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Biological Technique in Combating Desertification Processes Using a True Halophytic Plant

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Abstract: Desertification is one of the greatest challenges facing mankind. Its extent and impact on human welfare and the global environment are now greater than ever before. Particularly, in arid regions, the rate of desertification is frighteningly high and indeed, crop production and livestock husbandry are alarmingly at high risk. In such circumstances, a whole mixture of initiatives should be undertaken to curtail further desertification processes. These initiatives should include soil management, erosion control, reclamation, rehabilitation, which simply seek to halt desertification processes. A wide array of measures including various reclamation techniques for reducing soil salinity/sodicity, runoff barrier techniques such as vegetation strips and organic residues management techniques are developed to enhance soil productivity and to prevent further desertification progresses. Among these measures, revegetation of the arid lands, using plant species that are more adapted to the harsh and stressful conditions of the deserts is probably the most effective practice owing to its affordability in combating desertification. A permanent vegetation cover is the best protection against desertification. The moment vegetation is destroyed the condition becomes favorable for desertification process to accelerate. Bare areas are much more vulnerable to desertification compared to plant covered regions. Vegetation cover not only prevents desertification process, but also significantly improves soil and, in turn, the environmental condition of the region. Halophytes are particularly effective in this regard by reducing salinity level of the soil via removing the salts or by utilizing saline and low quality waters for their growth. Seashore paspalum (*Paspalum vaginatum* Swartz), a true halophyte, was used in this study to reduce the salinity levels of the growth medium by absorption and secretion of the salts from its leaves. The Sea Isle 2000 cultivar of this species was grown under various NaCl salinity levels (5,000, 10,000, 20,000 and 30,000 mg/l) of the culture medium. Bermudagrass (*Cynodon dactylon* L.), another halophytic plant, variety Tifway 419 was also used as a comparison with Seashore paspalum in this investigation. Four replications of each salt treatment were used in a RCB design in this experiment. The growth responses of the plants in terms of shoot and root lengths and biomass production (fresh and DM weights) were measured under the salinity stress conditions. The salinity levels of the culture medium were measured at the beginning and the termination of the experiment to evaluate the absorbed salts by subtracting the final salt content of the culture medium from the initial salt contents. The results showed that Seashore paspalum substantially reduced the salinity levels of the culture medium. Therefore, this species can be recommended for production under arid regions that are characterized with highly saline/sodic soils and low quality/saline waters. Consequently, establishment of this plant species in arid regions can effectively prevent further desertification processes in these areas or in similar regions that are vulnerable and are at high risks of desertification, therefore biologically combating desertification processes.

Key words: Halophyte • Biological technique • Combating desertification

INTRODUCTION

Soil salinity and water quality and quantity are major problems worldwide, especially in arid regions and water shortage areas [1-3]. Plant/crop growers and agricultural managers, particularly in 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

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(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.

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, 16-18].

Therefore, halophytic plants like seashore paspalum (*Paspalum vaginatum* Swartz) need to be evaluated at salinity regimes up to sea water level [8, 19] to select the best genotype. Salt problems in agricultural sites, especially in desert regions, are continually becoming more common.

The objectives of this study were to evaluate salt removal of the growth medium by Seashore paspalum compared with bermudagrass, to identify the most effective (superior) of this halophytic plant species for reducing the salinity level of the salt-affected soils and to recommend the superior species as biological soil salinity control species for arid lands reclamation and combating desertification processes.

MATERIALS AND METHODS

Seashore paspalum (*Paspalum vaginatum* Swartz), cv. Sea Isle 2000 and bermudagrass (*Cynodon dactylon* L.), cv. Tifway 419, were studied in a greenhouse to evaluate their salt removal from the growth medium under various NaCl salinity levels of the culture medium, using hydroponics technique.

The grasses were grown as vegetative propagules in cups, 9 cm diameter and 7 cm height, followed the procedures used by [20,19]. 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 half strength Hoagland solution No. 1 [21]. Four replications of each cultivar and each treatment were used 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 and develop uniform and equal size plants. 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 to have plants with uniform roots and shoots for the stress phase of the experiment.

The salt treatments were initiated by adding NaCl to the culture solutions for the various (5,000, 10,000, 20,000 and 30,000 mg/l) salinity treatments. The culture solution levels in the tubs were marked at the 10 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 60°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 60°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 [22]. 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 4th harvest) and the overall average of all the harvests are presented here in Tables 1 and 2, respectively.

