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Research Article

Saline water irrigation in agriculture: A case study of mangrove's salinity tolerance level

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ABSTRACT

Standardizing the saline water irrigation is an important step towards saline water irrigation in agriculture. An experiment was conducted to study the salinity tolerance level of mangrove plant, *Lumnitzera racemosa* Willd. Under pot culture system. different levels of salinity (0, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 mM NaCl) were imposed on the plants and the variations in mineral content levels was analyzed. Samplings were done on 60, 120 and 180th days after NaCl treatment. From the results it is clear that Mineral constituents such as nitrogen, phosphorus, potassium, calcium and magnesium were increased upto the optimum concentration and there by the tolerance level of this mangrove towards salinity was calculated.

INTRODUCTION

Current key factors affecting agricultural yields globally include drought and salinity, which are examples of environmental abiotic stress conditions [1]. Salinity, in particular, is a growing issue that affects 20% of the world's arable land and nearly 50% of the area irrigated, making genetic development of salt tolerance an important necessity for the future of agriculture in arid and semi-arid regions [2]. As world's arable land is getting reduced day by day owing to more salinity in both water and soil, it is important to identify ways to utilize saline water in irrigation [3].

As with many other abiotic stresses, the most prevalent effect of salt stress is the reduction of plant development. Only extreme dicotyledonous halophytes often show some stimulation of development at moderate NaCl concentrations (50 - 250 mM), but loss of growth rate is still found at greater concentrations [4].

All glycophytes and many halophytic species thrive best in the absence of salt. Halophytes are frequently capable of finishing their life cycles in high salinity environments, unlike glycophytes [5]. In addition to species differences, responses to salt stress vary within the same species depending on the stage of development [6].

Mangroves are group of plants growing in marshy lands with comparatively high levels of salt contents in their habitats [7]. Physio-chemical features of mangrove environment are a critical component of swampy plants determining other biotic elements [8].

Chapman [9] listed five most important variables namely, temperature, salinity, tides, rainfall and wind that influence mangroves. These factors either single or in combination, control the mangrove formation. Other physical oceanographic factors like littoral currents, sedimentation, sitation and basin morphology have direct bearing on the mangrove growth [10].

The aim of the present study is to examine the responses of *Lumnitzera racemosa* Willd. a typical true mangrove species to salinity under controlled experimental conditions.

MATERIALS AND METHODS

The seedlings of the dicotyledonous mangrove tree *Lumnitzera racemosa* Willd., (Fig. 1) a member of the Combretaceae family, served as the plant material for the current study. The local marshy areas were used to collect the seedlings. Healthy plants with a consistent height were screened for transplantation when the seedlings were around 10 cm tall. The seedlings were carefully removed from the mangrove belt with their undamaged root systems and thoroughly cleansed with fresh water. The individual polythene bags holding fresh soil (1:2:1) that contained red dirt, sand, and farmyard manure were then filled with the seedlings.

Fig. 1. *Lumnitzera racemosa* plant with flowers.

Meteorological data

Meteorological data during the experimental period was obtained from local weather station.

Salinity treatments

NaCl treatments were applied to seedlings that were one month old and fully grown. 0 (control), 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 mM NaCl were used as the treatments. Every one of the aforementioned NaCl concentrations was applied to fifty plants. A control of 50 plants was kept untreated for salt. Up until each plant received the requisite mM NaCl, the salt treatment was continued. *L. racemosa* seedlings could not survive over 800 mM NaCl one month after salt treatment.

For the investigations, sodium chloride (Laboratory AR grade assay 99.9%) was employed. To get the necessary concentrations, the required amount of salt was dissolved in distilled water. It was carefully monitored to ensure that each plant in each set received the full pre-calculated NaCl concentration.

On the 60th day following NaCl treatment, the initial samples for several experiments were taken. On the 120th and 180th days following the NaCl treatment, the second and third samples were taken. The 60th, 120th, and 180th days following salt treatments were administered to plants at various times in order to obtain experimental plants whenever needed for various experiments.

Estimation of Minerals

Total nitrogen content was measured by following standard methods [11] quoted by Yoshida et al. [12]. Estimation of sodium and potassium were done by the method of Williams and Twine [13]. Estimation of phosphorus contents were done by following the method of Black [14] quoted by Yoshida et al. [12]. Estimation of calcium was done by standard method [12]. Magnesium was estimated by following the method reported earlier [13]. Estimation of chloride was done by following Krishnamurthy and Bhagwat [15].

Statistical analysis

The results were analyzed statistically [16] to determine the significance.

RESULTS

Sodium

The effect of NaCl salinity on the sodium content of the leaf, stem and root was studied on the 60th, 120th and 180th day and the results are presented in Table 1. Sodium chloride increased the sodium content in all the plant tissues with increasing concentrations. The maximum accumulation of sodium (33.84 mg/g dry wt.) was found with 800 mM NaCl on the 180th day samples. The stem tissue had more sodium at all concentrations of NaCl when compared to those of leaf and root. The F values calculated for difference between the sampling days and between the treatments were significant at 1% level.

Nitrogen

The results on the effect of NaCl on the nitrogen content of leaf, stem and root are given in Table 2. With increasing NaCl salinity concentrations, increase in nitrogen content was registered upto 500 mM and thereafter it gradually declined. The leaf tissue always showed higher nitrogen at all concentrations than stem and root. The highest percentage of (73.33%) nitrogen in the leaf tissue was noticed on the 120th day. The F values calculated for difference between the sampling days and between the treatments were significant at 1% level.

