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Screening Various Cultivars of Seashore Paspalum (*Paspalum vagenitum* Swartz) for Salt Tolerance for Potential Use as a Cover Plant in Combatting Desertification

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Abstract: Continuous desertification of arable lands due to global warming and shortage of water, mandates use of low quality/saline water for irrigation that imposes more salt stress on plants which are already under stress in these regions. 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 are already growing under such harsh conditions and are adapted to these stresses, they are the most suitable candidates to be used for cultivation under these stressful conditions. My previous investigations at the University of Arizona indicated that Seashore Paspalum (*Paspalum vaginatum* Swartz), a halophytic grass species, has a great potential to be used under harsh and stressful arid environmental conditions, yet perform satisfactory growth. Therefore, growth responses of various cultivars of Seashore Paspalum were studied hydroponically in a greenhouse under different NaCl levels in a RCB design experiment with four replications. Shoots and roots' lengths and clippings fresh and DM weights were measured weekly and the grasses' general qualities were evaluated. At the termination of the experiment, roots were also harvested, fresh and DM weights were determined. The results showed significant differences in the shoot and root lengths as well as the shoot and root fresh and DM weights and general qualities of the various cultivars at all the salinity levels. Root length of Sea Dwarf was significantly higher than that of any other cultivar, followed by that of Aloha and Salam, which were followed by the rest of the cultivars. The shoot length was more severely affected by salt stress compared to the root length. Among all the cultivars, Sea Dwarf had consistently the lowest shoot length at all salinity levels. Salam and UG22 had the highest shoot fresh and DM weights, followed by that of Aloha which was followed by the shoot fresh and DM weights of the rest of the cultivars. In regards to roots, Sea Dwarf, UG22 and Salam had the highest root fresh and DM weights followed by that of Aloha which was followed by Sea Isle 1 and Sea Isle 2000. Statistically, there was no significant difference in grasses' general qualities at salinity levels of 5 to 20 dSm^{-1} NaCl. However, the grasses' general qualities of all the cultivars significantly decreased at the higher (EC of 25 and 30 dSm^{-1} NaCl) salinity levels. Among all the cultivars, Sea Isle 2000 had consistently numerically the highest general quality values compared to that of the rest of the cultivars. Overall, all the cultivars proved to have a satisfactory growth under the salinity levels of the experiment higher than the soil salinity of the harsh desert conditions. This indicates that Seashore Paspalum, a halophytic plant species, can be used for a sustainable production in desert regions with high salt content soils as well as low quality/saline waters, therefore, effectively combatting desertification.

Key words: Halophytic species・Combating desertification・Sustainable agriculture

INTRODUCTION

Desertification of the arable lands due to urbanization, global warming, shortage of water and conversion of the farmlands to saline soils, mandates use of marginal lands and saline soils and low quality/saline water, particularly associated with desert regions, for irrigation and cultivation of plant species with high degrees of salt and drought tolerance, especially in regions experiencing water shortage. Cultivation and

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agricultural practices on saline soils and 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. Thus, there is an urgent need for finding salt/drought tolerant plant species to survive/sustain under such stressful conditions. Since the native plants are already growing under such conditions and are adapted to these stresses, these plants are the best and the most suitable candidates to be manipulated under the minimum cultural practices and minimum inputs (water, fertilizer and other agrichemicals) for use under these stressful conditions. If stress tolerant species/genotypes/cultivars of these native plants 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. My previous investigations at the University of Arizona [1, 2, 3] indicated that Seashore Paspalum (*Paspalum vaginatum* Swartz), a halophytic grass species, has a great potential to be used under harsh and stressful environmental conditions, characterized with arid regions, yet perform very satisfactory growth. This grass has multiple usages, including soil conservation and stabilization against erosion as biological erosion control and use for lawns/parks/recreation areas as a desert landscaping plant species.

One strategy to enhance plant survival and recovery from salt stress is to use cultivars with superior salinity tolerance [4, 5, 6, 7, 8]. However, development of salt-tolerant cultivars is not simple because the trait is quantitative (controlled by many physiological mechanisms and genes) [9, 10, 11] and lacks a standardized screening protocol at both intra- and inter-species levels [4, 6, 12]. 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 being one of the most common stresses they encounter [1, 2, 3, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27]. Salinity stress can stunt growth, dehydrate, cause chemical imbalances and make the plants susceptible to injury.

Some grasses deal with salinity better than other species [1, 2, 3, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27]. 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 (shoot and root fresh and dry weights).

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 [1, 2, 3, 4, 5, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30].