Table 1: Shoot and root lengths, fresh and dry weights (harvest # 4) of bermudagrass and Seashore paspalum under various levels of NaCl salinity

		Length*		Shoot Weight*		Root Weight*	
	Salinity	Shoot	Root	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.
Grass species treatment	(mg/l NaCl)	(cm)		(g)			
Bermudagrass	Control (0)	0.91ef**	14.53de	0.38cd	0.26b	0.46cd	0.14c
	5,000	1.13cde	16.15cd	0.28cde	0.14cd	0.37cd	0.12c
	10,000	1.00def	13.35de	0.13ef	0.08de	0.25cd	0.10cd
	20,000	0.68ef	12.60de	0.12ef	0.07de	0.21cd	0.07cd
	30,000	0.48f	10.65e	0.03f	0.02e	0.09d	0.03d
Seashore paspalum	Control (0)	1.98ab	34.28ab	0.61ab	0.44a	1.74a	0.42a
	5,000	2.58a	37.75a	0.80a	0.52a	1.92a	0.44a
	10,000	2.05ab	29.25b	0.46bc	0.19bc	1.57a	0.38a
	20,000	1.73bc	21.45c	0.24de	0.15cd	1.10b	0.26b
	30,000	1.59bcd	16.60cd	0.21def	0.13cd	0.58c	0.12c

*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

Table 2: Shoot and root lengths, shoot fresh weight (FW) and dry matter (DM) weight, shoot succulence (fresh wt./dry wt.) and shoot/root ratio (shoot dry wt./root dry wt.) (overall average of all harvests) of bermudagrass and Seashore paspalum under various levels of NaCl salinity

		Length*		Shoot Weight*		Sh.DM./Rt.DM*	
	Salinity	Shoot	Root	Fresh	Dry	FW/DM	
Grass species treatment	(mg/l NaCl)	(cm)		(g)		ratio	
Bermudagrass	Control (0)	0.95de**	3.63cde	0.47bcd	0.32b	1.47c	9.14a
	5,000	1.86abc	4.04cde	0.39cde	0.20bcd	1.95ab	6.67b
	10,000	1.03de	3.34de	0.24def	0.15cde	1.60bc	6.00b
	20,000	0.89e	3.15e	0.16ef	0.09de	1.78abc	5.14bc
	30,000	0.76e	2.66e	0.08f	0.05e	1.60bc	6.67b
Seashore paspalum	Control (0)	2.48a	8.07ab	0.71ab	0.51a	1.39c	4.86bcd
	5,000	2.31ab	9.44a	0.84a	0.55a	1.53c	5.00bc
	10,000	2.23ab	7.31b	0.58abc	0.28b	2.07a	2.95d
	20,000	1.89abc	5.36c	0.35cdef	0.22bc	1.59bc	3.39cd
	30,000	1.63bcd	4.15cd	0.23def	0.14cde	1.64bc	4.67bcd

*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 Length: The data of the 4th harvest (Table 1) as well as the overall average of the all harvests (Table 2) show that the shoot lengths of both grasses were stimulated at all levels of NaCl salinity, except at the highest level (30,000 mg/l) of the NaCl application rate in the culture medium. The stimulation effect of NaCl was more significant for Seashore paspalum compared to bermudagrass. For both grass species, the lowest level of the NaCl salinity (5,000 mg/l) stimulated the shoot length the most. The overall average of the data for all the weekly harvests had essentially the same results as the 4th harvest (Tables 1 and 2). At either the control or any level of NaCl salinity the shoot length of Seashore paspalum was substantially higher than that of the bermudagrass.

Root Length: In contrast to the shoot length, the root length was less affected by the NaCl salinity (Tables 1 and 2). The stimulation effect of the NaCl salinity on the root lengths of both grass species was more than that for the shoots at the lowest level of NaCl salinity (Tables 1 and 2). This is in agreement with the reports of several investigators [23, 20, 24, 19, 25], as well as the common knowledge in plant physiology that under stress conditions (salinity, drought stress or lower levels of water and nutrients in the rhizosphere), roots grow more in search of water and/or nutrients. As was observed for the shoots, the root length of Seashore paspalum was substantially higher than that of bermudagrass for the controls or at any levels of salinity.

Table 3: Salt removal by bermudagrass and Seashore paspalum from the culture medium under various levels of NaCl application rates

		Electrical Conductivity (EC)*	Salt Removed*	
Grass species treatment	Salinity (mg/l NaCl)	Initial -------(dS/m)--------	Final --------------------------------(mg/l)----------------------------------	From Culture Soln.
Bermudagrass	Control (0)	0.85	0.83	------
	5,000	8.66	6.07	1658bc**
	10,000	16.47	13.51	1894b
	20,000	32.10	29.23	1837b
	30,000	47.72	45.81	1222c
Seashore paspalum	Control (0)	0.87	0.81	------
	5,000	8.68	5.57	1990b
	10,000	16.49	12.45	2585a
	20,000	32.12	28.20	2509a
	30,000	47.74	44.61	2003b

*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

Biomass Production: The shoots and the roots of both grasses were sampled and fresh biomass was determined (Tables 1 and 2). At each salinity level and at each harvest, the fresh weights of shoots and roots of Seashore paspalum were significantly higher than that of bermudagrass (Tables 1 and 2). Reduction in biomass production due to the highest level of salinity stress (30,000 mg/l NaCl) was more pronounced than in reduction in shoot lengths in both bermudagrass and paspalum. The decrease in plant biomass production due to the high level of salinity which was found in the present study may be attributed to low medium water potential, specific ion toxicity, or ion imbalance as reported by [26].