Phosphorus

Sodium chloride salinity upto 500 mM had increased the phosphorus content of the leaf, stem and root in all the three sampling days (Table 3). The leaf and stem tissues had more phosphorus than in the root. The maximum accumulation of phosphorus was recorded in the leaf tissue at 500 mM sodium chloride on the 180th day and this was 76.29% higher than that of control plants. The F values calculated for difference between the sampling days and between the treatments were significant at 1% level.

Potassium

Different concentrations of sodium chloride increased the potassium content of the leaf, stem and root of L. racemosa upto the optimum level of 500 mM (Table 4). The leaf had more potassium than that of stem and root in all the sampling days. The maximum accumulation of potassium (9.67 mg/g dry wt.) was recorded in the leaf tissue at 500 mM NaCl on the 180th day samples and this was 69.34% over that of control plants. The F values calculated for difference between the sampling days and between the treatments were significant at 1% level.

Calcium

The calcium content of the leaf, stem and root increased with increasing concentrations of NaCl upto 500 mM on all the three sampling days (Table 5). The leaf calcium content was always higher than that of stem and root. The maximum increase was 123.25% in the leaf tissue at 500 mM NaCl on the 180th day samples. Sodium chloride concentrations beyond 500 mM, decreased the calcium level on all the sampling days. The F values calculated for difference between the sampling days and between the treatments were significant at 1% level.

Magnesium

Sodium chloride treatments had increased the magnesium content of the leaf, stem and root with increasing concentrations upto 500 mM and at higher concentrations magnesium level was sharply decreased upto 800 mM (Table 6). The root tissue had always shown lesser magnesium than the leaf and stem at all concentrations on all the sampling days. The maximum accumulation of magnesium content (2.60% dry wt.) in the leaf tissue at 500 mM NaCl and minimum magnesium content (0.66% dry wt.) in the root tissue at 800 mM NaCl were found on the 180th day samples. The F values calculated for difference between the sampling days and between the treatments were significant at 1% level.

Chloride

The results on the effect of NaCl on the chloride content of the leaf, stem and root of L. racemosa are given in Table 7. Accumulation of chloride in all the plant tissues increased with increasing concentrations of sodium chloride and with the maximum accumulation was at 800 mM. The leaf tissue had more chloride content than the stem and root. The highest accumulation of chloride (24.30 mg/g dry wt.) was noticed in the leaf tissue at 800 mM NaCl, on the 180th day samples. It was 151.81% higher when compared to that of control plants. The F values calculated for difference between the sampling days and between the treatments were significant at 1% level.

Table 1. Effect of NaCl on the sodium content of leaves, stem and root of *Lumnitzera racemosa* (mg/g dry weight).

NaCl (mM)	Days after NaCl treatment								
	60	120	180	60	120	180	60	120	180
	Leaves			Stem			Root		
0	5.60	5.80	6.06	6.00	6.25	6.88	4.00	4.22	4.60
100	6.08 (+ 8.57)	7.12 (+ 22.75)	7.90 (+ 30.36)	7.25 (+ 208.33)	8.00 (+ 28.00)	8.73 (+ 26.88)	4.27 (+ 6.75)	4.83 (+ 14.45)	5.07 (+ 10.21)
200	6.70 (+ 19.64)	8.18 (+ 41.03)	9.22 (+ 52.14)	7.80 (+ 30.00)	8.60 (+ 37.6)	9.20 (+ 33.72)	4.63(+ 15.75)	5.26 (+ 24.64)	5.81 (+ 26.30)
300	7.50 (+ 33.92)	9.00 (+ 55.17)	10.07 (+ 66.17)	8.55 (+ 42.5)	9.36 (+ 49.76)	10.65 (+ 54.79)	4.95 (+ 23.75)	5.62 (+ 33.17)	6.03 (+ 31.08)
400	8.30 (+ 48.21)	9.60 (+ 65.51)	11.26 (+ 85.80)	9.15 (+ 52.5)	10.27 (+ 64.32)	11.40 (+ 65.69)	5.20 (+ 30.00)	5.89 (+ 39.57)	6.37 (+ 38.47)
500	8.62 (+ 53.92)	9.88 (+ 70.34)	11.60 (+ 91.41)	9.58 (+ 59.66)	10.50 (+ 68.00)	11.60 (+ 68.60)	5.44 (+ 36.00)	6.06 (+ 43.60)	7.00 (+ 52.17)
600	9.35 (+ 66.96)	10.47 (+ 80.5)	12.19 (+ 101.15)	11.00 (+ 83.33)	11.94 (+ 91.04)	12.78 (+ 85.75)	6.00 (+ 50.00)	7.04 (+ 66.82)	7.75 (+ 68.47)
700	9.75 (+ 74.10)	10.85 (+ 87.1)	12.32 (+ 103.30)	11.45 (+ 90.83)	12.06 (+ 92.96)	12.85 (+ 86.77)	6.17 (+ 54.25)	7.38 (+ 74.88)	7.90 (+ 71.73)
800	10.25 (+ 83.3)	11.03 (+ 90.1)	12.57 (+ 107.42)	12.00 (+ 100.0)	12.34 (+ 97.44)	13.12 (+ 90.69)	6.35 (+ 58.75)	7.55 (+ 78.90)	8.15 (+ 77.17)
	Leaves : F1 = 61.1996*	F2 = 71.2991*		Stem : F1 = 217.9488*		F2 = 98.4872*	Root: F1 = 57.8678*		F2 = 60.07971*

