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Saltgrass, a potential future landscaping plant and a suitable species for desert regions: A review

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Abstract
Continuous desertification of arable lands mandates use of low quality/ saline water for irrigation, especially in regions experiencing water shortage. Using low quality/ saline water for irrigation imposes more stress on plants that are already under stress in these regions. Thus, a logical solution will be to find a salt/ drought-tolerant plant species that will survive/sustain under such stressful conditions. As the native plants are already growing under such conditions and are adapted to these stresses, they are most suitable for use under these harsh arid environmental conditions. If stress-tolerant species/ genotypes of these native plants are identified, there will be substantial savings in inputs (i.e., water, fertilizers, and agrochemicals) in using them under these stressful conditions. My research studies at the University of Arizona on various native grasses indicate that saltgrass (*Distichlis spicata*) has a great potential to be used under harsh environmental desert conditions, to combat the desertification processes. The objectives of this review article are to introduce saltgrass, a halophytic plant species, which through my investigations on various salinity and drought-tolerant halophytic plant species has proven to be the most tolerant plant species for recommendation as the potential species for use in arid regions and in areas with saline soils and limited water supply or drought conditions, for sustainable agriculture and for combating desertification. In my various investigations, different saltgrass clones/accessions/genotypes were studied in a greenhouse, to evaluate their growth responses under salinity or drought stress conditions. The grasses were grown vegetatively either hydroponically in culture solution for salt tolerance or in galvanized cans that contained fritted clay for drought tolerance. For salt tolerance, the grasses were grown under four treatments (EC = 6 (control), 20, 34, and 48 dSm^{-1} salinity stress) with three replications in a *randomized complete block* (RCB) design experiment. During this period, the shoots were clipped bi-weekly for fresh and dry matter (DM) weight determination. At the last harvest, the roots were also harvested and the DM weights determined. For drought tolerance, the growth responses of the grasses were evaluated under a progressive drought condition for four months in a split plot design experiment with three replications. Shoots were harvested bi-weekly for DM determination. Although growth responses reduced at high salinity levels or as the drought period progressed, all the grasses showed a high degree of salinity/drought tolerance. However, there was a wide range of variations observed in salinity/ drought tolerance among the various clones/accessions/genotypes. The superior salinity/ drought-tolerant plants were identified, which could be recommended for sustainable production under arid regions and combating desertification.

Keywords: Combating desertification, halophytic plant species, sustainable agriculture.

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Introduction

Desert saltgrass (*Distichlis spicata* (L.) Greene var. *stricta* (Gould, 1993), a potential feed grass, landscaping plant, and turf species, grows in very poor- to fair-condition soils, in both salt-affected soils and soils under drought conditions. It grows in arid and semi-arid regions. The plant is abundantly found in areas of the western parts of the United States, as well as on the seashores of several Middle-Eastern countries, Africa, and South and Central American countries. The plant (Fig. 1) can be manipulated to increase its yield and productivity. This plant has multiple usages. It can be substituted for animal feeds such as alfalfa or it can be used in soil conservation for covering road sides and soil surfaces, in soils with a high-risk of erosion. The United States Golf Association (USGA) has shown a great deal of interest in financing research studies on this plant to use it as turfgrass and as a landscaping plant species. Most of these research studies are conducted at the University of Arizona and Colorado State University. Consequently, the USGA funds for the investigations on this grass species have been allocated to these institutions (Marcum *et al*., 1996–1999; Christensen *et al.*, 2002–2005; Kopec *et al*., 2008–2010; Pessarakli *et al*., 2009–2012; Kopec *et al*., 2013–2016).

Fig. 1. Various genotypes of saltgrasses growing in pots under normal condition

Positive and promising results have already been obtained from these studies (Kopec *et al*., 2000, 2001a, 2001b; Marcum *et al*., 2001, 2005; Pessarakli, 2005a, 2005b, 2011; Pessarakli *et al*., 2001a, 2001b, 2001c, 2003, 2005a, 2005b, 2008, 2011a, 2011b, 2012; Pessarakli and Kopec, 2003, 2008a, 2008b, 2011; Pessarakli and Marcum, 2000).

The above reports and those of Sigua and Hudnall (1991), Sowa and Towill (1991), Enberg and Wu (1995), Miyamoto *et al*. (1996), Rossi *et al*. (1996), and Miller *et al*. (1998), all deal with the growth of various genotypes/accessions/clones of this species.

