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RESEARCH ARTICLE

GROWTH AND SALT BALANCE OF THE HALOPHYTE *SALICORNIA BRACHIATA* IN RELATION TO SALINITY

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ABSTRACT

Salicornia brachiata is a stem succulent annual halophyte, which is widely distributed in the saltpans of Eastern Part of Pichavaram . Plant samples of *Salicornia brachiata* were collected from different localities around the East costal part of Tamilnadu, Pichavaram, during the months of June, July, August and September. Salinity and pH of the soils and plants was investigated and the relationship between these parameters tested statistically. The soil salinity values showed that the highest values were obtained in August, but after the rainfall in September these values started to decrease. The plant salinity values showed a parallel variation with the soil salinity values. The correlation between these two parameters was found to be positive and linear. No statistical relationship was obtained between soil–plant salinity and pH. This study reports the effect of salinity (0, 200, 400, 600, 800, and 1000mM 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. brachiata* plants were recorded at 400mM NaCl and the growth declined with a further increase in salinity. Both sodium (Na), chloride (Cl) and Nitrogen (N) contents of plants increased with an increase in salinity, while Phosphorus content decreased. Succulence of shoots increased at low salinity and decreased at high salinity.

INTRODUCTION

Halophytes are plants that can complete their life cycles in habitats that have moderate to high concentrations of salts in their soils (Munns et al., 1983; Flowers et al., 1986). Greenway and Munns (1980) divide the growth response to salinity of plants into four groups. Group IA (euhalophytes) have optimal growth (i.e., salt-stimulated growth) at moderate salinities (100–300 mmol/L NaCl) and continue to grow and survive at salinities up to 700 mmol/L. Group IB (miohalophytes) have optimal growth at very low salinities and continue to grow at reduced rates even at higher salinities. In group II halophytes and nonhalophytes, growth is greatly reduced even at moderate salinity, and salinities over 300 mmol/L are lethal. Group III are very salt-sensitive nonhalophytes that cannot survive when grown at salinities over 100 mmol/L. Halophytes occur in three subclasses of angiosperms (Kremer and Van Andel, 1995). In monocotyledons, halophytes are rare in the Alismatidae and clustered in a few related families in the Commelinidae; in the remaining angiosperms (dicotyledons, sensu lato), halophytes are found in fewer than 50% of families in the Carophyllidae (primarily within the Chenopodiaceae) Euhalophytic members of the Chenopodiaceae include *Suaeda* (Yeo and Flowers, 1980), *Atriplex* (Greenway, 1968; Miyamoto et al., 1996), and *Salicornia* (Ayala and O'Leary, 1996; Pfister, 1999).

In these genera, it is well established that maximum or optimal growth occurs at salinities ranging from 100 to 300 mmol/L and that growth is less under freshwaterconditions (Chapman, 1960; Yeo and Flowers, 1980; Flowers et al., 1986). Optimal growth of dicotyledonous euhalophytes is associated with succulence of leaves and stems (Pfister, 1999), Na1 accumulation in (and, in some cases, secretion from) leaves (Munns et al., 1983; Miyamoto et al., 1996), and a high ratio of Na : K in plant tissues (at least 5.0 to 10.0) (Gorham et al., 1980; Rozema, 1991). Reports of salt-stimulated growth (by the definition of Greenway and Munns [1980]) are rare among grasses, and optimal growth of halophytic grasses is not associated with high Na1 accumulation (Gorham et al., 1980; Glenn, 1987). Optimal growth under saline conditions has been observed to be nitrogen dependent in both halophytic dicotyledons (Rozema et al., 1983) and monocotyledons (Smart and Barko, 1980). The nitrogen dependence of halophytes is associated with production of quaternary

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ammonium compounds and free amino acids that are believed to contribute to osmotic adjustment and act as nitrogen sinks (Flowers et al., 1977).

Salicornia brachiata (Chenopodiaceae) is a highly salt tolerant annual species occurring in salt playas of the Great Basin desert (Ungar, 1965; Ungar, 1964). It forms a pioneer community, with plants being shorter and denser at the higher salinity (Chapman, 1974). It was also associated with *Salicornia utahensis*, *Allenrolfea occidentalis*, and *Distichlis spicata* along a gradient of reduced salinity. The annual precipitation ranges from 10 to 20 cm, mostly as snow with relatively little spring or summer rain. 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 (Pigot, 1969). *Salicornia sp.* have increased biomass production with salt increments in the growth medium ranging from 170 to 340mM NaCl (Cooper , 1982; Ungar, 1972). A similar promotion of growth at or below seawater was also reported for other halophytic species (Yeo and Flowers, 1980; Khan et al., 2000).