Table 2. Effect of NaCl on the total nitrogen content of leaves, stem and root of *Lumnitzera racemosa* (% dry weight)

NaCl (mM)	Days after NaCl treatment								
	60	120	180	60	120	180	60	120	180
	Leaves			Stem			Root		
0	1.78	2.40	2.85	1.35	2.00	2.21	1.08	1.40	1.68
100	1.86 (+ 4.49)	2.80 (+ 16.66)	3.14 (+ 10.17)	1.77 (+ 31.11)	2.42 (+ 21.00)	2.69 (+ 21.71)	1.38 (+ 27.77)	1.88 (+ 34.28)	2.25 (+ 33.92)
200	1.98 (+ 11.23)	3.05 (+ 27.08)	3.30 (+ 15.78)	1.85 (+ 37.03)	2.64 (+ 32.00)	2.88 (+ 30.31)	1.46 (+ 35.18)	2.07 (+ 47.85)	2.60 (+ 54.76)
300	2.15 (+ 20.78)	3.46 (+ 44.17)	3.84 (+ 34.73)	2.08 (+ 54.07)	2.97 (+ 48.5)	3.20 (+ 44.89)	1.90 (+ 75.92)	2.45 (+ 75.00)	3.00 (+ 78.57)
400	2.35 (+ 32.02)	3.90 (+ 62.5)	4.17 (+ 46.31)	2.19 (+ 62.22)	3.12 (+ 56.00)	3.58 (+ 61.99)	2.08 (+ 92.59)	2.80 (+ 100.00)	3.30 (+ 96.42)
500	2.65 (+ 48.87)	4.16 (+ 73.33)	4.88 (+ 71.22)	2.40 (+ 77.77)	3.66 (+ 83.00)	3.96 (+ 79.18)	2.17(+ 100.92)	2.98 (+ 112.85)	3.65 (+ 117.26)
600	2.10 (+ 17.97)	3.80 (+ 58.33)	4.00 (+ 40.35)	2.00 (+ 48.14)	2.82 (+ 41.00)	3.20 (+ 44.79)	1.76 (+ 62.96)	2.25 (+ 60.71)	2.60 (+ 54.76)
700	1.80 (+ 1.12)	2.67 (+ 11.25	3.06 (+ 7.36)	1.57 (+ 16.29)	2.30 (+ 15.00)	2.54 (+ 14.93)	1.20 (+ 11.11)	1.80 (+ 28.57)	2.10(+ 25.00)
800	1.61 (- 9.55)	2.28 (- 5.00)	2.52 (- 11.57)	1.27 (- 5.92)	1.65 (- 17.5)	1.83 (- 17.19)	1.00 (- 7.40)	1.25 (- 10.71)	1.50 (- 10.71)
	Leaves : F1 = 16.3859* F2 = 89.2417*			Stem : F1 = 35.6110* F2 = 108.0807*			Root : F1 = 40.8547* F2 = 85.2542*		

Table 3. Effect of NaCl on the phosphorus content of leaves, stem and root of *Lumnitzera racemosa* (mg/g dry weight)

Concentration of NaCl (mM)	Days after NaCl treatment								
	60	120	180	60	120	180	60	120	180
	Leaves			Stem			Root		
Control	1.35	2.36	2.70	1.25	1.80	2.10	0.96	1.37	1.55
100	1.62 (+ 20.00)	2.73 (+ 15.67)	3.06 (+ 13.33)	1.37 (+ 9.6)	2.15 (+ 19.44)	2.65 (+ 26.19)	1.30 (+ 35.41)	1.66 (+ 21.16)	1.87 (+ 20.64)
200	1.76 (+ 30.37)	3.00 (+ 27.11)	3.25 (+ 20.37)	1.58 (+ 26.4)	2.35 (+ 30.55)	2.70 (+ 28.57)	1.36 (+ 41.66)	1.80 (+ 31.38)	2.08 (+ 34.19)
300	1.98 (+ 46.67)	3.40 (+ 44.06)	3.75 (+ 38.88)	1.77 (+ 41.6)	2.73 (+ 51.66)	3.10 (+ 47.61)	1.75 (+ 82.29)	2.06 (+ 50.36)	2.26 (+ 45.80)
400	2.25 (+ 66.66)	3.70 (+ 56.77)	4.12 (+ 52.59)	2.08 (+ 66.4)	3.08 (+ 71.11)	3.35 (+ 59.52)	1.96 (+ 104.16)	2.35 (+ 71.53)	2.60 (+ 67.74)
500	2.60 (+ 92.59)	4.11 (+ 74.15)	4.76 (+ 76.29)	2.30 (+ 84.00)	3.55 (+ 97.22)	3.70 (+ 76.19)	2.06 (+ 114.58)	2.66 (+ 94.16)	3.00 (+ 93.54)
600	2.02 (+ 49.62)	3.46 (+ 46.61)	4.00 (+ 48.15)	1.80 (+ 44.00)	2.74 (+ 52.22)	3.05 (+ 45.23)	1.70 (+ 77.08)	2.05 (+ 49.63)	2.48 (+ 60.00)
700	1.50 (+ 11.12)	2.60 (+ 10.16)	2.90 (+ 7.40)	1.30 (+ 4.00)	2.10 (+ 16.66)	2.50 (+ 19.04)	1.15 (+ 19.79)	1.44 (+ 5.10)	1.66 (+ 7.09)
800	1.32 (- 2.22)	2.20 (- 6.77)	2.43 (- 10.00)	1.21 (- 3.2)	1.65 (- 8.33)	1.62 (- 22.85)	0.85 (- 11.45)	1.30 (- 5.10)	1.45 (- 6.45)
	Leaves: F1 = 35.9823*	F2 = 207.0215*		Stem: F1 = 29.4421*		F2 = 102.5559*	Root: F1 = 111.426*		F2 = 161.9881*

