are more efficient in phosphorus utilization and tolerant to toxic levels of aluminum in the soil. Foy (1974a) reported that a wide range of tolerance exists between and within plant species. Differences have been reported in wheat, barley, alfalfa, rice, soybeans, and corn (Foy, 1974a and Clark and Brown, 1974). Varietal differences for this characteristics have not been reported for sorghum.

Sorghum has been envisioned by many scientists to have a future in the "cerrado" of Brazil because os its drought tolerance. Considering the nature of the "cerrado" soils, rainfall distribution, and cost of lime and fertilizer, a sorghum variety must be developed which has greater tolerance to high levels of aluminum, a deeper root system, and more efficient phosphorus utilization.

During the 1973/74 agricultural year, Schaffert (1974) noted a wide range of drought tolerance in one replicated trial of experimental sorghum hybrids during a period without rain during anthesis. A relative scale of one to five was used to record these observations where a rating of one was given to plots with plants showing no visable stress and a rating of five was given to plots with plants near permanent wilting point. The trial was conducted on a typical "cerrado" soil near Sete Lagoas, Minas Gerais, Brazil where three tons of lime had been applied prior to planting. The soil pH at the time the observations were made was 4.8 with an average of 0.68 meg Al/100 g and 24 ppm P. The results are presented in Tables 1 and 2. An examination of the root systems indicated a high correlation between root development and drought tolerance. Foy (1974b) interpreted these data as variations in tolerance to toxic levels of aluminum in the soil.

Two experiments were conducted to verify if the differences observed were due to variation in tolerance to aluminum toxicity or some other factor. A virgin "cerrado" soil high in exchangable aluminum was selected from IPEACO for greenhouse studies. Soil analysis results were: pH 4.6, 1.56 meg Al/100 g, 2 ppm and 0.06 meg K/100 g. The soil was classified as a clay. In the first experiment 48 two liter plastic pots were filled with the above soil after adding 100 ppm of N as ammonium sulfate, 100 ppm P as phosphoric acid and 100 ppm K as potassium chloride. A randomized complete block design replicated four time was

TABLE 1. Production and drought resistance notes on experimental hybrids at IPEACO (Sete Lagoas, Minas Gerais, Brazil) for the 1973/74 agricultural year.

Treatment	Pedigree		Production*	Resistance to Drought**
01	PU932242	x TX2536	2.0	1.5
02	PU932242	x TX2555	2.5	2.5
03	PU932242	x PU932204	3.0	3.0
04	PU932242	x TX2523	2.0	1.0
05	PU932242	x KS-2	3.0	3.5
06	IS8361	x TX2536	3.0	1.0
07	IS8361	x TX2555	2.5	1.0
08	IS8361	x PU932204	4.0	3.0
09	IS8361	x TX2523	2.0	1.5
10	IS8361	x KS-6	4.0	3.0
11	IS0418	x TX2536	3.0	1.5
12	IS0418	x TX2555	2.5	1.5
13	IS0418	x PU032204	3.5	4.5
14	IS0418	x TX2523	2.5	3.5
15	IS0418	x KS-10	3.5	4.5
16	CK-60	x TX2536	2.0	1.5
17	CK-60	x TX2555	2.5	2.5
18	CK-60	x PU932204	4.0	3.0
19	CK-60	x TX2523	3.0	2.5
20	Redlan	x PU932204	3.0	3.5
21	Redlan	x TX2523	2.5	4.0
22	Redlan	x TX2540	3.0	2.5
23	KS-4	x TX2536	2.5	1.5
24	KS-5	x TX2536	2.5	1.5
25	KS-52	x TX2536	2.5	1.0
26	KS-51	x TX2536	3.0	1.0
27	KS-48	x TX2536	2.5	1.0
28	KS-47	x TX2536	3.0	2.0
29	Ag 1001		2.5	1.5
30	RS-610		4.5	5.0

* A relative scale 1 to 5 where 1 is high production and 5 is low production. (RS-610 in an adjcent replicated trial produced 2.70 t/ha and Ag 1001 produced 5.37 t/ha of dry grain under similiar conditions)

** A relative scale of 1 to 5 where 1 = tolerance to drought and 5 = severe damage due to drought.

TABLE 2. Production and drought resistance notes averaged across males and females on experimental hybrids at IPEACO (Sete Lagoas, Minas Gerais, Brazil) for the 1973/74 agricultural year.

Pedigree	Type of Line	Number of hybrids used in average	Production*	Resistance to Drought**
PU932242	A	5	2.50	2.30
IS8361	A	5	3.10	1.90
IS0418	A	5	3.00	3.10
CK-60	A	4	2.90	2.40
Redlan	A	3	2.80	3.33
TX2536***	R	10	2.60	1.35
TX2536	R	4	2.50	1.48
TX2555	R	4	2.88	2.38
PU932204	R	5	3.50	3.40
TX2523	R	5	2.40	2.50
KS-2	R	1	3.00	3.50
KS-6	R	1	4.00	3.00
KS-10	R	1	3.50	4.50
TX2540	R	1	3.00	2.50
KS-4	A	1	2.50	1.50
KS-5	A	1	2.50	1.50
KS-52	A	1	2.50	1.00
KS-51	A	1	3.00	1.00
KS-48	A	1	2.50	1.00
KS-47	A	1	3.00	2.00

* See notes for Table 1

** See notes for Table 1

*** Averaged over PU932242, IS8361, IS0418, CK-60.

used to study twelve sorghum varieties. Eight seeds were planted per pot on October 9, 1974 and thinned to four plants per pot after germination. The varieties used were, IS8361 B, Redlan B, PU932204, TX2536, IS8361 x PU932204, IS8361 x TX2536, Redlan x PU932204, Redlan x TX2536, RS-610, Taylor-Evans Y-101, Asgrow Dourado M and M35-1. Thirty days after planting the soil was removed from the roots by washing. Length of the longest root, average length of the secondary roots, shoot length, dry root weight and dry shoot weight were recorded for the four plants in each pot.

