A Research and Network Strategy for Sustainable Sorghum Production Systems for Latin America

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6.1. Introduction

The Latin America and Caribbean Program was initiated in 1976 by ICRISAT by stationing staff at CIMMYT, Mexico. The program aimed to develop early, dwarf and bold grain varieties for fertile soils in both the highlands and lowlands of Central America. The program was transformed as the Latin American Sorghum Improvement Program (LASIP) in 1990 and led by Varthan Guiragosian and Compton Paul, a cereals breeder. LASIP's work with the NARS in the development and improvement of cropping systems for small farmers in Latin America is well documented in Paul (1993). With coordination of the regional sorghum research network, the Comision Latinamericano Investigadores en Sorgo (CLAIS), LASIP maintained excellent contact with NARS, private companies and institutions, and farmers of the region. As of 1993, the ICRISAT-LASIP/CLAIS collaboration led to the training of 62 scientists in In-Service and Visiting Scientists categories at LASIP in Mexico and ICRISAT in India. An additional 77 scientists have received training in short courses. Several varieties were released and adopted based on the ICRISAT-led program, particularly by Mexico, El Salvador, Guatemala and other countries in the region. These are given in Chapter 7 (Table 7.6) and Chapter 8 (Section 8.4). Due to funding constraints, the program was discontinued in 1993. However, considering the interest in sorghum shown by the Latin American NARS, a program for improving sorghum for acid soil tolerance was initiated in 1996 with funding support from IADB.

The acid and infertile Oxisol areas (71 million ha) in tropical America are dominated by the Savanna system in the *Llanos* of Colombia and Venezuela, and the *Cerrados* of Brazil (Gourley 1991), which are traditionally used for grazing by livestock. Research at CIAT led to the replacement of native grasses with the more productive *Brachiaria* species. This increased productivity tenfold; as a consequence, one animal could be raised on each hectare of *Brachiaria* Savanna (Raul Vera, personal communication 1997). Given the growing awareness for the need to diversify agropastoral systems, CIAT has been experimenting with upland rice, mixed systems with a legume and *Brachiaria* species and maize. Sorghum and pearl millet are considered to have the potential to contribute to sustainable agropastoral systems. The INTSORMIL program identified 20 acid soil-tolerant sorghum lines in the 1980s (Gourley 1991), but they were susceptible to leaf diseases. At its centers in India and Africa, ICRISAT has developed diverse sets of high-yielding sorghum breeding materials useful as base material for testing in the acid soils of Latin America. Since 1996, ICRISAT, CIAT and the national programs of Brazil, Colombia, Honduras and Venezuela have jointly

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Reddy BVS, Rangel AF, Ramaiah B and Ortiz R. 2004. A research and network strategy for sustainable sorghum production systems for Latin America. Pages 139-148 *in* Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

implemented an IADB-funded project on “A research and network strategy for sustainable sorghum production systems for Latin America” whose objectives are:

- to assemble, multiply and evaluate grain and forage sorghum breeding lines for tolerance to acid soils and resistance to foliar diseases
- to develop a research network of scientists working on this crop in the region and train them in sorghum research
- to test the most promising genotypes in the target production systems.

This chapter summarizes the results and implications of breeding for acid soil-tolerant sorghum cultivars.

6.2. Breeding Processes

Introductions. In 1995, diverse sets of 378 pairs of grain sorghum A/B lines, 784 grain sorghum restorer lines/varieties and 94 forage sorghum lines were introduced into Colombia from ICRISAT. Of the sorghum R-lines, 101 were developed at ICRISAT-Bamako (Mali) while the rest of the sorghum materials were developed at ICRISAT-Patancheru (India). In addition, two ms_3-based grain sorghum (ICSP LG-large grain and ICSP B-maintainer) populations and a forage sorghum (ICSP HT-high tillering) population developed at ICRISAT-Patancheru were introduced. These populations were earlier bred for resistance to specific biotic constraints in Africa, and specific adaptation and high grain yield in neutral pH fertile soils in India.