Table 4. Effect of NaCl on the potassium content of leaves, stem and root of *Lumnitzera racemosa* (mg/g dry weight).

Concentration of NaCl (mM)	Days after NaCl treatment								
	60	120	180	60	120	180	60	120	180
	Leaves			Stem			Root		
Control	4.25	4.60	5.61	4.00	4.27	5.10	3.66	4.18	4.65
100	4.60 (+ 8.23)	5.86 (+ 27.39)	6.92 (+ 23.35)	4.43 (+ 10.75)	5.20 (+ 21.77)	6.44 (+ 26.27)	4.00 (+ 9.28)	4.62 (+ 10.52)	5.63 (+ 21.07)
200	5.70 (+ 34.11)	6.38 (+ 38.69)	8.11 (+ 44.56)	4.69 (+ 17.25)	5.83 (+ 36.53)	6.70 (+ 31.37)	4.63 (+ 26.50)	5.01 (+ 19.85)	5.92 (+ 27.31)
300	5.88 (+ 38.35)	7.00 (+ 52.17)	8.76 (+ 56.14)	5.72 (+ 43.00)	6.87 (+ 60.88)	7.35 (+ 44.11)	4.98 (+ 36.06)	5.58 (+ 33.49)	6.40 (+ 37.63)
400	6.60 (+ 55.29)	7.72 (+ 67.82)	9.50 (+ 71.12)	6.20 (+ 55.00)	7.00 (+ 63.93)	8.60 (+ 68.62)	5.38 (+ 46.99)	6.00 (+ 43.54)	6.88 (+ 47.95)
500	7.80 (+ 83.52)	8.30 (+ 80.43)	9.67 (+ 69.34)	6.55 (+ 63.75)	7.76 (+ 81.73)	8.89 (+ 74.31)	5.72 (+ 56.28)	6.57 (+ 57.17)	7.19 (+ 54.62)
600	6.42 (+ 51.05)	7.02 (+ 52.60)	8.90 (+ 58.64)	5.92 (+ 48.00)	6.60 (+ 54.56)	7.22 (+ 41.56)	5.00 (+ 36.61)	5.32 (+ 27.27)	6.24 (+ 34.19)
700	4.32 (+ 1.64)	5.48 (+ 19.13)	6.35 (+ 13.19)	4.35 (+ 8.75)	4.80 (+ 12.41)	5.97 (+ 17.05)	3.83 (+ 4.64)	4.45 (+ 6.45)	5.44 (+ 16.99)
800	4.05 (- 4.70)	4.27 (- 7.17)	4.62 (- 17.64)	3.80 (-5.00)	4.25 (- 2.81)	4.90 (- 3.92)	3.50 (- 4.37)	4.06 (- 2.87)	4.35 (- 6.45)
	Leaves : F1 = 39.2644* F2 = 61.0435*			Stem: F1 = 54.2969* F2 = 81.6248*			Root: F1 = 83.8087* F2= 151.8646*		

Table 5. Effect of NaCl on the Calcium content of leaves, stem and root of *Lumnitzera racemosa* (mg/g dry weight).

Concentration of NaCl (mM)	Days after NaCl treatment								
	60	120	180	60	120	180	60	120	180
	Leaves			Stem			Root		
Control	3.50	3.85	4.30	3.22	3.60	4.12	2.85	2.98	3.27
100	4.80 (+ 37.14)	5.50 (+ 42.85)	6.35 (+ 47.67)	3.70 (+ 14.90)	4.80 (+ 33.33)	5.96 (+ 44.66)	3.30 (+ 15.79)	3.80 (+ 27.51)	4.20 (+ 28.44)
200	5.40 (+ 54.28)	6.00 (+ 55.84)	7.30 (+ 69.76)	4.00 (+ 24.22)	5.67 (+ 57.5)	6.47 (+ 57.03)	3.64 (+ 27.71)	3.95 (+ 32.55)	4.66 (+ 42.50)
300	5.80 (+ 65.71)	6.60 (+ 71.42)	8.55 (+ 98.83)	5.35 (+ 66.14)	6.13 (+ 70.28)	7.07 (+ 71.60)	4.08 (+ 43.15)	4.56 (+ 53.02)	4.98 (+ 52.29)
400	6.08 (+ 73.71)	7.45 (+ 93.50)	9.14 (+ 112.55)	6.00 (+ 86.33)	6.73 (+ 86.94)	8.00 (+ 94.17)	4.62 (+ 62.10)	4.95 (+ 66.10)	5.34 (+ 63.30)
500	7.30 (+ 108.57)	8.00 (+ 10.77)	9.60 (+ 123.25)	6.40 (+ 98.75)	7.50 (+ 108.33)	8.60 (+ 108.73)	5.00 (+ 75.43)	5.69 (+ 90.93)	6.07 (+ 85.62)
600	6.00 (+ 71.42)	6.95 (+ 80.51)	8.20 (+ 90.69)	5.02 (+ 55.90)	6.00 (+ 66.67)	7.00 (+ 69.90)	4.28 (+ 50.17)	4.65 (+ 56.04)	5.26 (+ 60.85)
700	4.08 (+ 16.57)	4.67 (+ 21.29)	6.23 (+ 44.88)	3.50 (+ 8.69)	4.55 (+ 26.38)	5.65 (+ 37.13)	3.20 (+ 12.28)	3.60 (+ 20.80)	4.17 (+ 27.52)
800	3.00 (- 14.28)	3.60 (- 6.49)	4.00 (- 6.97)	3.05 (- 5.27)	3.40 (- 5.55)	3.64 (- 11.65)	2.80 (- 1.75)	2.88 (- 3.35)	3.08 (- 5.81)
	Leaves : F1 = 51.4273* F2 = 56.4038*			Stem: F1 = 52.1084* F2 = 64.1824*			Root: F1 = 103.5087* F2 = 63.5370*		

