Salinity Tolerance of Selected Seashore Paspalums and Bermudagrasses: Root and Verdure Responses and Criteria

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Abstract. Seashore paspalum (Paspalum vaginatum Swartz) is a warm season turfgrass that survives in sand dunes along coastal sites and around brackish ponds or estuaries. The first exposure to salt stress normally occurs in the rhizosphere for persistent turfgrass. Information on diversity in salinity tolerance of seashore paspalums is limited. From Apr. to Oct. 1997, eight seashore paspalum ecotypes (SI 94-1, SI 92, SI 94-2, ‘Sea Isle 1’, ‘Excalibur’, ‘Sea Isle 2000’, ‘Salam’, ‘Adalayd’) and four bermudagrass (Cynodon dactylon × C. transvaalensis Butt-Davy) cultivars (‘Tifgreen’, ‘Tifway’, ‘TifSport’, ‘TifEagle’) were investigated for levels of salinity tolerance based on root and verdure responses in nutrient/sand culture under greenhouse conditions. Different salt levels (1.1 to 41.1 dS·m−1) were created with sea salt. Measurements were taken for absolute growth at 1.1 (ECw0; electrical conductivity of water), 24.8 (ECw24), 33.1 (ECw32), and 41.1 dS·m−1 (ECw40), threshold ECw and ECw for 25% growth reduction from ECw0 growth (ECw25%). Varying levels of salinity tolerance among the 12 entries were observed based on root, verdure, and total plant yield. Ranges of root characteristics were inherent growth (ECw0 = 0.20 to 0.61 g dry weight (DW)); growth at ECw24 = 0.11 to 0.47 g; growth at ECw32 = 0.13 to 0.50 g; growth at ECw40 = 0.13 to 0.50 g; threshold ECw = 3.1 to 9.9 dS·m−1; and ECw25% = 23 to 39 dS·m−1. For verdure, ranges were inherent growth at ECw0 = 0.40 to 1.07 g DW; growth at ECw40 = 0.31 to 0.84 g; and ratio of yields at ECw40 to ECw0 = 0.54 to 1.03. Ranges for total growth were inherent growth at ECw0 = 0.72 to 2.66 g DW; growth at ECw24 = 0.55 to 2.23 g; growth at ECw32 = 0.54 to 2.08 g; growth at ECw40 = 0.52 to 1.66 g; threshold ECw = 2.3 to 12.8 dS·m−1; and ECw25% = 16 to 38 dS·m−1. Significant salinity tolerance differences existed among seashore paspalums and bermudagrasses as demonstrated by root, verdure, and total growth measurements. When grasses were ranked across all criteria exhibiting a significant F test based on root, verdure, and total growth, the most tolerant ecotypes were SI 94-1 and SI 92. Salinity tolerance of bermudagrass cultivars was relatively lower than SI 94-1 and SI 92. For assessing salinity tolerance, minimum evaluation criteria must include absolute growth at ECw0 and ECw40 dS·m−1 for halophytes, but using all significant parameters of root and total yield is recommended for comprehensive evaluation.

Salt-related problems have increased on turfgrass areas in the last 25 years in response to golf course construction near coastal sites, water shortages, and legal regulations requiring the use of nonpotable water (Carrow and Duncan, 1998; Marcum, 1999). One strategy to deal with salinity stress is to develop and use turfgrass species or cultivars with enhanced salinity tolerance. Hybrid bermudagrasses, widely used for turfgrass sites in the southern United States, have been reported to be relatively tolerant up to 35 dS·m−1 for 10 months in sand culture (Francois, 1988). However, the intraspecific and interspecific variabilities were also evident among the grasses evaluated based on salinity studies (Dudeck et al., 1983; Francois, 1988; Marcum and Murdoch, 1990). Seashore paspalum is a warm season turfgrass that inhabits sand dunes along coastal sites, and swampy ecosystems (Duncan, 1999a). It has considerable intraspecific diversity for various environmental stresses, including drought, wear, pests, and soil acidity (Duncan, 1999b; Trenholm et al., 1999). Seashore paspalum is considered to be more salt tolerant than the bermudagrasses, among turfgrasses that are available (Harivandi et al., 1984; Marcum and Murdoch, 1990, 1994). Also, the species displays a quite diverse salinity tolerance range, with a selection from Hawaii exhibiting shoot growth reduction of 50% at 40 dS·m−1, while a selection from Florida had 28.6 dS·m−1 (Dudeck and Peacock, 1985; Marcum and Murdoch, 1994). Therefore, information on relative salinity tolerance of seashore paspalums to the predominant bermudagrasses in areas for warm-season turfgrasses will provide breeders and turf managers with diverse choices.