The objectives of this review article were to report the available information on the growth responses of desert saltgrass grown under control and different levels of sodium chloride (NaCl) salinity stress and drought stress conditions, to introduce this halophytic plant species as a landscaping plant and its soil surface coverage in arid and semi-arid regions, as also to study its capacity for combating desertification.

Marcum *et al*. (2001, 2005) Pessarakli (2005a, 2005b, 2011) Pessarakli and Kopec (2008a, 2008b, 2011), and Pessarakli *et al*. (2001a, 2001b, 2001c, 2005a, 2005b, 2008, 2011a, 2011b, 2012) studied the growth responses of several accessions of saltgrass and compared them with Bermuda grass (*Cynodon dactylon* L.). These investigators found that various accessions of saltgrass were superior to Bermuda grass in respect to both salinity and drought tolerance. Saltgrass tolerated salinity level as high as that of the sea water (Figs. 2 and 3) and survived four months of drought stress (Figs. 4, 5, and 6) in these studies. Amazingly, all the accessions of saltgrass completely recovered after the salinity and drought stresses were alleviated. These investigations proved that this grass can survive under minimum water availability (drought), salinity stress, or very harsh environmental stress conditions (Figs. 2, 3, 4, 5, 6, 7, 8, and 9).

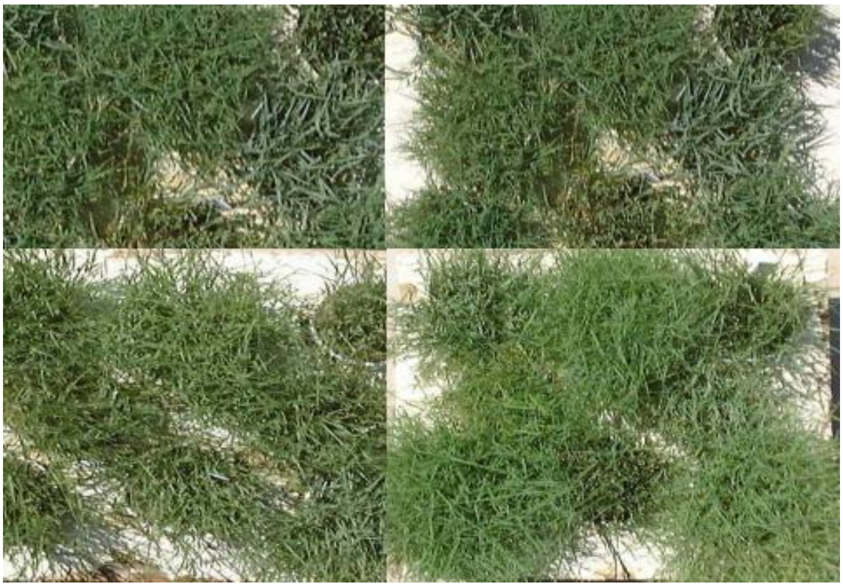

Fig. 2. Various genotypes of salt grasses growing in hydroponic systems under EC of 20 dS/m salinity stress (Source, Pessarakli *et al*., 2008)

Fig. 3. Saltgrass visual quality under control (EC = 6 dS m^{-1}) and various salinity stress levels (20, 34, and 48 dS m^{-1}). Tubs in each row, left to right, EC = 6, 20, 34, and 48 dS m^{-1}, respectively (Source, Pessarakli, 2011)

Fig. 4. Stainless steel galvanized can (one replication of the plant) containing 150 kg fritted clay and the cups just planted with saltgrass (*Distichlis spicata*) at the beginning of the plant establishment stage (Pessarakli, 2011)

Fig. 5. Stainless steel galvanized cans (three replications of the plants for each of the two mowing heights for the later drought phase of the experiment) containing 150 kg of fritted clay and the cups just planted with saltgrass (*Distichlis spicata*) at the beginning of the plant establishment stage (Pessarakli, 2011)

Fig. 6. Plants are either dead or in dormancy stage at the termination of the drought experiment (Pessarakli, 2011)

Fig. 7. Saltgrass (*Distichlis spicata*) as a potential turfgrass and landscaping plant species

Fig. 8. Saltgrass (*Distichlis spicata*) experimental field plots for mowing height tests