DISCUSSION

Sodium

Sodium chloride salinity increased the sodium content and the increase was more in the stem than in the leaf and root tissues, with increasing salt concentrations upto 800 mM in all the sampling days. Increased availability of sodium in the soil stimulated increased uptake of sodium by the seedlings. The results on the sodium content of *Lumnitzera racemosa* agree with the earlier studies on other accumulating halophytes such as *Atriplex calotheca* and *A. littoralis* [17], *Suaeda nudiflora* [18], *Excoecaria agallocha* [19] and in *Sesuvium portulacastrum* [20]. Accumulation of Na+ and Cl– in the shoots of *Sporobolus virginicus* was limit under high salinity due to excess of these ions required for osmotic adjustment [21].

Total nitrogen

The nitrogen content of the leaves, stem and root of *L. racemosa* increased with increasing sodium chloride concentrations upto 500 mM. The leaves had more nitrogen than the stem and root tissues. The increase in the nitrogen content could be attributed to the efficient use of nitrogen taken up by the plant, when salinity was in optimum. Sodium ions could not have influenced the uptake of nitrate ions as they are differing in their charges.

The significant increase in root and shoot nitrogen with an increase in salinity and nitrogen in the substrate suggests that the capacity for production of proline may be limited by nitrogen availability, especially in reduced substrates such as salt marshes [22]. The decrease in nitrogen content at higher salinity levels could be due to the Cl^- limiting influx of nitrate ions.

Table 6. Effect of NaCl on the magnesium content of leaves, stem and root of Lumnitzera racemosa (%/g dry weight)

Concentration of NaCl (mM)	Days after NaCl treatment								
	60	120	180	60	120	180	60	120	180
	Leaves			Stem			Root		
Control	0.60	0.75	0.97	0.46	0.68	0.75	0.40	0.60	0.72
100	0.68 (+ 13.33)	0.99 (+ 32.00)	1.16 (+ 19.58)	0.52 (+ 13.04)	0.85 (+ 25.00)	1.11 (+ 48.00)	0.48 (+ 20.00)	0.66 (+ 10.00)	1.07 (+ 48.61)
200	0.78 (+ 30.00)	1.25 (+ 66.66)	1.44 (+ 48.45)	0.65 (+ 41.30)	1.10 (+ 61.76)	1.30 (+ 73.33)	0.59 (+ 47.5)	0.85 (+ 41.66)	1.29 (+ 79.16)
300	0.90 (+ 50.00)	1.39 (+ 85.33)	1.85 (+ 90.72)	0.80 (+ 73.91)	1.28 (+ 88.23)	1.65 (+ 120.00)	0.74 (+ 85.00)	0.99 (+ 65.00)	1.41 (+ 95.83)
400	1.05 (+ 75.00)	1.55 (+ 106.66)	2.18 (+ 124.74)	0.98 (+ 113.04)	1.45 (+ 113.23)	1.90 (+ 153.33)	0.90 (+ 125.00)	1.20 (+ 100.00)	1.77 (+ 145.83)
500	1.30 (+ 11.66)	1.70 (+ 126.66)	2.60 (+ 168.04)	1.17 (+ 154.34)	1.58 (+ 132.35)	2.18 (+ 190.67)	1.02 (+ 155.00)	1.47 (+ 145.00)	1.85 (+ 156.94)
600	0.90 (+ 50.00)	1.50 (+ 100.00)	2.01 (+ 107.21)	0.82 (+ 78.26)	1.30 (+ 91.17)	1.84 (+ 145.33)	0.65 (+ 62.5)	0.98 (+ 63.33)	1.58 (+ 119.44)
700	0.65 (+ 8.33)	0.90 (+ 20.00)	1.08 (+ 11.34)	0.50 (+ 8.69)	0.79 (+ 16.17)	0.92 (+ 22.66)	0.45 (+ 12.5)	0.60 (+ 0.00)	0.86 (+ 19.44)
800	0.52 (- 13.33)	0.70 (- 6.66)	0.85 (- 12.37)	0.40 (- 13.04)	0.55 (- 19.11)	0.60 (- 20.00)	0.37 (- 7.5)	0.49 (- 18.33)	0.66 (- 8.33)