Many turfgrass scientists have explained root characteristics when evaluating turfgrass response to salinity stress, even though root aspects are not included in traditional salinity tolerance classification schemes for agronomic or horticultural crops (Maas and Hoffman, 1977). Root measurement as an indicator of salinity tolerance has been conducted for several grass species, including ‘Seaside’ creeping bentgrass (Agrostis palustris Huds.) (Kuo et al., 1994), Kentucky bluegrass (Poa pratensis L.) (Kim et al., 1991), ‘Dawson’ red fescue (Festuca rubra L.) (Ashraf et al., 1986), bermudagrass (Cynodon sp.) (Dudeck et al., 1983), st. augustinegrass (Stenotaphrum secundatum [Walt.] Kuntze) (Dudeck et al., 1993; Meyer et al., 1989), zoysiagrass (Zoysia sp.) (Kim et al., 1991; Marcum, 1999), and seashore paspalum (Dudeck and Peacock, 1985).

Regardless of the turfgrass species, extensive root growth is related to improved salinity tolerance, along with better plant survival, lower leaf firing, and higher shoot yield (Marcum and Kopec, 1997). Although less attention has been given to evaluate growth under salinity stress, growth of the crown was relatively unaffected by salinity stress even at a high salinity level (40 dS·m−1), while top growth declined greatly (Dudeck and Peacock, 1985; Dudeck et al., 1993).

Lee (2000) evaluated intraspecific salinity tolerance of seashore paspalum ecotypes based on the traditional approach of using only shoot responses (Maas and Hoffman, 1977) and revealed that: 1) most seashore paspalum ecotypes exhibited halophytic shoot growth patterns that were different from glycophytic crop plants; 2) many seashore paspalum ecotypes demonstrated a high degree of salinity tolerance within ranges of 20 to 41 dS·m−1 levels, while traditional salinity classification does not differentiate salinity tolerance classes above ECw10 dS·m−1; and 3) these differences revealed limitations of traditional salinity evaluation and classification criteria used for glycophytic crops (<10 dS·m−1 tolerance) when applied to halophytes (20 dS·m−1 tolerance). Assessing root and verdure growth criteria for inclusion in salinity tolerance determinations and classification would provide data on the below-ground component of salinity stress in turf plants.

The objectives of this study, therefore, were to 1) evaluate the degree of salinity tolerance among selected seashore paspalum ecotypes and bermudagrasses based on root, verdure, and total growth; 2) determine which evaluation criteria are associated with superior salinity tolerance; and 3) develop selection criteria for classification of salinity tolerance of halophytic grasses that would apply over ranges of salinity levels >10 dS·m−1.

Materials and Methods
Growing conditions and treatments. A solution–sand culture study was conducted at the Georgia Agricultural Experiment Station (Griffin) in a greenhouse from Apr. through Oct. 1997. Eight seashore paspalums (SI 94-1, SI 92, SI 94-2, ‘Sea Isle 1’, ‘Excalibur’,

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HortScience Vol. 39(5) August 2004
1143


1143
treatments were imposed on 1 Aug. 1997. To the microenvironment (2 months), sea-salt was constantly, changed weekly, and maintained in the solutions. To avoid algae growth, all solution (Hoagland and Arnon, 1950). The increased by the addition of 7.3 g·L–1 of sea salt mixture daily until each final salinity level was achieved (Dudek and Peacock, 1985). The average ECw levels measured during the experimental period were 1.1, 24.8, 33.1, and 41.4 dS·m–1. Since the sand in the pots was submerged in the salt soil solution, soil salinity (ECw) was considered to be equal to solution salinity (ECs).

Evaluation of salinity tolerance. After final salinity levels were attained on 6 Aug. 1997, shoots were clipped at 2.5 cm above the soil surface and discarded. An additional clipping was discarded the following week. Therefore, shoot clippings at 2.5 cm (Lee, 2000) were collected biweekly for 6 weeks. Immediately after the final shoot harvest, grass materials, including verdure (crown plus stem up to the mowing height of 2.5 cm) and roots, were carefully removed from the pot, thoroughly washed, and immediately dried in a paper bag at 70°C for 48 h. Roots were measured for dry weight (DW) and the remaining verdure, including crown regions plus grass stems less than the 2.5-cm mowing height, were considered as verdure tissues. Data from root and verdure were combined with the shoot data to determine total growth.

