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Seashore Paspalum, a High Salinity Stress Tolerant Halophytic Plant Species for Sustainable Agriculture in Desert Regions and Combating Desertification

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Abstract: Two cultivars (Aloha and Sea Dwarf) of Seashore paspalum (*Paspalum vaginatum* Swartz) were studied hydroponically in a greenhouse to evaluate their growth responses in terms of shoot and root lengths, shoot (clippings) fresh and dry-matter (DM) weights as well as the grass visual quality under salinity stress conditions. Grasses were grown for 6 weeks in Hoagland solution, salinized with sodium chloride (NaCl) to salinity levels of 15,000, 30,000 and 45,000 mg L^{-1} NaCl. Four replications of each treatment were used in a randomized complete block (RCB) design in this study. During the 6 weeks growth under salinity stress, the shoots were harvested weekly. Prior to each harvest, shoot and root lengths were measured and recorded and grass visual quality was also evaluated. The harvested clippings fresh and DM weights were measured. At the last harvest, roots were also harvested and fresh and DM weights determined. The results showed no difference in the shoot or root lengths and clippings fresh and DM weights of either cultivar at the first (15,000 mg L^{-1} NaCl) salinity level. However, the measured parameters significantly decreased at the second (30,000 mg L^{-1} NaCl) salinity level compared to the control plants. The grass growth ceased at the high (45,000 mg L^{-1} NaCl) salinity level. At each salinity level there were some numerical differences found in shoot and root lengths as well as the fresh and DM weights of the two cultivars. Under any salinity level, the root lengths of both cultivars were less severely affected than that of the shoot. Grass visual qualities followed the same pattern as the grass fresh and DM weights under salinity stress. At the 15,000 and 30,000 mg L^{-1} NaCl salinity levels, the quality scores of both cultivars were acceptable for desert landscaping. However, at the high (45,000 mg L^{-1} NaCl) salinity level, none of the cultivars had any acceptable quality scores after the first week of exposure to salinity stress. Both of these halophytic cultivars performed satisfactory under salinity levels up to 30,000 mg L^{-1} (about the salinity level of the sea water). These grasses proved to not only have a satisfactory growth under the salinity levels of the experiment significantly higher than the soil salinity levels of the harsh desert conditions, but also to substantially reduce salinity level of the culture medium rhizosphere. This indicates that Seashore paspalum can be used for biological salinity control or reclamation of desert saline soils, sustainable production under harsh conditions of the desert regions with high soil salinity levels and drought conditions and effectively combat desertification processes.

Key words: Halophytes · Combating desertification · Sustainable agriculture

INTRODUCTION

Desertification of arable lands due to urbanization, global warming and shortage of water mandates use of low quality/saline water for irrigation, especially in regions experiencing water shortage. Using low quality/saline water for irrigation imposes more salt stress on plants which are already under stress in these regions characterized with saline soils and shortage of water. Therefore, there is an urgent need for finding salt/drought tolerant plant species to survive/sustain under such stressful conditions. Since the halophytic plant species

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are already growing under such conditions and are adapted to these stresses, these plants are the most suitable candidates to be manipulated under the minimum cultural practices and minimum inputs (water and fertilizers) for production under these stressful conditions. If stress tolerant species/genotypes/cultivars of these plant species are successfully identified, there would be a substantial savings in cultural practices and inputs in using these plants by the growers and will result in substantial savings in the local, regional and the national currencies of the countries. Several of my investigations indicated that Seashore paspalum (*Paspalum vaginatum* Swartz) has a great potential to be used under harsh and stressful environmental conditions, characterized in arid regions, yet perform satisfactory growth. This grass has several major usages, including animal feed, soil conservation and use for lawns/parks/recreation areas.

Soil salinity and water quality and quantity are major problems worldwide, especially in the arid regions and the water shortage areas [1-3]. Plant/crop growers and agricultural practitioners, particularly in the desert areas, for perennial plant coverage 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 [4-6].

One strategy to enhance plant survival and recovery from salt stress is to use cultivars with superior salinity tolerance [7-11]. However, development of salt-tolerant cultivars is not simple because the trait is quantitative (controlled by many physiological mechanisms and genes) [12-14] and lacks a standardized screening protocol at both intra- and inter-species levels [7, 9, 15]. Therefore, reliable selection criteria are fundamental for developing salt-tolerant cultivars.