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 Seawater salinity level [1, 2, 3, 5] to select the best genotype.

Seashore Paspalum is a warm-season grass species grows worldwide as a turfgrass/landscaping plant, forage/pasture grass, or as a sustainable cover grass species for soil erosion control in a wide range of climates, soils and environmental conditions. The species is very tolerant to salinity stress, a characteristic of the desert areas where the soils are usually saline and water is limited for irrigation and other agricultural uses.

The objectives of this investigation were to evaluate and compare growth and performance of various cultivars of Seashore Paspalum in terms of shoot and root length and shoot (clippings) and root fresh and dry weights and the grass general quality under various levels of salinity [sodium chloride (NaCl)] stress for use under harsh and stressful desert conditions for sustainable agriculture and combating desertification.

MATERIALS AND METHODS

Growth responses of six cultivars of Seashore Paspalum (Aloha, Sea Dwarf, Sea Isle 1, Sea Isle 2000, UG22 and Salam) were studied hydroponically in a greenhouse under various NaCl levels (EC 5, 10, 15, 20, 25 and 30 dSm^{-1}) in a randomized complete block (RCB) design experiment with four replications. The grasses were grown at each of the above EC levels for one week.

The plants were grown as vegetative propagules in cups, 9 cm diameter and 7 cm height, followed the procedures used by Marcum and Pessarakli [13, 14], Marcum et al. [15], Pessarakli [16, 17, 18, 31], Pessarakli and Touchane [1, 2], Pessarakli and Kopec [19, 20, 21, 22, 23, 32], Pessarakli et al. [24, 25, 26, 27] and Pessarakli and McMillan [3]. 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 [33].

Plants were allowed to grow in this nutrient solution for eight weeks. During this period, the plant shoots (clippings) were harvested weekly in order to allow the Seashore Paspalum to reach full maturity and develop uniform and equal size plants. The harvested plant materials (clippings) were discarded. The culture solutions were changed biweekly to ensure adequate amount of plant essential nutrient elements for normal growth and development. At the last harvest (8th week), the roots were also cut to 0.5 cm length ensuring that all plants had uniform roots and shoots for the salt stress phase of the experiment.

The salt treatments were initiated by adding 3.2 g NaCl per liter of the culture solution per week for each EC 5 dSm^{-1}. The grasses were grown at EC 5 dSm^{-1} for the first week, then the growth measurements were taken and the shoots were harvested for the fresh and dry matter (DM) weights measurements. Then, the EC of the culture solutions were raised to 10 dSm^{-1} for the grasses to grow at this salinity level for a week and the second week growth and harvest were made. This procedure was continued for raising the EC of the culture solutions to 15, 20, 25 and 30 dSm^{-1} for the 3rd, 4th, 5th and the 6th weeks growth and harvests, respectively. The culture solution levels in the tubs were marked at the 10-liter volume level and maintained at this level by adding water as needed.

After each week growth at a specified EC level, plant shoots were harvested for the evaluation of the fresh and DM production. At each weekly harvest, both shoot and root lengths were measured and recorded. The harvested plant materials were oven dried at 70°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 70°C and DM weights were determined and recorded.

The data were subjected to Analysis of Variance (ANOVA), using SAS statistical package [34]. The means were separated, using Duncan Multiple Range test.

RESULTS AND DISCUSSION

Root Length: The effects of salinity stress on the cumulative length of roots are shown in Table 1. As shown in Table 1, cumulative root length of Sea Dwarf was significantly higher than that of any other cultivar at all salinity levels. Therefore, Sea Dwarf was statistically considered group 1 in regards to root length under salinity stress. It followed by the root lengths of the Aloha and Salam cultivars that were statistically considered as the second group. The root lengths of the rest of the cultivars (Sea Isle 1, Sea Isle 2000 and UG22), were statistically lower than that of these two groups [Sea Dwarf (group 1) and Aloha and Salam (group 2) cultivars] and were considered group 3.

Shoot Length: The shoot length was more severely affected under salt stress compared to the root length (Table 1). Among all the cultivars, Sea Dwarf had consistently the lowest shoot length at all salinity levels. The statistically significant difference among the shoot lengths of the various cultivars due to salinity stress was shown at all salinity levels, including the lowest (EC 5 dSm^{-1}) NaCl level. However, Pessarakli and Marcum [35] found that the effect of salinity on saltgrass (*Distichlis spicata* L.), another halophytic grass species, shoot length was statistically significant at 200 mM or more salinity levels compared to that of the control and the low (100 mM) level of NaCl. This is an indication of the difference in the salt tolerance of these two grass species (Seashore Paspalum vs. saltgrass) as well as the difference in the salinity tolerance of these cultivars of the Seashore Paspalum. The shoot lengths of all the cultivars decreased as salinity (NaCl) level increased. Reduction in the shoot length of all the cultivars was more pronounced at the highest level of NaCl salinity stress.

