Anales de Biología 31: 61-70, 2009 ARTICLE

Effect of soil salinity on growth, water status and nutrient accumulation in seedlings of *Suaeda nudiflora* (Chenopodiaceae)

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Received: 15 May 2009
Accepted: 14 September 2009
Published on-line: 29 September 2009

Resumen

Efectos de la salinidad del suelo en el crecimiento, estado hídrico y acumulación de nutrientes en semillas de Suadea nudiflora *(Chenopodiaceae)*

Se realizaron experimentos en invernadero para evaluar los efectos de de la salinidad del suelo en la emergencia, crecimiento, estado hídrico contenido de prolina y acumulación mineral en semillas de *Suaeda nudiflora* (Wild.) Moq. (Chenopodiaceae). Se añadió NaCl al suelo y se mantuvo la salinidad a 0,3; 3,9; 6,0; 7,9; 10,0; 12,1 y 13,9 dSm^{-1}. Esta especie arbustiva es tolerante a la sal en el estadío de semilla. La sal estimuló el crecimiento de las plantas y su crecimiento óptimo se produjo a una salinidad de 7,9 dSm^{-1}. El incremento del crecimiento de la planta se debió al ajuste osmótico y al aumento de la superficie foliar. Los resultados sugieren que *S. nudiflora* es una planta halofítica. Los perfiles de K y Na de esta planta sugieren dos rasgos diferentes: (i) afluencia elevada y/o baja salida de Na^+ en la membrana de la raíz y (ii) alta discriminación de K^+/Na^+. También se discute sobre las variaciones en los patrones de acumulación de otros nutrientes, en cada tejido y el conjunto de la planta, así como sobre posibles mecanismos para eludir la toxicidad del Na en esta especie.

Palabras clave: *Suaeda nudiflora*, macro- y micro-nutrientes, prolina, germinación de semillas, Crecimento de plántula, Salinidad del suelo, Potencial hídrico.

Abstract

Greenhouse experiments were conducted to assess the effects of soil salinity on emergence, growth, water status, proline content and mineral accumulation of seedlings of *Suaeda nudiflora* (Wild.) Moq. (Chenopodiaceae). NaCl was added to the soil and salinity was maintained at 0.3, 3.9, 6.0, 7.9, 10.0, 12.1 and 13.9 dSm^{-1}. This bush species is salt tolerant at seed germination stage. Growth of plants was stimulated by salt and their optimum growth was at 7.9 dSm^{-1} salinity. Increase in plant growth was due to osmotic adjustment and increased leaf area. Results suggested that *S. nudiflora* is a halophytic plant. The K and Na profiles of this plant suggested its two distinct traits: (i) high Na^+ influx and/or low Na^+ efflux on root plasma membrane and (ii) high K^+/Na^+ discrimination. Changes in tissues and whole-plant accumulation patterns of other nutrients, as well as possible mechanisms for avoidance of Na toxicity in this species in response to salinity, are discussed.

Key words: *Suaeda nudiflora*, Macro- and micro-nutrients, Proline, Seedling emergence, Seedling growth, Soil salinity, Water potential.

Introduction

Salinisation of soil is common in arid and semi-arid regions than in humid ones. High concentrations of salts have detrimental effects on seed germination and plant growth (Bernstein 1962, Garg & Gupta 1997, Taiz & Zeiger 2006, Patel & Pandey 2008). An understanding of growth and survival of plants under saline habitat is needed for (i) screening the plant species for the afforestation of saline deserts and (ii) understanding the mechanisms that plants use in the avoidance and/or tolerance of salt stress. *Suaeda nudiflora* (Wild.) Moq. (Chenopodiaceae) a bush species, grows abundantly in the lowlying area of Kutch (north-west saline desert) of Gujarat State of India. It is also found scattered in coastal area of Saurashtra, to the south of Kutch. Leafy shoots of this plant are highly palatable to camels and wood is used as fuel. However, the potential of this bush species to grow and survive in the saline desert of Kutch is not known. The present investigation was performed with the following objectives: (i) to understand the adaptive features of *S. nudiflora* that allow it to grow and survive in saline and arid regions and (ii) to assess the pattern of macro- and micro-nutrient accumulation within the tissues of this bush species in response to salt stress.

