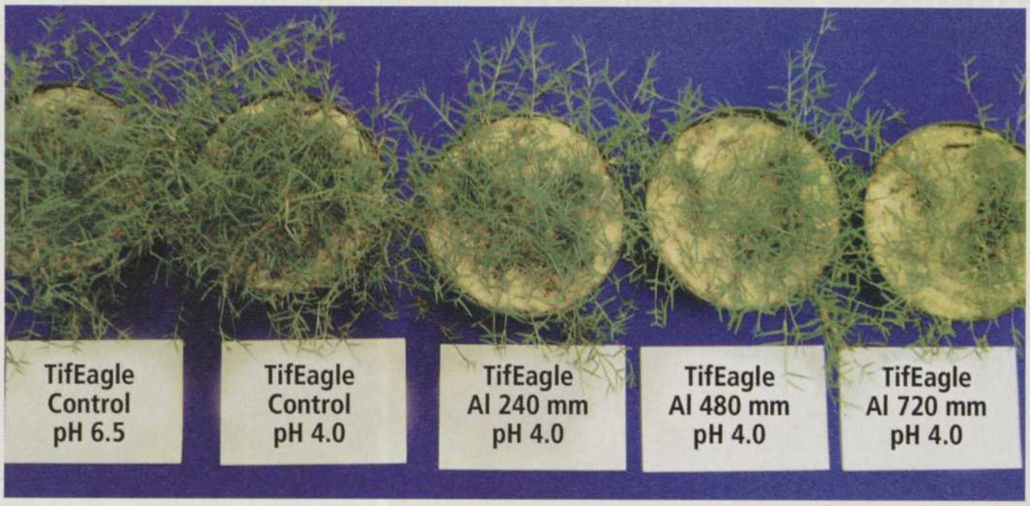
Aluminum Tolerances of 10 Warm-Season Turfgrasses

By Christian M. Baldwin, H. Liu, L.B. McCarty and W.L. Bauerle



Photograph 1. Shoot mass decline of TifEagle bermudagrass in response to 240, 480 and 720 millimeters of aluminum.

Aluminum (Al) toxicity has been studied since it was first identified as a major limiting factor of crop productivity grown in acid soils (Hartwell and Pember, 1918).

Most plants are sensitive to soil Al concentrations, even in micromolars.

Approximately 40 percent of arable land in the world is acidic (Kochian et al., 2004), including Southern and transitional zones of the United States where warm-season turfgrasses are grown. Aluminum toxicity is closely associated with low soil pH (under 5.0), where such soils release Al for uptake and therefore adversely affect plant growth. Generally, all soils contain about 8 percent Al by weight and become toxic only when the soil pH is lower than 5.0.

At low soil pH, soil Al becomes soluble being available for plant uptake. When soil pH is close to neutral or above, soil Al is precipitated and not available for plant uptake. Therefore, raising soil pH by liming is an efficient way to reduce Al toxicity in acid soils.

However, liming agents move slowly through the soil profile, and repeat applications add costs for agricultural production. Also, excessive lime applications may cause a new nutrient imbalance, such as potassium (K) deficiency (Foy et al., 1978).

When exposed to Al, plant growth is negatively affected because Al inhibits plant root tip cell division and cell elongation (Clarkson, 1965). In addition, plants grown in acidic soils experience nutrient imbalances and deficiencies (phosphorus [P], potassium [K], calcium [Ca] and magnesium [Mg]), reduced root and shoot growth (Photograph 1) and reduced stress tolerance (Marschner, 1991).

The effects of Al toxicity on nutrient uptake, especially P and Ca, for cool-season turfgrasses and wheat cultivars have been reported (Foy and Murray, 1998b). In addition, genetic differences in Al tolerance of cool-season turfgrasses have been reported (Liu et al., 1995; Foy and Murray, 1998a).

Research on warm-season turfgrass Al tolerance is limited. However, Liu (2005) reported differences in seeded bermudagrass cultivars to Al tolerance, and Wu et al. (1981) reported different Al tolerances of four vegetative-propagated bermudagrass cultivars. Therefore, the objectives of this study were to determine if genetic differences in Al tolerance existed among selected warm-season turfgrasses and how nutrient concentrations in root and shoot tissue were affected when exposed to micromolar Al concentrations.

