Growth Responses of Selected Warm-Season Turfgrasses under Salt Stress

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Abstract

Use of low quality/saline water for turf irrigation, especially in regions experiencing water shortage is increasing. This imposes more salt stress on turfgrasses which are already under stress in these regions. Therefore, there is a great need for salt tolerant turfgrasses to survive under such stressful conditions. This study was conducted in a greenhouse, using hydroponics system, to compare growth responses of three warm-season turfgrasses, bermudagrass (Cynodon dactylon L.), cv. Tifway 419, seashore paspalum (Paspalum vaginatum Swartz), cv. Sea Isle 2000, and saltgrass (Distichlis spicata L), accession A55 in terms of shoot and root lengths and DM, and canopy green color (CGC) under salt stress condition. Whole plants, stolons, and rhizomes were grown in Hoagland solution for 4 months prior to initiation of salt stress. Then, plants were grown for 12 weeks under 4 treatments (control, 7000, 14000, and 21000 mg/L NaCl) with 4 replications in a RCB design trial. During the stress period, shoots were clipped bi-weekly for DM production, shoot and root lengths were measured, and CGC was evaluated weekly. The bi-weekly clippings and the roots at the last harvest were oven dried at 60^{o} C and DM weights were recorded. Shoot and root lengths and shoot DM weights decreased linearly with increased salinity for bermudagrass and paspalum. However, for saltgrass these values increased at all NaCl levels compared with the control. For bermudagrass and paspalum, the highest values were obtained when the whole plants were used, and the lowest ones resulted when the rhizomes were used. The reverse was found for saltgrass. For the control plants, the measured factors were higher and the canopy colors were greener for bermudagrass and paspalum compared with saltgrass. The canopy color changed to lighter green for bermudagrass and paspalum as NaCl salinity increased, but saltgrass maintained the same color regardless of the level of salinity.

Introduction

Soil salinity and water quality and quantity are major problems worldwide, especially in desert regions which commonly encounter these problems (Glenn et al., 1997; Miyamoto et al., 1996; Westcot, 1988). Under these conditions, turfgrass managers must deal with reduced growth, tissue dehydration, nutritional imbalances, and specific ion toxicities, slow recovery from injury, and poor long-term persistence that can be caused by salinity stress whether originated from the soil or water (Carrow and Duncan, 1998; Katerji et al., 2000).

One strategy to enhance plants and turfgrasses survival and recovery from salt stress is to use cultivars with superior salinity tolerance (Ashraf, 1994; Flowers and Yeo. 1995; Glenn et al., 1999). However, development of salt-tolerant cultivars is not simple because the trait is quantitative, controlled by many physiological mechanisms and genes (Cushman and Bohnert, 2000; Grover et al., 1999; Holmberg and Bulow, 1998), and lacks a standardized screening protocol at both intra- and inter-species levels (Ashraf, 1994; Flowers and Yeo, 1995). Therefore, reliable selection criteria are fundamental for developing salt-tolerant cultivars.

Turfgrasses must maintain cosmetic appeal, adequate growth, and persistence under variable levels of soil salinity and low quality saline water conditions over several years. Successful assessment of salinity tolerance of perennial, halophytic turf grasses, therefore, should be based on growth under normal (non-saline), low, intermediate, and high salinity levels of soil and/or water. In addition to shoot evaluation, root and verdure parameters should be measured in tolerance assessment, especially for grasses exposed to combined biotic or abiotic stresses (Ashraf, 1994; Duncan and Carrow, 1999; Lee et al., 2004).