Empirical testing. The CIAT farm at Cali with its neutral soil pH was used for seed multiplication and selection for high yield and resistance to leaf diseases (leaf blight, anthracnose, rust, maize dwarf mosaic and sugarcane mosaic viruses) for four years during the first season (Jun 1996 to 1999). Quilichao, Matazul, La Libertad and Carimagua farms in Colombia with their acidic soils (pH $<$ 5.7) were used to screen the materials for acid soil tolerance and resistance to foliar diseases in the second season (Jul 1996 to Dec 1999). High early vigor, greater green leaf area at maturity, high grain/forage yields and resistance to foliar diseases (high Al^{3+}) were used as selection criteria to identify materials for acid soil tolerance. High tillering and recovery growth after first cut were used as selection criteria in advancing the forage sorghum lines. The soil characteristics of the farms, including La Libertad, are given in Table 6.1.

Genotype (G) × Environment (E) interaction studies. A set of sorghum R-lines (12) was evaluated for their response under three Al^{3+} (80, 60 and 40%) saturation levels to decide on the

Table 6.1. Soil characteristics at different acid soil locations in Colombia.

Location	O.M (%)	P ppm	pH	Al	Ca (meq/100g)	Mg	K	CICE	SAl (%)	B	S	Zn (ppm)	Mn	Cu	Fe
Carimagua	3.4	2.2	4.2	1.5	0.5	0.1	0.1	2.2	70.8	0.3	.	0.5	1.9	0.3	52.7
Matazul	2.6	3.2	4.7	1.8	0.4	0.3	0.1	2.5	72.1	0.7	21.6	.	.	.	.
La Libertad	2.3	5.0	5.2	1.2	0.6	0.1	0.1	2.0	60.6	0.2	.	0.4	1.5	0.4	22.0
Quilichao[1]	6.7	4.9	3.9	2.9	1.6	0.6	0.1	5.1	55.5	0.2	.	0.8	140.6	1.9	28.0

1. The soils at Zamorano (Honduras) are similar to those in Quilichao. They are low in aluminum saturation (36-55%) with low pH (3.9- 4.7) and high organic matter content (6.6-8.8%).

Source: Seventh season report of the Latin American Network Project.

breeding approach to be followed. Stability analyses (Eberhart and Russel 1966) were carried out for the data collected on grain sorghum R-lines, B-lines and forage lines for agronomic desirability (grain yield) and fresh forage yield. Agronomic desirability (R- and B-lines) and fresh fodder weight (forage lines) were the major criteria used in advancing the lines.

Backup breeding. Improved segregating sorghum populations (of crosses B- and R-lines) were empirically screened in highly acid soils. Large grained (ICSP LG) and maintainer (ICSP B) sorghum populations (ms_3-based) were merged and selected alternatively at the CIAT farm under neutral pH, and at Matazul under highly acid soils.

Hybrid testing. About 200 hybrids were made between the selected A-lines and R-lines and INTSORMIL R-lines, which were then screened for tolerance to acid soil conditions.

Network trials. Network trials involving the selected grain sorghum A/B-lines, R-lines and forage sorghum lines were distributed to national programs in Brazil, Colombia, Honduras and Venezuela from the second season (1997) onwards.

Training. Scientists from Brazil, Colombia and Venezuela were trained in sorghum breeding at ICRISAT-Patancheru from 1997 to 1998.

6.3. Outputs

Sorghum introductions from ICRISAT-Patancheru were tested empirically for grain and forage under acid soil conditions. Fifteen grain sorghum A/B-lines were selected for high yield, resistance to leaf diseases and tolerance to acid soil. Twenty-one restorer lines (on A_1 cytoplasm) were selected for high yields under acidic soils (Reddy et al. 2000b). Four forage sorghum lines (IS 31496, IS 13868, ICSR 93024-1 and ICSR 93024-2) were selected for tolerance to acid soils. The performance of the selected grain sorghum A/B-lines, R-lines and forage sorghum lines are given in Tables 6.2, 6.3 and 6.4.