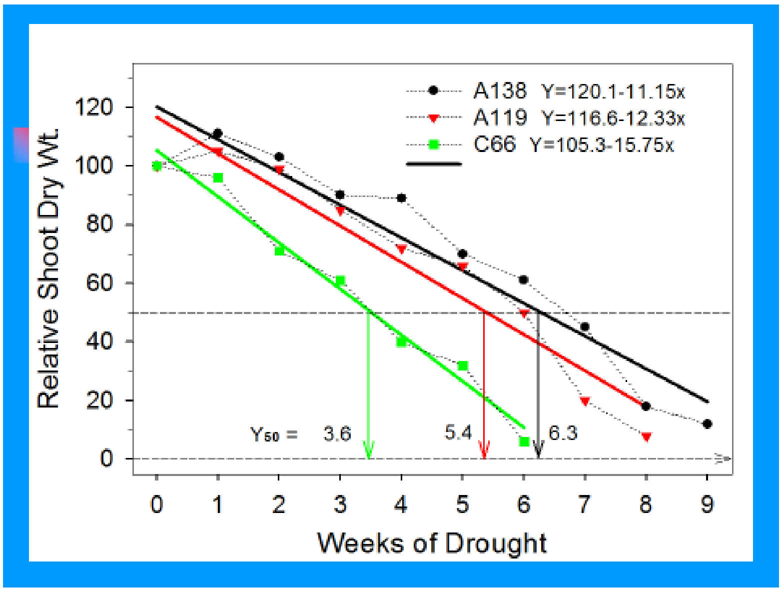

Fig. 9. Shoot dry weights of various genotypes of saltgrasses growing under nine weeks of progressive drought stress (Pessarakli, *et al*., 2001c)

In other studies, Pessarakli *et al*. (2003) and Pessarakli and Kopec (2008a) compared the establishment of saltgrass, Bermuda grass, and seashore paspalum (*Paspalum vaginetum* Swertz) under salinity stress conditions and found that for any plant parts used for the establishment, saltgrass performed better than both Bermuda grass and seashore paspalum under stress conditions. Pessarakli *et al*. (2005a) collected desert saltgrass accession WA 12, a prostrate physiotype, from a salt playa in Wilcox, Arizona, which had a soil with exchangeable sodium percentage (ESP) of about 50. No other grass was growing on this playa, except saltgrass. This is an indication of a very high salinity tolerance of this grass species. Pessarakli and his coworkers used this grass accession in a greenhouse experiment to evaluate its dry-matter yield and nitrogen absorption rates under control and salt (NaCl) stress conditions, using a hydroponic technique. These investigators found that this grass accession showed enhanced growth, up to 200 mM NaCl salinity, in the culture media (Pessarakli *et al*., 2005a).

In all Pessarakli and his co-workers' studies on saltgrass, the experiments on the grass performances under normal conditions were conducted in the fields (Kopec *et al*., 2000, 2001a, 2001b), the drought-tolerance experiments were carried out in the greenhouse using large galvanized cans containing 150 kg calcine clay (fritted clay) (Figs. 4, 5, 6 and 9) (Pessarakli, 2005b; Pessarakli and Kopec, 2008b, 2011; Pessarakli *et al*., 2001a, 2001c, 2011b). For the salinity stress studies, the plants were vegetatively grown in the greenhouse using the hydroponic system (Figs. 2 and 3) (Marcum *et al*., 2001, 2005; Pessarakli, 2005a, 2005b; Pessarakli and Kopec, 2003, 2008a; Pessarakli and Marcum, 2000; Pessarakli *et al*., 2001b, 2003, 2005a, 2005b, 2008, 2011a, 2012). Plants were grown in cups of 9 cm diameter and cut to 7 cm height. Silica sand was used as the plant's anchor medium. The cups were fitted in plywood lid holes and the lids were placed on 42 cm x 34 cm x 12 cm Carb-x polyethelene tubs (Figs. 2 and 3), containing half strength Hoagland nutrient solution (Hoagland and Arnon, 1950). Three or four replications of each treatment were used, for the drought and salinity stress, respectively, in these investigations. In each experiment, the plants were allowed to grow in the Hoagland nutrient solution (salinity stress) or in galvanized cans (drought stress) for 90 days. During this period, the plant shoots were harvested weekly in order to reach full maturity and develop uniform and equal sized plants for the next phase of the experiment (salinity or drought stress). The harvested plant materials were discarded. For the salinity stress studies, the culture solutions were changed biweekly to ensure adequate amount of plant essential nutrient elements for normal growth and development. At the last harvest, the roots were also cut to 2.5 cm length to have plants with uniform roots and shoots for the salinity stress phase of the experiment. Subsequently, the stress phases of the experiments were conducted as follows:

Salt stress

For the various salinity stress experiments, the salt treatments were initiated by adding a specific amount of salt (i.e., 50 mM, 2.925 g, of NaCl per liter of the culture solution) per day. Depending on the experiments, four to six treatments were used, including control (no salt addition), (i.e., 0, 100, 200, and 400 mM salinity levels), following the procedures of Marcum *et al*. (2001, 2005), Pessarakli (2005a, 2005b), Pessarakli and Kopec (2003, 2008a), Pessarakli and Marcum (2000), and Pessarakli *et al*. (2001b, 2003, 2005a, 2005b, 2008, 2011a, 2012). The culture solution levels in the tubs were maintained at the 10 liter volume and solution conductivity monitored/adjusted to maintain the prescribed treatment levels. After the final salinity levels were reached, the shoots were harvested and the harvested plant materials were discarded prior to the beginning of the salinity stress phase of the experiments.

Drought stress

For the drought stress studies, a dry-down fritted clay system, which mimics progressive drought (White *et al*., 1992; Pessarakli, 2005, 2011; Pessarakli and Kopec, 2008b; Pessarakli *et al*., 2001a, 2001c) was used. The system imposed a gradually prolonged drought stress to plants (i.e., various saltgrass clones/accessions/genotypes) planted in separate cups (experimental units).

In all the drought stress experiments, the drought stress was started by completely saturating the cans containing 150 kg fritted clay and the cups containing the grasses, and then depriving the grasses of water and fertilizer for a period of time (several months). During the stress period, while there was measurable growth, the shoots were clipped bi-weekly for the evaluation of growth and dry matter (DM) production.

Usually, about two months after the initiation of the drought period, the first sign of stress (leaf curling) was seen. Grasses gradually showed more signs of wilting (finally, permanent wilting, and eventually death or dormancy). At the end of the drought stress period, the majority of the plants was either dead or had gone into a stage of dormancy (Fig. 6). After this, all the grasses were re-watered for the recovery rate determination.

Root length

Pessarakli and his co-workers (Marcum *et al*., 2005; Pessarakli *et al*., 2005a, 2005b) found that in various salinity stress studies on the saltgrasses, the root lengths were enhanced under low-to-moderate levels of salinity (salinity levels of up to 200 mM NaCl), and then decreased under high levels of sodium chloride stress (400–800 mM NaCl) (Tables 1 and 2, Pessarakli *et al*., 2005a). This decrease was more pronounced as the exposure time to salinity increased. However, for the first few harvests the reduction in root length was usually not statistically significant (Table 1, Pessarakli *et al*., 2005a). Subsequently, with progress in exposure time to salinity stress, the reductions in root lengths due to salt stress were statistically significant.

Table 1. Root and shoot length, shoot fresh and dry weights, and root dry weight (only for the last harvest†) of seven weekly harvests of desert saltgrass under four salinity levels

Harvest	Salinity (mM)	Length (cm)		Shoot weight (g)		Root weight (g)
		Root	Shoot	Fresh	Dry	Dry
1	Control (0)	21.3a††	11.4a	0.487a	0.201a	
	100	19.3a	10.6a	0.457a	0.197a	
	200	20.0a	8.1ab	0.281ab	0.124ab	
	400	20.2a	5.9b	0.137b	0.068b	
2	Control (0)	28.0a	10.2a	0.484a	0.211a	
	100	26.2a	10.1a	0.444a	0.193a	
	200	24.5a	9.0a	0.529a	0.222a	
	400	26.2a	5.8b	0.187b	0.086b	
3	Control (0)	32.0a	12.8a	0.563ab	0.252ab	
	100	32.8a	12.1a	0.536ab	0.240ab	
	200	28.9a	11.1a	0.742a	0.304a	
	400	31.7a	6.7b	0.350b	0.168b	
4	Control (0)	37.6a	12.7a	0.801ab	0.309ab	
	100	34.7a	12.6a	0.740ab	0.281a	
	200	34.1a	12.1a	0.961a	0.349a	
	400	35.0a	7.8b	0.501b	0.202b	
5	Control (0)	42.5a	9.5a	0.386b	0.199b	
	100	37.2a	10.0a	0.447b	0.203b	
	200	37.0a	9.7a	0.651a	0.282a	
	400	36.7a	6.5b	0.420b	0.193b	
6	Control (0)	48.4a	7.8a	0.296b	0.129b	
	100	42.4ab	7.8a	0.396b	0.162b	
	200	39.7ab	7.6a	0.525a	0.206a	
	400	37.1b	5.8b	0.384b	0.157b	
7	Control (0)	50.8a	7.3a	0.301a	0.164a	0.441a
	100	43.9ab	7.2a	0.310a	0.166a	0.454a
	200	40.6b	6.5b	0.404a	0.205a	0.549a
	400	38.2b	5.6c	0.376a	0.183a	0.539a