Material and Methods

Study area

The present study was carried out in a greenhouse of the botanical garden of Saurashtra University at Rajkot (22°18'N Lat, 70°56'E Long) in Gujarat. For the emergence and growth of seedlings, the top 15 cm black-cotton soil, which is predominant in Saurashtra region of Gujarat, was collected from an agricultural field. This soil is a clayey loam containing 19.6% sand, 20.3% silt and 60.1% clay. The available soil water between wilting coefficient and field capacity ranged from 18.3% to 35.0%, respectively. The total organic carbon content was 1.3% and pH was 7.2. The electrical conductivity of soil was 0.3 dSm^{-1}. Nitrogen, phosphorus, potassium, calcium and sodium contents were 0.15%, 0.05%, 0.03%, 0.05% and 0.002%, respectively. This soil is fertile and fit for intensive agriculture. Physical and chemical properties of soil are given earlier (Pandya et al. 2004). The Kutch is tropical monsoonic and can be ecoclimatically classified as arid. Total annual rainfall is about 395 mm at Bhuj (23°16'N Lat, 69°49'E Long) in Kutch which occurs totally during the rainy season. Typically, there are three main seasons: summer (April–mid June), monsoon (mid June–September) and winter (November–February). The months of October and March are transition periods between rainy (monsoon) and winter and between winter and summer seasons, respectively. Details of climate are given earlier (Ramoliya et al. 2004).

Salinisation of soil

Surface soil was collected, air dried and passed through a 2mm mesh screen. Seven lots of soil, of 100 kg each, were separately spread, about 50 mm thick, over polyethylene sheets. Sodium chloride (NaCl) amounting to 280, 590, 690, 1090, 1410 and 1690 g was then thoroughly mixed with soil of six lots, respectively to give electrical conductivities of 3.9, 6.0, 7.9, 10.0, 12.1 and 13.9 dSm^{-1}. There was no addition of NaCl to seventh lot of soil that served as control. The electrical conductivity of control soil was 0.3 dSm^{-1} and this value was approximately equal to 3mM salinity. Measurement of electrical conductivity of soil followed (Ramoliya et al. 2004).

Seedling emergence

Fifteen polyethylene bags for each level of soil salinity were each filled with 5 kg of soil. Tap water was added to each bag to bring the soils to field capacity and soils were allowed to dry for 7 days. Bags were kept in a greenhouse. Soils in the bags were then raked using fingers and ten seeds were sown at the surface of soil in each bag on 15 August 2007. Seeds of *Suaeda nudiflora* were collected from the saline desert of Kutch. Immediately after sowing soils were watered and thereafter watering was carried out on alternate days. Emergence of seedlings was recorded daily over a period of 30 days. A linear model was fitted to cumulative proportion of seed germination and increasing soil salinity using the expression:

$$\mathrm{Sin}^{-1}\sqrt{P} = ß_0 + ß_1 X$$

where, $\mathrm{Sin}^{-1}\sqrt{P}$ is the proportion of cumulative seed germination, X is soil salinity and ß0 and ß1 are constants. Salt concentration at which seed germination was reduced to 50% (SG_{50}) was es-

timated using the model.

Seedling growth

For the growth studies, two seedlings that emerged first were left in each of 15 bags at each level of salinity and others were uprooted. Seedlings were allowed to grow for one month to get established. Moreover, only 4.8% seed germination was recorded in soil at 13.9 dSm^{-1} salinity and further experiments were not conducted on those seedlings. Following the establishment period, one seedling having better vigor was allowed to grow in each bag and another seedling was further uprooted. Thus fifteen replicates factorialzed with six grades of soil (0.3, 3.9, 6.0, 7.9, 10.0 and 12.1 dSm^{-1}) were prepared. This gave a total of 90 bags, which were arranged in fifteen randomized blocks. Seedlings were watered (about 300 ml water was added to raise the soil moisture to field capacity) at alternate days and experiment was terminated after 6 months. The mean maximum temperature of the greenhouse during the course of study increased from 31.7 ± 0.6°C in August to 34.5 ± 0.3 °C in October 2007 and declined thereafter to 28.7 ± 1.2°C in February 2008. Seedlings contained in 15 bags at each salinity level were washed to remove soil particles adhered to roots. Morphological characteristics of each seedling were recorded. Shoot height and root length (tap root) were measured. Leaf area was marked out on graph paper. Fresh and dry weights of tissues (leaves, stems, tap roots and lateral roots) were determined. Sum of leaf and stem weight was considered as shoot weight. Water content (gg^{-1} dry weight) in tissues was calculated using fresh and dry weight values. Data recorded for morphological characteristics, dry weight and water content of different components were analysed by one-way ANOVA to assess the effect of salinity on plant growth.

Determination of water potential and proline content

Five additional plants grown in soil at each level of salinity were used for measurement of water potential and proline determination in plant tissues. Water potential of leaves, stems, tap roots and lateral root tissues was measured by Dewpoint Potential Meter WP4. Concentration of proline in plant tissues was determinated following Bates et al. (1973). Extract of 0.5g fresh plant material with aqueous sulphosalicylic acid was prepared. The extracted proline was made to react with ninhydrin to form chromophore and quantified spectrophotometrically at 520 nm. Water potential and proline content of tissues were determined in triplicate. Data were analysed by one-way ANOVA.