In the Genotype (G) × Al^{3+} level trial, variances due to G × Al^{3+} level interactions were significant for agronomic desirability, highly significant for peduncle exersion and not significant for other traits such as head and grain weight. High soil acidity (80% Al^{3+} saturation) significantly reduced early vigor and green leaf area at maturity, and enhanced flowering. It also substantially reduced head and grain weight (Reddy and Rangel 2000). The highest head and grain weights were recorded at 60% Al^{3+} level (Table 6.5). It is possible that previous selection under acid soils might have eliminated the lines that performed well under less acidic (40% Al^{3+} saturation) soil conditions in the present test. Studies by INTSORMIL have also indicated that sorghum lines more tolerant to acid soils showed favorable growth and traits when grown under relatively severe acid soil (60% Al^{3+} saturation, pH 4.1) conditions (Flores et al.1988).

A detailed discussion on stability analyses across locations is reported in Reddy et al. (1998) and Reddy and Rangel (2000). The R-lines with high agronomic desirability and regression coefficient between 0 and 1 (showing wide adaptability) were IS 30469-1187-2, IS 30469C-1508T-2, ICSRs 110, 89005, 89012 and 90004. The R-lines with high agronomic desirability but with a regression coefficient significantly greater than 1.0 (indicating that these genotypes do well only under a more favorable environment) were ICSV 95072, ICSRs 74, 91008, 91012, 91020, 93033, 93042, IS 3049-1187-4, IS 3049-1187-5 and GD 27669. The R-lines with high agronomic

Table 6.2. The performance of male-sterile lines evaluated under six different acid soil conditions in Zamorano, Honduras (1997 and 1999, II season), Matazul (1997 and 1998, II season) and La Libertad (1998 and 1999, II season), Colombia, Latin America.

A/B lines	Pedigree	CIAT orgin	Vigor score[1]	Plant height (m)	Days to 50% flowering	Green leaf area score[2]	Leaf disease score[3]	Grain mold score[4]	Agronomic score[5]	Head weight (t ha^{-1})	Grain weight (t ha^{-1})
ICSB 604	[(ICSB 11 x PM 17500-2-1) x PM 17467B]3-2	SPMD 94036	2.0	1.3	73	3.6	2.5	2.4	2.3	3.3	2.8
ICSB 605	[(ICSB 11 x PM 17500-2-1) x PM 17467B]5-2-1-1	SPMD 94004	1.8	1.6	77	4.3	2.4	1.9	2.3	3.0	2.8
ICSB 607	[(ICSB 26 x PM 17467B) x PM 17467B]10-3	SPMD 94045	1.9	1.0	73	4.7	2.8	2.4	1.9	3.0	2.7
ICSB 608	[(SPV 373 x SPV 55) x PD-3-1-11]5-1-1-3-1	SPA_2 94021	1.6	1.4	74	3.7	2.1	1.6	2.2	2.7	2.7
ICSB 609	[(ICSB 101 x PM 17500-2-1) x PM 19268B]2-4-2	SPA_2 94013	1.7	1.7	72	4.5	2.9	1.6	2.3	2.8	2.6
ICSB 611	ICSP 1B/R MFR-S 10-41-2-9-3-2-1-1	SPA_2 94029	1.9	1.4	72	5.4	3.5	2.3	2.6	2.9	2.3
ICSB 614	(SC 108-3 x CSV 4)-51-1	SPA_2 94039	1.8	1.2	77	5.0	3.1	1.3	2.7	2.3	2.3
ICSB 613	(Ind. Syn. 422-1 x Rs/R-20-682)-5-1-6-2-1	ICSB 89002	2.5	0.9	74	4.7	3.3	2.4	2.4	2.6	2.2
ICSB 73	[(296B x SPV 105) x (2077B x M 35-1)]-19	ICSB 73	2.0	1.5	75	5.4	3.1	2.3	2.4	2.8	2.2
ICSB 606	[(ICSB 26 x PM 17467B) x PM 17467B]10-3-1-2	SPMD 94019	1.9	1.1	75	4.3	3.1	2.4	1.8	2.7	2.1
ICSB 601	[(BTx 623 x MR 862) x B lines bulk]-5-1-3-5	ICSB 38	1.7	1.3	72	5.0	2.7	1.7	2.1	3.1	2.1
ICSB 603	[(ICSB 11 x PM 17500-2-1) x PM 17467B]1-1-1-1	SPMD 94036	2.1	1.2	73	5.0	3.4	2.2	2.1	2.5	2.1
ICSB 94	[(296B x SPV 105) x (2077B x M 35-1)]-21	ICSB 94	3.3	1.4	73	5.8	3.8	2.0	2.8	2.7	1.6
ICSB 713	(IS 84 x ICSR 38)8-2-1-1-1-2	SPA_2 94016	1.4	1.3	72	5.1	4.3	2.8	1.7	2.1	1.6
ICSB 89	[(296B x SPV 105) x (2077B x M 35-1)]-8	ICSB 89	3.0	1.4	69	5.2	3.5	2.0	3.1	2.3	1.5
Checks											
REAL 60		Tolerant check	1.3	1.9	72	5.2	4.2	1.7	1.6	4.0	3.1
ICSB 338	(ICSB 51 x PM 1861)4-1-2-2	SPRU 94008 Susceptible check	3.6	1.0	66	5.2	3.3	2.7	4.1	2.1	0.9
Mean			2.1	1.3	72.8	5	3.2	2.1	2.4	2.8	2.2
SE ±			0.15	0.06	0.63	0.14	0.15	0.10	0.14	0.11	0.13
CV (%)			22.3	11.2	4.6	9.4	15.8	27.8	24.6	40.1	35.2