Grasses along with various other kinds of plants often have to endure environmental stresses, with salinity issues being one of the most common stresses they encounter [16-30]. Salinity stress can stunt growth, dehydrate, cause chemical imbalances, make the plant most susceptible to injury and salts can even be toxic in high levels.

Some grasses deal with salinity better than other species [16-18, 20-30]. To help aid in salinity tolerance, cultivars are selected and bread for having increased tolerance. For a grass to be considered tolerant to the saline conditions, it must meet some basic criteria such as having acceptable quality, reasonable growth and persistence at various levels of salinity. With that been said, assessment of salt tolerance in grasses should be evaluated under control (no salt), low, moderate and high salt levels. Factors to look for could be overall visual appeal, shoot length, root length and biomass production.

Perennial vegetation coverage in desert regions must maintain adequate growth and persistence under variable levels of soil salinity or salinity-laden water over several years. Successful assessment of salinity tolerance of perennial, halophytic plants, therefore, should be based on growth at no saline, intermediate and high salinity levels. In addition to shoot evaluation, root and verdure parameters should be measured in tolerance assessment, especially for plant species exposed to combined biotic or abiotic stresses [7, 8, 31-33].

Salt problems in agricultural sites, especially in desert regions, are continually becoming more common. Therefore, halophytic plants such as seashore paspalum (*Paspalum vaginatum* Swartz) need to be evaluated at salinity regimes up to sea water salinity level [8, 21, 21] to select the best genotype.

The objectives of this study were to evaluate the tolerance of two cultivars of Seashore paspalum: Aloha and Sea Dwarf to increasing salinity levels and to determine how their shoot and root lengths along with their fresh and dry weights as well as their visual quality were influenced by increasing salinity levels. Furthermore, to identify the most effective (superior) of this halophytic cultivars for reducing the salinity level of the salt-affected soils and to recommend the superior cultivar as biological soil salinity control plant for arid lands reclamation and combating desertification processes.

MATERIALS AND METHODS

Two cultivars of Seashore paspalum (*Paspalum Vaginatum* Swartz), Aloha and Sea Dwarf, were studied in a greenhouse to determine their growth and tolerance to different levels of NaCl salinity. This was measured in terms of shoot and root length, fresh and dry weights, grass visual quality and the salt removal from the growth medium. The grasses were grown using the hydroponics technique under various salinity levels; Control (no salt), 15,000, 30,000 and 45,000 mg L^{-1} NaCl.

The grasses were grown as vegetative propagules in cups, 9 cm diameter and 7 cm height, followed the procedures used by Marcum and Pessarakli [16, 17], Marcum *et al*. [18], Pessarakli [19, 34], Pessarakli and Touchane [19, 20], Pessarakli and Kopec [21-26, 35] and Pessarakli *et al*. [27-29]. 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 52 cm x 40 cm x 2 cm dimensions. The plywood sheets served as lids for the hydroponics tubs, supported the cups above the solution to allow for root growth and were placed on 48 cm x 36 cm x 18 cm Carb-X polyethylene tubs containing 1/2 strength Hoagland solution No. 1 [36]. Four replications of each treatment were used in a randomized complete block (RCB) design in this investigation.

The plants were allowed to grow in this nutrient solution for 60 days. During this period, the plant shoots were harvested weekly in order to reach full maturity. The harvested plant materials were discarded. The culture solutions were changed biweekly to ensure adequate amount of plant essential nutrient elements for normal growth and development. Before the initiation of the salinity phase of the experiment, the roots were also cut to 2.5 cm length for the stress phase of the experiment.

The salt treatments were initiated by adding NaCl to the culture solutions for the various (15,000, 30,000 and 45,000 mg L^{-1} NaCl) salinity treatments. The culture solution levels in the tubs were marked at the 16 liter volume and maintained at this level. After the final salinity levels were reached, the shoots were harvested and the harvested plant materials were discarded prior to the beginning of the data collection at the salinity stress phase of the experiment.

After the completion of the salt treatments, plant shoots were harvested weekly for the evaluation of the fresh and dry matter (DM) production. At each weekly harvest, both shoot and root lengths were measured and recorded. The harvested plant materials were oven dried at 65°C and DM weights were measured and recorded. The recorded data were considered the weekly plant DM production. At the termination of the experiment, the last harvest, plant roots were also harvested, oven dried at 65°C and DM weights were determined and recorded.

