Growth and Mineral Content of St. Augustinegrass Cultivars in Response to Salinity

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Abstract. This investigation documented growth and nutritional responses of St. Augustinegrass 'Floralawn', 'Floratam', 'Floratine', and 'Seville' in salinized (conductivity = 1.1 to 41.5 dS·m⁻¹) solution cultures. Averaged over all cultivars' tissue, Cl concentrations increased linearly as salinity increased, while Na concentrations reached a threshold at 10 dS·m⁻¹ during 3 months of growth. Tissue K concentration decreased nonlinearly with increased salinity to 10 dS·m⁻¹, with 'Floratine' being the least affected. All cultivars apparently substituted Na for K until an optimum level was reached. Leaf tissue concentration of P decreased linearly, while Ca and Mg decreased nonlinearly with increased salinity. The salinity level that caused a 50% reduction in Ca concentration was 24% lower for 'Floratine' than for other cultivars. Tissue color differences were more strongly correlated with Ca and Mg levels in 'Floratine' than 'Seville'. Differences in cultivar response were noted for K, P, Ca, and Mg, with 'Seville' being the most salt-tolerant among those evaluated, based on overall nutritional and growth responses.

Saltwater intrusion into groundwater supplies continues to be an increasing problem in Florida (Parker, 1975). Major differences in salt tolerance have been found among turfgrass cultivars in bermudagrass [*Cynodon* sp. (L.) Rich.] (Dudeck et al., 1983; Francois, 1988; Youngner and Lunt, 1967) and in Seashore paspalumgrass (*Paspalum vaginatum* Swartz.) (Dudeck and Peacock, 1985). St. Augustinegrass is the most widely used lawngrass in Florida, but it requires supplemental irrigation for optimum growth. Salt tolerance of St. Augustinegrass is reported to be excellent (Beard, 1973), but no information on the tolerances of various cultivars is available. This investigation was conducted to compare the effects of increasing salinity on plant growth response and nutritional status of the St. Augustinegrass cultivars Floralawn, Floratam, Floratine, and Seville when grown in differentially salinized solution cultures.

Materials and Methods

This experiment was conducted outdoors under a rain shelter during Summer 1983 using a solution-culture technique described by Dudeck and Peacock (1985). 'Floralawn', 'Floratam', 'Floratine', and 'Seville' were propagated vegetatively from authentic planting stock. On 20 Apr. 1983, four sprigs (each 6 to 8 cm long) of each cultivar were planted vertically in tapered plastic pots containing washed gravel. Each pot, 12.7 cm top diameter × 9.8 cm deep (≈ 1 liter), with a hole in the bottom, was suspended by a 1.25-cm-thick plywood lid so that 7 cm of the pot bottom was submersed in 10 liters of tap water in a plastic pan. Solutions were aerated constantly and changed weekly. Two weeks later, tap water was replaced with 6.6 liters of half-strength Hoagland's no. 2 solution,

which was formulated with deionized water to pH 6.3. The bottom of each pot extended 3.5 cm into the solution. Top growth 5 cm above the gravel was removed weekly.

All grasses were considered established by 24 June, visually rated for color and density, and blocked uniformly within five replications. All were of acceptable quality. A salt mixture was formulated to approximate the average individual salt composition of seawater (Svedrup et al., 1959); it contained (in mg·kg⁻¹ of dry salts) 788 NaCl, 94 MgSO₄, 73 CaCl₂, 7 KHCO₃, and 6 KCl. This salt mixture was added at 0, 6.4, 12.8, 19.2, 25.6, or 32.0 g·liter⁻¹ to the nutrient solution to give six average maximum electrical conductivity (EC at 25°C) levels of 1.1, 10.3, 18.8, 26.9, 34.5, or 41.5 dS·m⁻¹, respectively. Electrical conductivities were recorded just before and after weekly solution changes. To minimize osmotic shock to the plants, all salt concentrations were increased in increments of 6.4 g·liter⁻¹ at 2-day intervals over 10 days or until final treatment levels were reached.

