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Growth Traits Among Sorghum Genotypes in Response to Aluminum

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ABSTRACT

Aluminum (Al) has many detrimental effects on plant growth, and shoots and roots are normally affected differently. A study was conducted to determine differences among sorghum [*Sorghum bicolor* (L.) Moench] genotypes with broad genetic backgrounds for growth traits of plants grown at 0, 200, 400, 600, and 800 μM Al in nutrient solutions (pH 4.0). Genotypes were categorized into "Al-sensitive", "intermediate Al-tolerant", "Al-tolerant", and SC 283 (an Al-tolerant standard). As Al increased, shoot and root dry matter (DM), net main axis root length (NMARL), and total root length (TRL) became lower than controls (0 Al). Aluminum toxicity and/or nutrient deficiency symptoms become more severe, and shoot to root DM ratios and specific RL (TRL/root DM) values also changed as Al in solution increased. Root DM had greater changes among genotypes than shoot DM, and NMARL at 400 μM Al, and TRL at 200 μM Al had greater differences among genotypes

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than root DM, ratings for toxicity and/or deficiency symptoms, and other DM and RL traits. The wide differences among genotypes for NMARL and TRL could be used more effectively to evaluate sorghum genotypes for tolerance to Al toxicity than the other growth traits.

INTRODUCTION

Aluminum toxicity is a major problem for plants grown on acidic soils, and has many detrimental effects on plant growth (Foy, 1992). Plants grown in media with Al normally exhibit Al toxicity and/or mineral deficiency symptoms, which often vary with plant genotype (Grundon et al., 1987). The short and stubby roots of Al affected plants usually have inhibited uptake of water and nutrients and cannot contact sufficient media to obtain needed nutrients, especially for soil-grown plants, to maintain optimum growth. As such, Al affected plants do not normally grow well.

Liming has been the main management practice to correct soil acidity (Al toxicity) problems (Foy, 1984). Even though liming is relatively effective for alleviating soil acidity, this practice requires extensive monetary input and may not be practical in many plant production systems. An alternative solution for using extensive inputs for overcoming soil acidity has been to grow plants tolerant to the existing conditions (Foy, 1993). Many plant species and cultivars within species are known to tolerate soil acidity conditions, and have been used successfully in many plant production systems (Maranville et al., 1993).

Many traits have been used to select, identify, and evaluate plants for tolerance to Al toxicity in greenhouse/growth chamber studies, and many of these results have been verified in field studies (Flores et al., 1988; Foy, 1984; Howeler and Cadavid, 1976; Urrea-Gómez et al., 1996; L.M. Gourley, Mississippi State University, personal communication). Studies to evaluate germplasm for and understand Al toxicity tolerance problems as well as appropriate technologies to manage acid soil problems have been discussed and featured in various symposia in recent years (Barrow, 1993; Date et al., 1995; Maranville et al., 1993; Wright et al., 1991). Traits to distinguish Al-tolerant and Al-sensitive germplasm are important for screening and identifying plant tolerance to Al toxicity.

This study was conducted to determine differences among sorghum genotypes with broad genetic background for growth traits when grown at varied levels of Al.

MATERIALS AND METHODS

Sorghum seeds treated with captan [N-(trichloromethylthio)-4 cyclohexene-1,2 dicarboximide] were germinated in rolled paper towels (Clark, 1982), and 4-day-old seedlings were transferred to 6-L of aerated 0.5-strength nutrient solution and grown for five days. Uniform-sized 9-day-old seedlings of each genotype

were transferred to 1.9-L containers (four plants container⁻¹) containing full-strength nutrient solution with treatments. The composition of full-strength nutrient solution was 19.88 (6:1 nitrate:ammonium) nitrogen (N), 7.54 calcium (Ca), 7.24 potassium (K), 1.94 chlorine (Cl), 1.82 S, 1.55 magnesium (Mg), and 0.20 sodium (Na) in mM; and 65 P, 50 B, 49 iron (Fe) [as FeHEDTA (ferric hydroxyethyl-ethylene diaminetriacetate)], 18 manganese (Mn), 4.6 zinc (Zn), 1.6 molybdenum (Mo), and 1.2 copper (Cu) in μM (Clark, 1982). Treatments consisted of Al at 0, 200, 400, 600, and 800 μM as $\text{KAl}(\text{SO}_4)_2$ at pH 4.0 ± 0.1 which was monitored every other day and adjusted as needed during plant growth.

Plants were grown in growth chambers with light/dark conditions of 16/8 h, $28/23 \pm 1^\circ\text{C}$, and $50/60 \pm 5\%$ relative humidity. Light was $300 \mu\text{mol m}^{-2} \text{s}^{-1}$ photon flux density at plant height and was provided by low pressure sodium and metal halide lamps. Because of the number of genotypes tested and space limitations, four similar experiments were conducted over time. Genotypes included in each experiment were selected at random with a standard sorghum genotype (SC 283) included in each. The experimental design was completely randomized with factorial arrangements for Al level and genotypes with four replications.