Electrical conductivity (EC) of the culture solutions were initially measured and recorded. At the termination of the experiment, the EC of the culture solutions were also measured and recorded (Final EC). By subtracting the final EC from the initial EC values, the quantity of the salts removed by the plants from the culture medium was estimated.

The data were subjected to Analysis of Variance, using SAS statistical package [37]. The means were separated, using Duncan Multiple Range test.

RESULTS AND DISCUSSIONS

The results of the weekly harvests and the overall average of all the harvests were essentially the same, indicating that the plants had similar behavioral and response patterns during the course of the experiment. Therefore, the data for one of the harvests (the 6th harvest) and the overall average of all the harvests are presented here in Tables 1 and 2, respectively.

Shoot Length: The data of the final (6th) harvest (Table 1) and the averages of all the harvests (Table 2) show the growth of both cultivars at all NaCl salinity levels, except at the highest (45,000 mg L^{-1} NaCl) where there was no measurable growth. At this high level of salinity shoot

Table 1: The 6th harvest shoot and root lengths, shoot and root fresh and dry weights of Aloha and Sea Dwarf Paspalum cultivars grown at various levels of NaCl salinity

Salinity Level (mg L^{-1} NaCl)		Shoot Length (cm)	Root Length (cm)	Shoot Fresh weight (g)	Shoot Dry weight (g)	Root Fresh weight (g)	Root Dry weight (g)
0	Control Alo	10.8a	23.1bc	12.53a	3.16a	5.04a	0.39a
15,000	S1 Alo	9.2ab	26.2bc	4.85c	1.44bc	4.72a	0.46a
30,000	S2 Alo	5.5c	20.1c	0.42e	0.14d	0.40c	0.13bc
45,000	S3 Alo	--	--	--	--	0.22c	0.07c
0	Control SD	7.6b	51.5a	11.89a	3.13a	4.02a	0.32ab
15,000	S1 SD	7.2b	36.0b	5.58c	2.15b	4.14a	0.35ab
30,000	S2 SD	5.1c	29.4b	1.17d	0.46cd	2.19b	0.23b
45,000	S3 SD	--	--	--	--	0.23c	0.07c

Alo = Aloha cultivar, SD = Sea dwarf cultivar, S1 = 15,000 mg L^{-1}, S2 = 30,000 mg L^{-1}, S3 = 45,000 mg L^{-1} NaCl,

The values are averages of 4 replications of each species per treatment level.

The values followed by the same letters in each column are not statistically different at the 0.05 probability level.

Note: At the last harvest (harvest 6), there was no shoot growth for either cultivar at the highest (45,000 mg L^{-1} NaCl) salinity level, therefore, it is shown by "--" in this Table. However, since the root growth was cumulative, there is measurement for the root values.

Table 2: Shoot and root lengths, shoot and root fresh and dry weights, shoot succulence (fresh weight/dry weight) and shoot/root ratio (shoot dry weight/root dry weight) of Aloha and Sea Dwarf Paspalum cultivars grown at various levels of NaCl salinity.

Salinity Level (mg L^{-1} NaCl)	Treatment ID	Shoot Length (cm)	Root Length (cm)	Shoot Fresh weight (g)	Shoot Dry weight (g)	Root Fresh weight (g)	Root Dry weight (g)	Shoot Succulence (Fresh wt./ Dry wt.)	Shoot/Root Ratio (Dry)
0	Control Alo	10.87a	29.27b	11.16a	2.67a	3.49b	0.37a	4.18a	7.21a
15,000	S1 Alo	8.93ab	25.56bc	5.56b	1.64b	4.70a	0.48a	3.39b	3.42bc
30,000	S2 Alo	5.48c	22.08c	0.59c	0.20c	0.75d	0.06bc	2.95bc	3.33bc
45,000	S3 Alo	0.15d	3.14d	0.11d	0.04d	0.24e	0.03c	2.75c	1.33d
0	Control SD	7.98b	48.9a	9.77a	2.27ab	5.38a	0.47a	4.30a	4.83b
15,000	S1 SD	7.35b	26.75bc	4.46b	1.54b	3.46b	0.31a	2.90bc	4.97b
30,000	S2 SD	5.20c	25.75bc	0.89c	0.36c	1.24c	0.13b	2.47c	2.77c
45,000	S3 SD	0.12d	4.08d	0.12d	0.05d	0.36de	0.03c	2.40c	1.67d

Alo = Aloha cultivar, SD = Sea dwarf cultivar, S1 = 15,000 mg L^{-1}, S2 = 30,000 mg L^{-1}, S3 = 45,000 mg L^{-1} NaCl,

The values are averages of 4 replications of all the harvests for each cultivar for each treatment.