1. Measured on a 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 9 scale, where 1= green leaf area, 2 = 1-5% of green leaf area reduced, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 = 51-75% and 9 = > 75% green leaf area reduced.
3. Measured on a 1 to 9 scale, where 1= free of leaf diseases, 2 = 1-5% of leaf area affected, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 = 51-75% and 9 = > 75% of leaf area affected.
4. Measured on a 1 to 9 scale, where 1= no mold and 9 = >50% surface of grain with mold.
5. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.

Table 6.3. The performance of the restorer lines evaluated under six different acid soil conditions in Zamorano, Honduras (1997 and 1999, II season), Matazul (1997 and 1998, II season) and La Libertad (1998 and 1999, II season), Colombia, Latin America.

R-lines/CIAT origin	Pedigree	Vigor score[1]	Plant height (m)	Days to 50% flowering	Green leaf area score[2]	Leaf disease score[3]	Grain mold score[4]	Agronomic score[5]	Head weight ($t\ ha^{-1}$)	Grain weight ($t\ ha^{-1}$)
ICSR 91012	(SPV 475 x DKV 74)-1-2-1	1.8	1.6	74	4.8	2.8	1.6	2.1	2.9	2.8
ICSR 93033	NTJ 2122	1.9	1.5	74	4.6	3.2	1.8	2.5	2.3	2.7
ICSR 110	[MR 836 x (CK 60B x IS 84)]-4-1	2.1	1.2	68	4.8	3.1	1.8	2.4	2.6	2.7
ICSV 93042	(ICSV 705 x YT-2-37-2)-10-1-2-1-1	1.9	1.5	77	5.0	3.0	1.7	2.7	2.2	2.6
ICSR 91020-1	(SPV 475 x DKV 74)-1	1.8	1.6	67	4.9	2.5	1.4	2.1	2.5	2.6
ICSR-143	(FLR 101 x CSV 4)-4-1-2-3-1-1	2.3	1.5	75	4.9	3.1	1.6	2.5	2.2	2.5
IS 30469-1187-4	IS 30469-1187-4	1.9	1.6	71	4.7	3.3	1.6	2.4	2.5	2.5
ICSR 194	(PQ 213 x M 35-1)-5-2-2-1	1.9	2.2	66	4.7	3.3	1.7	2.2	2.9	2.5
ICSR 102	[(148 x E 35-1)-4-1 x CSV 4]-1-1-1	1.9	1.2	72	4.7	3.3	1.9	2.4	2.1	2.4
ICSV 1177 BF	GD 27669	1.6	1.6	66	4.9	2.9	2.3	2.3	2.5	2.2
ICSV 95126	(ICSV 705 x YT-2-37-2)-14-1-1-1-1	2.1	1.9	71	4.9	2.5	1.7	2.4	2.2	2.0
IS 30469-1187-2	IS 30469-1187-2	1.9	2.1	70	5.0	2.9	1.6	2.3	2.2	2.0
IS 21629	IS 21629	2.2	2.7	66	5.1	3.2	1.4	2.7	1.3	1.7
Checks										
Real 60 (tolerant)		1.2	1.9	70	5.4	3.9	1.7	1.4	3.2	2.9
SPRU 94008 (susceptible)	(ICSB 51 x PM 1861)4-1-2-2	2.8	0.9	64	5.5	3.5	3.0	3.9	1.7	1.1
Mean		1.96	1.67	70	4.94	3.09	1.77	2.43	2.35	2.34
SE ±		0.09	0.11	1.02	0.06	0.09	0.10	0.13	0.12	0.12
CV (%)		25.8	5.7	7.8	8.0	15.4	19.5	23.9	43.6	37.7