Leaves : $F1 = 13.0983^*$ $F2 = 33.3555^*$ Stem : $F1 = 19.1109^*$ $F2 = 41.0064^*$ Root: $F1 = 20.4380^*$ $F2 = 56.3232^*$

Table 7. Effect of NaCl on the chloride content of leaves, stem and root of *Lumnitzera racemosa* (mg/g dry weight)

Concentration of NaCl (mM)	Days after NaCl treatment								
	60	120	180	60	120	180	60	120	180
	Leaves			Stem			Root		
Control	7.20	8.50	9.65	6.05	7.80	8.32	5.00	5.60	6.15
100	9.35 (+ 29.86)	11.25 (+ 32.35)	13.00 (+ 34.72)	7.82 (+ 29.26)	9.36 (+ 20.00)	12.25 (+ 47.24)	6.30 (+ 26.00)	7.98 (+ 42.5)	9.28 (+ 50.89)
200	10.62 (+ 47.5)	12.13 (+ 42.70)	15.27 (+ 58.24)	8.95 (+ 47.93)	10.27 (+ 31.67)	13.93 (+ 67.43)	7.80 (+ 56.00)	9.22 (+ 64.64)	11.34 (+ 84.39)
300	12.05 (+ 67.36)	13.06 (+ 53.65)	17.10 (+ 77.20)	10.64 (+ 75.87)	12.66 (+ 62.31)	15.26 (+ 83.41)	8.28 (+ 65.6)	10.66 (+ 90.36)	12.55 (+ 104.07)
400	13.90 (+ 93.06)	15.80 (+ 85.88)	18.90 (+ 95.85)	12.32 (+ 103.64)	13.30 (+ 70.51)	17.00 (+ 104.33)	10.57 (+ 111.4)	12.00 (+ 114.29)	14.20 (+ 130.89)
500	15.08 (+ 109.44)	16.38 (+ 92.70)	20.34 (+ 110.78)	13.95 (+ 130.58)	15.20 (+ 94.87)	19.05 (+ 128.97)	11.35 (+ 127.00)	14.35 (+ 156.25)	16.68 (+ 171.22)
600	16.20 (+ 125.00)	18.23 (+ 114.47)	21.09 (+ 118.55)	14.87 (+ 145.79)	16.28 (+ 108.72)	20.33 (+ 144.35)	11.95 (+ 139.00)	15.25 (+ 172.32)	17.08 (+ 177.72)
700	17.50 (+ 143.06)	20.15 (+ 137.06)	23.05 (+ 138.86)	16.00 (+ 164.46)	18.09 (+ 131.92)	21.65 (+ 160.22)	12.26 (+ 145.2)	16.30 (+ 191.07)	18.30 (+ 197.56)
800	19.03 (+ 164.31)	21.80 (+ 156.47)	24.30 (+ 151.81)	17.67 (+ 192.07)	19.22 (+ 146.41)	22.60 (+ 171.63)	13.67 (+ 173.4)	17.06 (+ 204.64)	19.20 (+ 212.20)

Leaves: $F1 = 152.9102^*$ $F2 = 127.1082^*$ Stem : $F1 = 139.1885^*$ $F2 = 135.2564^*$ Root : $F1 = 64.3249^*$ $F2 = 59.5143^*$

Phosphorus

The phosphorus content was increased with increasing NaCl salinity upto the optimum level. At higher concentrations, the level of phosphorus was decreased. Phosphorus plays a key role in energy metabolism requirements as it takes part in the formation of ADP, NAD and NADP which plays key roles in photosynthesis [23].

The results on the phosphorus content in the present study in *L. racemosa* agree with the previously studied halophytes such as *Kandelia candel* [24], *Acanthus ilicifolius* [25] and *Saintpaulia ionantha* [26]. Salinity caused an increase in both acid and alkaline phosphotase (ALP) activity with a significant decrease in phosphate level in *Bruguiera parviflora* [27].

Potassium

The potassium content of the leaf, stem and root increased with increasing concentration of sodium chloride upto optimum level of 500 mM. Potassium is an essential macronutrient. Increased sodium chloride salinity increased the potassium content in the tissues of several halophytes; *Suaeda nudiflroa* [28] and in *Excoecaria agallocha* [19]. Potassium content has been reported to decline at higher NaCl salinity level in *Suaeda maritima* [29] and in *Atriplex prostrata* [30].

The K^+ contents of leaf and stem tissues remained constant with moderate salinity and the K+ levels of the roots were unaffected by 100 mol m^{-3} NaCl for *Atriplex spongiosa* [31]. Shoots of *Sporobolus virginicus* maintained relatively constant K+ concentrations with increasing salinity [21].

Calcium

Sodium chloride salinity stimulated the calcium accumulation upto the optimum level of 500 mM. At higher concentrations, calcium content was inhibited in *L. racemosa*. The accumulation of Ca^{2+} is considered to produce protective effects on salt stress and sodium toxicity [32].