Shoot Dry Matter (DM) Weight: The shoot DM weight responses of the grasses followed essentially the same pattern as that of the shoot fresh weights. The values significantly decreased at the high levels of the NaCl application rates. This is clearly shown for the 4th harvest (Table 1) as well as for the overall average of all harvests (Table 2). However, the effect of the NaCl salinity was more pronounced at the later harvests and at the highest level (30,000 mg/l) of the NaCl salinity stress. As was observed for the shoot lengths and shoot fresh weights of the grasses, shoot DM weight of bermudagrass was more severely affected by NaCl salinity than that of the Seashore paspalum (Tables 1 and 2).

Root Dry Matter (DM) Weight: The root DM weights of both grass species significantly decreased at the higher levels of NaCl application rates (Table 1). The lower levels of NaCl salinity not only did not have an adverse effect on root DM weights of the grasses, but stimulated the root DM weights. It appears that both grasses readily absorbed the nutrients and water, translocated and utilized the absorbed elements for the shoot growth. In the previous hydroponics studies, numerous experiments (Pessarakli and Marcum, unpublished reports) showed very little root growth for some grasses, but substantial shoot growth for the same grass species. The differences in growth rates between bermudagrass and Seashore paspalum followed similar trends both in the presence or absence of NaCl salinity. The higher biomass of shoots and roots of Seashore paspalum in comparison with that of bermudagrass (Tables 1 and 2) may have been due to more vigorous and higher growth rate of paspalum under any (control or stress) growth condition, particularly under salinity stress. The lower transpiration rate of paspalum compared to bermudagrass as reported by Chen *et al.* (2002) may be another reason for this phenomenon, particularly under the NaCl stress condition.

In short, the genotypic growth difference played the dominant role in determining biomass production of these grasses grown with or without salinity stress as clearly shown in plant succulence (the ratios of the shoot fresh weights to dry weights) of both species (Table 2). Root growth was less affected by NaCl salinity than shoot growth, leading to a decrease in shoot to root ratios (Table 2).

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 3).

As shown in Table 3, at each salinity level, Seashore paspalum removed substantially more salts from the culture medium compared to bermudagrass. Therefore, this halophytic species would be more effective in biologically reclaiming desert saline soils than bermudagrass. Nevertheless, bermudagrass that is also a halophytic species was very effective in removing the salts from the culture medium and thereby reclaiming desert saline soils. Thus, both of these halophytic species could be effectively used in biologically reclaiming desert saline soils and combating desertification processes, especially in arid regions.

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 from the culture medium.

CONCLUSIONS

Two major halophytic grass species [Bermudagrass (*Cynodon dactylon* L.), cv. Tifway 419 and Seashore paspalum (*Paspalum vaginatum* Swartz), cv. Sea Isle 2000] were studied hydroponically in a greenhouse. The study was conducted to evaluate the growth responses of these halophytic plants in terms of shoot and root lengths, shoot fresh biomass production and shoot and root dry matter (DM) weights as well as salt removal by each species from the culture medium under various levels of NaCl salinity. The objective of this investigation was to recommend these grass species for production under arid and dry-land conditions to combat desertification processes.

The results showed that shoot and root lengths of both grass species were stimulated at the low levels of the NaCl salinity, but decreased at the high levels of NaCl application rates. The most pronounced reduction in these parameters occurred at the highest level (30,000 mg/l) of NaCl salinity in the culture medium. Shoot and root fresh and DM weights were more severely affected than the shoot and root lengths by salinity stress. For both grass species, shoot lengths and dry matter (DM) weights were more severely affected than that of the roots by the NaCl salinity. For any study parameters, at any harvest and at any salinity level, bermudagrass was more severely affected than Seashore paspalum by NaCl salinity stress. Since the growth rates of the grasses, particularly Seashore paspalum, were affected only under high levels of NaCl salinity stress and the roots were stimulated under lower and medium levels of salinity, it can be concluded that these halophytic plant species are suitable candidates for growth and production under arid, desert regions and dry-land conditions to effectively combat desertification processes in these regions.

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