Shoot Fresh Weight: The weekly shoot fresh weights of all the cultivars are presented in Table 2. As shown in Table 2, at all salinity levels, Salam and UG22 cultivars had the highest shoot fresh weights and were statistically considered as group 1 in regards to salt stress tolerance. The shoot fresh weights of the Aloha cultivar at almost all the salinity levels followed the shoot fresh weights of the Salam and UG22 cultivars (Table 2), therefore, Aloha cultivar was statistically considered the second group in

Table 1: Seashore Paspalum weekly shoot length and cumulative root length under various NaCl salinity levels

	Salinity levels (EC, dSm^{-1})											
	5	10	15	20	25	30	5	10	15	20	25	30
	Shoot length*						Root length*					
Grass ID	(cm)											
Aloha	8.7b**	6.7b	6.4c	6.2b	5.7b	5.6c	12.7a	21.8b	33.2b	38.7b	41.4b	47.7b
SD***	7.1c	5.6c	5.3d	5.1c	4.6c	3.5d	13.7a	30.2a	40.4a	48.5a	52.8a	56.0a
SI 1***	10.3a	8.7a	8.8a	8.1a	8.6a	8.0a	9.2bc	18.7cd	31.3c	40.0b	41.2b	42.8c
SI 2***	8.1b	8.3a	8.3ab	8.4a	8.0a	6.8b	10.2b	17.7d	32.2b	40.0b	41.5b	44.0c
UG22	9.1b	8.7a	7.8b	8.4a	8.3a	6.3bc	8.8c	19.1c	29.2cd	32.4c	35.8c	36.3d
Salam	7.0c	7.9a	7.0c	7.7a	6.6b	6.7b	12.8a	21.7b	34.4b	42.3b	42.5b	48.0b

*The values are the means of 4 replications at each salinity level.

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

***SD, SI 1 and SI 2; Sea Dwarf, Sea Isle 1 and Sea Isle 2000, respectively.

Table 2: Seashore Paspalum weekly shoot fresh weight (FW) and dry weight (DW) under different NaCl salinity levels

	Salinity levels (EC, dSm^{-1})											
	5	10	15	20	25	30	5	10	15	20	25	30
	Shoot FW*						Shoot DW*					
Grass ID	(g)											
Aloha	2.74b**	2.04b	1.45b	1.40b	1.83a	1.62a	0.82b	0.67a	0.56ab	0.54ab	0.55ab	0.53ab
SD***	1.38c	1.75b	1.33b	1.33bc	1.38b	1.24b	0.51c	0.60a	0.49b	0.55ab	0.46b	0.48bc
SI 1***	1.59c	1.27c	1.47b	1.20bc	1.90a	1.11b	0.50c	0.49ab	0.55ab	0.56ab	0.64a	0.44c
SI 2***	1.95bc	0.97c	1.22b	0.95c	1.34b	0.88b	0.64bc	0.36b	0.48b	0.40b	0.48b	0.36c
UG22	3.46a	2.77a	2.32a	1.86a	2.22a	1.63a	0.98a	0.81a	0.77a	0.69a	0.65a	0.58a
Salam	4.30a	2.49a	1.89a	1.83a	2.11a	1.64a	1.11a	0.68a	0.66a	0.70a	0.66a	0.62a

*The values are the means of 4 replications at each salinity level.

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

***SD, SI 1 and SI 2; Sea Dwarf, Sea Isle 1 and Sea Isle 2000, respectively

regards to salinity stress tolerance. The shoot fresh weights of the rest of the cultivars (Sea Dwarf, Sea Isle 1 and Sea Isle 2000), were statistically lower than that of these two groups [Salam and UG22 (group 1) and Aloha (group 2) cultivars] and were statistically considered as group 3 in regards to salt stress tolerance (Table 2). Generally, the shoot fresh weights of all the cultivars decreased as salinity stress levels increased (Table 2). However, Pessarakli and Marcum [35] found that there was no significant difference detected on the saltgrass, another halophytic grass species, shoot fresh weights between the high (400 mM) salinity level compared with the low (100 mM) NaCl stress and the control. These investigators also found that as the stress period progressed, the medium (200 mM NaCl) salinity stress enhanced the saltgrass shoot fresh weight. Pessarakli and Tucker [36] and Pessarakli [37] also reported enhancement of cotton (*Gossypium hirsutum* L.), a salt tolerant plant, growth and protein synthesis by this plant under low level of NaCl stress.