Bhivare and Nimbalkar [33] reported that the Ca^{2+} increased in the leaves and decreased in roots with increasing salinity in French beans. While the Ca^{2+} content of stem was favored by NaCl, and Na_2SO4 adversely affected it. The similar trends have been reported in *Atriplex prostrata* [30]. Calcium concentration was extremely low in shoots of *Kochia scoparia* [34] plants growing at high salinity this agreed with the results found for *Kandelia candel* [35].

Magnesium

There was a steady increase in the magnesium content of the plant tissues of *L. racemosa* with increasing sodium chloride salinity upto the optimum level of 500 mM. The magnesium is an essential plant nutrient in leaves and roots and is taken up as a cation. It is needed by all green plants as a constituent of chlorophyll, the only mineral constituent of chlorophyll molecule and as a co-factor for several enzymes and is beneficial to various biochemical processes.

Magnesium ion uptake is also interfered by large quantities of potassium ions or calcium ion, because of ion antagonism. Magnesium together with calcium is believed or is suggested to confer the tolerance to salinity [36]. Magnesium concentration was increased by sodium chloride salinity, and when supplemented with Ca^{2+}, the magnesium content was reduced in Citrus cells [37] and in Barley [38]. Salinity had little effect on the accumulation of magnesium. At higher salinity level, magnesium ions decreased in *Salicornia bigelovii* [39]. The results of the present study agree with other halophytes [40] and in *Salicornia rubra* [41].

Chloride

The chloride content was increased with increasing NaCl concentration upto 800 mM. The leaf tissue had more chloride content when compared to those of stem and root. Chloride is viewed as physiologically a neutral anion and it is tolerated over a wide range of concentrations [36].

Chloride uptake is believed to be an active process, since there was a lower electrical potential of the cytoplasm than outside the cells [37]. Chloride was taken up by the roots of halophytes in non-equivalent quantities. Chlorides differ also in the patterns of their distribution within the plant organs.

The increase in the chloride content with increased NaCl treatment in the present study was in conformity with the results of several other halophytes such as *Excoecaria agallocha* [19].

CONCLUSION

Accumulation of sodium and chloride ions increased in their tissues upto 800 mM NaCl salinity. Mineral constituents such as nitrogen, phosphorus, potassium, calcium and magnesium were increased upto the optimum concentration.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

REFERENCES

1. Haggag WM, Abouziena HF, Abd-El-Kreem F, Habbasha E. Agriculture biotechnology for management of multiple biotic and abiotic environmental stress in crops. J Chem Pharm Res. 2015;7(10):882–9.
2. Pitman MG, Läuchli A. Global impact of salinity and agricultural ecosystems. In: Salinity: Environment - Plants - Molecules. Dordrecht: Kluwer Academic Publishers; 2006. p. 3–20.
3. Shrivastava P, Kumar R. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi J Biol Sci. 2015;22(2):123–31 http://dx.doi.org/10.1016/j.sjbs.2014.12.001
4. Netondo GW, Onyango JC, Beck E. Sorghum and salinity: I. Response of growth, water relations, and ion accumulation to NaCl salinity. Crop science. 2004;44:797–805.
5. Grigore MN, Toma C, Boscaiu M. Dealing with halophytes: an old problem, the same continuous exciting challenge. Analele Stiintifice ale Universitatii. Alexandru Ioan Cuza" din Iasi Biologie Vegetala. 2010;56(1):21–32.
6. de Oliveira AB, Mendes Alencar NL, Gomes-Filho E. Comparison between the water and salt stress effects on plant growth and development. In: Responses of Organisms to Water Stress. InTech; 2013.
7. Clarke LD, Hannon NJ. The mangrove swamp and salt marsh communities of the Sydney district: III. Plant growth in relation to salinity and waterlogging. J Ecol. 1970;58(2):351. http://dx.doi.org/10.2307/2258276
8. El-Gawad A, El-Amier AM. Anatomical features of three perennial swampy plants of Poaceae, grown on the water stream banks in Nile Delta. Egypt. J Med Bot. 2017;1:58–64. http://dx.doi.org/10.25081/jmb.2017.v1.863
9. Chapman VJ. Salt marshes and salt deserts of the world. In: Reimold RJ, Queen WH, editors. Ecology of Halophytes. Academic Press, Inc. New York; 1974. p. 3–19.
10. Kjerfve B. Manual for investigation of hydrological processes in mangrove ecosystems. 1990.
11. Jackson ML. Soil chemical analysis. Englewood Cliffs, New Jersey: Prentice Hall Inc; 1958.
12. Yoshida S, Forno DA, Cock J, Gomez KA. Laboratory manual for physiological studies of rice. IRRI, Philippines; 1972.
13. Williams CH. Modern Methods of Plant Analysis. Peach K, Tracey MV, editors. Berlin: Springer-Verlag; 1960.
14. Black CA. Method for soil analysis, Part- 2, Chemical and microbiological properties. Madison, Winconcin: American Society of Agronomy, Inc; 1965.
15. Krishnamurthy R, Bhagwat KA. A rapid and simplified method for determination of chloride in plant material. Indian J Exp Biol. 1990;28(2):198–200.
16. Gomez KA, Gomez AA. Statistical procedures for agricultural research with emphasis on rice. Statistical procedures for agricultural research with emphasis on rice. 1976.
17. Freitas H, Breckle SW. Accumulation of nitrate in bladder hairs of *Atriplex* species. Plant Physiol Biochem. 1993;31:887–92.
18. Shekhawat VPS, Kumar A, Neumann KH. Effect of sodium chloride salinity on growth and ion accumulation in some halophytes. Commun Soil Sci Plant Anal. 2006;37(13–14):1933–46. http://dx.doi.org/10.1080/00103620600767165