The data are presented in Table 3. Highly significant differences were observed for the five traits studied. Comparing the four lines, TX2536 did not have the characteristic dark brown discolored roots that is commonly associated with aluminum toxicity (Foy, 1974a). PU932204 was significantly inferior to the other lines in the study. PU932204 had more leaf discoloration resembling bronzing in rice that is caused by excess aluminum in certain soils of Ceylon. TX2536 did not express this bronzing.

The hybrid combinations with PU932204 were inferior to TX2536 in root development but not shoot development. Heterosis was present for all the traits studied with the hybrid superior to the mid-parent in all cases and superior to the best parent in all cases except secondary root length for the hybrid Redlan x pU932204. In hybrid combinations, IS8361 was slightly superior to Redlan in root and shoot weight but nearly equal in root and shoot length. The failure to observe greater differences was probably due to the extremely high level of aluminum in this trial as was indicated by the second experiment.

Taylor-Evans Y-101 and Asgrow Dourado M, hybrids reported to have

TABLE 3. Average root and shoot length and dry weight of 12 sorghum varieties grown for 30 days in an acid "cerrado" soil with 1.56 meg Al/100 g.

Variety	Root Length		Shoot	Dry Shoot	Dry root
	Longest cm*	Secondary cm*	Length cm*	Weight g**	Weight g**
IS8361 B	18.7	9.5	26.2	0.29	0.07
Redlan B	20.3	12.5	25.1	0.28	0.11
TX2536	18.2	11.9	19.6	0.21	0.08
PU932204	7.7	5.0	18.5	0.17	0.05
IS8361 x TX2536	26.7	13.3	30.8	0.47	0.23
IS8361 x PU932204	20.8	12.3	33.6	0.54	0.17
Redlan x TX2536	26.4	13.4	30.6	0.43	0.20
Redlan x PU932204	19.9	11.5	28.6	0.41	0.13
Taylor-Evans Y-101	25.1	14.4	32.9	0.49	0.27
Asgrow Dourado M	22.2	13.1	30.2	0.46	0.21
RS-610	18.1	10.4	28.6	0.44	0.14
M35-1	11.0	6.6	25.5	0.32	0.08
$s\bar{x}$	1.34	1.11	1.28	0.029	0.016
LSD.05	3.85	3.20	3.68	0.085	0.046

* Average of four plants

** Total weight of four plants.

more drought tolerance in "cerrado" soils (Schaffert, 1974) were superior to RS-610 reported to be highly suceptible to drought for the traits observed. M35-1 was intermediate between the tolerant and nontolerant lines in root development.

A second greenhouse experiment was conducted using the same soil as the first experiment with six lime rates. The rates were zero, 250, 500, 1,000, 2,000, and 4,000 parts per million lime (80% Ca_2CO_3 and 20% $MgCO_3$). These rates corresponded to zero, 0.5, 1.0, 2.0, 4.0, and 8.0 tons per hectare of lime, respectively, The lime was mixed with the soil and incubated for ten days prior to planting. One hundred ppm N, 100 ppm P and 126 ppm K were applied as NH_4NO_3 and KH_2PO_4. Two corn lines, OH40B and B-57, and five sorghum varieties, PU932204, TX2536, IS8361 x TX2536, RS-610 and Taylor-Evans Y-101 were planted on November 1, 1974 in two liter pots using a randomized complete block design with 3 replications. The pots were thinned to 4 plants per pot after germination. Twenty-five days after planting the soil was removed from the roots by washing with water. The data are currently being tabulated and analyzed.

The two corn lines used in this experiment, OH40B and B-57 have been reported by Clark (1974) to be suceptible and tolerant, respectively, to high levels of aluminum in the soil. The root development of B-57 was slightly superior to OH40B in the no lime treatment. The differences were greatly increased at the 250 ppm (0.5 t/ha) lime treatment. The differences were less dramatic at the higher lime rates and appeared to disappear at the 2,000 and 4,000 ppm rates.

Of the two sorghum lines, TX2536 and PU932204, in this experiment TX2536 had superior root development at the lower lime rates. The greatest differences were at 250 ppm (0.5 t/ha) and 500 ppm (1.0 t/ha) of lime. The differences in root development between the sorghum hybrids, IS8361 x TX2536, Taylor-Evans Y-101 and RS-610, were also the greatest at 250 and 500 ppm lime. IS8361 x TX2536 and Taylor-Evans Y-101 were similiar in root development and much greater than RS-610. The differences in root development in sorghum lines and hybrids were less dramatic at the higher lime rates and appeared to disappear at the 2,000 and 4,000 ppm rates.

Root development appeared to have been slightly reduced at the 4,000 ppm (8.0 t/ha) for both corn and sorghum.

Sorghum was evaluated, using preliminary techniques, for tolerance to high exchangable aluminum in the soil. A large amount of genetic variation was observed for root development indicating that selection for tolerance to high exchangable aluminum should be successful. IS8361 and TX2536 appeared to be tolerant to high exchangable aluminum and PU932204 was not tolerant. These preliminary studies are being followed up with additional greenhouse and field studies.

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