Therefore, halophytic turfgrasses like bermudagrass, seashore paspalum, and saltgrass need to be evaluated at salinity regimes up to sea water level, $\sim EC_w = 54$ dS m^{-1} or $\sim$34,560 mg L^{-1} (Duncan and Carrow, 1999) to select the best genotype. Unfortunately, salt problems in turfgrass sites are continually becoming more common. However, fortunately, turfgrass researchers and turf breeders are continuously working and are finding more stress tolerance turf species/cultivars for growth under stressful (i.e., salinity and drought) conditions (Ashraf, 1994; Chen and Murata, 2002; Cushman and Bohnert, 2000; Duncan and Carrow, 1999; Flowers and Yeo, 1995; Grover et al., 1999; Holmberg and Bulow, 1998; Lee et al., 2004; Marcum et al., 2005; Pessarakli et al., 2006). These turfgrass species/cultivars can grow and perform satisfactory growth in a wide range of climates, soils, and environmental conditions. Furthermore, these grasses can be manipulated to produce dwarf varieties which require less mowing as well as more stress (i.e., salinity and drought) tolerant cultivars/genotypes which require less maintenance and grow in poor soil conditions (Duncan and Carrow, 1999; Lee et al., 2004).

These characteristics can be substantially beneficial for plant and turfgrass growth in arid and semi-arid regions where the soils are usually saline/sodic and water is limited for irrigation and other agricultural uses. Preliminary tests of any new species/cultivars for growth under stressful conditions would prevent the unexpected results of their use under similar conditions in the real world.

Objectives

The objectives of this study were to compare growth responses of bermudagrass, seashore paspalum, and saltgrass in terms of shoot and root lengths and dry weights (shoot clippings weight) under different levels of sodium chloride (NaCl) salinity stress conditions in the culture medium.

Materials and Methods

Bermudagrass (*Cynodon dactylon* L.), cv. Tifway 419, Seashore Paspalum (*Paspalum vaginatum* Swartz), cv. Sea Isle 2000, and Saltgrass (*Distichlis spicata* L., Greene), var. stricta (Gray) Beetle, accession A55 were studied in a greenhouse located at the Campus Agricultural Center, College of Agriculture and Life Sciences at the University of Arizona), using hydroponics system, to compare their establishment and growth responses in terms of shoot and root lengths and dry matter (DM) weights (shoot clippings weight), and canopy green color (CGC) under sodium chloride (NaCl) salinity stress conditions.

The grasses were grown vegetatively (whole plants, stolons, and rhizomes) in cups, 9 cm diameter and 7 cm height. Silica sand was used as the plant anchor medium. Each cup was fitted into one of the 9 cm diameter holes cut in a rectangular plywood sheet 46 cm (length) X 37 cm (width) X 2 cm (thickness). The plywood sheets served as lids for the hydroponics tubs and supported the cups above the solution to allow for root growth. The lids were placed on 42 cm (length) X 34 cm (width) X 12 cm (depth) Carb-X polyethylene tubs, containing half strength Hoagland solution No. 1 (Hoagland and Arnon, 1950; Marcum et al., 2005; Pessarakli and Kopec, 2004; Pessarakli et al., 2006).

The grasses were allowed to grow in this nutrient solution which was salinized with NaCl at a rate of 7,000 mg L^{-1} per day until the desired salinity levels of 7,000, 14,000, and 21,000 mg L^{-1} were reached. Total of four treatments [control (0), 7,000, 14,000, and 21,000 mg NaCl L^{-1} culture solution] were resulted for this experiment. Four replications of each treatment were used in a randomized complete block (RCB) design trial. The culture solution levels in the tubs were marked at the 10-liter volume level and maintained at this level by adding distilled water containing respective salinity levels as needed. The culture solutions with the respective salinity levels were changed bi-weekly to maintain the desired plant nutrient levels. The grasses were allowed to grow under these conditions for 12 weeks. The grass shoots were harvested weekly for four weeks to reach uniform and equal size plants. These four weeks harvested materials (clippings) were discarded. Then, the grass shoots were harvested bi-weekly and the clippings were used for the evaluation of the dry matter (DM) production. The harvested plant materials were oven-dried at 60^{o} C and DM weights were measured and recorded. At each harvest, shoot and root lengths were measured and recorded. The canopy green color (CGC) was rated weekly and recorded. At the termination of the experiment, the last harvest, plant roots were also harvested, oven dried at 60^{o} C, and DM weights were determined and recorded.

Statistical Analysis

The data were subjected to Analysis of Variance, using SAS statistical package (SAS Institute, 1991). The means were separated, using Duncan Multiple Range test.

Results and Discussion

The results for the average of five bi-weekly evaluated response parameters and the average of the 10 weekly ratings of the grasses are presented in Tables 1-5.