Mineral analyses of plant materials

Mineral analyses were performed on leaves, stems, tap roots and lateral root tissues. Plant parts of the seedlings grown in soil at same level of salinity were pooled separately and ground using mortar and pestle. Three subsamples of plant tissues were analyzed. Total nitrogen was determined by Kjeldahl method and phosphorus content estimated by the chlorostannous molybdophosphoric blue colour method in sulphuric acid (Piper 1944). Concentrations of Ca, Mg, Na, K, Zn, Fe, Mn and Cu were determined by Shimadzu double beam atomic absorption spectrophotometer AA-6800 after triacid (HNO_3:H_2SO_4:$HClO_4$ in the ratio of 10:1:4) digestion. Mineral data were analyzed by one-way ANOVA. Correlations and linear regression equations between mineral content and salt concentrations were determined.

Results

Effect of salinity on seedling emergence

Seedlings began to emerge 2 days after sowing and 91.7% seedling emergence was achieved over a period of 17 days under control (0.3 dSm^{-1} salinity) conditions (Fig. 1). Seedling emergence in saline soils was recorded 2-6 days after sowing. Emergence lasted for 21, 20, 20, 20, 18 and 14 days in soils with salinities of 3.9, 6.0, 7.9, 10.0, 12.1 and 13.9 dSm^{-1} respectively, and corresponding seed germination was 78.6%, 69.5%, 59.6%, 48.1%, 35.5% and 4.8%. There was a significant reduction in germination of seeds ($p<0.01$) with increasing salt stress. A negative relationship between proportion of cumulative seed germination and concentration of salt was obtained according to the following expression:

$$Y = 79.437-4.039X \ (R^2_{Adj}=0.92, p<0.01)$$

where, Y is arcsine (degrees) of proportion of cumulative seed germination and X is salt concentration.

Effect of salinity on stem and root elongation and leaf expansion

Salinity significantly promoted ($p<0.01$) stem and root elongation. Stem height and root length increased until 7.9 dSm^{-1} salinity, but declined above this salinity level (Table 1). However, root length was equal to stem height under control and saline conditions. A positive relationship was obtained for shoot height and root length with increasing salt concentration ($p<0.01$). Increasing salinity promoted leaf expansion ($p<0.01$). Leaf area increased until 7.9 dSm^{-1} salinity, but decreased when salinity exceeded this level. A positive relationship was obtained between leaf area and salt concentration in soil ($p<0.01$).

Effect of salinity on dry weight

Dry weight significantly increased for leaves, stems, shoots (leaves + stems), tap roots, lateral roots and total roots (tap roots + lateral roots) ($p<0.01$). Dry weight of tissues increased until soil salinity of 7.9 dSm^{-1}, but declined thereafter (Table 1). There was a positive relationship between salt concentration in soil and dry weight of leaves, stems, shoots, tap roots, lateral roots and total roots ($p<0.01$). Root/shoot dry weight ratios were 0.45, 0.48, 0.45, 0.43, 0.43 and 0.44 for plants grown in soil at 0.3, 3.9, 6.0, 7.9, 10.0

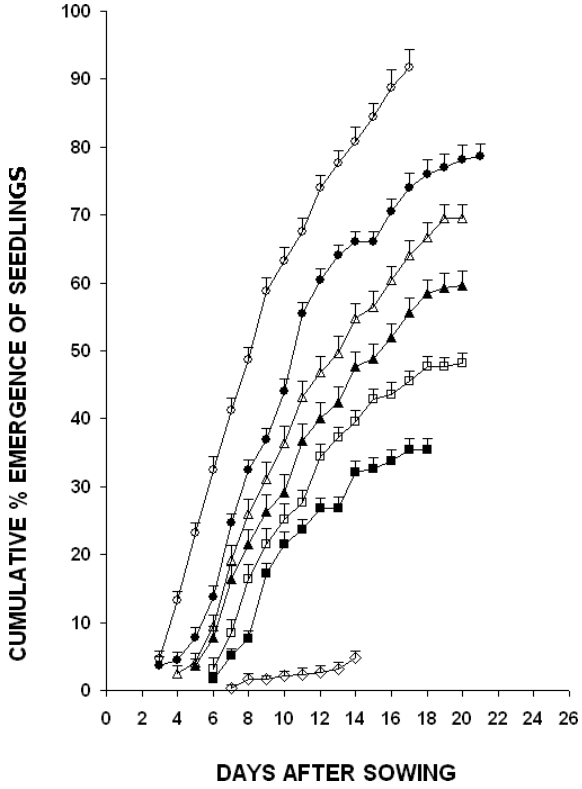

Figura 1. Emergencia acumulada de semillas de *Suaeda nudiflora* en respuesta a a la salinidad del suelo. 0,3 dSm^{-1}(○), 3,9 dSm^{-1} (●), 6,0 dSm^{-1} (Δ), 7,9 dSm^{-1} (▲), 10,0 dSm^{-1} (□), 12,1 dSm^{-1} (■) and 13,9 dSm^{-1} (◊). Las barras de error representan ES.