Low to moderate Al exposure

Study I consisted of three Al treatments (240 μm, 480 micrometers [μm] and 720 μm) at pH of 4.0

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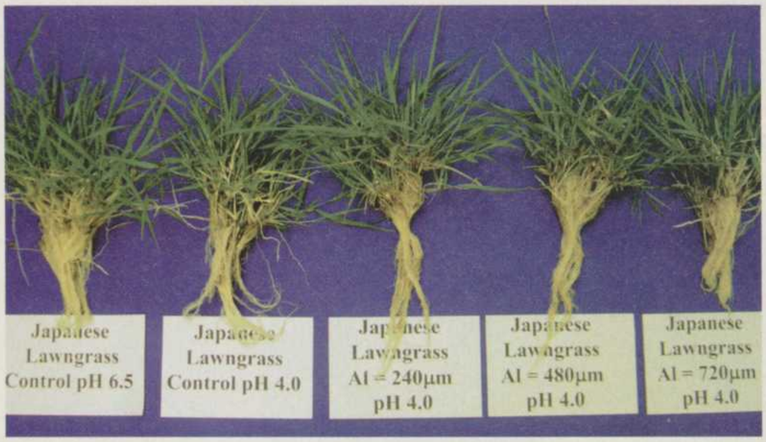

Picture 2. Shoot and root biomass of Japanese Lawngrass unaffected in response to 240, 480, 720 millimeters of aluminum.

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with two controls (0 μm of Al) at pH 4.0 and 6.5 for six weeks under greenhouse conditions.

Treatments were arranged in a randomized complete block design with three replications. Pot dimensions were 15 centimeters (cm) (6 inches) in diameter and 12 cm (4.8 inches) in height with eight holes (0.40 inches) at the bottom to allow for drainage. For each turf species selected (Table 1), 30 single meristem shoots from 2-year old well-rooted turf were planted in 100 percent sand obtained from Golf Agronomics, with roots and shoots clipped to ensure similar length.

All turfgrasses were fertilized daily (50 milliliters [ml] to 100 ml) using a modified half-strength Hoagland's nutrient solution [Hoagland and Arnon, 1956]. Aluminum was added to the solution as $Al_2(SO_4)_3 18H_2O$ and was adjusted to pH of 4.0 (+/-0.1). Deionised distilled water was used to make all solutions.

Moderate to high exposure

Study II was similar in design as study I, except Al was increased to 480 μm, 960 μm and 1440 μm and P concentrations were reduced to 0.0425 kilograms (kg) per hectare per day.

Treatments were arranged in a randomized complete block design and the same 10 species were selected as in study I. Unless otherwise stated, materials and experiment duration were identical to study I.

Relative values were used for all data collected due to the inherent variability among turfgrasses selected. Relative nutrient recovery was determined and dry weight of shoots and roots were measured in both studies and used to cal-

TABLE 1

Turfgrass Species	Scientific Name	Cultivar
Bahiagrass	*Paspalum notatum* Flugge.	'Pensacola'
Buffalograss	*Buchloe dactyloides* [Nutt] Engelm.	
Seashore Paspalum	*Paspalum vaginatum* Swartz.	'Isle'
Centipedegrass	*Eremochloa ophiuroides* (Munro) Hack.	
Common Carpetgrass	*Axonopus affinis* Chase.	
Common Bermudagrass	*Cynodon dactylon* var. *dactylon*	'Princess 77'
Japanese Lawngrass	*Zoysia japonica* Steud.	'Meyer'
Manilagrass	*Zoysia matrella* (L.) Merr.	
St. Augustinegrass	*Stenotaphrum secundatum* (Walt.) Kuntze.	'Raleigh'
Hybrid Bermudagrass	*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy	'TifEagle'

Warm-season turfgrass species and cultivars selected for studies I and II.