1. Measured on a 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 9 scale, where 1= green leaf area, 2 = 1-5% of green leaf area reduced, 3 = 6-10%, 4 = 11-20%, 5= 21-30%, 6= 31-40%, 7=40-50%, 8=51-75% and 9 = > 75% of green leaf area reduced.
3. Measured on a 1 to 9 scale, where 1= free of leaf diseases, 2 = 1-5% of leaf area affected, 3= 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 =51-75% and 9 = > 75% of leaf area affected.
4. Measured on a 1 to 9 scale, where 1= no mold and 9 = 50% surface of grain with mold.
5. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.

Table 6.4. The performance of forage sorghum lines evaluated under eight different acid soil conditions in Carimagua (1996, II season), La Libertad (1996 and 1997, II season; 1998, I and II season and 1999, II season) and Matazul (1997 and 1998, II season) in Colombia, Latin America.

Forage lines/ CIAT orgin	Vigor score[1]	Plant height (m)	Number of tillers	Days to 50% flowering	Green leaf area score[2]	Leaf disease score[3]	Forage yield ($t\ ha^{-1}$)	Recovery score	Grain yield ($t\ ha^{-1}$)	Agronomic score[4]
IS 31496	1.9	2.0	2	79	2.5	2.3	19.3	2.0	3.5	1.7
IS 13868	1.3	2.3	2	73	2.7	2.2	16.9	2.6	0.8	2.0
IS 31446	1.8	1.8	.	81	1.0		16.1			1.2
ICSR 93024-2	2.9	2.0	1	71	3.5	2.4	14.1	3.6	0.4	2.5
ICSR 93024-1	3.5	1.6	2	75	3.2	2.1	9.7	4.0		2.6
GD 47805	3.3	1.7	2	72	2.2	1.8	8.7	4.0		2.3
IS 19667	2.3	2.2		76	1.0		8.6			1.7
ICSR 93024	2.5	1.7		83	1.3		8.3			2.0
ICSR 93024-3	3.7	.	2	77	2.5	2.7	7.8	4.0		1.8
IS 32811	2.2	2.0		71	1.0		6.7			1.8
GD 47818	2.5	1.7		74	1.7		6.6			2.2
GD 27668	1.7	1.7		73	1.0		6.3			2.8
ICSR 93026	3.3	1.6		71	2.7		5.8			3.2
ICSR 93011	2.7	1.7		74	1.3		5.4			3.0
IS 19669	2.2	1.8		74	1.7		4.5			2.7
Checks										
Sikuani (maize)	1.6	1.8	1	63	3.8	3.0	14.4	2.7		2.9
Sudax (forage hybrid for sorghum check)	2.6	2.2	1	60	2.3	1.7	13.9	2.7	2.3	2.5
Mean	2.0	1.8	2.6	59.5	1.8	2.1	13.8	2.5	1.7	2.1
VAR	0.5	0.0	1.3	261.2	0.6	0.1	43.6	0.7	0.5	0.3
SD	0.7	0.2	1.1	16.2	0.8	0.4	6.6	0.9	0.7	0.6
SE ±	0.13	0.04	0.24	2.90	0.14	0.08	1.48	0.15	0.18	0.10
CV (%)	35.1	10.2	42.7	27.2	42.4	17.2	47.7	34.5	41.4	26.8

1. Measured on a 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 9 scale, where 1 = green leaf area, 2 = 1-5% of green leaf area reduced, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 = 51-75% and 9 = > 75% of green leaf area reduced.
3. Measured on a 1 to 9 scale, where 1= free of leaf diseases, 2 = 1-5% of leaf area affected, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 = 51-75% and 9 = > 75% of leaf area affected.
4. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.