Shoot Dry Matter (DM) Weight: For all the cultivars of Seashore Paspalum, at all salinity levels, shoot DM weights essentially followed the same pattern as the shoot fresh weights. As was reported for the shoot fresh weights, at all salinity levels, two cultivars (Salam and UG22) produced significantly higher shoot DM weights than any other cultivar (Table 2). This was followed by the shoot DM weights of the Aloha cultivar. The rest of the cultivars (Sea Dwarf, Sea Isle 1 and Sea Isle 2000) produced significantly lower shoot DM weights compared to the above cultivars (Salam, UG22 and Aloha). For all the cultivars, shoot DM weights linearly decreased as the salinity levels increased (Table 2). However, Pessarakli and Marcum [35] found that there was no significant difference detected on the saltgrass, another halophytic grass species, shoot DM weights between the high (400 mM) salinity level compared with the low (100 mM) NaCl stress and the control. According to these reporters, the low levels of salinity enhanced the shoot DM weights of saltgrass. Pessarakli and Tucker [36] and Pessarakli [37] also reported enhancement of cotton (*Gossypium hirsutum* L.), a salt tolerant plant, growth and protein synthesis by this plant under low level of NaCl stress. These differences reflect the levels of salinity stress tolerance of these various plant species.

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

Root Fresh Weight: For all the cultivars, the root fresh weights were reduced at all salinity levels. Table 3 shows the cumulative mean values of the root fresh weights of all the cultivars. Sea Dwarf, UG22 and Salam had the highest root fresh weights and were statistically considered as group 1. Aloha had lower shoot fresh weight than the above cultivars (Sea Dwarf, UG22 and Salam), therefore, was statistically considered as group 2, followed by Sea Isle 1 as group 3 and Sea Isle 2000 as group 4 that hat the lowest root fresh weight (Table 3).

Root Dry Matter (DM) Weight: The root DM weight essentially followed the same pattern as the root length and root fresh weight. For all the cultivars, the root DM weights were reduced at all salinity levels. Table 3 shows the cumulative mean values of the root DM weights. Sea Dwarf and UG22 had the highest root DM weights and were statistically considered as group 1, followed by Salam and Aloha, statistically considered as the second group that were followed by Sea Isle 1 and Sea Isle 2000 cultivars that were statistically considered as the third group with the lowest root DM weights.

Shoot Succulence: The shoot succulence (Fresh Wt./Dry Wt.) of the six cultivars of Seashore Paspalum ranged between 2.68 to 3.22 (Table 4). In respect to the shoot succulence, the six cultivars were separated into two statistical groups. Group 1 included Salam, UG22 and Aloha cultivars with the succulence values of 3.22, 3.18 and 3.02, respectively. The remaining three cultivars of Sea Dwarf, Sea Isle 2000 and Sea Isle 1 with shoot succulence values of 2.72, 2.69 and 2.68, respectively, were included in the second statistical group (Table 4). However, Aloha cultivar with the shoot succulence value of 3.02 laid in both statistical groups (Table 4).

Shoot to Root Ratio: The shoot to root ratios of the grasses are presented in Table 4. Two cultivars, Sea Isle 2000 and Sea Isle 1, had the highest shoot to root ratios and were statistically the same, therefore, they were considered group 1. The shoot to root ratio of Salam cultivar (5.75) followed the shoot to root ratios of the above two cultivars, but it was statistically the same as that of Sea Isle 1 and Aloha cultivars. Therefore, these cultivars were statistically considered group 2 (Sea Isle 1 with the shoot to root ratio of 6.12, statistically laid in both groups 1 and 2) (Table 4). UG22 cultivar was statistically in group 3 and the Sea Dwarf cultivar with the lowest shoot to root ratio was statistically in group 4. Therefore, there were significant differences found in the shoot to root ratios of the six studied cultivars of the Seashore Paspalum.

