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Effect of Saline Irrigation on Growth Characteristics and Mineral Composition of Two Local Halophytes Under Saudi Environmental Conditions

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Abstract: A field experiment was carried out to determine the growth characteristics and mineral composition of two local halophytes (*Atriplex halimus* and *Salvadora persica*) under saline irrigation at Kind Abdulaziz City for Science and Technology (KACST), Research Station Al-Muzahmyia, Riyadh. The experiment treatments were one soil (sandy), four irrigation waters of different salinities (2000, 8000, 12000 and 16000 mg L^{-1} TDS), two halophytes (*Salvadora persica* and *Atriplex halimus*) and one irrigation level (irrigation at 50% depletion of moisture at field capacity). Mean fresh biomass yield and fresh plant root weight of *A. halimus* increased while that of *S. persica* decreased significantly with increasing irrigation water salinity in all the treatments. Soil salinity increased significantly with increasing water salinity. A positive correlation (r = 0.987) existed between the irrigation water salinity and the soil salinity resulting from saline irrigation. The plant tissue protein contents increased in *A. halimus*, but decreased in *S. persica* with increasing irrigation water salinity. The Na ion uptake by plant roots was significantly less than K in *A. halimus* compared to *S. persica* which indicated adjustment of plants to high soil salinity and high Na ion concentration for better growth. The order of increasing salt tolerance was *A. halimus* > *S. persica* under the existing plant growing conditions. Among the two halophytes, *A. halimus* showed great potential for establishing gene banks of local species, because it has more forage value due to high protein contents than *S. persica* for range animals.

Key words: Halophytes, *Salvadora persica*, *Atriplex halimus*, salt tolerance, irrigation water salinity, plant protein and mineral contents

INTRODUCTION

Increased use of brackish groundwater or saline sewage effluent in many areas of the world for landscape irrigation has resulted in a need for breeding salt tolerant plant species or selection of suitable halophytes. Detrimental effects of salinity on plant growth result from direct effect of ion toxicity (Hasegawa *et al*., 1986) or indirect effects of saline ions on the soil water potential which causes soil/plant osmotic imbalance. Avoidance of toxicity may involve ion exclusion at the root cortex (Jeschke, 1984), redistribution of excess ions to senescing leaves or other parts of plants (Yeo and Flowers, 1984), secretion or sequestration of ions into salt glands or bladders (Marcum and Murdoch, 1990). Miyamoto *et al.* (1996) carried out lysimeter investigation in the coastal deserts of Sonora, Maxico on salt tolerance, salt uptake and water use of four halophytes (*Atriplex nummularia*, *Distichlis palmeri*, *Batis maritime* and *Suada esteroa*) using saline irrigation water. They stated that frequent irrigation at higher leaching fractions may be required at higher salinities. Congming *et al.* (2002) stated that increasing salt concentration decreased significantly leaf water potential and evaporation rate while there was no change in leaf water content. Salt stress also resulted in a significant accumulation of sodium and chloride in leaves of halophyte *Suaeda salsa.*

The Chenopodiaceae *Suaeda salsa* L. is one of the most important halophytes in China (Wang *et al*., 2001) and has important economic value because its seeds contain approximately 40% oil, rich in unsaturated fatty acids, which can be easily converted to chemical compounds for industrial use. *Suaeda salsa* is native to saline soils and adapted to the high salinity region in the North of China (Zhao, 1998). Whereas, Wang *et al.* (2002) reported 50% yield reduction of egg plant when EC of irrigation water increased more than 5-25 dS m^{-1}. Ramoliya and Pandey (2002) found that *Salvadora oleoides* (Salvadoraceae) at seed germination stage exhibited a negative relationship with increasing concentration of salts and showed that this tree specie is salt tolerant at this stage. Seedlings survived and grew up to 16.5 dS m^{-1}. Moreover, plant species differ in their sensivity or tolerance to salts (Troech and Thompson, 1993).