Experimental design and data analysis. Each container had 12 different grasses subjected to one salinity level. The experimental design was a randomized complete block with six replications in a split plot arrangement, with salinity as the main plot and grass entry as the subplot. All data were statistically analyzed with analysis of variance, using least significant difference (LSD) to separate the means among entries, with emphasis on identifying the entries in the top (best) statistical category for the significant measurements based on F test (SAS Institute, 1988). Therefore, all grasses that were found to be statistically similar to the best entry within a column were considered in the top group (Trenholm et al., 1999). Pearson correlation coefficients were examined to determine degree of association between variables.

For the evaluation of salinity tolerance of root and total growth, the following growth and physiological parameters as a function of electrical conductivity were used: Growth ECw0 (control), Growth ECw24, Growth ECw32, and Growth ECw40 (i.e., root growth at 0 = control, 24.8, 33.1, 41.4 dS·m–1, respectively); threshold ECw (threshold ECw is the salinity level associated with maximum root growth after which growth decreases); and ECw25% (salinity level indicating 25% growth reduction from the control). Absolute growth data in dry weight were plotted over the salinity by grass and replication, and threshold ECw and ECw25% were determined by the definition on the plot. Verdure growth was evaluated based on growth at ECw0 and ECw40, and the yield ratio of ECw40 to ECw0.

Results

Inherent growth (growth at ECw0 or the control). Inherent root, verdure, and total yields measured at ECw0 were significantly different among the 12 entries (Tables 1, 2, and 3). Ranges were 0.20 to 0.61 g (3-fold difference) in root weight, 0.40 to 1.07 g (2.7-fold) in verdure weight, and 0.72 to 2.66 g (3.7-fold) in total growth weight. The top seashore paspalum was SI 94-1 for root, verdure, and total growth categories at ECw0. ‘TifEagle’ exhibited the best growth among hybrid bermudagrass cultivars at ECw0, which was 62% (0.38 g) for root, 63% (0.67 g) for verdure, and 43% (1.15 g) for total growth compared to the SI 94-1 seashore paspalum. All seashore paspalums and ‘TifEagle’ bermudagrass exhibited significantly higher root growth at the control than ‘Adalayd’. The SI 94-1 and five seashore paspalums (SI 94-1, SI 92, SI 94-2, ‘Sea Isle 1’, and ‘Sea Isle 2000’) had significantly higher verdure and total growth than ‘Adalayd’ at ECw0, respectively. ‘Adalayd’ comparisons were made, since this cultivar has been the most researched seashore paspalum (Duncan and Carrow, 2000).

Growth at ECw24 and ECw32. Significant differences in root and total growth at ECw24 and ECw32 were found at P < 0.001 levels among 12 entries (Tables 1 and 3). Absolute root growth of seashore paspalum ecotypes at ECw24 ranged from 0.11 to 0.47 g DW, a 4.3-fold difference. Range for total growth was 0.55 to 2.23 g (4-fold). Also, ranges at ECw32 were 0.13 to 0.50 g (3.8-fold difference) for root growth, and 0.54 to 2.08 g (3.8-fold) for total growth.

Four experimental seashore paspalums were grouped in the highest statistical rank for ECw24 root growth with ≥0.38 g DW, while three ecotypes were in the top category for total growth with ≥1.77 g (Tables 1 and 3). Among

Table 1. Root growth characteristics of 12 seashore paspalum and bermudagrass entries responding to increasing salinity levels.