TABLE 2

Species	Relative Root Mass			Relative Shoot Mass		
	480	960	1440	480	960	1440
	%					
Seashore Paspalum	0.70c*	0.71	0.57c	0.88abc	0.65	0.54d
Common Carpetgrass	0.99abc	1.00	1.15ab	0.87abc	0.90	1.31a
Japanese Lawngrass	1.01abc	1.23	0.79bc	0.84bc	0.93	0.74cd
Manilagrass	1.24a	1.03	1.30a	1.03ab	1.04	0.97b
Bahiagrass	0.82c	0.94	0.71c	0.80bc	0.67	0.71cd
Common Bermudagrass	0.86bc	0.79	0.77c	0.69bc	0.59	0.62cd
Buffalograss	0.88abc	0.67	0.45c	0.55c	0.67	0.67cd
Centipedegrass	1.23ab	1.16	0.66c	1.18a	0.94	0.72cd
St. Augustinegrass	0.69c	0.63	0.50c	0.92ab	0.80	0.83bc
Hybrid Bermudagrass	0.77c	0.66	0.73c	0.72ab	0.71	0.66cd
LSD	0.38	ns	0.36	0.34	ns	0.24
p-value	0.05**	0.17	0.01	0.05	0.34	0.01

*VALUES WITHIN A COLUMN FOLLOWED BY THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT AT P 0.05 BY PROTECTED LSD.

**SIGNIFICANCE AT THE PROBABILITY LEVEL P 0.05.

Relative root and shoot biomass based on control pH 4.0 of 10 warm-season species affected by aluminum at 480, 960 and 1440 millimeters, study II.

culate relative root and shoot mass.

Roots were extracted from the soil and thoroughly washed until all soil was removed. Once clean, roots were clipped from the base of the shoot tissue. All relative values were based on the control pH of 4.0 and calculated:

Relative root mass [RRM = (root mass with Al/root mass without Al) x 100], relative shoot mass [RSM = (shoot mass with Al/shoot mass without Al) x 100], relative nutrient recovery [RNR = (nutrient concentration with Al/nutrient concentration without Al) x 100].

Fresh weight of roots and shoots were collected and placed in an oven at 80 degrees Celsius (C) (176 degrees Fahrenheit [F]) and dried for 48 hours. Once dried, samples were weighed for root and shoot mass and analyzed by the Clemson University soil testing laboratory for P, K, Ca, Mg, sulfur (S), chlorine (Cl), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), Al and boron (B).

Relative growth parameters

All statistical computations were conducted using analysis of variance (ANOVA) within the Statistical Analysis System (SAS Institute, 1999). Means were separated by the Fisher's Least Significant Difference (LSD) test. An alpha of 0.05 was used for relative shoot and root mass and for all Al and nutrient analyses of soil and plant tissue.

No differences were found in study I for RRM or RSM. In study II, Japanese lawngrass exhibited a 23 percent increase in RRM at 960 μm of Al, but as Al increased to 1440 μm, a 21 percent decrease in rooting occurred (Table 2).

Carpetgrass and manilagrass produced greater RRM (15 percent and 30 percent) at 1440 μm of Al compared to the other eight selected species. Buffalograss, seashore paspalum, bahiagrass and St. Augustinegrass, however, consistently performed poorly with a 55 percent, 43 percent, 29 percent and 50 percent decrease in RRM at 1440 μm of Al, respectively. All species had decreased RSM at 1440 μm of Al, except carpetgrass (31 percent increase).

Liu et al. (1995) observed Kentucky bluegrass (*Poa pratensis* L.) cultivars enhanced root and shoot growth when exposed to 320 μm of Al.

Relative nutrient recovery

Under high Al stress in studies I and II, relative concentrations of P and Ca were significantly reduced in the root tissues (Tables 3 and 4). At 720 μm of Al, Japanese lawngrass increased relative root P recovery 5 percent, while manilagrass minimized relative root P loss (15 percent) (Table 3).