Khasa *et al.* (2002) found a significant interaction between salt treatments and seed lots within species as well as between salt treatments and plant species for weight and necrosis indicating that the plant genotype responded differently to salt treatment. However, Ungar (1998) observed that the influence of physiochemical and biotic factors is important to the distribution and establishment of halophytes.

Viegas *et al.* (2004) stated that plants grown in 25 and 50 mmol L^{-1} NaCl accumulated a total Dry Mass (DM) and shoot N content greater than the control. However, at 75 and 100 mmol L^{-1} NaCl such parameters were diminished. Salinity did not influence shoot (80%) and root (70%) Water Contents (WC) but reduces the K content of shoot while that of root was not affected. Increasing external NaCl concentration increased K/Na ratio of both plant parts (shoot and root). Salt tolerance has been partially linked to the regulation of shoot Cl and Na concentration (Teleisnik and Grunberg, 1994). Plant growth under salinity stress is the result of processes such as ion transport and compartmentation, synthesis and accumulation of osmotic solutes (Viegas *et al.*, 2001). These processes lead to osmotic adjustment and particularly exclusion and/or compartmentation of specific ions such as Na at a level compatible to plant growth (Munns and Termaat, 1986; Silveira *et al.*, 2003). However, with respect to the plasma membrane, Na can displace Ca which constitutes a primary response to salinity stress (Cramer *et al.*, 1985) and K selectivity may be altered. According to Niu *et al.* (1995), increased K/Na ratio and the selectivity of the K uptake system might represent a significant adaptation to high concentration NaCl.

In saline environments, plant adaptation to salinity during germination and early stages of growth is crucial for the establishment of species (Unger, 1995, 1996). Plant growth is affected by the interaction of Na or Cl, as well as by mineral nutrients, causing imbalance in nutrient availability, uptake, or distribution within plants. Thus a high concentration of Na in the external solution causes a decrease in both K and Ca concentration in plant tissues. This decrease could be due to the antagonism of Na and K, or Ca at sites of uptake of roots (Lynch and Lauchli, 1998). Recently, Abo-Kassem (2007) stated that high salinity delayed radical emergence and decreased germination percentage in all plants including Atriplex hortensis specie. $CaSO_4$ alone reduced plant growth to a greater degree than total high salinity.

Plants may be categorized as halophytes or glycophytes depending upon their response to soil and water salinity. Sensitivity of plants to salinity varies with plant growth stages, plant species and environmental factors which interact with salinity to influence crop salt tolerance. Inadequate fresh water supplies advocated on the use of high salinity waters and highly salt tolerance plant species for establishing landscapes and increasing agro-forestry to develop sustainable rangelands to improve the socio-economic conditions of the community in Saudi Arabia.

A very little information is available on the salt tolerant limits of local rangeland halophyte species. It is, therefore, imperative to study the salt uptake mechanism of local halophytes for developing sustainable landscape and rangelands, establish gene bank of economically promising halophytes, apply genetic engineering and molecular biotechnology to breed or propagate local halophytes for improving socio-economic conditions of the country. The main objectives of this study were to determine growth characteristics and mineral composition of local halophytes with saline irrigation under Saudi environmental conditions.

MATERIALS AND METHODS

The experiment was carried out at KACST, Research station, Al-Muzahmiyah around 70 km West of Riyadh during 2005-2006.

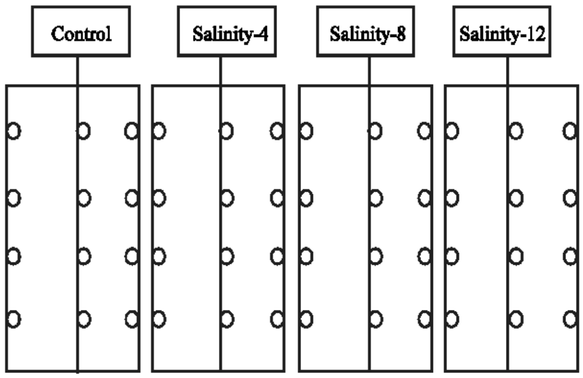
Two promising local halophytes (landscape trees) namely *Salvadora persica* and *Atriplex halimus* were selected for experiment. The field experiment was setup at the Research Station, KACST, Al-Muzahmiyah, Riyadh by following a complete randomized block design. The experimental treatments are shown below:

Experimental treatments:

- Soil = 1 (sandy)
- Irrigation water salinity = 4 (2, 8, 12 and 16 thousand mg L^{-1})
- Plant species = 2 (*Salvadora persica* and *Atriplex halimus*)
- Irrigation level = 1 (irrigation at 50% moisture depletion at field capacity)
- Replications = 3
- Total No. of plants = 1×4×2×1×3 = 24

Statistical design: A complete randomized block design

Experimental procedure: The selected halophytes were planted in field at Al-Muzahmiyah Research Station. Each block was 2×2 m^2. The plants were allocated following complete randomized block design. Plants of uniform height (around 30 cm tall) were transplanted into the experimental plots in October, 2005. The plants were



Control: Fresh water (TDS = 2,000), Salinity-4 (TDS = 8,000), Salinity-8 (TDS = 12,000), Salinity-12 (TDS = 16,000), The figures in braces indicate water salinity in mg L^{-1}. Indicate the holes for plants with row to row distance of 1 m and plant distance of 2 m

Fig. 1: Layout of experiment

irrigated with the desired salinity waters with irrigation interval ranging from 2-3 days between the two irrigations during the growth period. The plants were irrigated to fulfill the soil field capacity level. The experimental soil is sandy with a field capacity of 8% by weight, EC_e of 2.25 dS m^{-1}, SAR of 1.75 and 3.75% $CaCO_3$. The total amount of irrigation water came to about 2-4 L per irrigation per plant during the whole growing season.

Composition of irrigation waters: Irrigation waters of desired salinities were prepared by mixing freshwater (well water) and the evaporation pond water (Saline waste water from RO-water treatment plant) in an appropriate combination. The plants were irrigated at 50% moisture depletion of the total available moisture at soil field capacity. The irrigation schedule was prepared for each season depending upon the variation in the climatic conditions. Water sample were collected after each preparation and analyzed for chemical composition. Mean chemical composition of irrigation waters is shown in Fig. 1.

Establishment of irrigation system: The irrigation system was established by placing one water tank of 3 m^3 capacity for each water salinity treatment. A small water pump of 1-Horsepower was installed at the base of each water tank for applying irrigation water. However, the control treatment plots received irrigation directly from the main freshwater supply line.

Soil measurements: Three composite soil samples were collected from 0-15 and 15-30 cm depth before and after each harvesting season for the experimental soil and analyzed for physical and chemical properties. These measurements included soil texture, soil pH, EC_e, cations and anions and $CaCO_3$ contents (Table 1). The soil samples were analyzed by following by the various analytical methods given in USDA Handbook No. 60, 1954.

Table 1: Mean chemical composition of well, evaporation pond and treatments waters

Parameters	Pond water	Treatments T_1 Control	T_2	T_3	T_4
EC (dS m^{-1})	27.72.1	2.45	13.75	18.6	25.38
pH	7.8	7.6	8.7	7.7	7.64
TDS (mg L^{-1})	17,760	1,621	8,767	11,906	16,244
Calcium (mg L^{-1})	1512	208	731	947	1239
Magnesium (mg L^{-1})	798	58	370	492	680
Sodium (mg L^{-1})	4398	222	1930	2786	3800
Potassium (mg L^{-1})	251	15	109	160	166
Chloride (mg L^{-1})	8394	640	4319	5464	7740
Carbonate (mg L^{-1})	18	0	16	6.9	30
Bicarbonate (mg L^{-1})	172	149	130	110	147
SAR	24	3.4	16.6	20.2	21.45

Plant growth measurements: Plant growth parameters included fresh biomass yield, fresh root weight, root to shoot ratio and observation of nutrient deficiency or ion toxicity symptoms of plants and other information related to the adverse effects of saline irrigation on plant growth were recorded for treatment evaluation during the growing season.

