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 (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.
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 x 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 x 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-
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), alkaliagrass (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 \( \approx 10 \text{ dS·m}^{-1} \) 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 alkaliagrass, 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 \( \approx 10 \text{ dS·m}^{-1} \). 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...
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

![Graphs showing the influence of salinity on P and K concentration in topgrowth of St. Augustinegrass cultivars.](image)

**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 (Mg) | K (Ca) |
|-----------|---------|--------|
| Floratam  | 17.5 a' | 14.3 b |
| Floralawn | 17.4 a  | 14.8 b |
| Seville   | 17.1 a  | 14.2 b |
| Floratine | 13.4 b  | 19.4 a |

$^a$Mean 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'                 | 6.6 a | 6.7 a |
| Floralawn | 6.5 a                  | 6.9 b | 6.2 b |
| Floratam  | 6.4 a                  | 5.8 b | 6.1 b |
| Floratine | 5.5 b                  | 5.0 c | 5.2 c |

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

J. Amer. Soc. Hort. Sci. 118(4):464-469. 1993.
regression analysis, but tissue content of Mg decreased 27%, 16%, 14%, and 13% at 10.3 dS·m⁻¹ in 'Floratine', 'Floratam', '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

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

NS, *, **, *** Nonsignificant or significant at P ≥ 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.

**Literature Cited**

Ahmad, I., S.J. Wainwright, and G.R. Stewart. 1981. The solute and water relations of Agrostis stolonifera ecotypes differing in their salt tolerance. New Phytol. 87:615-629.

Beard, J.B. 1973. Turfgrass: Science and culture. Prentice Hall, Englewood Cliffs, N.J.

Bernstein, L. and H.E. Hayward. 1958. Physiology of salt tolerance. Annu. Rev. of Plant Physiol. 9:25-46.

Cope, Jr., J.T., R. Bradfield, and M. Peech. 1953. Effects of sodium fertilization on yield and cation content of alfalfa and cotton. Soil Sci. 76:65-74.

Cordukes, W.E. and E.V. Parups. 1971. Chloride uptake by various turfgrass species and cultivars. Can. J. Plant Sci. 51:485-490.

Devitt, D., L.H. Stolzy, and W.M. Jarrell. 1984. Responses of sorghum and wheat to different K/Na ratios at varying osmotic potentials. Agron. J. 76:681-685.

Dudeck, A.E., S. Singh, C.E. Giordano, T.A. Nell, and D.B. McConnell. 1983. Effects of sodium chloride on Cynodon turfgrasses. Agron. J. 75(6):927-930.

Dudeck, A.E. and C.H. Peacock. 1985. Effects of salinity on Seashore Paspalum turfgrasses. Agron. J. 77(1):47-50.

Elgabaly, M.M. 1955. Specific effects of absorbed ions on plant growth: 1. Effect of different combinations of calcium, magnesium, and sodium on barley seedlings. Soil Sci. 80:235-238.

Francois, L.E. 1988. Salinity effects in three turf bermudagrasses. HortScience. 23:706-708.

Greenway, H. and R. Munns. 1980. Mechanism of salt tolerance in nonhalophytes. Annu. Rev. Plant Physiol. 31:149-190.

Harivandi, M.A., J.D. Butler, and P.N. Soltanpour. 1982. Effects of seawater concentrations on germination and ion accumulation in alkali grass (Puccinellia spp.). Commun. Soil Sci. Plant Anal. 13(7):507-515.

Hewitt, E.I. 1963. The essential nutrient elements: Requirements and interactions in plants. vol. III, p. 137-360. In: F.C. Steward (ed.). Plant physiology, a treatise. Academic Press, New York.

Hughes, T.D., J.D. Butler, and G.D. Sanks. 1975. Salt tolerance and suitability of various grasses for saline roadsides. J. Environ. Quality 4(1):65-68.

Lunt, O.R., V.B. Youngner, and J.J. Oertli. 1961. Salinity tolerance of five turfgrass varieties. Agron. J. 53:247-249.

Marschner, H. 1986. Mineral nutrition of higher plants. Academic Press, New York.

Mitchell, Jr., C.C. and R.D. Rhue. 1979. Procedures used by the University of Florida Soil Testing and Analytical Research Laboratories. Soil Sci. Res. Rpt. 79-1. Univ. of Fla., Inst. Food Agr. Sci., Gainesville.

Nittler, L.W., and T.J. Kenny. 1972. Cultivar differences among calcium-deficient Kentucky bluegrass seedlings. Agron. J. 64:73-75.

Osmond, C.B. 1963. Oxalate and ionic equilibria in Australian salt bushes. Nature. 198:503-504.

Parker, G.G. 1975. The hydrogeology and problems of peninsular Florida’s water resources. Proc. Fla. Turf Grass Mgt. Conf. 22:13-36.

Rathert, G. 1982. Influence of extreme K:Na ratios and high substrate salinity on plant metabolism of crops differing in salt tolerance. V. Ion-specific salinity effects on invertase in leaves of bushbean and sugarbeet plants. J. Plant Nutr. 5(2):97-109.

Shannon, M.C. 1978. Testing salt tolerance variability among tall wheatgrass lines. Agron. J. 70:719-722.

Svedrup, H.V., M.W. Johnson, and R.H. Fleming. 1959. The oceans, their physics, chemistry, and general biology. Prentice Hall, Englewood Cliffs, N.J.

Wu, L. 1981. The potential for evolution of salinity tolerance in Agrostis stolonifera L. and Agrostis tenuis Sibth. New Phytol. 89:471-486.

Youngner, V.B. and O.R. Lunt. 1967. Salinity effects on roots and tops of Bermudagrass. J. British Grassland Soc. 22:257-259.