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EFFECT OF SALINITY ON THE GROWTH AND ION CONTENT OF *SALICORNIA RUBRA*

M. Ajmal Khan, Bilquees Gul, and Darrell J. Weber*

Department of Botany and Range Science, Brigham Young University, Provo, UT 84602

ABSTRACT

Salicornia rubra is a stem succulent annual halophyte, which is widely distributed in the saltpans of Northern Utah playas. This study reports the effect of salinity (0, 200, 400, 600, 800, and 1000 mM NaCl) on the growth, succulence, osmotic and water relations of the species under greenhouse conditions. Fresh and dry weight of plants increased with an increase in salinity. Optimal growth of *S. rubra* plants were recorded at 200 mM NaCl and the growth declined with a further increase in salinity. Both sodium (Na) and chloride (Cl) contents of plants increased with an increase in salinity, while Ca^{2+}, Mg^{2+}, and K^{+} content decreased. Succulence of shoots increased at low salinity and decreased at high salinity. Water potential of plants become more negative with an increase in salinity. The Fv/Fm ratio was more affected by higher salinity and irradiation stress during growth.

*Corresponding author. Current address: Department of Botany, University of Karachi, Karachi 75270, Pakistan.

INTRODUCTION

Salicornia rubra Nels. (Chenopodiaceae) is a highly salt tolerant annual species occurring in salt playas of the Great Basin desert (1,2). It forms a pioneer community, with plants being shorter and denser at the higher salinity (3). It was found in pure stands on the most saline location of an inland salt playa at Goshen, UT. It was also associated with *Salicornia utahensis*, *Allenrolfea occidentalis*, and *Distichlis spicata* along a gradient of reduced salinity. In the Great Basin of the western United States, the annual precipitation ranges from 10 to 20 cm, mostly as snow with relatively little spring or summer rain. Just east of the town of Goshen, UT is a number of playas, which in the spring are shallow lakes with a water depth of a few centimeters. During the hot, dry summer water evaporates leaving a white deposit of salt (mostly sodium chloride) in the central and lowest part of the playa. No vegetation will grow in the salt crust. However, concentric circles of salt tolerant species are found growing around the saltpan. *Salicornia rubra*, a small annual forb is found nearest the saltpan followed by the perennial forb, *Salicornia utahensis* and a grass *Distichlis spicata*.

Salicornia sp. are included among the group of halophytes where they grow larger and benefited from NaCl concentrations above the minimal required as micronutrients in plants (4). *Salicornia* sp. have increased biomass production with salt increments in the growth medium ranging from 170 to 340 mM NaCl (5–9). A similar promotion of growth at or below seawater was also reported for other halophytic species (10–18).

Salinity may decrease biomass production because it causes a lowering of plant water potentials, specific ion toxicities, or ionic imbalances (19). Plants protect themselves from NaCl toxicity by minimizing Na^+ uptake and transport to the shoot (20). Osmotic adjustment under saline condition may be achieved by ion uptake, synthesis of osmotica or both (21–23). Halophytes differ widely in the extent to which they accumulate ions and overall degree of salt tolerance (24). Stem and leaf-succulent chenopods are commonly known salt-accumulators and have high Na^+ and Cl^-, content (15–19,25–27). Chlorophyll fluorescence has been used for detecting tolerance to chilling, freezing, drought, and air pollution stress and it may prove equally useful for detecting salt effects before visible damage occurs (28) or for salinity tolerance screening (29,30).

The main objective of this study was to determine the salt tolerance of *Salicornia rubra* under green house conditions.

MATERIALS AND METHODS

Salicornia rubra seedlings were collected from an inland salt playa located on the east of Goshen, northwestern Utah (39:57:06N 111:54:03W, 4530 ft).