Plant analysis: Plant samples were collected at the time of harvest, air-dried, ground in a Willy Mill for analysis. The plant samples were analyzed for P, Na, K, Ca, Mg and protein contents to evaluate the nutritional value of plants for animal forage. The plant samples were analyzed by following by the different analytical methods as given in USDA Handbook No. 60, 1954. Also, K /Na ions ratio of plant roots and shoots were calculated to estimate salt uptake by plants for determining salt tolerant limits.

RESULTS AND DISCUSSION

Fresh biomass yield: Mean fresh biomass yield (kg $plant^{-1}$) ranged from 2.98-4.25 (*A. halimus*) and 0.89-1.65 (*S. persica*) in different water salinity treatments (Table 2). Mean biomass yield increased significantly for *A. halimus* in the saline irrigation treatments than the control treatment, than *S. persica* which showed significant decreases in biomass yield with increasing irrigation water salinity. The research findings suggest that highly saline irrigation water proved a source of nutrition to *A. triplex* than *S. persica*. In conclusion, the order of increasing salt tolerance was *A. halimus* > *S. persica* under the existing plant growing conditions.

Fresh weight of plant roots: Mean fresh weight of plants roots (kg $plant^{-1}$) ranged from 0.91-1.11 (*A. halimus*) and 0.17- 0.98 (*S. persica*) in different water salinity treatments

Table 2: Effect of irrigation water salinity on fresh biomass and fresh root weight of plants (kg plant^{-1})

	Water salinity levels			
Tree	2000	8000	12000	16000
Biomass yield (kg plant^{-1})				
A. halimus	2.98a	4.25a	3.78a	3.45a
S. persica	1.65b	1.45b	1.44b	0.89b
Plant root fresh weight (kg plant^{-1})				
A. halimus	0.91a	1.09a	1.11a	1.10a
S. persica	0.89a	0.40b	0.32b	0.17b
Plant root/Shoot ratio (kg plant^{-1})				
A. halimus	0.31a	0.26a	0.29a	0.32a
S. persica	0.54b	0.28b	0.22b	0.17b

Values in a row followed by the same letter(s) are not significantly different by $LSD_{0.05}$

(Table 2). Mean fresh weight of roots increased significantly in *A. halimus* than *S. persica* which showed significant decreases with increasing irrigation water salinity. This could be due to high osmotic potential of soil solution which might have inhibited the root development of different plant species encountering high salinity of the soil solution in the plant root zone.

Plant root/shoot ratio: Mean ranges of root to shoot ratio of different plants were 0.26-0.32 (*A. halimus*) and 0.54-0.17 (*S. persica*) in different water salinity treatments (Table 2). The plant root/shoot ratio decreased significantly with increasing water salinity in both the plants. The root/shoot ratio of *S. persica* was less than *A. halimus*. The results reveal that increasing irrigation water salinity significantly affected the plant root development thus causing appreciable reduction in plant root development and plant biomass production.

Soil salinity: Mean soil salinity (EC_e expressed as dS m^{-1}) of surface 0-30 cm depth of soil was 3.85 (T_1, control), 8.00 (T_2), 12.92 (T_3) and 17.37 (T_4) in different water salinity treatments during 2005 growing season (Table 3). During 2006 growing season, the mean soil salinity (EC_e as dS m^{-1}) was 4.35 (T_1, control), 8.92 (T_2), 14.21 (T_3) and 119.50 (T_4) in different water salinity treatments (Table 3). The soil salinity increased significantly with increasing irrigation water salinity even with the application of 15% excess water above the soil field capacity as leaching requirement to maintain soil salinity within the acceptable limits for normal plant growth.