Grass General Quality: The general qualities of the six cultivars of Seashore Paspalum under various NaCl salinity levels are presented in Table 5. Statistically, there was not any significant difference found in grasses' general qualities at salinity levels of 5, 10, 15 and 20 dSm^{-1} NaCl (Table 5). However, the grasses' general qualities of all the six cultivars significantly decreased at the higher (EC 25 and 30 dSm^{-1} NaCl) salinity levels and the most reductions in all the six cultivars' general qualities were found at the highest salinity level (EC 30 dSm^{-1}). Among all the cultivars, Sea Isle 2000 had consistently numerically the highest general quality values and there was statistically a significant difference between the general quality of this cultivar compared to any other cultivars at the highest salinity level (EC 30 dSm^{-1}) (Table 5). Despite the significant reduction in the general qualities of the grasses at the higher salinity levels (EC 25 and 30 dSm^{-1} NaCl), the general qualities of all the six cultivars of Seashore Paspalum were still acceptable (according to the NTEP, National Turfgrass Evaluation Program, quality scores of 6 or higher are acceptable) even at these high levels of salinity (Table 5).

Table 3: Seashore Paspalum root fresh weight (FW) and root dry weight (DW) (Cumulative) under NaCl salinity stress

Grass ID	Root FW*	Root DW*
	---(g)---	
Aloha	9.78b**	0.74b
Sea Dwarf	12.54a	0.95a
Sea Isle 1	6.75c	0.52c
Sea Isle 2000	4.66d	0.38c
UG22	11.65a	1.03a
Salam	10.90ab	0.77b

*The values are the means of 4 replications.

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

Table 4: Seashore Paspalum succulence (overall shoot Fresh Wt./Dry Wt.) and overall shoot to root ratio under NaCl salinity stress

Grass ID	Shoot Succulence*	Shoot/Root*
Aloha	3.02ab**	4.96bc
Sea Dwarf	2.72b	3.25d
Sea Isle 1	2.68b	6.12ab
Sea Isle 2000	2.69b	7.16a
UG22	3.18a	4.35c
Salam	3.22a	5.75b

*The values are the means of 4 replications.

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

Table 5: Seashore Paspalum general qualities under NaCl salinity stress

	Grass General Quality*					
	Grass ID					
NaCl salinity (EC, dSm^{-1})	Aloha	Sea Dwarf	Sea Isle 1	Sea Isle 2000	UG22	Salam
5	10a**	10a	10a	10a	10a	10a
10	9.7a	9.6a	9.8a	10a	9.8a	9.7a
15	9.2a	9.0a	9.3a	9.5a	9.3a	9.2a
20	8.7ab	8.5ab	8.8ab	9.0a	8.8ab	8.7ab
25	8.1b	7.8bc	8.2b	8.5ab	8.2b	8.1b
30	7.5c	7.2c	7.6c	8.0b	7.6c	7.5c

*The Values are the means of 4 replications at each salinity level.

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

CONCLUSIONS

At all salinity levels, root length of Sea Dwarf was significantly higher than that of any other cultivar, followed by that of Aloha and Salam, which were followed by the rest of the cultivars. The shoot length was more severely affected under salt stress compared to the root length. Among all the cultivars, Sea Dwarf had consistently the lowest shoot length at all salinity levels. Salam and UG22 had the highest shoot fresh and DM weights, followed by that of Aloha which was followed by the shoot fresh and DM weights of the rest of the cultivars. Sea Dwarf, UG22 and Salam had the highest root fresh and DM weights followed by that of Aloha which was followed by Sea Isle 1 and Sea Isle 2000. Salam, UG22 and Aloha cultivars had the highest shoot succulence. The remaining three cultivars had statistically the same shoot succulence, but significantly lower than the above cultivars. Sea Isle 2000 and Sea Isle 1, had the highest shoot to root ratios followed by Salam which was followed by Aloha that was followed by the shoot to root ratios of UG22 and Sea Dwarf, respectively. Statistically, there was no significant difference found in grasses' general qualities at salinity levels of 5 to 20 dSm^{-1} NaCl. However, the grasses' general qualities of all the six cultivars significantly decreased at the higher (EC 25 and 30 dSm^{-1} NaCl) salinity levels. Among all the cultivars, Sea Isle 2000 had consistently the highest general quality values and there was statistically a significant difference between the general quality of this cultivar compared to that of the rest of the cultivars at the highest (EC 30 dSm^{-1} NaCl) salinity level. Despite the significant reduction in the general qualities of the grasses at the higher salinity levels (EC 25 and 30 dSm^{-1} NaCl), the general qualities of all the six cultivars were still acceptable even at these high levels of salinity. Overall, all the cultivars proved to have a satisfactory growth under the salinity levels of the experiment higher than the soil salinity of the harsh desert conditions. This indicates that Seashore Paspalum, a true halophytic plant species, can be used for a sustainable production in desert regions with high salt content soils as well as low quality/saline waters, therefore, combatting desertification.

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