<table>
<thead>
<tr>
<th>Entry</th>
<th>ECw0</th>
<th>ECw24</th>
<th>ECw32</th>
<th>ECw40</th>
<th>Threshold ECw (%)</th>
<th>ECw25% (dS·m–1)</th>
<th>ECw40 to ECw0</th>
<th>Times in top statistical group</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI 94-1 paspalum</td>
<td>0.61</td>
<td>0.43</td>
<td>0.42</td>
<td>0.50</td>
<td>6.3 (0.72)</td>
<td>29 a–c</td>
<td>5/3</td>
<td>2.66 g (3.7-fold)</td>
</tr>
<tr>
<td>SI 92 paspalum</td>
<td>0.47</td>
<td>0.47</td>
<td>0.42</td>
<td>0.42</td>
<td>3.1 (0.51)</td>
<td>33 a–c</td>
<td>5/3</td>
<td>2.75 g (3.7-fold)</td>
</tr>
<tr>
<td>Sea Isle 1 paspalum</td>
<td>0.43</td>
<td>0.40</td>
<td>0.40</td>
<td>0.50</td>
<td>9.4 (0.58)</td>
<td>34 a–c</td>
<td>4/3</td>
<td>2.75 g (3.7-fold)</td>
</tr>
<tr>
<td>Excalibur paspalum</td>
<td>0.41</td>
<td>0.23</td>
<td>0.32</td>
<td>0.31</td>
<td>4.7 (0.45)</td>
<td>23 c</td>
<td>0/5</td>
<td>2.23 g (4-fold)</td>
</tr>
<tr>
<td>Sea Isle 2000 paspalum</td>
<td>0.38</td>
<td>0.31</td>
<td>0.50</td>
<td>0.36</td>
<td>7.3 (0.54)</td>
<td>34 a–c</td>
<td>2/5</td>
<td>1.15 g (3.8-fold)</td>
</tr>
<tr>
<td>TifEagle bermuda</td>
<td>0.36</td>
<td>0.36</td>
<td>0.31</td>
<td>0.28</td>
<td>8.2 (0.46)</td>
<td>38 a</td>
<td>1/5</td>
<td>0.23 g (4-fold)</td>
</tr>
<tr>
<td>Salam paspalum</td>
<td>0.38</td>
<td>0.39</td>
<td>0.32</td>
<td>0.29</td>
<td>9.9 (0.42)</td>
<td>39 a</td>
<td>1/5</td>
<td>0.50 g (3.8-fold)</td>
</tr>
<tr>
<td>Tifgreen bermuda</td>
<td>0.30</td>
<td>0.27</td>
<td>0.30</td>
<td>0.23</td>
<td>1.3 (0.21)</td>
<td>25 bc</td>
<td>0/5</td>
<td>0.11 g (4-fold)</td>
</tr>
</tbody>
</table>

| F test | **NS** | **NS** | **NS** | **NS** | **NS** |
| cv (%) | 40     | 33     | 36     | 34     | 99     | 32     |

a Growth at control, 24.8, 33.1, and 41.4 dS·m–1, respectively.

b Values in the parentheses represent the absolute shoot growth (g DW) at the threshold salinity.

c Denotes the number of times of the grass ranked in the top (best) group for the measurements with a significant F test; namely, ECw0, ECw24, ECw32, ECw40, and ECw25%.

Means (n = 6) followed by the same letter within a column do not differ at P ≤ 0.05.

***NS*** = Non-significant or significant at P ≤ 0.001, respectively.
hybrid bermudagrass cultivars, ‘TifEagle’ had the highest root and total yield at ECw24 (0.36 and 1.37 g, respectively). Six seashore paspalums with root growth ≥0.39 g and four seashore paspalums with total growth ≥1.64 g were in the top statistical group at ECw32. ‘TifWay’ had the highest root and total yield at ECw32 among hybrid bermudagrass cultivars (0.31 and 1.23 g, respectively).

Two seashore paspalums (SI 92 and ‘Salam’) exhibited equal root growth and two ecotypes, SI 94-2 and ‘Salam’, had increased total growth from ECw0 to ECw24. Only ‘TifWay’ among hybrid bermudagrasses exhibited increased root and total growth from ECw0 to ECw24, but this cultivar had low inherent root (0.22 g) and total (0.72 g) growth (36% and 27% of root and total growth of the best seashore paspalum, respectively), which was statistically similar to ‘Adalayd’ (0.20 and 1.00 g, respectively).

Enhanced root and total yield with increasing salinity from ECw24 to ECw32 was also evident (Tables 1 and 3). The three seashore paspalum ecotypes showing the greatest root increase (>30%) were, ‘Sea Isle 2000’ (61%), ‘Excalibur’ (39%), and ‘Sea Isle 1’ (31%). Also, two ecotypes with total growth >10% increase were ‘Excalibur’ (19%) and SI 92 (11%). Among hybrid bermudagrass cultivars, ‘TifSport’ (7%) and ‘TifGreen’ (4%) in root growth and ‘TifGreen’ (17%) in total growth also exhibited increased yield at ECw32 from ECw24, but had relatively low inherent root and total growth at ECw0 (34% and 49% for root and 41% for total growth of the best seashore paspalum, respectively).