Figure 1. Cumulative emergence of seedlings of *Suaeda nudiflora* in response to soil salinity. 0.3 dSm^{-1}(○), 3.9 dSm^{-1} (●), 6.0 dSm^{-1} (Δ), 7.9 dSm^{-1} (▲), 10.0 dSm^{-1} (□), 12.1 dSm^{-1} (■) and 13.9 dSm^{-1} (◊). Error bars represent SE.

Salinity (dSm^{-1})	Stem height (cm)	Root length (cm)	Leaf area (cm^2 $plant^{-1}$)	Leaf weight (mg $plant^{-1}$)	Stem weight (mg $plant^{-1}$)	Shoot weight (leaf+stem) (mg $plant^{-1}$)	Tap root weight (mg $plant^{-1}$)	Lateral root weight (mg $plant^{-1}$)	Total root weight (mg $plant^{-1}$)
0.3	18.5 ± 0.9	18.8 ± 0.3	13.5 ± 1.2	258.7 ± 6.7	288.0 ± 14.4	546.7 ± 18.3	113.3 ± 4.0	132.0 ± 4.1	245.3 ± 6.7
3.9	18.6 ± 0.8	20.6 ± 0.3	19.4 ± 0.6	295.3 ± 12.6	296.7 ± 18.1	592.0 ± 24.5	143.3 ± 5.8	136.0 ± 5.8	279.3 ± 7.4
6	20.6 ± 0.7	21.2 ± 0.3	25.7 ± 1.0	335.3 ± 8.2	326.0 ± 16.4	661.3 ± 21.8	152.0 ± 5.5	144.0 ± 8.9	296.0 ± 10.5
7.9	24.6 ± 0.9	23.0 ± 0.3	33.5 ± 1.3	394.7 ± 10.4	391.3 ± 16.5	786 ± 24.9	166.7 ± 5.8	171.3 ± 10.0	338.0 ± 12.1
10	21.2± 0.9	21.0 ± 0.4	25.4 ± 0.7	377.3 ± 9.0	348.7 ± 10.6	726.0 ± 12.3	152.7 ± 4.5	160.7 ± 10.5	313.3 ± 12.4
12.1	20.2 ± 0.8	19.8 ± 0.3	14.5 ± 0.9	335.3 ± 6.6	327.3 ± 12.5	662.7 ± 15.1	142.0 ± 3.3	150.0 ± 4.4	292.0 ± 4.2
α	18.87	19.91	18.42	272.78	293.82	566.63	127.50	132.81	260.30
β	0.26	0.12	0.58	8.93	5.35	14.26	2.61	2.42	5.02
r	0.268	0.28	0.3	0.608	0.32	0.510	0.42	0.29	0.43
$LSD_{0.05}$	2.4	0.9	2.7	25.9	42.4	56.7	13.8	21.9	26.5

Relationship is significant at $p < 0.01$.

Tabla 1. Efecto de la salinidad del suelo en las características de la hoja, tallo y raíz de *Suaeda nudiflora* indicado por la media ± SEM y las constantes de la ecuación de regresión.

Table 1.Effect of soil salinity on leaf, stem, shoot and root characteristics of *Suaeda nudiflora* as indicated by mean ± SEM and regression equation constants.

and 12.1 dSm^{-1} salinity, respectively. Root/shoot dry weight ratio did not change with increasing soil salinity.

Effect of salinity on water content, water potential and proline content of tissues

Water content significantly increased ($p<0.01$) in leaves, stems, tap roots and lateral roots with increasing soil salinity (Fig. 2A). A positive relationship was obtained between salt concentration and water content of tissues ($r=0.509$, 0.477, 0.475 and 0.315, $p<0.01$, for leaves, stems, tap roots and lateral roots, respectively). There was maximum water content in leaves and minimum in tap roots and lateral roots. Tissues according to their water content can be arranged in the following decreasing order: leaves > stems > tap roots = lateral roots. Water potential significantly became more negative in tissues ($p<0.01$) as soil salinity increased (Fig. 2B). However, it became more negative until 7.9 dSm^{-1} salinity, but did not change considerably when salinity exceeded this level. There was a negative relationship between soil salinity and water potential of leaves ($r=-0.769$, $p<0.01$), stems ($r=-0.475$, $p<0.05$), taproots ($r=-0.809$, $p<0.01$) and lateral roots ($r=-0.538$, $p<0.05$), respectively. Proline content significantly increased ($p<0.01$) in leaves, stems, tap roots and lateral root tissues with increase in soil salinity (Fig. 2C). However, concentration of proline increased in tissues until 7.9 dSm^{-1} salinity, but declined thereafter. Tissues according to their proline content can be arranged into the following decreasing order : leaves = stems > tap roots > lateral roots. There was a positive relationship between salt concentration and proline content of tissues ($r=0.584$, 0.578, 0.666 and 0.579, $p<0.01$, for leaves, stems, taproots and lateral roots, respectively).