Table 6.5. The effect of Al^{3+} saturation levels on the performance of sorghum lines, Matazul, Colombia, July-December 1997.

Al^{3+} saturation (%)	Early vigor[1]	Days to flowering	Green leaf area[2]	Agronomic score[3]	Head weight[4]	Grain weight[4]
40	1.52b[5]	76.63a	1.55b	1.88^{b}	2.32^{b}	1.71^{b}
60	1.41b	75.77a	1.66b	2.05^{b}	2.61^{z}	1.94^{a}
80	2.13a	73.97b	2.16a	3.25^{a}	1.92^{c}	1.43^{c}
SE±	0.20	0.83	0.07	0.08	0.20	0.15

1. Measured on 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 5 scale, where 1 = maximum green leaf area and 5 = least green leaf area.
3. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.
4. Measured in $t\ ha^{-1}$.
5. Values followed by the same letter within a column do not differ significantly ($P<0.05$)

Source: Reddy and Rangel (2000).

desirability but with a regression coefficient significantly lower than 0 (showing greater sensitivity to acid soil conditions) were ICSVs 102, 112 and 95126, ICSR 143, ICSR 194, IS 18758C-710-3 and IS 30469-C-1518T-3. It must be noted that as expected, the acid soil-tolerant check Real 60 fell under the first group with wide adaptability (regression coefficient 0.571 ± 0.057), and the susceptible check SPRU 94008 fell under the susceptible group (regression coefficient -0.856 ± 0.0412) with low mean value.

Among the selected B-lines, ICSBs 73, 81, 102, 88004 and 89002, SPMD 94004, SPMD 94019, SPAN 94008, SPHB 94006, SPA_2 94021 and SPA_2 94039 showed wide adaptability. Lines ICSB 94 and SPA_2 94029 were more responsive to the favorable environment. Lines ICSB 93, SPMD 94006 and SPMD 94036 showed high mean and were more tolerant to acid soils.

Among the selected forage lines, IS 31496 was better adapted to the favorable environment and showed high fresh fodder weight across the locations. Sikuani, the maize check, showed high fresh fodder weight and wide adaptability. On the other hand, ICSR 93024 and IS 32811 showed wide adaptability but less fodder weight. Details of the stability parameter estimated for all the groups of lines are given in ICRISAT (1997).

In a back-up breeding program, large grain (ICSP LG) and maintainer (ICSP B) sorghum populations (ms_3 based) were merged and selected alternatively at the CIAT farm under neutral pH, and at Matazul under acid soil conditions. Some of the selections (male fertiles) were advanced through pedigree breeding. Several promising progenies were also selected from the segregating materials of the specific crosses made among the lines selected for acid-soil tolerance and less susceptibility to foliar diseases.

Nearly 200 sorghum hybrids were evaluated at Matazul (60% Al^{3+} and 4.6% organic matter). Three hybrids produced more than 5.0 t ha^{-1} grain yield, while the Al^{3+} tolerant check Real 60 yielded 4.01 t ha^{-1}. The outstanding hybrids (Table 6.6) were ICSA 38 × Real 60, ICSA 73 × ICSR 110, ICSA 89002 × Real 60 and SPMD-A 94045 × A 2267-2 (Table 6.6), of which further details are given in ICRISAT (2000). These were less susceptible to leaf diseases, greener at maturity, and also taller than the check Real 60. Biomass in these is expected to be higher than in Real 60. Hybrids therefore hold promise for improving the sustainability of acid Savannas.