**Growth at ECw40.** Significant differences among the 12 entries were found at P < 0.001 level in root, verdure, and total growth at ECw40 (Tables 1, 2, and 3). Root growth range of seashore paspalums at ECw40 was from 0.13 to 0.50 g DW (3.8-fold difference) and range of bermudagrasses was 0.15 to 0.28 g. Growth of verdure ranged from 0.31 to 0.84 g (2.7-fold) and 0.31 to 0.68 g for seashore paspalums and bermudagrasses, respectively. Range for total growth at ECw40 was 0.52 to 1.66 g (3.2-fold) and 0.53 to 1.03 g for seashore paspalums and bermudagrasses, respectively.

Three seashore paspalum ecotypes were in the top statistical group in root growth at ECw40, which was ≥0.39 g (Table 1). At ECw40, six seashore paspalums ranked in the top category in verdure growth and two in total growth with ≥0.63 and 1.53 g, respectively (Tables 2 and 3). Among hybrid bermudagrass cultivars, ‘TifEagle’ had the highest root, verdure, and total growth, but was ranked in the top group only in verdure growth category. Eight seashore paspalums had significantly greater root, verdure, and total yield than ‘Adalayd’ at ECw40 (Tables 1, 2, and 3). Four hybrid bermudagrass cultivars had higher root, verdure, and total yield than ‘Adalayd’, but only ‘TifEagle’ exhibited significantly higher for the three categories.

SI 94-1 ecotype exhibited 19% increased root growth at ECw40 compared to ECw32 (Table 1). In the ratio between ECw0 and ECw40, one seashore paspalum cultivar, ‘Salam’ showed increased verdure yield at ECw40 than at ECw0 (Table 2). ‘TifEagle’ had the highest in verdure growth at ECw40 among hybrid bermudagrasses. ‘TifEagle’ and ‘TifWay’ bermudagrasses showed slight increases (1% and 3%, respectively) in verdure growth at ECw40 compared to ECw0.

**Threshold ECw.** Both root and total growth threshold ECw of paspalums showed a nonsignificant F-test, where threshold ECw of roots ranged from 3.1 (SI 92) to 9.4 dS·m–1 (SI 94-2) and threshold ECw of total growth was from 2.3 (‘Excalibur’) to 12.8 dS·m–1 (SI 94-2) (Tables 1 and 3). Threshold ECw for root growth for ‘Adalayd’ was 5.0 dS·m–1, compared to hybrid bermudagrass cultivars ranging from 4.1 (‘TifSport’) to 9.9 dS·m–1 (‘TifWay’). Threshold ECw for total growth of ‘Adalayd’ was 4.1 dS·m–1 and the hybrid bermudagrass cultivars ranged from 3.9 (‘TifSport’) to 9.1 dS·m–1 (‘TifWay’).

**ECw25%.** ECw for 25% reduction was significantly different among the 12 entries at P < 0.001 level in root and total growth (Tables
1 and 3, ECw 25% in root growth varied from 23 (‘Excalibur’) to 37 dS·m–1 (‘Salam’) and ‘Tifway’ had the highest ECw 25% value (39 dS·m–1) among the 12 entries (Table 1). Comparatively, the values of ECw 25% for total growth were from 16 (‘Excalibur’) to 38 dS·m–1 (‘Salam’). ‘Tifway’ showed the highest (35 dS·m–1) among bermudagrasses. Six seashore paspalums and four bermudagrass cultivars among the 12 entries were in the top statistical group for ECw 25% reduction in root and total growth except for ‘Excalibur’ and ‘Adalayd’ (Tables 1 and 3).

**Pearson correlation coefficients.** Root growth at ECw0 was positively correlated with root growth at ECw 24, ECw 32, and ECw 40 at r = 0.68, 0.65, and 0.61, respectively (Table 4). Two seashore paspalums, SI 94-1 and SI 92, in the top group in root growth at ECw 0 appeared in the top group at ECw 40 (Table 1). Significant correlation (P < 0.001) of total growth at ECw 0 vs. ECw 24, ECw 32, and ECw 40 were r = 0.65, 0.65, and 0.67, respectively (Table 4). Two seashore paspalum ecotypes, SI 94-1 and SI 92, were ranked in the best category at ECw 40 growth and they were also appeared in the best group for measurements at ECw 24 and ECw 32. Correlation coefficients of threshold ECw to other variables were mostly nonsignificant, but yield at the threshold ECw, indicating the maximum growth, was highly correlated with yield measurements at other salinity levels for both root and total growth (Table 4).