The length of the longest main axis root (MARL) was recorded when plants were put into treatment solutions (initial), and a series of plants were harvested at this time to provide initial DM. Plants were grown in treatments for 15 days after which experiments were terminated. At the conclusion of each experiment, severity of visual Al toxicity and/or mineral deficiency symptoms on each genotype was rated (1=no symptoms to 5=severe symptoms). Shoots were severed from roots, and shoots were dried at 70°C and weighed. Roots were thoroughly rinsed with distilled water, final MARL measurements recorded, and fresh weights determined. Roots were cut into 1-2 cm segments, thoroughly mixed, and subsamples (~ 10 g fresh weight) were taken for TRL measurements using a gridline intersect method (Newman, 1966; Tennant, 1975). The remainder of the roots were dried and weighed as were root samples taken for TRL. The DM was final DM minus initial DM and NMARL was final MARL minus initial MARL.

The 25 genotypes tested (Table 1) were categorized into four groups according to NMARL readings. Genotypes with NMARL at 400 μM Al of $>70\%$ those of SC 283 (standard Al-tolerant genotype) were categorized as "Al-tolerant" (B 68181, BTX 623, IS 7180, and IS 7440); genotypes with NMARL of $<20\%$ those of SC 283 were categorized as "Al-sensitive" (RTX 430, BTX 2783, BTX 3042, IS 9187, IS 9919, and B Wheatland); genotypes with NMARL between 20 and 70% those of SC283 were categorized as "Intermediate Al-tolerance" (14 other genotypes listed in Table 1 not listed as Al-tolerant or Al-sensitive); and SC 283 was categorized as its own group.

Data were statistically analyzed using analyses of variance procedures in a General Linear Model of SAS (SAS, 1985) and converted to percent of controls (0 Al). The LSD values at $P=0.05$ were used to make relative comparisons among each genotypic group using the mean value of the genotypes making up that specific group.

TABLE 1. Names, origin, and classification of sorghum germplasm grown with varied levels of Al.

Genotype	Origin	Classification	Other information
SC 283	Tanzania	Conspicuum	IS 7173 B line
ICA-Nataima	Colombia		
BTX 631	USA-Texas		B line
B 68181	USA-Georgia		B line
BOK 11	USA-Oklahoma		B line
BTX 3042	USA-Texas	Redlan selection	B line
BTX 623	USA-Texas		B line
B Redlan	USA-Texas		TX 378 B line
BTX 2783	USA-Texas		B line
B Wheatland	USA-Texas		TX 399 B line
RTX 430	USA-Texas	(TX 2536 x SC 170)	R line
RTX 432	USA-Texas		R line
IS 11296	Ethiopia	Caudatum, bicolor	PI 329544
RTX 430 TCR-20	USA-Georgia		Tissue culture R line
RTX 430 TCR-30	USA-Georgia		Tissue culture R line
RTX 430 TCR-50	USA-Georgia		Tissue culture R line
IS 2782	East Africa	Durra-Kaura	
IS 7180	Nyssaland†	Conspicuum	
IS 7809	Nigeria	Caudatum-Kaura	SC 402 R line
IS 7318	Nigeria	Caudatum	
IS 9187	Somaliland†	Durra	
IS 7440	Nigeria	Caudatum	SC 346 R line
IS 9785	Sudan	Caudatum	
IS 9919	Sudan	Caudatum	
IS 7243	Nigeria	Caudatum	

†Nyssaland is now Malawi and Somaliland is now Somalia, Djibouti, and a part of eastern Ethiopia.

RESULTS AND DISCUSSION

Visual symptoms for Al toxicity on upper leaves of plants are normally not specific, but interveinal chlorosis and pale green color commonly appear (Grundon et al., 1987). Aluminum-induced symptoms of phosphorus (P), Ca, Mg, and Fe deficiencies may be common on leaves of some genotypes. Aluminum toxicity symptoms on roots are manifest by reduced lengths or lack of extension, less lateral branching, enlarged diameters, and usually dark in color. Lateral roots especially become short and stubby, usually bunched together (coralloid), near tips of main roots. Numbers of nodal roots initiated may also increase, but extension is usually limited.

Visual symptoms of the various genotypes became more severe as Al increased (Table 2), and genotypes had varied degrees of symptoms on both leaves and roots. Rating genotypes for Al toxicity tolerance using visual symptoms appeared feasible at the 200 μM Al level, but was difficult at the higher Al levels. Plants grown with 400 and 600 μM Al had fairly severe Al toxicity symptoms, and plants grown at 800 μM Al had severe symptoms.