Salinity may decrease biomass production because it causes a lowering of plant water potentials, specific ion toxicities, or ionic imbalances (Neumann, 1997). Plants protect themselves from NaCl toxicity by minimizing Na^+ uptake and transport to the shoot (Cramer, 1985). Osmotic adjustment under saline condition may be achieved by ion uptake, synthesis of osmotica or both (Popp, 1995; Cheeseman,1988). Halophytes differ widely in the extent to which they accumulate ions and overall degree of salt tolerance (Glenn et al., 1996). Stem and leaf-succulent chenopods are commonly known salt-accumulators and have high Na^+ and Cl_2, content (Gul et al., 2000; Neumann, 1997; Breckle , 1969; Gorham ,1980). The present study was designed to verify and to amplify the results of *Salicornia brachiata* on pH value of soil, growth parameters and Mineral nutrition.

MATERIAL AND METHODS

Salicornia brachiata, halophyte species belonging to the family Chenopodiaceae was used for the present investigation. This species was naturally growing in abundance in the salt marshes in the mangrove area of Pichavaram on the east coast of Tamil Nadu, India, about 10 km east of Annamalai University campus. Plant samples collected from different localities were carefully removed from the soil together with roots, placed in labelled polyethylene bags and brought to the laboratory. The stem and branches of the collected samples were broken into pieces, put in the polyethylene bags and deepfreezed. The same method was used for the soil extracts. pH measurements of soil saturation and plant extracts were determined using a "Beckman" pH meter. uprooted without damaging the root system and they were planted individually in polythene bags (7"X5") filled with the homogenous mixture of garden soil containing red earth, sand and farm yard manure (1:2:1). The planted seedlings were irrigated with tap water and maintained in the Botanical garden, Arignar Anna Government Arts College, Villupuram. One month old well established seedlings were selected and treated with concentrations of NaCl (100-1000 mM). Above 700 mM NaCl concentrations, seedlings were not survived. The experimental yard was rooted with transparent polythene sheet at a height of 3 m from the ground in order to protect the plants from rain. The samples were collected periodically at 60 day intervals and the data were analysed statistically with Standard Error.

RESULT

Soil and plant samples collected from different localities (A, B and C) during June, July, August, and September showed that electrical conductivity values in soil saturation extracts varied between 90–204 mm.hos.cm–2. The soil salinity value in July was 19.78 % higher than in June, but in September, it was 21.64 % lower than in August, in locality A. Similarly in locality B, soil salinity value in July was 18.84% higher than in June, and in September it was 6.84 % lower than that in August. A similar situation can be seen in locality C, where soil salinity value in July was 40.64 % higher than in June and it was 22.00 % lower in September than in August. The similarity among the results in all three investigations showed that an increase in temperature during August caused aridity and due to evaporation of minerals from the groundwater reached the surface forming a crust at the top. The rains during September washed the soil profile and salinity was reduced. pH is a parameter which affects distribution and ecology of plants. The results on pH are given in Table 1. In general, all three localities showed neutral values, however, pH of plant extracts in the three localities varied between 5.34 and 5.90. No relationship was determined between these two parameters.

Table 1. pH values of soil saturation and plant extracts obtained from samples collected in different localities during the investigation period.

Month	Soil			Plant		
	Mean ± standard error			Mean ± standard error		
	Locality A	Locality B	Locality C	Locality A	Locality B	Locality C
June	6.81±0.01	6.48±0.02	6.61±0.00	5.49±0.02	5.34±0.03	5.37±0.03
July	6.95±0.03	6.40±0.01	6.59±0.00	5.65±0.03	5.43±0.01	5.59±0.01
August	7.16±0.01	6.86±0.01	6.91±0.01	5.70±0.01	5.73±0.01	5.88±0.01
September	6.75±0.00	6.07±0.01	6.25±0.02	5.68±0.01	5.90±0.01	5.87±0.01

A significant individual effect of salinity, plant part and their interactions in affecting fresh and dry weights of *S. brachiata* plants (Table 2). Optimal growth (shoot fresh and dry weight) of S. rubra plants were recorded at 400mM NaCl and the growth declined with a further increase in salinity. Most plants survived at 1000mM NaCl treatment. Root fresh and dry weight was both significantly inhibited at higher salinities (Table 2).

weight peaked at moderate salinity [400mM NaCl]. Succulence at low and high salinity was not significantly different (Table2). Moisture Content of *S. brachiata* plants progressively Increased with increasing in salinity *of Salicornia brachiata* plants were progressively stressed with increasing salinity (Table 2).

significant promotion of plant growth at 200mM NaCl and plants survived at 1M salinity with stunted growth. Stem succulent halophytes like *Arthrocnemum macrostachyum*, *Allenrolfea occidentalis*, *Halosrachia pergranulata*, *S. herbacea*, and *S. brachystachya* also showed stimulation from 170 to 340mM NaCl and could survive at very high salinity (Cooper, 1982).