**Discussion**

Traditional salinity tolerance classification criteria are based only on shoot parameters (Maas, 1987; Maas and Hoffman, 1977). Shoot parameters are important, and seashore paspalum ecotypes have been classified into several groups relative to salinity tolerance over the ECw 20 to 41 dS·m–1 range, based solely on shoot aspects (Lee, 2000). High salinity, however, can potentially influence root and verdure tissues through: 1) direct specific ion toxicity; 2) reduced water uptake; or 3) ion toxicity and uptake into shoot tissues that result in reduced photosynthesis or increased respiration (Carrow and Duncan, 1998). Therefore, for perennial turfgrass that may exhibit halophytic characteristics and be used in salt-affected soils, root and verdure responses should be also considered in salinity tolerance assessment.

Turfgrass scientists have found root differences related to salinity stress for several turf species. For a salt-affected site, a turfgrass needs to have inherently vigorous root growth under low salinity and be able to maintain high root growth when exposed to salt-induced growth reductions. Furthermore, high inherent production of root or verdure tissues would provide better adaptation through competitive growth and rapid recovery under other adverse abiotic/edaphic stresses, such as low soil oxygen and moisture, high soil strength and temperature, toxicities, and nutrient problems, on sodic or saline-sodic soils (Duncan and Carrow, 1999).

If a limited set of root parameters is used for assessing turfgrass salinity tolerance, our results suggest that absolute growth at ECw 0 and ECw 40 dS·m–1 would be the most useful. At ECw 40, seashore paspalums ranked in the top group could further be separated based on whether: 1) the ecotype had a high inherent root growth rate, and was able to sustain adequate growth; or 2) an entry exhibited more modest inherent root growth, but had a strong positive growth response with increased salinity (Lee, 2000). A high ECw 25% may appear to be a useful criterion for ranking grasses for root salinity tolerance, but this criterion provided poor separation of ecotypes (Table 1).

A more complete set of root criteria for salinity tolerance classification incorporating parameters across a wide range of salinity levels would be to use all root parameters exhibiting a significant ecotype F-test. All root parameters except threshold ECw statistically separated entries (Table 1). Based on the number of times ranked in the top statistical group, only SI 94-1 and SI 92 ranked in the top for all five significant measurements in root growth. Some seashore paspalums (SI 92, ‘Sea Isle 1’, ‘Excalibur’, ‘Sea Isle 2000’, ‘Salam’) had higher root growth in response to increasing salinity (ECw 24 or 32) than at ECw = 0 dS·m–2 salinity (Table 1). Halophytes often exhibit positive shoot or root responses as salinity increases, but this is normally observed at salinity levels between ECw 10 to 20 dS·m–1 rather than ECw >20 dS·m–1. Salinity tolerance of roots may be associated with incorporation of short chain fatty acids in root plasma membranes (Kuiper, 1984; Wu et al., 1998), increased ATPase activities in root membranes (Kuiper, 1984; Mansour et al., 1998), increased glucose incorporation into root cell wall polysaccharides (Sweet et al., 1990; Zhong and Lauchli, 1993), or synthesis of osmolytes in roots (Bohnert and Shen, 1999; Ishitani et al., 1996).

High inherent verdure growth at low and high salinity would be desirable, since root regrowth comes from this region and carbohydrate allocation under stress conditions in this region will dictate persistence of roots and shoots. Both verdure growth at ECw 0 and ECw 40 separated ecotypes, but not the ratio of ECw 40 to ECw 0 growth (Table 2). Only SI 94-1 ranked in the top growth group for both attributes.

Total growth incorporates roots, verdure, and the aboveground shoot data (Lee, 2000). Higher inherent total growth (absolute growth basis) is also important for recreational grasses under stress, which require vigorous growth to overcome wear as well as the salinity decline (Lee, 2000). For frequency of appearance in the top statistical group for total growth measurements (five significant parameters except threshold ECw), SI 94-1 appeared in the top group for the five measurements. SI 92 seashore paspalum ecotype ranked in four out of five and followed by SI 94-2, ‘Sea Isle 1’, ‘Sea Isle 2000’, and ‘Salam’ (two times in the top group).