Shoot and root DM decreased dramatically as Al increased, regardless of genotypic group (Figure 1, upper). No significant differences for shoot DM were noted among genotypic groups, but differences for root DM were noted between Al-tolerant and Al-sensitive groups. Although genotypic differences for root DM were noted among genotypes, root DM differences were not as wide for evaluating plants for Al toxicity tolerance as NMARL and TRL, especially NMARL (Figure 1, lower). For example, neither SC 283, an Al tolerant genotype (Duncan, 1991), nor ICA-Nataima, a fairly Al-sensitive genotype (Flores et al., 1988; Galvez and Clark, 1991), had significant differences in shoot and root DM when grown with ≥ 400 μM Al.

Shoot to root DM ratios of plants grown with increased levels of Al were consistently higher for the Al-sensitive genotypes (Table 2). However, the intermediate Al-tolerant and Al-tolerant genotypes did not increase shoot to root DM ratios above those of controls until plants were grown with ≥ 600 μM Al. Shoot to root DM ratios for SC 283 grown with all levels of Al remained near or below that of the controls. Higher shoot to root DM ratios for plants grown with Al compared to no Al indicated that Al toxicity affected roots more than shoots. Similar responses have been reported by others (Baligar et al., 1989; Foy, 1984).

Large differences in NMARL were noted between Al-tolerant and Al-sensitive genotypic groups when plants were grown with 400 μM Al (Figure 1, lower left). Wide differences among genotypes were noted for TRL when plants were grown at 200 and 400 μM Al (Figure 1, lower right), but these differences were relatively narrow as Al increased above 400 μM . Specific RL ($\text{TRL} \div \text{root DM}$) was higher for SC 283 and the Al-tolerant genotypes compared to the Al-sensitive genotypes for plants grown with up to 400 μM Al, and erratic for plants grown with > 600 μM Al (Table 2). Widest differences among genotypes for growth traits were

TABLE 2. Ratings of visual Al toxicity symptoms, shoot to root dry matter (DM) ratios, and specific root lengths (RL) of sorghum genotypes grown with varied levels of Al.

Trait	Genotypic group	Level of Al (μM)				
		0 ^a	200	400	600	800
Visual	SC 283	1.0	1.8	3.0	3.5	4.3
Al toxicity	Al-tolerant	1.0	2.0	3.2	3.8	4.6
rating ^b	Intermediate Al-tolerant	1.0	2.6	3.4	3.8	4.5
	Al-sensitive	1.0	2.7	3.4	4.0	4.4
	LSD (0.05)			0.4		
percent of control						
Shoot to	SC 283	100 (1.40)	89	95	95	95
root DM	Al-tolerant	100 (1.54)	88	96	111	159
ratio	Intermediate Al-tolerant	100 (1.59)	96	103	118	131
	Al-sensitive	100 (1.53)	106	123	150	179
	LSD (0.05)			11		
percent of control						
Specific RL ^c	SC 283	100 (132)	111	88	59	49
	Al-tolerant	100 (130)	120	106	61	60
	Intermediate Al-tolerant	100 (131)	88	58	58	58
	Al-sensitive	100 (128)	77	71	84	71
	LSD (0.05)			6		

^aNumbers in parentheses are actual shoot to root DM ratio and specific RL values for controls.

^bVisual symptoms are 1=no symptoms to 5=severe symptoms.

^cSpecific RL=total RL÷root DM (m g^{-1}).

FIGURE 1. Shoot and root dry matter (upper) and net main axis root length (NMARL) and total root length (TRL) (lower) of sorghum genotypes grown with varied levels of Al [$I=LSD$ ($P=0.05$)].

noted for NMARL, which was used to categorize the genotypes into the groups of this study. In other studies, longest adventitious root lengths and NMARL were the best traits to evaluate sorghum for Al toxicity tolerance compared to shoot and root DM, visual symptoms, number of adventitious roots initiated, and mean seminal RL (Furlani and Clark, 1987). However, visual symptoms, fresh root weights, and total and lateral root lengths were effective in separating tolerant and sensitive maize (*Zea mays* L.) in the greenhouse for evaluation in the field (Urrea-Gómez et al., 1996). The Al-tolerant genotypes and SC 283 had higher specific RL than Al-sensitive genotypes when grown with Al, which indicated that roots of Al-tolerant genotypes remained finer, smaller in diameter, and had more branching than roots of Al-sensitive genotypes.

In summary, root DM had fairly wide differences among genotypes when plants were grown with various levels of Al, but shoot DM did not. Total RL and NMARL had large differences among genotypes, and these two traits could be used more effectively than root DM to evaluate differences among sorghum genotypes for tolerance to Al toxicity.

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