The values followed by the same letters in each column are not statistically different at the 0.05 probability level.

growth had ceased completely and the grass visually was yellowish brown all over. Both cultivars exhibited stunted growth and color compared to the control with each increase in salinity level. For both cultivars, the shoot length was statistically the same at the lowest salinity level (15,000 mg L^{-1} NaCl) compared to the control, but the Aloha cultivar visually looked greener and exhibited more growth (taller shoots) at each salinity level as compared to the Sea Dwarf cultivar. Therefore, considering the shoot length data (Tables 1 and 2), Aloha cultivar had a slightly higher salinity tolerance than the Sea Dwarf cultivar.

Root Length: In contrast to the shoot length, the root length of the Aloha cultivar was relatively unaffected by the increase in salinity levels (Tables 1 and 2). Other than the complete cease of grown at the highest (45,000 mg L^{-1} NaCl) level of salinity, the root lengths, while not as long as the roots of the control plants, grew to a similar length (Tables 1 and 2). The root length of the Aloha cultivar was reduced substantially under salinity stress compared to that of the control plants. Under control (non-saline) condition, Aloha cultivar had significantly longer roots compared to the control Sea Dwarf cultivar (Tables 1 and 2). However, at any salinity level, the root length of the Sea Dwarf cultivar was substantially higher than its corresponding value for the Aloha cultivar (Tables 1 and 2).

Biomass Production: The shoots and the roots of both cultivars were harvested and weighed fresh and then dried at 65°C in an oven and weighed again (Tables 1 and 2). As a result of increasing salinity level, biomass productions of both cultivars were stunted and even ceased in salinity concentrations of 30,000 mg L^{-1} or higher. For both cultivars, biomass production significantly decreased as salinity levels increased (Tables 1 and 2). The reduction in biomass production due to the salinity stress seems to be more apparent in the shoot lengths than it is in the root lengths in both cultivars.

The decrease in plant biomass production due to the high level of salinity which was found in the present study may be attributed to the low medium water potential, specific ion toxicity, or ion imbalance as reported by Greenway and Munns [38].

Shoot Dry Matter (DM) Weight: Dry matter weight of the shoots (clippings) also decreased in the same way as the fresh weights, as the salinity levels increased, the shoot dry weights decreased. This has been made visual in both Tables 1 and 2. By the last harvest, most of the grass had fallen victim to the effects of the salinity.

Shoot Succulence: Shoot succulence decreased as the salinity level increased (Table 2). As seen with the shoot lengths, the Aloha cultivar seems to do better than the Sea Dwarf in response to salinity content in regards to shoot succulence (Table 2).

Root Dry Matter (DM) Weight: As it was observed with the shoot DM weights, the root DM weights seemed to follow the same trends. Except at the low level of salinity (15,000 mg L^{-1} NaCl), as the salinity level increased the root DM weights of both cultivars decreased (Tables 1 and 2). Although the roots grew to similar lengths, they looked visually different. The roots of the grasses in the lower salinity levels were plumper and looked much healthier compared to the threadlike roots of the moderate salinity specimens.

Table 3: Visual quality of Aloha and Sea Dwarf Paspalum cultivars grown at various levels of NaCl salinity

Salinity Level (mg L^{-1} NaCl)		Week 1 Evalua.	Week 2 Evalua.	Week 3 Evalua.	Week 4 Evalua.	Week 5 Evalua.	Week 6 Evalua.	Average Values
0	ControlAlo	10	10	10	10	10	10	10
15,000	S1 Alo	10	10	10	9.5	9	9	9.6
30,000	S2 Alo	9	9	8.5	8	7.5	7	8.2
45,000	S3 Alo	6.5	5	3.5	2.5	1.5	0	3.2
0	Control SD	10	10	10	10	10	9	9.8
15,000	S1 SD	10	9.5	9	8.5	7	7	8.5
30,000	S2 SD	8.5	7.5	7	6.5	6	6	6.9
45,000	S3 SD	5.5	3.5	2.5	1.5	0	0	2.2

Alo = Aloha cultivar, SD = Sea dwarf cultivar, S1 = 15,000 mg L^{-1}, S2 = 30,000 mg L^{-1}, S3 = 45,000 mg L^{-1} NaCl,

The values are averages of 4 replications for each cultivar per treatment level.