TABLE 3

Species	Study I			Study II		
	240	480	720	480	960	1440
	%					
Seashore Paspalum	0.94bc*	0.81ab	0.60bc	0.71	0.57	0.54
Common Carpetgrass	0.87bc	0.78ab	0.55bc	1.17	0.66	0.66
Japanese Lawngrass	1.56a	0.56bc	1.05a	0.99	0.72	0.65
Manilagrass	0.77bc	0.52bc	0.85ab	0.74	0.57	0.47
Bahiagrass	0.82bc	0.66bc	0.65bc	1.26	0.87	0.85
Common Bermudagrass	1.09ab	0.79ab	0.71ab	0.90	0.87	0.77
Buffalograss	0.51c	0.35c	0.28c	0.79	0.57	0.60
Centipedegrass	0.81bc	0.81ab	0.67b	0.66	0.47	0.47
St. Augustinegrass	1.12ab	1.03a	0.75ab	0.91	0.55	0.64
Hybrid Bermudagrass	0.48c	0.34c	0.56bc	0.71	0.43	0.43
LSD	0.51	0.37	0.37	ns	ns	ns
p-value	0.01**	0.01	0.04	0.43	0.30	0.66

*VALUES WITHIN A COLUMN FOLLOWED BY THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT AT P 0.05 BY PROTECTED LSD.

**SIGNIFICANCE AT THE PROBABILITY LEVEL P 0.05.

Relative phosphorus (%) recovery in root tissue based on pH 4.0 of 10 warm-season species affected by aluminum at 240, 480 and 720 mm, study I; and 480, 960, and 1440 mm, study II.

TABLE 4

Species	Study I			Study II		
	240	480	720	480	960	1440
	%					
Seashore Paspalum	0.90	0.82	0.57bc*	0.40	0.41e	0.33d
Common Carpetgrass	0.89	0.76	0.76ab	0.79	0.72abcde	0.62abcd
Japanese Lawngrass	1.16	0.82	0.77ab	1.16	1.06a	0.87
Manilagrass	1.04	0.94	0.81ab	1.15	0.65bcde	0.39cd
Bahiagrass	0.66	0.74	0.88a	1.10	1.00ab	0.75abc
Common Bermudagrass	1.15	0.99	0.84a	1.17	1.06a	0.81ab
Buffalograss	1.05	0.97	0.88a	1.30	0.98abc	0.82ab
Centipedegrass	1.02	0.88	0.86a	0.97	0.61cde	0.33d
St. Augustinegrass	1.13	0.87	0.71ab	1.02	0.93abcd	0.86ab
Hybrid Bermudagrass	0.50	0.59	0.40c	1.03	0.58de	0.52bcd
LSD	ns	ns	0.24	ns	0.38	0.42
p-value	0.08	0.44	0.01**	0.06	0.01	0.05

*VALUES WITHIN A COLUMN FOLLOWED BY THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT AT P 0.05 BY PROTECTED LSD.

**SIGNIFICANCE AT THE PROBABILITY LEVEL P 0.05.

Relative calcium (%) recovery in root tissue based on pH 4.0 of 10 warm-season species affected by aluminum at 240, 480 and 720 mm, study I; and 480, 960 and 1440 mm, study II.

However, a 35 percent, 72 percent and 44 percent decrease in relative root P concentration occurred for bahiagrass, buffalograss, and hybrid bermudagrass, respectively. Study I results agree with Foy and Murray's (1998b) observations where P concentrations in shoots and roots of tall fescue (*Festuca arundinacea* Schreb.) cultivars decrease when exposed to Al treatments.

In study II, relative root P concentrations were unaffected by Al levels (Table 3). This was probably because of drastic reductions in P levels for all treatments. However, most species had reduced relative root P concentration as Al treatments increased, which were similar to the results in study I.

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Regardless of species, relative root Ca concentrations were reduced as Al increased in both studies (Table 4). This is consistent with observations reported by Krizek and Foy (1988). No definitive trends for K recovery in shoot or root tissues occurred in studies I or II (Data not shown).

Japanese lawngrass (Picture 2), manilagrass, and carpetgrass are relatively tolerant of Al levels. In study II, carpetgrass and manilagrass were the only warm-season turfgrass species that produced superior rooting at 1440 μm of Al with an increase of 15 percent and 30 percent, respectively. Al impacted nutrient recovery in most turfgrass species.

In both studies, as Al increased, relative Ca recovery generally decreased in root and shoot tissues. K levels, however, were unaffected by Al at any treatment level.

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In these greenhouse studies, zoysiagrass and carpetgrass performed well when exposed to acid media with Al. Future research is needed to investigate the two species at the cultivar level to understand their mechanisms of Al tolerance.

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