Shoot Length

For bermudagrass and seashore paspalum, shoot lengths numerically decreased linearly with increasing NaCl salinity for any plant parts used (Table 1). However, for both of these grass species, except at the low level (7,000 mg L^{-1}) of NaCl salinity compared with the control, the reductions in shoot lengths due to salinity stress were statistically significant. The effect of salinity was more pronounced on bermudagrass compared with seashore paspalum. In contrast, for saltgrass, shoot length increased at any levels of NaCl salinity compared with the control for any plant parts used. The highest values for the shoot length of saltgrass were obtained under 7000 mg L^{-1} NaCl salinity level (Table 1). This indicates that NaCl enhanced saltgrass growth which in turn is an indication that saltgrass is a true-halophyte and benefits from low levels of salt in the culture medium.

For bermudagrass and seashore paspalum, the highest values for shoot lengths were obtained when the whole plants were used, while the lowest ones were resulted when the rhizomes were used. The reverse was found for saltgrass.

For the control (non-salinized) treatments, shoot lengths were higher for both bermudagrass and seashore paspalum compared with that of the saltgrass.

Root Length

Although the root lengths data were taken weekly at each harvest, the cumulative values of the root lengths data for the first two weeks growth are reported here. There were no differences detected in the root lengths of bermudagrass and seashore paspalum at the low (7,000 mg L^{-1}) level of NaCl salinity compared with the control (Table 2). However, at both, the medium (14,000 mg L^{-1}) and at the high (21,000 mg L^{-1}) of NaCl salinity, there were significant reductions in roots lengths of both bermudagrass and seashore paspalum. Compared with the shoots lengths, the roots lengths of these two grasses were less severely affected by NaCl salinity stress (Tables 1 and 2). This is in agreement with the reports of several investigators on the effects of stress on warm-season or more stress tolerant grasses/halophytes (Marcum et al., 2005; Pessarakli and Kopec, 2004; Pessarakli et al., 2005; Sagi et al., 1997). All these investigators found that under stress conditions, plant/grass roots of halophytes and more tolerant species were less affected than shoots. Roots lengths of saltgrass were stimulated under low (7,000 mg L^{-1}) and medium (14,000 mg L^{-1}) levels of NaCl salinity (Table 2). As mentioned for the shoot length of saltgrass, this indicates that NaCl enhanced saltgrass growth which in turn is an indication that saltgrass is a true-halophyte and benefits to some extent from salt in the culture medium. However, the high (21,000 mg L^{-1}) level of NaCl salinity slightly reduced the root length of saltgrass.

As was observed for the shoot lengths, for both bermudagrass and seashore paspalum, the highest values for root lengths were obtained when the whole plants were used, while the lowest ones were resulted when the rhizomes were used. Again, the reverse was found for saltgrass.

For the control (non-salinized) treatments, root lengths were higher for both bermudagrass and seashore paspalum compared with that of the saltgrass.

Shoot Dry Weight

Shoot dry matter (DM) weights of both bermudagrass and seashore paspalum followed the same pattern as the shoot lengths, numerically decreased linearly with increased NaCl salinity for any plant parts used (Table 3), and except at the low level (7,000 mg L^{-1}) of NaCl salinity compared with the control, the reductions in shoot DM weights of both of these grass species due to salinity stress were statistically significant. For both of these grass species, the most marked reductions in shoot DM weights were resulted at the highest level (21,000 mg L^{-1}) of NaCl salinity. The effect of salinity was more pronounced on bermudagrass compared with seashore paspalum. In contrast, for saltgrass, shoot DM weight increased, as was observed for the shoot length of this grass, at any levels of NaCl salinity compared with the control for any plant parts used (Table 3). Once again, this indicates that NaCl enhanced saltgrass growth which in turn is an indication that saltgrass is a true-halophyte and benefits from the salt content of the culture medium. The highest value for the shoot DM weight of saltgrass was obtained under 7000 mg L^{-1} NaCl salinity level.

As was observed for the shoot and root lengths, for both bermudagrass and seashore paspalum, the highest values for shoot DM weights were obtained when the whole plants were used, while the lowest ones were resulted when the rhizomes were used, and the reverse was found for saltgrass.