Equal-sized seedlings (about 1 sq cm in size) were transplanted into 12.7-cm-diameter × 12.7-cm-tall plastic pots containing nutrient free sand. Five salinities (0, 200, 400, 600, 800, and 1000 mM NaCl) using four pots each were used for each treatment group and potted plants were grown in plastic trays containing half-strength Hoagland's nutrient solution. Pots were sub-irrigated, and the water level was adjusted daily to correct for evaporation. Salt solutions were completely replaced once a week to avoid build-up of salinity in pots. At the initiation of the experiment, salinity concentrations were gradually increased by 200 mM at 1-d intervals to reach the maximum salinity levels of 1000 mM NaCl in eight d.

Fresh and dry weight of the plant shoots and roots were measured 60 d after the highest salt concentration was reached. Dry mass was determined after drying for 48 h in a forced-draft oven at 80°C. For measurement of ion concentration, 0.5 gram of plant material was boiled in 25 mL of water for two hours at 100°C using a dry heat bath. This hot water extract was cooled and filtered using Whatman no. 2 filter paper. One mL of hot water extract was diluted with distilled water for ion analysis (31,32). Chloride, nitrate and sulfate ion contents were measured with a DX-100 ion chromatograph. Cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) of the plant organs were analyzed using a Perkin Elmer model 360 atomic absorption spectrophotometer. The level of stress in plants growing at different salinities was measured with Morgan CF-1000 chlorophyll fluorescence measurement system. The stress is measured as a ratio of F_v (variable fluorescence) to F_m (maximum fluorescence). Water potential was measured using a plant moisture stress instrument (PMS Instrument Co.). The results of growth, ion contents, water potential and stress were analyzed with one-way ANOVA to determine if significant differences were present among means. A Bonferroni test was carried out to determine if significant ($P < 0.05$) differences occurred between individual treatments (33).

RESULTS

A two way ANOVA showed a significant individual effect of salinity, plant part and their interactions in affecting fresh and dry weights of *S. rubra* plants (Table 1). Optimal growth (shoot fresh and dry weight) of *S. rubra* plants were recorded at 200 mM NaCl and the growth declined with a further increase in salinity. Most plants survived at 1000 mM NaCl treatment (Fig. 1). Root fresh and dry weight were both significantly inhibited at higher salinities (Fig. 1).

Succulence, when expressed as g tissue water g^{-1} dry weight peaked at moderate salinity [400 mM NaCl (Fig. 2)]. Succulence at low and high salinity was not significantly different. A two-way ANOVA showed non-significant individual effects of salinity and plant part and their interactions (Table 1). Water

Table 1. Results of Two-Way Analysis of Variance of Characteristics by Salinity (S) and Plant Part (P)

Dependent Variable	Salinity (S)	Plant Part (P)	S × P
Fresh weight	11.1***	119.7***	2.6*
Dry weight	3.7**	34.4***	0.99$^{n.s.}$
Tissue water	1.9$^{n.s.}$	0.6$^{n.s.}$	1.6$^{n.s.}$
Calcium	2.8*	68.4***	2.3*
Magnesium	9.4***	295.5***	27.2***
Nitrate	0.8$^{n.s.}$	1.1$^{n.s.}$	3.8**
Sulphate	2.8*	3.4*	6.5***

Note: Numbers represent F values, *$P < 0.01$, **$P < 0.001$, ***$P < 0.0001$.
n.s. non-significant.

potential of *S. rubra* plants progressively decreased with increase in salinity reaching −5.8 MPa at 1000 mM NaCl (Fig. 3). *Salicornia rubra* plants were progressively stressed with increasing salinity (Fig. 4). The ratio of F_v/F_m decreased as the salinity increased. These values reflect a decrease in the fluorescence from photosystem 2 (34).

A two-way ANOVA showed significant individual effects of plant part, salinity and their interactions on ion contents (Table 1). Total of cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) and the anion (Cl^-) content increased with increase in salinity (Tables 2 and 3). Ion concentrations in shoots were comparatively higher than those in roots (Tables 2 and 3). At all NaCl concentrations, the increase in total inorganic ions resulted from increased Na^+, and Cl^- while K^+, Ca^{2+}, and Mg^{2+} concentrations decreased with an increase in salinity.