Table 2. Effect of NaCl on Shoot length, root length, fresh weight of shoot, dry weight of shoot and moisture content of *Salicornia brachiata* 60 days of treatment

Concentration	Shoot length (g plant^{-1})	Root length (g plant^{-1})	Fresh weight (g plant^{-1})	Dry weight (g plant^{-1})	Moisture content (g plant^{-1})
100	16.9 ± 0.84	8.5 ± 0.42	4.8 ± 0.24	2.1 ± 0.10	3.9 ± 0.19
200	18.6 ± 0.93	9.2 ± 0.46	5.3 ± 0.26	3.3 ± 0.16	4.2 ± 0.21
300	19.5 ± 0.97	10.2 ± 0.51	6.6 ± 0.33	3.9 ± 0.19	5.1 ± 0.25
400	20.5 ± 1.02	11.1 ± 0.55	7.1 ± 0.35	4.3 ± 0.21	6.6 ± 0.33
500	19.8 ± 0.99	10.6 ± 0.53	6.5 ± 0.32	3.8 ± 0.19	5.8 ± 0.29
600	17.5 ± 0.87	9.2 ± 0.46	5.9 ± 0.29	3.1 ± 0.15	5.0 ± 0.25
700	16.7 ± 0.83	8.5 ± 0.42	5.0 ± 0.25	2.9 ± 0.14	4.2 ± 0.21

± Standard Error

A showed significant individual effect of plant part, salinity and their interactions on ion contents (Table 3). Total of cations (Na^+) and the anion (Cl_2) content increased with increase in salinity (Table 3).

Haloxylon recurvum, and *Sarcocrnia natalensis* are reported to survive under highly saline condition but also showed optimal growth from 200 to 600mM NaCl (Gul et al., 2000). *Salicornia sp*. such as S. *europaea, S. bigelovii,*

Table 3. Effect of NaCl on sodium, chloride, phosphorus and nitrogen of *Salicornia brachiata* 60 days of treatment

Concentration	Sodium (mg g^{-1}dr.wt	Chloride (mg g^{-1}dr.wt	Phosphorus (mg g^{-1}dr.wt)	Nitrogen (mg g^{-1}dr.wt)
100	16.50 ± 0.82	18.31 ± 0.91	0.65 ± 0.03	2.35 ± 0.11
200	18.35 ± 0.91	20.50 ± 1.02	0.73 ± 0.03	2.62 ± 0.13
300	20.15 ±1.00	22.66 ± 1.13	0.88 ± 0.04	2.85 ± 0.14
400	21.00 ±1.05	23.15 ± 1.15	0.91 ± 0.04	2.95 ± 0.14
500	23.00 ±1.15	26.15 ± 1.30	0.85 ± 0.04	2.63 ± 0.13
600	25.00 ±1.25	28.50 ± 1.42	0.63 ± 0.03	2.41 ± 0.12
700	27.50 ±1.18	31.50 ± 1.57	0.41 ± 0.02	2.16 ± 0.10

± Standard Error

on concentrations in shoots were comparatively higher than those in roots (Table 3). At all NaCl concentrations, the increase in total inorganic ions resulted from increased Na^+, and Cl_2 while Phosphorus concentrations decreased with an increase in salinity.

DISCUSSION

The salinity values of the soils and the plants showed a good correlation. A positive correlation existed between the two parameters and relation progressed linearly during the investigation period (Table 1). Zeybek (1969) has carried out studies on the relationship between soil and plant salinity.

Our results fully coincide with his findings, but go against those of Onal (1966) who denied that salinity level increased in plants with increasing NaCl in the soil. This could lead to toxic effects on the plant. To overcome this effect, plants can increase absorption power and absorb more water and accumulate it in the Vocuoles for protection against the negative effects of salts on enzymatic activity (Munns, 2002).

Present study showed that *Salicornia brachiata* is a highly salt tolerant species during growth. There was a accumulation (Ungar, 1991). 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 (Eddin and Doddema, 1981; Reimann and Breckle, 1995). However, our results showed the optimal growth of *S. brachiata* at 400mM NaCl and highest succulence value at 700mM NaCl. Measurement of water potential through plant water status console showed that the water potential of *S. brachiata* plants became increasingly more negative with the increase in salinity. It may be suggested, therefore, that enhancement of dry mass production from 0- to 400-molm23 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 (Ungar, 1991). Growth and survival of halophytes is dependent on the high level of ion accumulation for the maintenance of turgor and osmotic adjustment (Flower et al., 1977). In dicotyledonous halophytes, water relations and the ability to adjust osmotically have been seen as important determinants of the growth response (Munns et al., 1983). 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 (Munns et al., 1983) or excessive demand on the energy requirement of such systems (Gale and Zeroni, 1985). Other factors such as nutrient deficiencies (Marschner, 1995) 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. brachiata* shoots and roots grown in the 0 NaCl solution was high because the seedlings for all of the tests were obtained from saline sites. Phosphorus of the shoots of plants grown at optimal salinity represent levels adequate for growth (Epstein, 1972). Calcium and magnesium concentrations were extremely low in shoots of plants grown at high salinity agreeing with the results found for other halophytes (Flowers and Yeo, 1986).

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