19. Natarajan S, Venkatesan A. Effect of salinity on growth and mineral constituents of *Excoecaria agallocha* L. J Theor Exp Biol. 2006;2(3 & 4):111–7.
20. Slama I, Ghnaya T, Messedi D, Hessini K, Labidi N, Savoure A, et al. Effect of sodium chloride on the response of the halophyte species *Sesuvium portulacastrum* grown in mannital-induced water stress. J Plant Res. 2007;120(2):291–9.
21. Marcum KB, Murdoch CL. Salt tolerance of the coastal salt marsh grass, *Sporobolus virginicus* (L.) kunth. New Phytol. 1992;120(2):281–8. http://dx.doi.org/10.1111/j.1469-8137.1992.tb05665.x
22. Valiela I, Teal JM. Nutrient limitation in salt marsh vegetation. In: Reimold RJ, Queen WH, editors. Ecology of Halophytes. New York: Academic Press; 1974. p. 547–63.
23. Joshi GV, Sontakke S, Bhosale L, Waghmode AP. Photosynthesis and photorespiration in mangroves. Teas HJ, editor. The Hague: W. Jank Publishers; 1984.
24. Chen MJ. Study on the relationship between mineral nutrients and the growth of *Kandelia candel* (L.) Druce in chuwei mangroves swamp. Hualien, Taiwan; 1998.
25. Ravindran KC, Venkatesan A, Ranganathan R, Eswaran K. Salinity induced changes in growth and mineral constituents of *Acanthus ilicifolius* L. A halophyte. J Ind Bot Soc. 1999;78:127–31.
26. Rida AS, Sawwan J, Swaidat I, Tahat M. Increased phosphorus (P) Mitigates the adverse effects of salinity in tissue culture. Soil Sci Pl Anal Agr. 2001;32:429–40.
27. Parida A, Das AB. Effects of NaCl stress on nitrogen and phosphorus metabolism in a true mangrove *Bruguiera parviflora* grown under hyroponic culture. J Plant Physiol. 2004;161:921–8.
28. Joshi AJ, Iyengar ERR. Salinity effect on seed germination of *Suaeda nudiflora* Moq. J Ind Bot Soc. 1985;64:362–4.
29. Clipson NJW. Salt tolerance in the halophyte *Suaeda maritima* L. Dum. growth, ion and water relations and gas exchange in response to altered salinity. J Exp Bot. 1987;38:1996–2004.
30. Wang L-W, Allan M, Showalter M, Ungar IA. Effect of salinity on growth, iron content and cell wall chemistry in *Atriplex prostrata* (Chenopodiaceae). Am J Bot. 1997;84:1247–55.
31. Storey R, Jones RG. Responses of *Atriplex spongiosa* and *Suaeda monoica* to Salinity. Plant Physiol. 1979;63(1):156–62. http://dx.doi.org/10.1104/pp.63.1.156
32. Bressan RA, Hasegawa PM, Pardo JM. Plants use calcium to resolve salt stress. Trends Plant Sci. 1998;3(11):411–2. http://dx.doi.org/10.1016/s1360-1385(98)01331-4
33. Bhivare VN, Nimbalkar JD. Salt stress effects on growth and mineral nutrition of French beans. Plant Soil. 1984;80(1):91–8. http://dx.doi.org/10.1007/bf02232942
34. Khan A, Gul B, Webber DJ. Effect of salinity and temperature on the germination of *Kochia scoparia*. Wetlands Ecol Manage. 2001;9:483–9.
35. Hwang YH, Chen SC. Effects of ammonium, phosphate and salinity on growth, gas exchange characteristics and ionic contents of seedlings of mangrove *Kandelia candel* (L.) Druce. Bot Bull Acad Sinica. 2001;42:131–9.
36. Clarkson DT, Hanson JB. The mineral nutrition of higher plants. Annu Rev Plant Physiol. 1980;31(1):239–98. http://dx.doi.org/10.1146/annurev.pp.31.060180.001323
37. Ben-Hayyim G, Kafkafi U, Ganmore-Neumann R. Role of internal potassium in maintaining growth of cultured citrus cells on increasing NaCl and $CaCl_2$ concentrations. Plant Physiol. 1987;85(2):434–9. http://dx.doi.org/10.1104/pp.85.2.434
38. Cramer GR, Epstein E, Lauchli A. Effects of sodium, potassium and calcium on salt-stressed barley. II. Elemental analysis. Physiol Plant. 1991;81(2):197–202. http://dx.doi.org/10.1111/j.1399-3054.1991.tb02129.x
39. Ayala F, O'Leary JW. Growth and Physiology of Salicornia bigelovii Torr. at Suboptimal Salinity. Int J Plant Sci. 1995;156(2):197–205. http://dx.doi.org/10.1086/297241
40. Naidoo G, Rughunanan R. Salt tolerance in the succulent coastal halophyte *Sarcocornia natalensis*. J Exp Bot. 1990;41:497–502.
41. Khan MA, Gul B, Weber DJ. Germination responses of *Salicornia rubra* to temperature and salinity. J Arid Env. 2000;45(3):207–14.