DISCUSSION

Present study showed that *Salicornia rubra* is a highly salt tolerant species during growth. There was a significant promotion of plant growth at 200 mM NaCl and plants survived at 1 M salinity with stunted growth. Stem succulent halophytes like *Arthrocnemum macrostachyum*, *Allenrolfea occidentalis*, *Halosrachia pergranulata*, *Haloxylon recurvum*, and *Sarcocrnia natalensis* are reported to survive under highly saline condition but also showed optimal growth from 200 to 600 mM NaCl (15–18,35,36). *Salicornia* sp. such as *S. europaea*, *S. bigelovii*, *S. herbacea,* and *S. brachystachya* also showed stimulation from 170 to 340 mM NaCl and could survive at very high salinity (5–9).

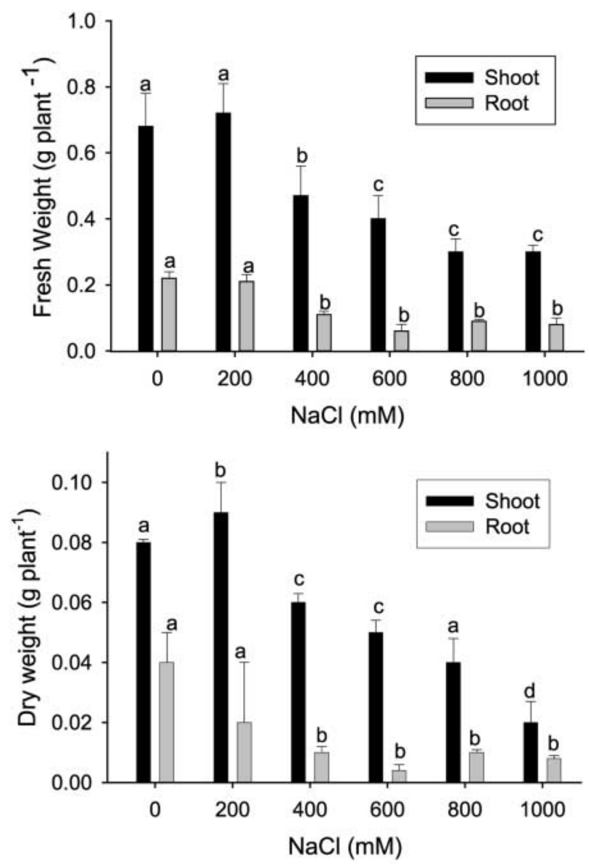

Figure 1. Effect of NaCl (0, 200, 400, 600, 800, and 1000 mM) on the fresh and dry weight in *Salicornia rubra* plants. Bars represent mean ± standard error. Different letters above bars represent a significant difference ($P < 0.05$) between treatments.

Succulence is thought to contribute to salt regulation by increasing the vacuolar volume available for ion accumulation (37–39). Exposure to salinity concentrations increases the tissue water of stem succulent species and the optimal NaCl concentration for growth was also the NaCl concentration for highest succulence and a further increase in salinity caused a decline in both succulence and growth (15–18,35,36,40,41). However, our results showed the optimal growth of *S. rubra* at 200 mM NaCl and highest succulence value at 600 mM NaCl. Measurement of water potential through plant water status console showed that the water potential of *S. rubra* plants became increasingly