Again, as was reported for the shoot and root lengths, for the control (non-salinized) treatments, shoot DM weights were higher for both bermudagrass and seashore paspalum compared with that of the saltgrass.

Root Dry Weight

There was no difference among the root dry matter (DM) weights of either bermudagrass or seashore paspalum for any plant parts used at any levels of NaCl salinity (Table 4). The low level of salinity (7000 g L^{-1} NaCl) slightly enhanced root DM weights of both of these grass species. This phenomenon of growth enhancement of these grass species due to salt content of the culture medium indicates that like saltgrass, bermudagrass and seashore paspalum are also true-halophytes and benefits from low levels of salt in the culture medium. For saltgrass, root DM weight increased at any levels of NaCl salinity compared with the control for any plant parts used (Table 4).

Overall, there was either no difference between the root DM weights of these grasses under control or any levels of NaCl salinity as the results show for bermudagrass and seashore paspalum or there was enhancement in root DM weight of the grass under salinity stress as shown for bermudagrass and seashore paspalum at the low level of salinity or for saltgrass at any levels of NaCl salinity. As was reported for the roots lengths, this is in agreement with the findings reported by several investigators on the warm-season halophytic plants/grasses (Marcum et al., 2005; Pessarakli and Kopec, 2004; Pessarakli et al., 2005; Sagi et al., 1997).

Once again, as was reported for the shoot and root lengths and shoot DM weights, for the control (non-salinized) treatments, root DM weights were higher for both bermudagrass and seashore paspalum compared with that of the saltgrass.

Canopy Green Color (CGC)

The canopy green color (CGC) turned to lighter green for both bermudagrass and seashore paspalum as NaCl salinity level increased, however, saltgrass maintained the same color regardless of the level of NaCl salinity (Table 5). This is an indication of the higher salinity tolerance of saltgrass compared with bermudagrass and seashore paspalum.

For the control (non-salinized) treatments and the lower level of NaCl salinity treatments, the canopy color was greener for both bermudagrass and seashore paspalum, scores of 8 and 9, respectively (as naturally is) compared with that of the saltgrass (score of 7) which was the same for the control (non-salinized) and salinized satgrass. (Table 5)

Conclusions

Shoot and root lengths and shoot DM weights numerically decreased linearly with increased NaCl salinity for both bermudagrass and seashore paspalum for any plant part used. For both of these grass species, at the high level (21,000 mg L^{-1}) of NaCl salinity, the reductions in shoot lengths were statistically significant. There was no difference among the root DM weights of these two species for any plant part used at any level of NaCl salinity. The low level of salinity (7000 mg L^{-1} NaCl) slightly enhanced root DM weights of both of these species. In contrast, for saltgrass, both shoot and root lengths as well as shoot and root DM weights increased at any level of NaCl salinity compared with the control for any plant part used. The highest values for the shoot and root lengths and shoot DM weights were obtained under 7000 mg L^{-1} NaCl salinity level. However, the root DM weight of saltgrass numerically increased linearly with increasing NaCl salinity.

For both bermudagrass and seashore paspalum, the highest values for shoot and root lengths and shoot DM weights were obtained when the whole plants were used, while the lowest ones were resulted when the rhizomes were used. The reverse was found for saltgrass. For the control (non-salinized) treatments, shoot and root lengths as well as shoot and root DM weights were higher for both bermudagrass and seashore paspalum compared with those of the saltgrass.

The canopy color turned to lighter green for both bermudagrass and paspalum as NaCl level increased. However, saltgrass maintained the same color regardless of the level of NaCl salinity. For the control (non-salinized) treatments and the lower level (7,000 mg L^{-1}) of NaCl salinity treatments, the canopy color was greener for both bermudagrass and paspalum (as naturally is) compared with that of the saltgrass.

Overall, among the three species, bermudagrass was the most and saltgrass the least adversely affected by NaCl salinity stress.

References

Ashraf, M. 1994. Breeding for salinity tolerance in plants. Crit. Rev. Plant Sci. 13, 17–42.