The quality scores are on the scale of 0 to 10 according to the National Turfgrass Evaluation Program (NTEP). 0 = bare soil, no grass; 10 = excellent grass quality; < and = 5 not acceptable quality; > 5 =acceptable quality.

Table 4: Salt removal by Seashore paspalum from the culture medium under various levels of NaCl application rates

Grass cultivar	Salinity treatment	Electrical Conductivity (EC)* Initial	Final	Salt Removed* from Culture Soln.
	(mg/l NaCl)	--------------------(dS/m)	----------------------	(mg/l)
Aloha	Control (0)	0.86	0.84	------
	15,000	24.30	21.51	1786a**
	30,000	47.74	45.13	1670b
	45,000	71.17	69.82	864c
Sea Dwarf	Control (0)	0.85	0.82	------
	15,000	24.28	21.50	1779a
	30,000	47.73	45.21	1613b
	45,000	71.16	69.87	826c

*The Values are means of 4 replications of each treatment.

**The values in each column followed by the same letter are not statistically different at the 0.05 probability level.

Shoot to Root Ratio: The shoot to root ratio of Aloha cultivar significantly decreased under salinity stress compared with that of the control plants. However, this ratio was the same under both the low level (15,000 mg L^{-1} NaCl) and the higher level (30,000 mg L^{-1} NaCl) of salinity for this cultivar (Table 2). The effect of salinity was significantly less on the shoot to root ratio of the Sea Dwarf cultivar. This ratio was statistically the same for these plants under the low level (15,000 mg L^{-1} NaCl) of salinity compared with the control plants (Table 2). However, the higher level (30,000 mg L^{-1} NaCl) of salinity significantly reduced the shoot to root ratio of this cultivar (Sea Dwarf) compared with the control or plants under the low level (15,000 mg L^{-1} NaCl) of salinity (Table 2).

Grass Visual Quality: Any level of the salinity stress had a significant adverse effect on the grass visual quality (Table 3). The average of the quality scores for the two cultivars ranged from 10 to 1.0 at different salinity levels. The quality scores are on the scale of 0 to 10 according to the National Turfgrass Evaluation Program (NTEP); 0 = bare soil, no grass; 10 = excellent grass quality; < and = 5 not acceptable quality; > 5 = acceptable quality. At the salinity levels of upto 30,000 mg L^{-1} NaCl, the quality scores for both cultivars were greater than 6 (acceptable score for grass quality). However, at the highest level (45,000 mg L^{-1} NaCl) of salinity, none of the cultivars had any acceptable quality scores after the first week of the exposure to these levels of salinity (Table 3). Aloha at the 45,000 mg L^{-1} NaCl) salinity level after the week 5 did not have any green tissue (Table 3). This was observed after the week 4 for the Sea Dwarf cultivar. This indicates that regarding the grass visual quality, the Aloha cultivar exhibited higher salinity tolerance compared to the Sea Dwarf cultivar.

Salt Removal by the Plants from the Culture Medium: The quantity of the salts removed by the plants from the culture medium was estimated by subtracting the final electrical conductivity (EC) of the culture medium from the initial EC values of the salinized nutrient solutions (Table 4).

As shown in Table 4, at each salinity level, Aloha cultivar removed slightly more (statistically non-significant) salts from the culture medium compared to Sea Dwarf cultivar. Nevertheless, both halophytic plant cultivars were very effective in removing the salts from the culture medium and thereby reclaiming saline condition. Thus, both of these halophytic plant cultivars could be effectively used in biologically reclaiming desert saline soils and combating desertification processes, especially in arid regions. However, it should be noted that hydroponics media is much more favorable growth condition compared to desert or natural condition. Therefore, the salt removal by these grasses under natural and desert conditions would be with much less magnitude compared to the hydroponics condition of the present study. The results of an unpublished research (Pessarakli *et al.*, unpublished report) on various cultivars of Seashore paspalum (Aloha, Sea Dwarf, Sea Isle 1, Sea Isle 2000, UG22 and Salam) showed that the EC of the culture medium from the initial value of 20 dS/m decreased to 15 dS/m after 4 months of growth period of these plants. This indicates that a substantial amount of salt was absorbed by these halophytic grasses and removed from the culture medium.