† The values are means of six replications.
†† All the values followed by the same letter in each column are not statistically different at the 0.05 probability level. (Source, Pessarakli *et al*., 2005a)

Table 2. Cumulative and average values† of shoot length, fresh and dry weights of desert saltgrass at four salinity levels for all harvests

Salinity (mM)	Shoot					
	Length (cm)		Weight (g)			
			Fresh wt.		Dry wt.	
	Cum	Aveg.	Cum	Aveg.	Cum	Aveg.
Control (0)	71.8a††	10.3a	3.318a	0.474a	1.465a	0.209a
100	70.4a	10.1a	3.330a	0.476a	1.442a	0.206a
200	64.2a	9.2a	4.093a	0.585a	1.692a	0.242a
400	44.0b	6.3b	2.355b	2.355b	2.355b	0.151b

† The values are means of six replications.
†† All the values followed by the same letter in each column are not statistically different at the 0.05 probability level. (Source, Pessarakli *et al*., 2005a)

Table 3. Root and shoot length, shoot fresh and dry weights, and root dry weight values† of desert saltgrass at four salinity levels based on the percent of the control

Salinity (mM)	Length (cm)		Weight (g)		
			Shoot		Root
	Root	Shoot	Fresh	Dry	Dry
	% of the Control				
Control (0)	100.0	100.0	100.0	100.0	100.0
100	86.3	98.1	100.4	98.6	103.0
200	79.8	89.4	123.4	115.8	124.5
400	75.2	61.3	70.9	72.3	122.2

† The values are means of six replications. (Source, Pessarakli *et al*., 2005a)

Shoot length

The shoot lengths of the saltgrasses in numerous salinity stress investigations carried out by Pessarakli and his co-workers (Marcum *et al*., 2005; Pessarakli *et al*., 2005a, 2005b) were more severely affected under high levels of salinity stress, 400 mM or more of sodium chloride stress, compared to the root lengths (Tables 1 and 2, Pessarakli *et al*., 2005a). The effects of stress on the shoot lengths at high levels of salinity were seen from the first harvest.

Pessarakli (2005b, 2011), Pessarakli and Kopec (2008b, 2011), and Pessarakli *et al*. (2001a, 2001c) found that in several drought stress studies, the shoot lengths of the saltgrass decreased as the drought period progressed. There was a wide range of differences found in shoot lengths on account of drought stress among the various clones/ accessions/ genotypes in these studies.

Shoot fresh weight

Marcum *et al*. (2001, 2005) and Pessarakli *et al*. (2005a, 2005b, 2008, 2011a, 2012) in several experiments, with various levels of salinity on saltgrass, found that for the first few harvests, the high (400 mM or more) levels of NaCl stress significantly reduced the shoot fresh weight compared to the other levels of salinity (Table 1). However, at the later harvests, there were no significant differences detected in the shoot fresh weights among the high (400 mM) salinity level, the low (100 mM or lower) NaCl stress, and the control. As the stress period progressed, the medium (200–300 mM) sodium chloride stress enhanced the fresh weights of the shoots (Table 1, Pessarakli *et al*., 2005a). This beneficial effect of NaCl on the shoot fresh weight was statistically significant at the last few harvests (Table 1, Pessarakli *et al*., 2005a). This phenomenon is probably because of the fact that saltgrass is a true halophytic plant species and true halophytes use Sodium as an essential nutrient element.

The findings of Pessarakli and Tucker (1985a, 1985b) and Pessarakli (2014) showed enhancement of cotton (*Gossypium hirsutum*), a salt-tolerant plant. The growth and protein synthesis of this plant under a low level of NaCl stress supports this result. Growth stimulation under moderate salinity level was also reported in the salt-tolerant grass, *Sporobolus virginicus* (Marcum and Murdoch, 1992). At the final harvest, despite the higher numerical values of the shoots, with respect to the fresh weights for the medium (200–300 mM) stressed plants, there were no statistically significant differences between any of the treatments (Table 1, Pessarakli *et al*., 2005a). This was probably because, as the plants grew older, they developed more tolerance physiologically, by adjusting themselves to stress. This observation was recorded by Pessarakli and Tucker (1985a, 1985b) for cotton and by Al-Rawahey *et al*. (1992) for tomatoes.