Roots extraneous to the pot were removed monthly for 3 months. Top growth extending beyond the circumference of the pot was removed biweekly in a vertical plane along with leaf tissue 25 cm above the gravel. Tissue was dried in preweighed aluminum envelopes at 60°C for 48 h to determine dry weights. Rate of top growth was based on the total of 6 biweekly harvests. At the end of the experiment, root tissue within pots was separated from crown tissue, and both were dried as noted. Crown tissue was defined as stems and leaves below the 5-cm clipping height. Dry crown and root tissues were weighed, ashed at 450°C for 12 h, reweighed, and the difference was taken as total crown or root weight to eliminate errors caused by small gravel or sand clinging to the tissue.

Leaf tissue for the last four harvests was bulked and ground in a Wiley mill fitted with a 20-mesh screen. Subsamples of 300 mg were then placed in 50-ml beakers and ashed at 450°C. Beakers were then cooled, the ash dissolved in 0.3 M HNO₃, filtered through no. 42 Whatman filter paper, and the filtrate brought to 30-ml volume. Aliquots were then analyzed for Ca, K, Mg, Na, Fe, Cu,

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Abbreviation. EC, electrical conductivity.

Table 1. Significance levels for dry weights and top growth elemental content in St. Augustinegrass cultivars as affected by electrical conductivity (EC) in solution medium.

Source	df	Dry weight												
		Top	Crown	Root	Ca	Mg	P	K	Na	Cl	Fe	Mn	Zn	Cu
Block	4	***	***	NS	*	NS	***	***	**	***	***	***	***	***
EC	5	***	***	***	***	**	***	***	***	***	**	***	*	NS
Error A	20													
Cultivar (C)	3	***	***	***	**	***	***	***	***	**	**	***	***	NS
C × EC	15	***	NS	***	**	*	**	***	NS	NS	NS	**	NS	NS
Error B	72													

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Zn, and Mn using a Perkin-Elmer Model 460 atomic emission spectrophotometer. Aliquots were analyzed for Cl colorimetrically (Mitchell and Rhue, 1979). Turf color scores were recorded on a 1 to 9 scale, where 9 = best.

The design was a split plot with five replications in which salinity was the main plot effect and cultivar was the subplot effect. All data were subjected to analysis of variance or regression analysis. Inverse regression analyses within replicates of each cultivar were used to predict the yield decrements. With the nonlinear regression models, the best fit is expressed with the percent variability of the experimental model. Means between cultivars were then separated based on the Waller-Duncan K-ratio t test, with K-ratio = 100.

Results and Discussion

Interactions of cultivar × solution EC were observed for top and root growth, but not for crown growth (Table 1). Based on growth responses, 'Seville' was the most salt-tolerant cultivar, especially at low salt concentrations.

No interactions of cultivar × EC were found for leaf elemental content of Na, Cl, Fe, Zn, or Cu (Table 1). Tissue Cu concentrations were not different among cultivars and were not affected by salinity. The Fe, Mn, and Zn levels were affected by salinity levels, but the data did not fit linear regression analyses. Correlation of tissue Fe with EC was significant only for 'Floratine' ($r = -0.37$, $P = 0.05$) and 'Seville' ($r = 0.46$, $P = 0.05$) (Table 2). Tissue Mn content was correlated with EC levels for 'Floratine' ($r = -0.41$, $P = 0.05$). All other correlations of microelements with tissue con-

Table 2. Correlation of leaf elemental content and dry weight of roots and tops of four cultivars of St. Augustinegrass and electrical conductivity of the solution medium.