From 1997 to 1999, about 30 network trial sets each with grain sorghum B-lines (32), grain sorghum R-lines (49) and forage sorghum lines (6) were distributed to national programs. Three trial sets were distributed to private sector seed companies. The best sorghum lines selected from these trials in Honduras were ICSB 93 and SPA_2 94029B among female parents, and ICSR 110, ICSV 95072 and CEM 336/10-1-1 among sorghum R-lines. The best sorghum forage lines selected in Colombia were IS 13868, IS 31868 and ICAR 93024-2.

Pedro Jose Garcia (Venezuela), Paulo Cesar Magalhaes, and Fredolino Santos Giacomini (Brazil) and Jaime Humbeto Bernal, Andres Felipe Rangel Becerra and Luis Alfonso Rodriguez Gonzalez (Colombia) were provided training at ICRISAT during 1997-98.

A workshop was conducted at Corporacion Colombiana de Investigation Agropecuaria (CORPOICA), La Libertad, Colombia, from 24-26 Nov 1998, with 25 scientists from Brazil, Colombia, Honduras and Venezuela, ICRISAT and CIAT participating. The workshop reviewed the IADB-funded project's research and identified future needs. These included extending research to other zones (such as fertile neutral areas and drought-prone areas) in addition to the acid Savanna soils, enhancing research on sorghum by 70%, taking up nutrient uptake efficiency studies and exploring the use of sorghum grain as feed (Reddy et al. 2000a).

Genotype	Seedling vigor score[1]	Plant stand	Plant height (m)	Days to 50% flowering	Green leaf area score[2]	Agronomic desirability score[3]	Leaf disease score[4]	Converse bird damage[5]	Grain yield ($t\ ha^{-1}$)[6]
ICSA 38 × Real 60	1.3	32	2.5	65	5.0	1.0	4.3	0.93	5.63
ICSA 73 × ICSR 110	1.5	36	2.0	68	4.0	1.0	3.0	0.89	5.25
ICSA 89002 × Real 60	1.0	40	2.3	61	5.3	1.0	5.0	0.88	5.10
SPMD-A 94045 × A 2267-2	1.7	45	2.1	68	4.0	1.0	2.3	0.91	5.00
SPHB-A 94006 × CEM 328/3-3-1-1	1.0	37	2.2	65	4.3	1.0	2.3	0.76	4.93
SPMD-A 94045 × ICSV 93042	2.3	31	1.5	68	3.7	1.0	2.0	0.89	4.87
ICSA 89 × ICSR 194	1.7	39	2.1	64	6.3	1.0	3.3	0.93	4.80
ICSA 73 × ICSR 143	1.7	42	1.9	68	3.7	1.0	2.7	0.92	4.73
SPMD-A 94045 × ICSR 91012	1.3	47	1.6	68	4.0	1.0	1.3	0.92	4.73
ICSA 73 × ICSV 93042	1.3	43	2.3	71	4.7	1.0	2.0	0.90	4.67
ICSA 89002 × ICSR 110	1.3	25	1.9	65	4.0	1.0	3.0	0.91	4.57
SPHB-A 94006 × Icaravan	1.0	47	2.4	70	5.3	1.0	4.3	0.96	4.57
ICSA 94 × ICSR 194	1.7	22	2.3	67	4.0	1.0	3.0	0.92	4.40
ICSA 89002 × ICSR 102	1.3	25	1.8	67	8.0	1.0	3.3	0.87	4.40
SPMD-A 94006 × ICSR 93033	1.3	34	1.6	62	5.0	1.0	2.7	0.89	4.37
ICSA 73 × ICSR 194	1.3	37	2.2	76	5.0	1.0	2.7	0.95	4.33
SPMD-A 94045 × ICSR 93033	1.3	43	1.6	67	2.7	1.0	1.7	0.82	4.33
ICSA 73 × ICSR 102	1.3	37	1.9	58	2.7	1.0	2.3	0.91	4.20
SPA_2 94021 × Icaravan	1.0	39	1.9	63	6.0	1.0	4.7	0.95	4.13
ICSA 89002 × ICSR 93033	1.0	37	1.7	66	7.3	1.0	3.3	0.88	3.95
SPMD-A 94036 × ICSR 102	1.3	24	1.6	62	6.0	1.0	2.3	0.87	3.87
SPHB-A 94006 × A 2267-2	1.0	45	2.2	62	3.3	1.3	1.7	0.85	3.87
ICSA 89 × ICSR 143	1.0	42	2.0	65	4.0	1.3	2.3	0.87	3.80
ICSA 73 × IS 30469-1187-2	2.0	27	2.7	73	6.7	1.3	2.3	0.79	3.70
SPMD-A 94019 × ICSR 93033	2.7	26	1.5	68	3.3	1.0	2.0	0.89	3.67
SPMD-A 94019 × ICSR 102	2.7	27	1.4	70	5.0	1.0	2.3	0.88	3.60
SPMD-A 94036 × ICSR 143	2.7	21	1.6	69	3.0	1.0	2.3	0.90	3.20
SPMD-A 94004 × ICSR 194	2.7	14	2.0	69	4.7	1.3	2.7	0.92	2.87
Checks									
Real 60	1.33	30.0	1.77	72.0	6.00	1.00	5.33	1.00	4.03
SPRU 94008	3.67	28.7	0.93	67.7	5.33	4.00	2.00	0.89	1.50
Mean	1.60	32.78	1.93	66.3	4.64	1.13	2.89	0.88	3.95
SD (±)	0.62	10.03	0.35	4.63	1.42	0.48	1.14	0.07	0.81
CV (%)	33.9	18.9	8.0	6.6	25.2	19.9	20.9	9.1	16.1