Deficiency or toxicity symptoms during growth: The plants did not show any nutrient deficiency or toxicity symptoms during the growth period. This could be attributed to the initial low soil salinity and or fertility levels. Because, most of these halophytes belong to the leguminous family and are capable of fixing atmospheric nitrogen to fulfill its nutrient needs particularly for nitrogen element. Besides this, the soil salinity did not reach to a very high level which is above the salt tolerant limits of the trees under investigation.

Table 3: Effect of irrigation water salinity on soil salinity (EC_e = dS m^{-1})

Soil depth (cm)	Water salinity levels (mg L^{-1}) 2000	8000	12000	16000
Season 2005				
0-15	3.35	8.49	12.61	16.23
15-30	4.34	7.23	13.24	18.53
0-30	3.85	8.00	12.92	17.37
Season 2006				
0-15	3.85	9.55	13.85	18.54
15-30	4.86	8.28	14.57	20.45
0-30	4.35	8.92	14.21	19.50

Table 4: Mean mineral (expressed as %) composition of experimental plants

	Water salinity (TDS mg L^{-1})			
Tree/plant	2000	8000	12000	16000
Protein				
A. halimus	11.25	11.89	12.35	15.75
S. persica	9.66	8.75	7.33	5.52
Phosphorus (P)				
A. halimus	0.145	0.135	0.092	0.085
S. persica	0.079	0.070	0.059	0.035
Potassium (K)				
A. halimus	1.32	1.22	1.13	1.04
S. persica	0.72	0.42	0.12	0.09
Calcium (Ca)				
A. halimus	1.45	1.65	1.78	1.89
S. persica	0.35	0.44	0.53	0.56
Magnesium (Mg)				
A. halimus	0.95	0.80	0.69	0.48
S. persica	0.59	0.48	0.31	0.22
Sodium (Na)				
A. halimus	0.29	0.37	0.45	0.61
S. persica	1.14	2.44	3.72	4.13

Mineral composition of plant shoots

***Atriplex halimus*:** The ranges of mean contents (expressed as %) of different minerals were 11.25-15.75 (Protein), 0.085-0.145 (P), 1.04-1.32 (K), 1.45-1.89 (Ca), 0.48-0.95 (Mg) and 0.29-0.61 (Na) in different water salinity treatments (Table 4). The protein contents of plants showed significant increases with increasing water salinity. The P, K and Mg contents of plants decreased whereas other minerals Ca and Na significantly increased with increasing water salinity.

***Salvadora persica*:** The ranges of mean contents (Expressed as %) of different minerals were 5.52-9.66 (Protein), 0.035-0.079 (P), 0.09-0.72 (K), 0.35-0.56 (Ca), 0.22-0.59 (Mg) and 1.14- 4.13 (Na) in different water salinity treatments (Table 4). The protein contents of plants showed significant decreases with increasing water salinity. The P, K and Mg decreased whereas Ca and Na increased with increasing water salinity treatments.

Table 5: Mean mineral (expressed as %) composition of plant roots

Tree/plant	Water salinity (TDS mg L^{-1}) 2000	8000	12000	16000
Potassium (K)				
A. halimus	0.69	0.63	0.55	0.50
S. persica	0.38	0.24	0.08	0.05
Calcium (Ca)				
A. halimus	2.18	2.50	2.66	2.84
S. persica	0.55	0.67	0.81	0.86
Magnesium (Mg)				
A. halimus	0.69	0.50	0.46	0.34
S. persica	0.39	0.34	0.21	0.15
Sodium (Na)				
A. halimus	0.49	0.57	0.68	0.92
S. persica	1.04	2.21	3.37	3.86

Mineral composition of plant roots

***Atriplex halimus*:** The ranges of mean contents (expressed as %) of different minerals were 0.50-0.69 (K), 2.18-2.84 (Ca), 0.34-0.69 (Mg) and 0.49-0.92 (Na) in different water salinity treatments (Table 5). Mean mineral contents of K and Mg decreased with increasing irrigation water salinity whereas Na and Ca contents increased with increasing salinity.