Cultivar and criterion	K	Ca	Mg	Cl	Na	Cu	Fe	Mn	Zn	EC
Floralawn										
EC	-0.75 ***	-0.62 ***	-0.26 NS	0.93 ***	0.76 ***	0.12 NS	-0.30 NS	0.14 NS	0.28 NS	---
Top	0.71 ***	0.64 ***	0.36 *	-0.89 ***	-0.73 ***	0.50 NS	-0.04 NS	0.20 NS	-0.31 NS	-0.96 ***
Root	0.73 ***	0.63 ***	0.35 *	-0.89 ***	-0.75 ***	0.62 NS	-0.83 NS	-0.15 NS	0.40 NS	-0.95 ***
Floritam										
EC	-0.72 ***	-0.63 ***	-0.32 NS	0.96 ***	0.78 ***	0.14 NS	-0.01 NS	0.07 NS	0.25 NS	---
Top	0.73 ***	0.65 ***	0.41 *	-0.94 ***	-0.79 ***	0.18 NS	0.56 NS	-0.24 NS	-0.64 NS	-0.96 ***
Root	0.76 ***	0.68 ***	0.38 *	-0.89 ***	-0.79 ***	-0.02 NS	0.44 NS	0.71 NS	-0.16 NS	-0.89 ***
Floratine										
EC	-0.79 ***	-0.61 ***	-0.52 **	0.92 ***	0.81 ***	0.09 NS	-0.37 *	-0.41 *	0.05 NS	---
Top	0.71 ***	0.54 **	0.45 **	-0.88 ***	-0.75 ***	0.43 NS	-0.16 NS	-0.57 NS	-0.17 NS	-0.97 ***
Root	0.72 ***	0.59 ***	0.38 *	-0.80 ***	-0.71 ***	0.40 NS	0.08 NS	0.24 NS	0.41 NS	-0.85 ***
Seville										
EC	-0.63 ***	-0.60 ***	-0.34 ***	0.91 NS	0.72 ***	0.11 ***	-0.46 NS	-0.02 **	0.05 NS	---
Top	0.46 **	0.45 **	0.18 NS	-0.79 ***	-0.56 ***	0.72 NS	-0.17 NS	-0.25 NS	0.39 NS	-0.94 ***
Root	0.35 *	0.37 *	0.04 NS	-0.60 ***	0.40 *	0.46 NS	-0.16 NS	-0.54 NS	0.13 NS	-0.69 ***

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Fig. 1. Composite Cl and Na tissue response of St. Augustinegrass cultivars to salinity.

centrations and with top growth and root growth were nonsignificant within cultivars (Table 2).

Since there was no cultivar $\times$ EC interaction for Na and Cl, data for regression analyses were averaged over all cultivars. As solution EC increased, tissue Cl increased linearly from 15 g·kg⁻¹ at 1.1 dS·m⁻¹ to 53 g·kg⁻¹ at 41.5 dS·m⁻¹ (Fig. 1). Increased tissue Cl concentrations with no apparent maximum have been noted in other grass species, including bermudagrass (Dudeck et al. 1983), bentgrass (*Agrostis stolonifera* L.) (Ahmad et al., 1981), alkaligrass [*Puccinellia distans* (L.) Parl.] (Lunt et al., 1961), Seashore paspalum (Dudeck and Peacock, 1985), Highland bentgrass (*A. tenuis* Sibth.), Italian ryegrass (*Lolium multiflorum* Lam.), timothy (*Phleum pratense* L.), perennial ryegrass (*L. perenne* L.), tall fescue (*Festuca arundinacea* Schreb.), Kentucky bluegrass (*Poa pratensis* L.), and creeping red fescue (*F. rubra* L.) (Cordukes and Parups, 1971). Restriction of Na transport, but not Cl, does occur in other plants: however, it usually is associated with species labeled as salt-sensitive rather than salt-tolerant (Marschner, 1986). Accumulation of Na reached a maximum at ≈ 10 dS·m⁻¹ and then remained unchanged (Fig. 1).

St. Augustinegrass maintained top growth with increased tissue Cl levels, indicating that it may inherently use compartmentalization to prevent toxicity of Cl. Tissue P levels decreased linearly with increasing salinity, and there was a cultivar $\times$ EC interaction (Fig. 2). While some species have demonstrated an ability to absorb Cl without reductions of other anions (Bernstein and Hayward, 1958), tall wheatgrass (*Agropyron elongatum* L.) had reduced P with increased Cl in leaves (Shannon, 1978). In a comparison among bermudagrass cultivars, Francois (1988) found that tissue P levels were reduced under increased soil salinity; this apparently also occurs in St. Augustinegrass. Comparing P responses, 'Floratine' was the most sensitive cultivar based on the slope ($b = -0.061$) of the regression line (Fig. 2). Salt-stressed plants exhibit symptoms similar to P-deficiency, including smaller, darker-green leaves, a decreased shoot : root ratio, decreased tillering, and prolonged dormancy of lateral buds (Hewitt, 1963). Symptoms similar to these have been observed under salinity stress in alkaligrass, although it was not attributed to P-deficiency, since tissue nutrient levels were not determined (Harivandi et al.,

1982). St. Augustinegrass growth reductions observed in this study could, in part, be attributed to lower salinity-induced tissue P concentrations.