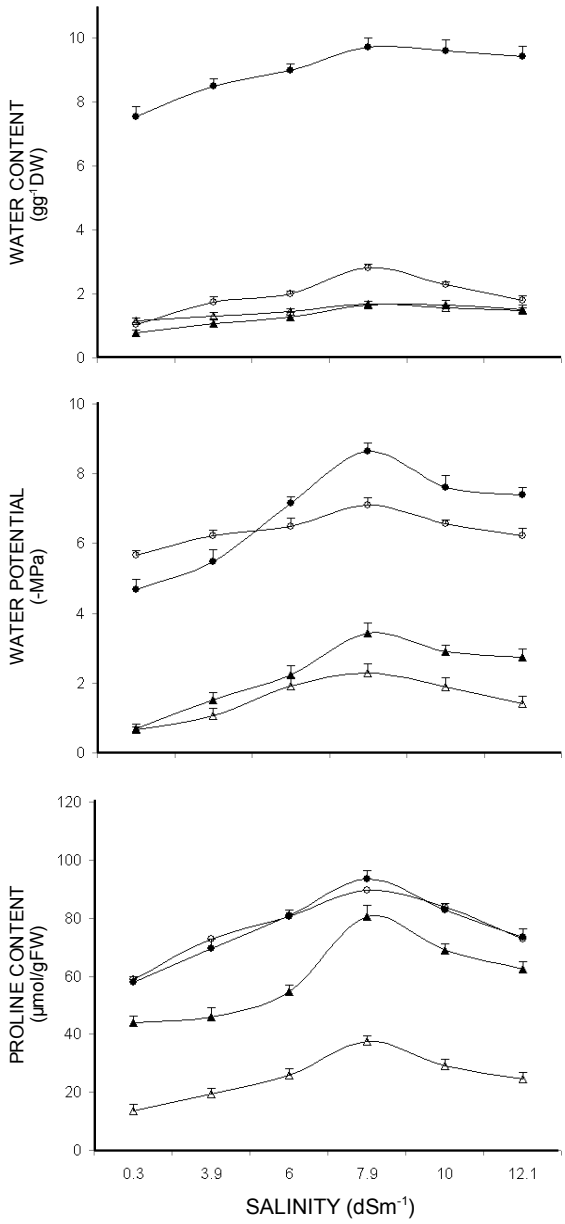

Figura 2. Efecto de la salinidad del suelo en: **A.**. contenido de agua (gg^{-1} DW): **B**. potencial hídrico (-MPa); **C.** contendo de prolina (µmol/g FW) de hojas (●), tallos (○), raices primarias (▲) y secundarias (Δ) de *Suaeda nudiflora*. Las barras de error representan SE.

Figure 2. Effect of salinisation of soil on: **A.**. water content (gg^{-1} DW): **B**. water potential (-MPa); **C.** proline content of leaves (µmol/g FW) (●), stems (○), tap roots (▲) and lateral roots (Δ) of *Suaeda nudiflora*. Error bars represent SE.

Effect of salinity on mineral accumulation

In general, concentration of N, Na and Ca was greater than that of P, K and Mg, in tissues of plants under control and salt-stress conditions. Potassium and sodium content significantly increased ($p<0.01$) in leaves, stems, tap roots and lateral root tissues in response to increasing soil salinity (Table 2). There was a positive relationship between K and Na content of tissues and increase in salt concentration in soil ($p<0.01$). The K/Na ratio did not change in tissues in response to increasing soil salinity. Nitrogen content significantly increased ($p<0.01$) in leaves, stems, tap roots and lateral roots in response to increasing salt concentration in soil. A positive relationship was obtained between salt concentration and N content of tissues ($p<0.01$). On the contrast, P and Ca content significantly decreased ($p<0.01$) in leaves, stems, tap roots and lateral roots in res-