In several drought-stress studies, reduction in the fresh weight of saltgrass shoots under drought stress has also been reported by Pessarakli (2005b, 2011), Pessarakli and Kopec (2008b, 2011), and Pessarakli *et al.* (2001a, 2001c). As was reported for the shoot length, there was a wide range of differences found in the fresh weights of shoots because of drought stress among the various clones/accessions/genotypes in these studies.

Shoot dry weight

In numerous salinity stress tolerance investigations, Pessarakli and his co-workers (Marcum *et al*. 2005: Pessarakli *et al*., 2005a, 2005b) observed that the dry weights of the shoots of saltgrasses essentially followed the same pattern as the fresh weights of shoots (Tables 1 and 2, Pessarakli *et al*., 2005a). For both fresh and dry weights of the shoots, except for the last harvest, the gap between the means of the medium-stressed (200–300 mM) plants and the other treatments was wider, as the exposure time to salt stress progressed (Table 1, Pessarakli *et al*., 2005a).

The dry weight of the shoots of saltgrass decreased in several drought-stress studies conducted by Pessarakli and his co-workers (Pessarakli, 2005b, 2011; Pessarakli and Kopec, 2008b, 2011; Pessarakli *et al*., 2001a, 2001c). In all these studies the reduction in shoot dry weights followed the same pattern as the reduction in shoot fresh weights under drought-stress conditions. As was reported for the shoot fresh weights, there was a wide range of differences found in the shoot dry weights among the various clones/accessions/genotypes in these studies.

Shoot succulence

Pessarakli *et al*. (2005a) found that shoot succulence (Fresh Wt./Dry Wt.) increased from the control to the moderate salinity (200 mM NaCl) level, and then declined at the high (400 mM NaCl or more) salinity level (Table 3).

Root dry weight

Although the root dry weights were enhanced at the medium (200–300 mM NaCl) and high (400 mM NaCl) sodium chloride levels, there were no statistically significant differences detected between the means of the different treatments (Tables 1 and 2, Pessarakli *et al*., 2005a). Sagi *et al*. (1997) also found that the adverse effects of salinity stress were more pronounced on the shoot than the root growth.

Cumulative and average values

Pessarakli *et al*. (2005a, 2005b, 2008, 2011a, 2012) made an attempt to examine the cumulative and the average values of the studied parameters in various investigations. These observations indicated that for both cumulative and the average values, all the parameters (shoot length and shoot fresh and dry weights) were similarly affected by sodium chloride stress (Tables 1 and 2, Pessarakli *et al*., 2005a). Only the high levels of stress (400 mM or more) had statistically significant adverse effects on these parameters. The shoot and the root lengths and weights, under salinity stress, were calculated on the basis of the percentage of the control (Table 3, Pessarakli *et al*., 2005). In all the studies, both root and shoot lengths decreased as salinity levels increased. However, the dry weights of the shoots substantially increased under the medium sodium chloride (200–300 mM NaCl) stress compared to any other treatment. All the NaCl stress levels enhanced the root dry weights (Pessarakli *et al*., 2005a, 2005b, 2008, 2011a, 2012).

Conclusions

From numerous salinity and drought stress studies of Pessarakli and his co-workers, it was concluded that saltgrass shoot and root lengths decreased with increasing salinity levels or as the drought period progressed. However, both the fresh and dry weights of shoots significantly increased at medium (200–300 mM NaCl) salinity when compared with the control. Root dry weights at up to 400 mM NaCl salinity were significantly higher than the control. Shoot succulence (Fresh wt./ Dry wt.) increased from control to moderate salinity levels (200-300 mM NaCl salinity), and then declined.

It can also be suggested that saltgrass growing even under poor soil conditions (salt-affected soils, drought or limited water resources) can be beneficial, and still yield a favorable economical return. This grass proved to have satisfactory growth under conditions of drought and limited water resources, as well as, under high salinity stress (harsh desert conditions) in general and substantially reduced the salinity level of the rhizosphere. All this indicates that saltgrass can be considered a suitable plant species for sustainable agriculture in arid and semi-arid regions and can be effectively used for biological salinity control or reclamation of desert saline soils and for combating desertification processes.

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