Tissue Na concentration increased nonlinearly, with an 89% increase at 10.3 dS·m⁻¹; however, tissue K concentration was the reverse of that for Na, with concentration in all cultivars decreasing nonlinearly with increased salinity. The largest K decreases occurred at relatively low salt solution concentrations in comparison to dry weights. A comparison of conductivities at the 50% reduction point of K levels in the tissue (Table 3) reveals 'Floratine' to be the most efficient absorber of K; the salinity level necessary to effect a 50% reduction in leaf tissue concentrations was 27% higher than for other cultivars. This decline in tissue K levels with increased salinity has been noted in other grass species, including bermudagrass (Dudeck et al., 1983), bentgrass (Ahmad et al., 1981), and Seashore paspalumgrass (Dudeck and Peacock, 1985). The decrease in tissue K concentration and increase in Na both exhibited a nonlinear response, with a maximum at ≈ 10 dS·m⁻¹. This pattern may represent a substitution of Na for K within the plant until a threshold level is reached. Sodium can substitute for K in substantial quantities with no growth reduction (Cope et al., 1953), although there can be an interaction with other cations.

Plant response to Na varies greatly depending on the species, the ratio of Na to other cations, and the total concentration (Devitt et al., 1984; Elgabaly, 1955; and Rathert, 1982). Accumulation of Na in *Puccinellia distans* also appears to reach a maximum concentration at 80 meq/100 g tissue content (Lunt et al., 1961), while tissue Na concentrations in *Agrostis stolonifera* continued to increase up to 300 mM NaCl in the rhizosphere (Ahmad et al., 1981). Francois (1988) found that tissue Na increased as soil salinity increased with three bermudagrass cultivars. Wu (1981) noted that a lack of salt tolerance in certain genotypes of *A. stolonifera* and *A. tenuis* may be due to an inability of those varieties to exclude Na. Data from our research support a maximum for absorption and substitution of Na for K ions, which also could compete effectively with other cations and affect overall plant nutritional balance. Despite K fertilization not normally being strongly linked to increased top growth responses in turfgrasses, there was a strong correlation of tissue K levels to both

Fig. 2. Influence of salinity on P and K concentration in topgrowth of St. Augustinegrass cultivars.

top growth and root growth for all cultivars (Table 2).

Cultivars varied in their ability to absorb Ca and Mg under salt stress. Leaf tissue content of Ca and Mg decreased nonlinearly with increased salinity (Fig. 2). All cultivars initially had higher Ca contents than Mg in their tissue. At the first salt increment, tissue Ca levels fell rapidly below the Mg concentration. 'Floratine' was the least efficient absorber based on reduction of both Ca and Mg tissue concentrations under increased salinity (Table 3; Fig. 3). Tissue Ca concentration response of 'Floratine' to increased salinity was the opposite of K. The EC level that effected a 50% reduction in tissue Ca content was 24% lower for 'Floratine' than for other cultivars (Table 3). This nutritional difference apparently has no direct connection to yield, since top growth was more closely correlated to K than Ca or Mg (Table 2). Calcium is linked

to membrane permeability and osmotic adjustment, and growth can be affected when Na : Ca ratios exceed 17: 1 (Greenway and Munns, 1980). In this study, even with 'Floratine', which had the lowest leaf tissue Ca concentration, the Na : Ca ratio did not exceed 14: 1 and, therefore, Ca levels may have been adequate to maintain nutritional balance.

Intensity of greenness is used as an indicator of plant vigor. Color scores of St. Augustinegrass were taken at 7 and 8 weeks and averaged over all salinity levels (Table 4). 'Seville' had the highest color scores and 'Floratine' the lowest. 'Floralawn' and 'Floratam' were intermediate, although similar to 'Seville' at 7 weeks. There was a stronger correlation of color to tissue Ca ($r = 0.712$, $P = 0.001$) and Mg ($r = 0.629$, $P = 0.001$) levels in 'Floratine' than in 'Seville' (Table 5). Data for Mg were too variable to permit inverse

Table 3. Predicted electrical conductivity of the solution medium to effect a 50% reduction in leaf tissue levels of Ca and K for St. Augustinegrass cultivars.