Tissue	Salinity (dSm^{-1})	N ($mg\ g^{-1}$)	P ($mg\ g^{-1}$)	K ($mg\ g^{-1}$)	Na ($mg\ g^{-1}$)	Ca ($mg\ g^{-1}$)	Mg ($mg\ g^{-1}$)	K/Na ratio	Zn ($\mu g\ g^{-1}$)	Mn ($\mu g\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)	Fe ($\mu g\ g^{-1}$)
Leaf	0.3	25.3±1.2	1.8±0.1	6.8±0.2	13.2±0.2	11.8±0.2	3.4±0.1	0.5±0.0	36.0±1.2	31.0±1.2	142.3±5.8	201.4±10.4
	3.9	27.8±0.9	1.7±0.1	7.6±0.2	13.6±0.2	11.6±0.3	3.5±0.2	0.6±0.0	36.8±1.1	36.0±1.7	150.9±5.2	257.9±13.9
	6.0	30.3±0.9	1.6±0.1	8.0±0.3	13.8±0.1	11.4±0.2	3.6±0.1	0.6±0.0	38.5±1.5	37.9±1.4	156.8±6.4	263.9±14.5
	7.9	33.0±1.2	1.5±0.0	8.3±0.2	14.0±0.1	11.1±0.2	3.7±0.1	0.6±0.0	44.9±1.6	40.2±1.2	166.2±5.6	318.2±11.4
	10.0	31.0±1.0	1.4±0.1	9.3±0.2	14.2±0.2	10.7±0.1	3.8±0.1	0.7±0.0	55.3±1.0	45.8±1.5	170.0±4.6	349.9±14.4
	12.1	30.0±1.2	1.3±0.1	9.6±0.2	14.5±0.2	10.5±0.3	3.9±0.1	0.7±0.0	60.3±1.2	66.8±1.2	206.7±6.2	351.5±14.4
	α	26.41	1.79	6.64	13.18	11.95	3.35	NS	30.39	25.65	133.48	199.07
	β	0.47	-0.04	0.24	0.11	-0.12	0.04	NS	2.22	2.58	4.78	13.64
	r	0.640	-0.87	0.82	0.86	-0.805	0.746	NS	0.9	0.86	0.84	0.92
	LSD 0.05	3.2	0.2	1.4	0.5	0.7	0.3	NS	3.8	4.1	17.2	40.2
Stem	0.3	22.0±1.2	1.5±0.0	6.5±0.2	10.0±0.2	9.6±0.2	2.4±0.1	0.7±0.0	10.1±1.3	8.6±0.6	55.7±4.2	107.8±15.6
	3.9	25.0±1.0	1.4±0.1	7.4±0.3	10.4±0.2	8.9±0.3	2.5±0.1	0.7±0.0	14.3±1.2	10.0±0.5	64.9±2.5	111.8±11.6
	6.0	27.3± 1.2	1.3±0.1	7.8±0.2	10.8±0.2	8.6±0.2	2.5±0.1	0.7±0.0	18.4±1.6	10.8±0.5	68.9±3.4	156.3±9.2
	7.9	29.3±0.9	1.3±0.1	8.1±0.2	11.2±0.1	8.5±0.2	2.6±0.2	0.7±0.0	18.7±1.6	10.9±0.5	69.8±3.4	186.3±12.7
	10.0	28.1±1.2	1.2±0.1	9.3±0.3	12.6±0.1	7.1±0.3	2.7±0.1	0.7±0.0	19.2±1.4	11.4±0.6	75.3±2.7	202.7±15.6
	12.1	26.8±0.9	1.0±0.2	9.5±0.3	12.8±0.1	7.0±0.4	2.8±0.1	0.7±0.0	20.0±1.6	12.4±0.7	88.8±2.5	215.3±13.3
	α	23.41	1.59	6.33	9.58	9.83	2.34	NS	11.19	8.69	53.95	93.81
	β	0.46	-0.04	0.26	0.26	-0.23	0.04	NS	0.84	0.30	2.48	10.38
	r	0.63	-0.81	0.93	0.930	-0.89	0.67	NS	0.81	0.82	0.88	0.88
	LSD 0.05	3.2	0.3	0.8	0.5	0.8	0.3	NS	4.3	1.7	9.6	39.9

Relationship is significant at $p < 0.01$, NS = non significant.

Tabla 2. Efecto de la salinidad del suelo en el contenido de nutrientes de los tejidos (hoja, tallo, raíz primaria y secundaria) de *Suaeda nudiflora* indicado como media ± SEM and constantes de la ecuación de regresión.

Tablae 2. Effect of soil salinity on nutrient content of tissues (leaf, stem, tap root and lateral root) of *Suaeda nudiflora* as indicated by mean ± SEM and regression equation constants.