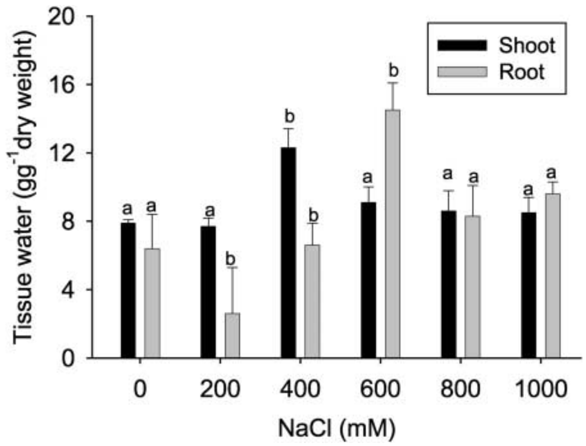

Figure 2. Effect of NaCl (0, 200, 400, 600, 800, and 1000 mM) on tissue water content in *Salicornia rubra* plants. Bars represent mean ± standard error. Different letters above bars represent a significant difference ($P < 0.05$) between treatments.

more negative with the increase in salinity. It may be suggested, therefore, that enhancement of dry mass production from 0- to 200-mol m^{-3} NaCl is due primarily to ion uptake. Halophytes are characterized by their capacity to adjust tissue water potential to a level that is lower than that of the soil water potential of the habitat in which they are growing (39). Growth and survival of halophytes is

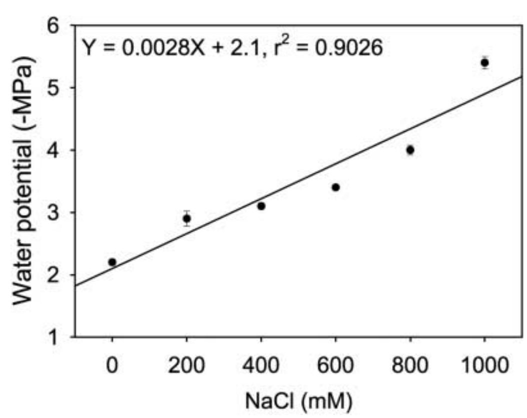

Figure 3. Effect of NaCl (0, 200, 400, 600, 800, and 1000 mM) on water potential in *Salicornia rubra* plants. Lines represent mean ± standard error. Different letters above lines represent a significant difference ($P < 0.05$) between treatments.

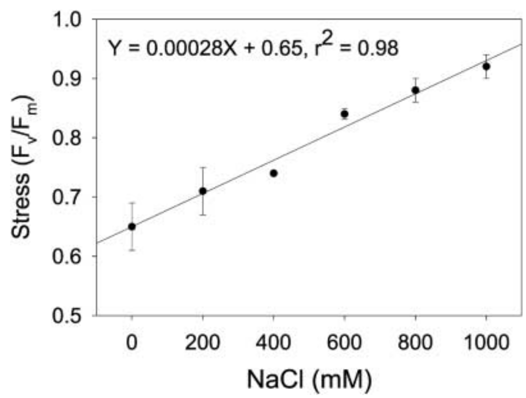

Figure 4. Effect of NaCl (0, 200, 400, 600, 800, and 1000 mM) on stress in *Salicornia rubra* plants. Lines represent mean ± standard error. Different letters above lines represent a significant difference ($P < 0.05$) between treatments.

dependent on the high level of ion accumulation for the maintenance of turgor and osmotic adjustment (42). In dicotyledonous halophytes, water relations and the ability to adjust osmotically have been seen as important determinants of the growth response (15–18,42,43). It would appear that the growth response at moderate salinities may be largely the consequence of an increased throughput of solutes required to derive cell expansion—although this does not result in increased turgor pressure. At high salinities, growth reduction might be caused by a reduced ability to adjust osmotically, as a result of saturation of solute uptake system (43) or excessive demand on the energy requirement of such systems (44). Other factors such as nutrient deficiencies (45) may also play an important role.