Carrow, R.N. and R.R. Duncan. 1998. Salt-affected Turfgrass Sites: Assessment and Management. Wiley, Hoboken,NJ., 232p.

Chen, T.H.H. and N. Murata. 2002. Enhancement of tolerance of abiotic stress by metabolic engineering of betaines and other compatible solutes. Current Opinion in Plant Biology 5, 250–257.

Cushman, J.C. and H.J. Bohnert. 2000. Genomic approaches to plant stress tolerance. Curr. Opin. Plant Biol. 3, 117–124.

Duncan, R.R. and R.N. Carrow. 1999. Turfgrass molecular genetic improvement for biotic/edaphic stress resistance.Adv. Agron. 67, 233–305.

Flowers, T. and A. Yeo. 1995. Breeding for salinity resistance in crop plants: where next? Aust. J. Plant Physiol. 22,875–884.

Glenn, E.P., J.J. Brown, and E. Blumwald. 1999. Salt tolerance and crop potential of halophytes. Crit. Rev. Plant Sci.18, 227–255.

Glenn, E.P., S. Miyamoto, D. Moore, J.J. Brown, T.L. Thompson, and P.W. Brown. 1997. Water requirements for cultivating *Salicornia bigelovii* Torr. with seawater on sand in a coastal desert environment. J. Arid Environ.36, 711–730.

Grover, A., C. Sahi, N. Sanan, and A. Grover. 1999. Taming abiotic stresses in plants through genetic engineering: current strategies and perspective. Plant Sci. 143, 101–111.

Hoagland, D.R. and D.I. Arnon. 1950. The water-culture method for growing plants without soil. California Agr. Exp. Stn. Circular 347.

Holmberg, N. and L. Bulow. 1998. Improving stress tolerance in plants by gene transfer Trends Plant Sci. 3, 61–66.

Katerji, N., J.W. van Hoorn, A. Hamdy, and M. Mastrorilli. 2000. Salt tolerance classification of crops according to soil salinity and to water stress day index. Agric. Water Manage. 43, 99–109.

Lee, G.J., R.N. Carrow, and R.R. Duncan. 2004. Salinity tolerance of selected seashore paspalums and bermudagrasses: root and verdure responses and criteria. Hort. Science .39 (2):1136-1142.

Marcum, K.B., M. Pessarakli, and D.M. Kopec. 2005. Relative salinity tolerance of 21 turf-type desert saltgrasses compared to bermudagrass. HortScience 40(3):827-829.

Miyamoto, S., E.P. Glenn, and M.W. Olsen. 1996. Growth, water use, and salt uptake of four halophytes irrigated with highly saline water. J. Arid Environ. 32, 141–159.

Pessarakli, M. and D.M. Kopec. 2004. Growth responses of bermudagrass and seashore Paspalum to different levels of FerroGrow multi-nutrient fertilizer. Journal of Food, Agriculture & Environment (JAFE),Vol.2(3&4):284-286.

Pessarakli, M., K.B. Marcum, and D.M. Kopec. 2005. Growth Responses and Nitrogen-15 Absorption of Desert Saltgrass (*Distichlis spicata* L.) to Salinity Stress. Journal of Plant Nutrition, 28(8):1441-1452.

Pessarakli, M., K.B. Marcum, and D.M. Kopec. 2006. Interactive Effects of Salinity and Primo on the Growth of Kentucky Bluegrass. Journal of Agriculture, Food, and Environment (JAFE), Vol. 4(1):325-327.

Sagi, M., N.A. Savidov, N.P. L'vov, and S.H. Lips. 1997. Nitrate reductase and molybdenum cofactor in annual ryegrass as affected by salinity and nitrogen source. Physiol. Plant., 99:546-553.

SAS Institute, Inc. 1991. SAS/STAT User's guide. SAS Inst., Inc., Cary, NC.

Westcott, D.W., 1988. Reuse and disposal of higher salinity subsurface drainage water: a review. Agric. Water Manage. 14, 483–511.

Table 1. Bermudagrass, paspalum, and saltgrass shoot growth responses under salinity stress conditions.