Tissue	Salinity (dSm^{-1})	N ($mg\ g^{-1}$)	P ($mg\ g^{-1}$)	K ($mg\ g^{-1}$)	Na ($mg\ g^{-1}$)	Ca ($mg\ g^{-1}$)	Mg ($mg\ g^{-1}$)	K/Na ratio	Zn ($\mu g\ g^{-1}$)	Mn ($\mu g\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)	Fe ($\mu g\ g^{-1}$)
Tap root	0.3	18.9±1.0	1.5±0.1	5.9±0.3	7.7±0.2	9.4±0.5	1.4±0.1	0.8±0.0	13.1±1.2	11.0±0.6	63.3±2.3	103.0±10.4
	3.9	21.7±1.0	1.3±0.2	7.3±0.3	9.4±0.2	8.9±0.3	1.5±0.2	0.8±0.0	13.5±1.5	11.5±0.3	65.8±2.9	128.1±11.5
	6.0	24.2±1.0	1.3±0.1	8.0±0.3	10.1±0.1	8.6±0.3	1.6±0.1	0.8±0.0	16.1±1.4	11.7±0.4	67.5±4.0	150.3±14.4
	7.9	26.5±1.3	1.0±0.2	8.2±0.4	10.3±0.2	8.3±0.2	1.7±0.1	0.8±0.0	18.2±1.1	12.0±0.4	70.8±3.4	246.7±18.5
	10.0	25.3±1.2	0.9±0.1	8.4±0.3	10.5±0.2	6.9±0.3	1.8±0.1	0.8±0.0	19.8±1.2	12.1±0.2	83.1±3.9	315.8±14.8
	12.1	22.8±1.0	0.8±0.1	8.8±0.5	10.7±0.2	6.8±0.2	1.8±0.1	0.8±0.0	22.2±1.2	14.8±0.5	86.9±4.7	331.2±16.7
	α	20.34	1.56	6.18	8.14	9.18	1.40	NS	11.69	10.46	58.77	64.65
	ß	0.43	-0.06	0.24	0.25	-0.23	0.04	NS	0.82	0.26	2.11	22.07
	r	0.58	-0.83	0.84	0.9	-0.86	0.75	NS	0.849	0.75	0.8	0.93
	LSD 0.05	3.2	0.3	1.1	0.6	1.0	0.3	NS	3.9	1.2	11.0	44.5
Lateral root	0.3	17.8±1.2	1.3±0.1	2.9±0.1	4.2±0.2	10.9±0.4	1.6±0.1	0.7±0.0	48.8±1.6	27.3±1.2	255.1±8.7	976.7±18.3
	3.9	20.6±1.0	1.2±0.1	3.1±0.1	4.9±0.2	8.0±0.3	1.7±0.0	0.6±0.0	49.5±1.4	33.3±1.2	268.1±7.5	1072.7±22.4
	6.0	22.2±1.0	1.2±0.1	3.2±0.2	5.0±0.1	7.6±0.3	1.7±0.1	0.6±0.0	66.0±1.7	35.5±0.8	315.7±9.1	1092.9±21.3
	7.9	24.2±1.0	1.1±0.2	3.5±0.2	5.3±0.1	6.1±0.2	1.8±0.2	0.7±0.0	69.2±2.2	41.0±1.2	343.6±7.9	1098.7±25.8
	10.0	23.2±1.0	0.9±0.1	3.9±0.1	5.5±0.1	5.8±0.2	1.9±0.1	0.7±0.0	78.9±2.2	43.5±1.1	353.7±9.2	1119.3±20.1
	12.1	21.8±1.1	0.7±0.0	4.2±0.2	5.7±0.1	5.4±0.2	2.0±0.1	0.7±0.0	85.1±1.3	47.3±1.1	369.1±5.2	1153.9±25.5
	α	19.07	1.37	2.72	4.30	10.35	1.56	NS	43.69	26.53	246.08	995.42
	ß	0.38	-0.05	0.11	0.12	-0.46	0.03	NS	3.37	1.71	10.67	13.47
	r	0.59	-0.79	0.89	0.92	-0.94	0.73	NS	0.95	0.97	0.94	0.83
	LSD 0.05	2,8	0,3	0,4	0,4	0,9	0,3	NS	5,4	3,3	24,4	67,9

Relationship is significant at $p < 0.01$, NS = non significant.

Tabla 2. Efecto de la salinidad del suelo en el contenido de nutrientes de los tejidos (hoja, tallo, raíz primaria y secundaria) de *Suaeda nudiflora* indicado como media ± SEM and constantes de la ecuación de regresión.

Tablae 2. Effect of soil salinity on nutrient content of tissues (leaf, stem, tap root and lateral root) of *Suaeda nudiflora* as indicated by mean ± SEM and regression equation constants.

ponse to salinity. There was a negative relationship for P and Ca contents in tissues with salt concentration ($p<0.01$). Magnesium content exhibited a significant increase ($p<0.01$) in leaves, stems, tap roots and lateral roots in response to increase in salt stress. There was a positive relationship between Mg content in tissues and salt concentration in soil ($p<0.01$). The concentration of Zn, Cu, Mn and Fe significantly increased ($p<0.01$) in leaves, stems, tap roots and lateral roots in response to increase in salt-stress. A positive relationship was obtained between soil salinity and concentration for Zn, Cu, Mn and Fe in tissues ($p<0.01$).

Discussion

Earlier work (Ramoliya et al. 2004) indicated that seedling emergence of salt–tolerant legume tree *Acacia catechu* was reduced to 50% (SG_{50}) in soil with salinity of 6.0 dSm^{-1}, but for S. nudiflora SG_{50} was obtained at 7.3 dSm^{-1}. That would suggest that this plant species is relatively salt-tolerant at seed germination. However, salt concentration exceeding 12.1 dSm^{-1} salinity was detrimental to seed germination that can be attributed to decreasing osmotic potential of soil solution. Further, it is reported that salinity reduces protein hydration (Slater et al. 2003) and induces changes in the activities of many enzymes (Dubey & Rani 1990) in germinating seeds.