Our results indicated that sodium and chloride concentration in shoots and roots increased with salinity. The cation content in *S. rubra* shoots and roots grown in the 0 NaCl solution was high because the seedlings for all of the tests were obtained from saline sites. Magnesium, calcium, and potassium of the shoots of plants grown at optimal salinity represent levels adequate for growth (46). Calcium and magnesium concentrations were extremely low in shoots of plants grown at high salinity agreeing with the results found for other halophytes (15–18,35,36,47–50). Analysis of cations in *S. rubra* by acid digestion from saline sites in Canada gave values of 431.9 mM Na, 56.9 mM K, and 75 mM Mg (51). The hot water extraction procedure for ion analyses gave higher values for *S. rubra* for seedlings obtained from saline sites in Utah.

In summary *S. rubra* is a highly salt tolerant annual halophyte, which grow in a saltpan in Great Basin desert of Utah. This plant has the ability to germinate and complete its life cycle under very high media salinity. It accumulates a large

Table 2. The Effect of Salinity on the Concentration of Cations and Anions in Shoots of *Salicornia rubra*. Values Represent Means ± Standard Error

NaCl (mM)	Na^{+} (mM)	K^{+}(mM)	Ca^{2+}(mM)	Mg^{2+}(mM)	Cl^{-}(mM)	SO_4^{2-}(mM)	NO_3^{-} (mM)
0	1030 ± 11.2	10.6 ± 0.5	0.6 ± 0.1	78.6 ± 0.3	971 ± 56.2	35.9 ± 10.5	2.1 ± 1.6
200	1102 ± 14.6	9.3 ± 0.4	0.6 ± 0.3	74.4 ± 2.0	1262 ± 85.3	98.7 ± 15.0	9.9 ± 6.7
400	1233 ± 13.8	7.7 ± 0.6	0.7 ± 0.2	77.4 ± 2.7	1503 ± 73.3	33.9 ± 8.3	9.3 ± 1.1
600	1535 ± 30.2	7.3 ± 0.5	0.9 ± 0.5	63.7 ± 5.7	1732 ± 119	34.2 ± 6.5	19.5 ± 8.5
800	1735 ± 32.1	6.4 ± 0.6	0.6 ± 0.02	61.9 ± 0.48	1719 ± 74	39.9 ± 3.9	8.9 ± 0.3
1000	1873 ± 41.5	6.2 ± 0.8	0.5 ± 0.2	59.4 ± 2.4	1933 ± 30	21.7 ± 4.4	27.3 ± 4.5

Table 3. The Effect of Salinity on the Concentration of Cations and Anions in Roots of *Salicornia rubra*. Values Represent Means ± Standard Error

NaCl (mM)	Na^+ (mM)	K^+ (mM)	Ca^{2+} (mM)	Mg2$^+$ (mM)	Cl^- (mM)	SO_4^{2-} (mM)	NO_3^- (mM)
0	1139 ± 41.0	6.1 ± 0.8	2.9 ± 0.7	32.1 ± 0.7	376 ± 69	24.1 ± 3.7	19.8 ± 5.5
200	1157 ± 22.4	5.4 ± 0.9	3.9 ± 1.2	34.7 ± 1.1	1044 ± 13	17.1 ± 2.6	7.8 ± 1.2
400	1248 ± 7.8	6.8 ± 0.5	7.7 ± 3.6	56.1 ± 1.6	1165 ± 13	13.7 ± 2.4	7.6 ± 5.1
600	1455 ± 20.0	4.9 ± 0.4	5.2 ± 3.9	55.5 ± 1.3	1251 ± 19	34.3 ± 19	11 ± 7.2
800	1716 ± 19.7	6.2 ± 0.7	2.9 ± 0.6	43.6 ± 1.7	1364 ± 8	46.6 ± 14.8	103 ± 6.0
1000	1915 ± 20.8	5.8 ± 0.4	4.5 ± 0.8	55.8 ± 2.2	1587 ± 14	57.1 ± 16.0	3.3 ± 0.2

amount of Na^+ and Cl^- to achieve osmotic balance across the soil–water–plant gradient.

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