Salinity (mg/L)	Shoot length (cm)							
	Bermuda			Paspalum			Saltgrass	
	Plt.	Rhiz.	Stol.	Plt.	Rhiz.	Stol.	Plt.	Rhiz.
Control (0)	3.33a	2.83a	3.50a	3.30a	2.47a	2.93a	2.57c	3.00b
7000	2.73ab	2.17ab	2.63b	2.86ab	2.11ab	2.69ab	3.87a	4.00a
14000	2.57b	1.87b	2.30bc	2.63b	1.93ab	2.45ab	3.30ab	3.67ab
21000	2.27b	1.67b	1.94c	2.35b	1.70b	2.27b	3.00bc	3.60ab

The values are means of 4 replications and 4 bi-weekly harvests.
All the values followed by the same letter in each column for each grass species are not statistically different at the 0.05 probability level.

Table 2. Bermudagrass, paspalum, and saltgrass root growth responses (root length after two weeks) under salinity stress conditions.

Salinity (mg/L)	Root length (cm)							
	Bermuda			Paspalum			Saltgrass	
	Plt.	Rhiz.	Stol.	Plt.	Rhiz.	Stol.	Plt.	Rhiz.
Control (0)	17.7a	17.7a	19.8a	17.2a	15.6a	17.1a	12.1b	12.5b
7000	16.7a	17.6a	17.3a	16.1a	15.3a	16.6a	15.4a	15.9a
14000	12.9b	11.7b	13.1b	13.5ab	11.7b	13.3b	12.9ab	12.8ab
21000	9.8b	8.8b	10.7b	10.3b	10.0b	11.5b	10.7b	11.2b

The values are means of 4 replications.
All the values followed by the same letter in each column for each grass species are not statistically different at the 0.05 probability level.

Table 3. Bermudagrass, paspalum, and saltgrass shoot growth responses under salinity stress conditions.

Salinity (mg/L)	Shoot DM (g)							
	Bermuda			Paspalum			Saltgrass	
	Plt.	Rhiz.	Stol.	Plt.	Rhiz.	Stol.	Plt.	Rhiz.
Control (0)	0.51a	0.46a	0.49a	0.55a	0.41a	0.43a	0.37c	0.38c
7000	0.48ab	0.35b	0.45a	0.52ab	0.37a	0.41a	0.54a	0.51a
14000	0.44bc	0.28c	0.36bc	0.47b	0.30b	0.39ab	0.50ab	0.46ab
21000	0.41c	0.25c	0.32c	0.43b	0.27b	0.34b	0.47b	0.41bc

The values are means of 4 replications and 4 bi-weekly harvests.
All the values followed by the same letter in each column for each grass species are not statistically different at the 0.05 probability level.

Table 4. Bermudagrass, paspalum, and saltgrass root growth responses (root DM, cumulative values) under salinity stress conditions.

Salinity (mg/L)	Root DM (g)							
	Bermuda			Paspalum			Saltgrass	
	Plt.	Rhiz.	Stol.	Plt.	Rhiz.	Stol.	Plt.	Rhiz.
Control (0)	1.98a	1.81a	2.37a	2.96a	2.84ab	3.03a	1.15b	0.93b
7000	2.22a	1.92a	2.43a	2.99a	3.03a	2.98a	1.43ab	0.97ab
14000	2.01a	1.89a	2.30a	2.86a	2.72ab	3.55a	1.41ab	1.21a
21000	1.88a	1.79a	2.09a	2.73a	2.43b	3.43a	1.50a	1.18a

The values are means of 4 replications.
All the values followed by the same letter in each column for each grass species are not statistically different at the 0.05 probability level.

Table 5. Bermudagrass, paspalum, and saltgrass canopy green color (CGC) under salinity stress conditions.

Salinity (mg/L)	CGC							
	Bermuda			Paspalum			Saltgrass	
	Plt.	Rhiz.	Stol.	Plt.	Rhiz.	Stol.	Plt.	Rhiz.
Control (0)	8	8	8	9	9	9	7	7
7000	8	8	8	9	9	9	7	7
14000	7	7	7	8	8	8	7	7
21000	6	6	6	7	7	7	7	7

The values are means of 4 replications and 10 weekly ratings.