***Salvadora persica*:** The ranges of mean contents (Expressed as %) of different minerals were 0.05-0.38 (K), 0.55-0.86 (Ca), 0.15-0.39 (Mg) and 1.04-3.86 (Na) in different water salinity treatments (Table 5). Mean Ca and Na contents of plants showed significant increases with increasing water salinity whereas, the other minerals K and Mg decreases with increasing irrigation water salinity.

Potassium/Sodium ions (K/Na) ratio in plants: The K/Na ratios were determined to evaluate salt uptake mechanism of different plants. Because under saline soil and saline irrigation water growth conditions, the uptake of different nutrient elements is a complex phenomena due to nutrient imbalance. Wyn Jones *et al.* (1979) suggested a threshold K^+/Na^+ ratio of one for normal growth of plants subjected to soil and irrigation water salinity.

Plant shoots: The K/Na ratio ranged from 1.71 -4.55 (*A. halimus*) and 0.02-0.63 (*S. persica*) in different irrigation water salinity treatments (Table 6). The K/Na ratio decreased significantly for both the trees. The higher K/Na ratio shows that plants K uptake was significantly more than Na ion. The results show that *A. halimus* absorbed more K than Na. The results proved that these halophytes can grow better under saline soil and saline irrigation water conditions.

Plant roots: The K/Na ratio ranged from 0.54- 1.41 (*A. halimus*) and 0.01-0.36 (*S. persica*) in different irrigation water salinity treatments (Table 6). The K/Na ratio decreased significantly for both the plants and also was less than plant shoots. The higher K/Na ratio indicated that K ion uptake by plant roots was significantly more than Na uptake which indicated adjustment of plants to high soil salinity and saline irrigation water conditions. The *A. halimus* absorbed more K than *S. persica*. In other words the plants absorbed less Na than K and proved more salt tolerant.

Table 6: Effect of irrigation water salinity on K/Na ratios in plant shoots and plant roots

Tree/plant	Water salinity (TDS mg L^{-1}) 2000	8000	12000	16000
Plant shoots				
A. halimus	4.55	3.29	2.29	1.71
S. persica	0.63	0.17	0.03	0.02
Plant roots				
A. halimus	1.41	1.11	0.81	0.54
S. persica	0.36	0.11	0.02	0.01

DISCUSSION

Saline irrigation is detrimental to plants growth due to its high osmotic effects resulting from increased salt accumulation in soils. However, mean fresh biomass and plant root yield of *A. halimus* increased than *S. persica* with increasing irrigation water salinity in all the treatments. Soil salinity increased significantly with increasing water salinity. A positive correlation (r = 0.987) was found between irrigation water salinity and the soil salinity resulting from irrigation water salinity.

Information on ion accumulation differences among different species and the patterns of accumulation of ions in various parts of a plant is very important in evaluation of salinity tolerance and to understanding salinity tolerance mechanisms employed by the plant. Wyn Jones *et al.* (1979) suggested a threshold K^+/Na^+ ratio of one for normal growth of plants subjected to salinity. Shannon (1978) studied salt tolerance of 32 lines of tall wheatgrass; he found that salinity tolerance was associated with maintenance of K^+/Na^+ ratio more than one. The values of K/Na ratio indicate that Na ion uptake by plant roots was significantly less than K in *A. halimus* as compared to *S. persica* thus indicating plants adjustment to high soil salinity and high Na ion toxicity conditions for better growth.

In conclusions, the order of increasing salt tolerance was *A. halimus* > *S. persica* under the existing plant growing conditions. No nutrient deficiency or ion toxicity (Na, B, Cl) symptoms were observed on any of the experimental plants/trees during the experimental period. The protein contents increased in *A. halimus* than *S. persica* with increasing irrigation water salinity. Among the different plants/trees investigated, *A. halimus* showed great potential for establishing gene banks of these local plant species, because one of two plants is palatable and has forage value for range animals. Further detailed studies are required including other halophytes and landscape trees having forage value for desert greenification in an arid environment.

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