Growth of plant tissues was stimulated by salt and optimum growth was at 7.9 dSm^{-1} salinity. Similar results have been reported for halophytes that have optimal growth in the presence of salt (Tester & Davenport 2003). The enhanced growth rate of *S. nudiflora* seedlings in presence of salt evinces that it is a halophytic plant. Root/shoot dry weight ratios of seedlings grown in soil with increasing salinity did not differ because salinity stimulated the growth of shoots and roots equally. Leaves of *S. nudiflora* are small, linear and succulent. It is considered that succulence is a morphological adaptation in salt-tolerant species (Marschner 1995). Water content in tissues increased and seedlings adjusted water potential of tissues to more negative level until 7.9 dSm^{-1} salinity. In dicotyledonous halophytes, water relations and ability to adjust osmotically are 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 uptake of solutes that are required to induce cell expansion, since this maintains the pressure potential in plant tissues. Moreover halophytes effectively compartmentalize salt (Na^+) into the vacuoles of cells. High sodium concentration may cause a stimulus to the growth of tolerant plants by its effect on generation of turgor and thereby cell expansion (Marschner 1995). In the present study, increase in leaf area with increase of salinity can be attributed to cell expansion. Consequently increase in growth of *S. nudiflora* with increase of salinity can be attributed to its osmotic adjustment and increased leaf area. At high salinity (>7.9 dSm^{-1}), growth reduction might either be caused by a reduced ability to adjust osmotically as a result of saturation of the solute uptake system, or because of excessive demand on energy requirement of such systems (Munns et al. 1983). Other factors such as nutrient deficiencies may also play an important role in growth reduction of salt stressed seedlings. In some plant species, salt tolerance is associated with accumulation of organic solutes in cytoplasm to balance the osmotic pressure of ions in the vacuoles (Hasegawa et al. 2000). The concomitant increase in proline content of the tissues and growth of seedlings with increase in salinity indicates that higher proline accumulation may contribute to the alleviation of NaCl stress in the plant.

In halophytic plants, Na substitutes potassium in several physiological processes (Marschner 1995). A greater concentration of Na than that of K in all tissues of plants grown under both control and saline conditions, on the one hand, and increase in growth of seedlings with salinity, on the other, suggested that *S. nudiflora* is a natrophilic species. It is reported that uptake mechanisms of K and Na are similar (Watad et al. 1991, Schroeder et al. 1994). Plants utilize two systems for K acquisition, low- and high-affinity uptake mechanisms. Na^+ cannot move through the plasma membrane lipid bilayer, but the ion is transported through both low- and high-affinity transport systems, which are necessary for K^+ acquisition. As a consequence Na^+ could enter the cell through high affinity K^+ carriers or through low affinity channels called non selective cation channels. However, the K and Na profiles of *S. nudiflora* in response to salinity suggested its two distinct

traits: (i) high Na^+ influx and/or low Na efflux on root plasma membrane and (ii) high K^+/Na^+ discrimination to select K from soils with high Na concentration. This plant is also efficient in long-distance Na transport to stems and leaves, that is a mechanism for salt tolerance. In the present study, P and Ca were the limiting factors for growth of seedlings when salinity exceeded 7.9 dSm^{-1}. Cramer et al. (1987) reported that salinity can alter Ca^{2+} uptake and transport leading to Ca^{2+} deficiency in plants. It is evidenced that Ca^{2+} causes closure of non-selective cation channels and restricts Na^+ uptake (Rus et al. 2001). Consequently decrease in Ca content may allow entry of large amount of Na^+ into root cells that may cause reduction in plant growth at high salinity. In general salinity reduces N accumulation in plants (Feigin 1985), but in this plant N increased with salinity. Dubey and Rani (1989) reported that protein level in several crops under salinisation increases due to the increased synthesis of pre-existing and certain new sets of proteins. Besides the role of Mg^{2+} in chlorophyll structure and as an enzyme cofactor, another important role of Mg^{2+} in plants is in the export of photosynthates (Marschner & Cakmak 1989). Increase of Mg^{2+} in tissues may be of importance for plant growth and survival in saline soil. Salinity generates an increase in reactive oxygen species (*ROS*) which have deleterious effects on cell metabolism (Borsani et al. 2001). Superoxide dismutases (*SODs*) detoxify and may contain Cu, Zn, Mn and Fe as metal components (Slater et al. 2003). Increase in concentration of these trace elements at the whole-plant level might be the requirement of this plant for survival in saline soils.

Acknowledgement

This study was supported with funds from Departmental Special Assistance provided by the University Grants Commission, New Delhi, Govt. of India.

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