Cultivar	Ca <i>ds·m⁻¹</i>	K
Floratam	17.5 a ²	14.3 b
Floralawn	17.4 a	14.8 b
Seville	17.1 a	14.2 b
Floratine	13.4 b	19.4 a

²Mean within columns by the Waller-Duncan K-ratio *t* test, $P \leq 0.05$.

Table 4. Color scores of four St. Augustinegrass cultivars averaged over salinity levels after 7 and 8 weeks of salinization.

Cultivar	Time of rating (week)		Mean
	7	8	
Seville	6.8 a ²	6.6 a	6.7 a
Floralawn	6.5 a	5.9 b	6.2 b
Floratam	6.4 a	5.8 b	6.1 b
Floratine	5.5 b	5.0 c	5.2 c

²Mean separation within columns by the Waller-Duncan K-ratio *t* test, $P \leq 0.05$.

Fig. 3. Influence of salinity on Mg and Ca concentration in topgrowth of St. Augustinegrass cultivars.

regression analysis, but tissue content of Mg decreased 27%, 16%, 14%, and 13% at 10.3 dS·m⁻¹ in 'Floratine', 'Floratum', 'Floralawn' and 'Seville', respectively, compared to the lowest salinity treatment. Relationship of color to Mg content is well-known based on chlorophyll production. However, correlation of Ca to color is not as clear. In Kentucky bluegrass, color differences have been noted among cultivars in seedlings in Ca-deficient soil (Nittler and Kenny, 1972). Therefore, color differences found here may be due to differential Ca absorption under saline conditions. Possibly in the presence of low Ca or high Na, other cations, such as Fe, were precipitated in the cytoplasm by organic acids, which were produced in response to salinity stress (Osmond, 1963).

Top growth and root growth correlated better with solution conductivity than with leaf elemental content (Table 2). This relationship suggests that the bulk of the growth reductions were due to osmotic effects and not a nutritional imbalance. This conclusion is similar to that formed by Hughes et al. (1975), that tissue nutrient content does not always relate directly to salinity tolerance. Differences in growth between 'Seville' and the other three cultivars may be related, in part, to nutritional differences. Tissue concentrations of Ca, Mg, and K were not as highly correlated with top growth of 'Seville' as with the other three cultivars. Chlorine and Na also appear to be involved in the cultivar differences. Chlorine content of leaves correlated very highly to

Table 5. Correlation coefficients of elemental content of leaves and color scores for four St. Augustinegrass cultivars grown in six levels of saline solution medium.

Cultivar	Ca	K	Mg	Na	Cl
Floralawn	0.685 ***	0.587 ***	0.304 NS	-0.513 **	-0.320 NS
Floratum	0.559 ***	0.567 ***	0.318 NS	-0.379 *	-0.220 NS
Floratine	0.712 ***	0.529 **	0.629 ***	-0.473 **	-0.246 NS
Seville	0.400 *	0.398 *	0.401 *	-0.265 NS	-0.217 NS

NS, *, **, *** Nonsignificant or significant at $P \geq 0.05$, 0.01, and 0.001, respectively.

solution conductivities for all four cultivars, but Cl was not as highly correlated with top growth in 'Seville' as with top growth in the other three cultivars. The same pattern held true for Na, although correlation coefficients are of a lower magnitude (Table 2). This, combined with the fact that no significant interaction was found for leaf Cl or Na content with EC (Table 1), suggests that 'Seville' is more efficient at synchronizing uptake and compartmentalizing these ions than at differentiating ion uptake and assimilation.

Growth reductions in St. Augustinegrass due to excess soluble salts in the root zone are a function of loss of turgor potential and ionic imbalances in the tissue (Marschner, 1986). The relative contributions of these two factors are difficult to ascertain, but this research suggests that osmotic stress is more important in overall growth reductions, while ionic differences in the tissue account for cultivar differences in St. Augustinegrass. 'Seville' is by far the most tolerant to salinity in the root zone among these four cultivars.

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