CONCLUSIONS

The growth rates of the grasses were affected only under the highest level of salinity stress and the roots were stimulated under the lower and the medium salinity levels. While both cultivars seemed to follow the same trends among most of the criteria screened for, overall the Aloha cultivar showed slightly more tolerance to salinity stress than the Sea Dwarf cultivar.

From the results of this study, it can be concluded that these halophytic plant cultivars are suitable for growth and production under arid, desert regions and Seashore paspalum can effectively be used for biological salinity control or reclamation of desert saline soils, sustainable production under harsh conditions of the desert regions with high soil salinity levels and drought conditions and effectively combat desertification processes.

REFERENCES

1. Glenn, E.P., S. Miyamoto, D. Moore, J.J. Brown, T.L. Thompson and P. Brown. 1997. Water requirements for cultivating *Salicornia bigelovii* Torr. with seawater on sand in a coastal desert environment. Journal of Arid Environment, 36: 711-730.
2. Miyamoto, S., E.P. Glenn and M.W. Olsen, 1996. Growth, water use and salt uptake of four halophytes irrigated with highly saline water. Journal of Arid Environment, 32: 141-159.
3. Westcot, D.W., 1988. Reuse and disposal of higher salinity subsurface drainage water: a review. Agricultural Water Management, 14: 483-511.
4. Carrow, R.N. and R.R. Duncan, 1998. Salt-affected Turfgrass Sites: Assessment and Management. Wiley, Hoboken, NJ., pp: 232.
5. 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. Agricultural Water Management, 43: 99-109.
6. Romero-Aranda, R., J.L. Moya, F.R. Tadeo, F. Legaz, E. Primo-Millo and M. Talon, 1998. Physiological and anatomical disturbances induced by chloride salts in sensitive and tolerant citrus: beneficial and detrimental effects of cations, Plant Cell Environment, 21: 1243-1253.
7. Ashraf, M., 1994. Breeding for salinity tolerance in plants. Critical Review of Plant Sciences, 13: 17-42.
8. Duncan, R.R. and R.N. Carrow, 1999. Turfgrass molecular genetic improvement for biotic/edaphic stress resistance. Advances in Agronomy, 67:233-305.
9. Flowers, T. and A. Yeo, 1995. Breeding for salinity resistance in crop plants: where next? Australian Journal of Plant Physiology, 22: 875-884.
10. Glenn, E.P., J.J. Brown and E. Blumwald, 1999. Salt tolerance and crop potential of halophytes. Critical Review of Plant Science, 18: 227-255.
11. Munns, R., S. Husain, A.R. James, A.G. Condon, M.P. Lindsay, E.S. Lagudah, D.P. Schachtman and R.A. Hare, 2002. Increasing salt tolerance in crops and the role of physiologically-based selection traits, Avenues for Assessment and Management. Ann Arbor Press, Chelsea, MI. Plant and Soil, 247: 93-105.
12. Cushman, J.C. and H.J. Bohnert, 2000. Genomic approaches to plant stress tolerance. Current Opinion in Plant Biology, 3: 117-124.
13. Grover, A., C. Sahi and N. Sanan, 1999. Taming abiotic stresses in plants through genetic engineering: current strategies and perspective. Plant Science, 143: 101-111.
14. Holmberg, N. and L. Bulow, 1998. Improving stress tolerance in plants by gene transfer. Trends in Plant Science, 3: 61-66.