Table 6.6. Performance of selected sorghum preliminary hybrids at Matazul, Colombia, July-December, 1999.

1. Measured on a 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 9 scale, where 1 = maximum green leaf area and 9 = least green leaf area.
3. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.
4. Measured on a 1 to 9 scale, where 1 = free of leaf diseases, 2 = 1-5% of leaf area affected, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 41-50%, 8 = 51-75% and 9 = > 75% of leaf area affected.
5. Converse of bird damage in fractions.
6. Grain production at 15% moisture.

Source: ICRISAT (2000).

6.4. Implications

The acid soil locations (Quilichao, Carimagua, La Libertad and Matazul) varied in their organic content (Table 6.1). The absence of significant G × Al^{3+} interaction variances for important economic traits meant that genotypes bred under neutral/high-fertility conditions would also do well under acid soil conditions, thereby doing away with the need for a specific breeding program for acid soils. However, the following reasons outweigh this interpretation.

- In a set of varied genotypes, G × E interactions were significant for agronomic desirability, which to a large extent reflects grain weight. G × E interaction was also significant for this trait.
- The Al^{3+} levels study involved selected lines with narrow variability, and did not include lines that performed well under less severe acid soil conditions.
- Decrease in yield levels (26%) due to increase in soil acidity (from 60 to 80% Al^{3+} saturation) was far greater than the increase in head and grain weight (12% from 40 to 60% Al^{3+} level).

Therefore, breeding programs should aim at specific adaptations.

The most standard effect of Al^{3+} toxicity is the inhibition of root growth (Delhaize and Ryan 1995), usually reflected in shoot growth and grain or forage yield. Delhaize and Ryan (1995) and Kochian (1995) reviewed the literature on the mechanisms of resistance. These included Al^{3+} interaction with the root cell wall; Al^{3+} disruption of plasma membrane and plasma membrane transport processes; and Al^{3+} interaction with such synplasmic constituents as calmodulin, a Ca^{2+} binary protein.

Resistance mechanisms differ depending on Al^{3+} levels (or environments); thus genotypes with varied selection histories might vary in their resistance mechanisms. It is likely that ICRISAT-bred lines and INTSORMIL-selected lines (such as Real 60) have different resistance mechanisms. Malate and phosphate exudates contribute to Al^{3+} tolerance, as in wheat that is controlled by dominant alleles in at least two loci (Pellet et al. 1996). There is a need to study resistance mechanisms and their genetics in selected sorghum lines.

6.5. References

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