Encompassing root, verdure, and total growth measurements, the most salinity-tolerant entries were SI 94-1 and SI 92, based on the number of times ranked in the top group for the significant measurements. Hawaiian selections were reported earlier as ecotypes with excellent salinity tolerance, based only on shoot responses (Marcus and Murdoch, 1994). Four hybrid bermudagrass cultivars had equal or lower salinity tolerance compared to the other seashore paspalums in terms of root, verdure, and total growth.

Salinity tolerance is complex. With perennial turfgrasses, interactions between levels of salt stress and other abiotic/edaphic constraints compound the problem. The first exposure to salt-related problems normally occurs in the rhizosphere, and selection criteria for persistent grasses should realistically include root measurements and other criteria linked to genetic root tolerance. Also, turfgrasses capable of maintaining high inherent total and root growth under salinity stress should be desirable, since growth reductions of 50% are not uncommon. Additional research to elucidate the multiple tolerance mechanisms involved in halophytic responses to saline conditions would be valuable. Genetic improvements in the salt tolerance mechanisms may further enhance the long-term performance and persistence of turfgrasses when exposed to salt-laden effluent, brackish water, or even seawater (Duncan and Carrow, 1999; Yeo, 1998).

The first step for turfgrass performance improvement for salinity tolerance is to identify

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**Table 4. Pearson correlation coefficients for inherent root and total growth (GECw 0), growth at ECw 24, ECw 32, ECw 40 (GECw 24, GECw 32, and GECw 40, respectively), threshold ECw, growth at threshold ECw (GTECw), ECw for 25% growth reduction (ECw 25%).**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GECw 24</th>
<th>GECw 32</th>
<th>GECw 40</th>
<th>Threshold ECw</th>
<th>GTECw</th>
<th>ECw 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root growth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GECw 0</td>
<td>0.68***</td>
<td>0.65***</td>
<td>0.61***</td>
<td>-0.28***</td>
<td>0.94***</td>
<td>0.03***</td>
</tr>
<tr>
<td>GECw 24</td>
<td>0.85**</td>
<td>0.85**</td>
<td>0.85**</td>
<td>0.06**</td>
<td>0.78***</td>
<td>0.43***</td>
</tr>
<tr>
<td>GECw 32</td>
<td>0.88**</td>
<td>0.88**</td>
<td>0.88**</td>
<td>0.02**</td>
<td>0.75**</td>
<td>0.39***</td>
</tr>
<tr>
<td>GECw 40</td>
<td>0.03*</td>
<td>0.03*</td>
<td>0.03*</td>
<td></td>
<td>0.70***</td>
<td>0.38***</td>
</tr>
<tr>
<td>Threshold ECw</td>
<td>-0.06 -0.06</td>
<td>-0.06 -0.06</td>
<td>-0.06 -0.06</td>
<td></td>
<td>0.52***</td>
<td>0.19***</td>
</tr>
<tr>
<td>GTECw</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Total growth</td>
<td>0.65***</td>
<td>0.65***</td>
<td>0.67***</td>
<td>-0.19*</td>
<td>0.94***</td>
<td>-0.18***</td>
</tr>
<tr>
<td>GECw 24</td>
<td>0.88**</td>
<td>0.88**</td>
<td>0.88**</td>
<td>0.24**</td>
<td>0.79***</td>
<td>0.27***</td>
</tr>
<tr>
<td>GECw 32</td>
<td>0.92**</td>
<td>0.92**</td>
<td>0.92**</td>
<td>0.19**</td>
<td>0.77***</td>
<td>0.24***</td>
</tr>
<tr>
<td>GECw 40</td>
<td>0.17**</td>
<td>0.17**</td>
<td>0.17**</td>
<td>0.80**</td>
<td>0.22***</td>
<td></td>
</tr>
<tr>
<td>Threshold ECw</td>
<td>0.06 0.06</td>
<td>0.06 0.06</td>
<td>0.06 0.06</td>
<td></td>
<td>0.51***</td>
<td>-0.05***</td>
</tr>
</tbody>
</table>

NS, *, **, ***: NONSIGNIFICANT OR SIGNIFICANT AT P ≤ 0.05, 0.01, and 0.001, respectively.
the most tolerant types. For halophytes like seashore paspalum, traditional shoot-based criteria and evaluation at <20 dS m⁻¹ salinity are not sufficient. Significant ecotype differences can be identified at salinity levels greater than 10 to 41 dS m⁻¹ ECw range, and ecotypes with very high salinity tolerance in the upper region of this range can be identified.

**Literature Cited**