15. Isla, R., R. Aragues and A. Royo, 1998. Validity of various physiological traits as screening criteria for salt tolerance in barley. Field Crops Research, 58: 97-107.
16. Marcum, K.B. and M. Pessarakli, 2006. Salinity Tolerance and Salt Gland Excretion Activity of Bermudagrass Turf Cultivars. Crop Science Society of America Journal, 46(6): 2571-2574.
17. Marcum, Kenneth B. and Mohammad Pessarakli, 2010. Salinity Tolerance of Ryegrass Turf Cultivars. HortScience, 45: 1882-1884.
18. 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.
19. Pessarakli Mohammad, 2011. Saltgrass, a High Salt and Drought Tolerant Species for Sustainable Agriculture in Desert Regions. International Journal of Water Resources and Arid Environments (ISSN: 2079-7079), 1(1): 55-64.
20. Pessarakli, M. and Hayat Touchane, 2006. Growth Responses of Bermudagrass and Seashore Paspalum under Various Levels of Sodium Chloride Stress. Journal of Food, Agriculture and Environment (JFAE), 4(3&4): 240-243.
21. Pessarakli, Mohammad and Hayat Touchane, 2011. Biological Technique in Combating Desertification Processes Using a True Halophytic Plant. International Journal of Water Resources and Arid Environments (ISSN: 2079-7079), 1(5): 360-365.
22. Pessarakli, M. and D.M. Kopec, 2005. Responses of Twelve Inland Saltgrass Accessions to Salt Stress. USGA Turfgrass and Environmental Research Online 4(20):1-5. http:// turf.lib.msu.edu/ tero/ v02/ n14.pdf
23. Pessarakli, M. and D.M. Kopec, 2008. Establishment of Three Warm-Season Grasses under Salinity Stress. Acta HortScience, ISHS, 783: 29-37.
24. Pessarakli, M. and D.M. Kopec, 2009a. Screening Various Ryegrass Cultivars for Salt Stress Tolerance. Journal of Food, Agriculture and Environment (JFAE), 7(3&4): 739-243.
25. Pessarakli, Mohammad and David Kopec, 2009b. Salinity Tolerance of Turfgrasses. Cactus Clippings Magazine, Golf Course Superintendents Association of Arizona (GCSAA), September-October 2009 Issue (5): 17-18.
26. Pessarakli, Mohammad and David M. Kopec, 2010. Growth Responses and Nitrogen Uptake of Saltgrass (*Distichlis spicata*.), a True Halophyte, under Salinity Stress Conditions using the ^{15}N Technique. Proceedings of the International Conference on Management of Soils and Ground Water Salinization in Arid Regions, Vol. 2, 1-11, Muscat, Sultanate of Oman.
27. Pessarakli, M. K.B. Marcum and D.M. Kopec, 2005. Growth Responses and Nitrogen-15 Absorption of Desert Saltgrass (*Distichlis spicata*) to Salinity Stress. Journal of Plant Nutrition, 28(8): 1441-1452.
28. 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), 4(1): 325-327.
29. Pessarakli, M., N. Gessler and D.M. Kopec, 2008. Growth Responses of Saltgrass (*Distichlis spicata*) under Sodium Chloride (NaCl) Salinity Stress. USGA Turfgrass and Environmental Research Online, October 15, 2008, 7(20):1-7. http://turf.lib.msu.edu/tero/v02/n14.pdf
30. Pessarakli, Mohammad, David M. Kopec and Dennis T. Ray, 2011. Growth Responses of Various Saltgrass (*Distichlis spicata*) Clones under Salt Stress Conditions. Journal of Food, Agriculture and Environment (JFAE), 9(3&4): 660-664.
31. Lee, G.J., R.N. Carrow and R.R. Duncan, 2004a. Salinity tolerance of selected Seashore paspalums and bermudagrasses: root and verdure responses and criteria. HortScience, 39(2): 1136-1142.
32. Lee, G.J., R.R. Duncan and R.N. Carrow, 2004b. Salinity tolerance of Seashore paspalum ecotypes: shoot growth responses and criteria. HortScience, 39(2): 1143-1147.
33. Munns, R. and A. Termaat, 1986. Whole plant responses to salinity, Australian Journal of Plant Physiology, 13: 143-160.
34. Pessarakli, M., 2007. Growth Responses of Bermudagrass to Various Levels of Nutrients in Culture Medium. *In*: *Handbook of Turfgrass Management and Physiology* (M. Pessarakli, Ed.), pp: 57-63, CRC Press, Taylor and Francis Group, Florida.
35. 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 and Environment (JFAE), 2(3&4): 284-286.

36. Hoagland, D.R. and D.I. Arnon, 1950. The water-culture method for growing plants without soil. California Agriculture Experiment Station, Circular, pp: 347.
37. SAS Institute, Inc. 1991. SAS/STAT User's guide. SAS Inst., Inc., Cary, NC.
38. Greenway, H. and R. Munns, 1980. Mechanisms of salt tolerance in non-halophytes. Annual Review of Plant Physiology, 31: 149-190.