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Experimental assessment of salinity tolerance of *Ceriops tagal* seedlings and saplings from the Indus delta, Pakistan

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Abstract

Propagules of *Ceriops tagal* (*C. tagal*) collected from the Indus delta were grown in pots containing sandy soil sub-irrigated with 0, 25, 50, 75 and 100% seawater fortified with nitrogen. Seedlings were experimentally grown for 6 months and saplings for 12 months. Maximum growth was observed in 50% seawater and declined with increasing salinity. Water relations data showed that this species progressively adjusted its internal water potential in response to change in external water potential, i.e. responded as an osmoconformer. *C. tagal* is also a non-secretor and accumulated a larger quantity of sodium and chloride ions while availability of other ions were severely restricted. Our result suggests that *C. tagal* is almost as salt tolerant as *Avicennia marina* but would not be able to tolerate a sudden major shift in salinity. This species could, thus, probably be used to rehabilitate inter-tidal areas, which receive a regular supply of fresh water.

Keywords: Indus delta; Inter-tidal zone; Ions; Mangrove; Salinity; Water potential; Wetlands

1. Introduction

Mangrove vegetation is found in tropical and sub-tropical marine inter-tidal zones (Duke, 1992) and is dominated by halophytic woody species (Suarez et al., 1998). A large variation in spatial, temporal and seasonal variation in salinity is characteristic of mangrove habitats, particularly in arid sub-tropical regions (Gordon, 1993). Dense mangrove forests are present along the entire coastal regions of the Sindh province (Pakistan), especially in the vicinity of the Indus delta. In contrast, Balochistan coast is barren except for few places like Miani Hor (Ansari, 1987). Detailed taxonomic and ecological surveys of the area have not

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been conducted, but, earlier investigations reported the presence of eight species: *Bruguiera conjugata*, *Ceriops tagal* (*C. tagal*), *C. roxburghiana*, *Rhizophora apiculata*, *Rhizophora mucronata* (*R. mucronata*), *Aegiceras corniculata*, *Avicennia marina* and *Sonneratia caseolaris* (Stewart, 1972). A more recent survey showed that *Avicennia marina* is the dominant species (98%) followed by few populations of (*R. mucronata*), *C. tagal*, and *A. corniculatum* (Qureshi, 1993) while other species could not be located. Mangrove populations in Pakistan are threatened because of over-exploitation, pollution, and a decline in fluvial discharge into the Indus delta (Ansari, 1987; IUCN, 1988; Qureshi, 1993). A decrease in fluvial discharge would result in increased salinity of seawater, which reportedly prevents fruiting, and causes senescence of immature flowers and buds (Qureshi, 1993). It is estimated that mangrove cover has decreased by 15% in past 20 years due to reduction in Indus discharge (IUCN, 1988).

Mangrove species often show growth stimulation at low salinity (25% seawater) and then a decline in growth with further increases in salinity (Clough, 1984; Downton, 1982; Naidoo, 1987; Burchett et al., 1989; Karim and Karim, 1993). They possess a variety of adaptations to extreme environmental stresses such as: (i) salt exclusion by root ultrafiltration (Hegemeyer, 1997), (ii) salt recretion via glands (Roth, 1992), (iii) Ion accumulation in leaf cells (Popp, 1994), and (iv) Leaf succulence (Roth, 1992). Whereas the most common species in the Indus delta, *Avicennia marina*, is fairly well studied and known to respond as osmoregulator (Aziz and Khan, 2000), the other more common species have received little attention (Tomlinson, 1986). The paper presents findings from pot experiments with *C. tagal* (Perr.) C.B. Rob. seedlings and saplings. We investigated whether (1) *C. tagal* growth would also be maximal at 25% seawater as in other species; (2) there would be a difference in growth and salinity tolerance of *C. tagal* at seedling and sapling stages, and (3) whether *C. tagal* would respond as osmoconformer or osmoregulator with increasing salinity.

2. Materials and methods

Propagules of *C. tagal* were collected during summer 1992 from the Indus delta populations near Karachi, Pakistan. These were immediately transferred to 36 cm diameter plastic pots filled with acid washed beach sand. The pots with the drainage were arranged in a randomized block design and five plants per treatment with five replicate pots each were used. Plants were grown to seedlings (6 months) and saplings (12 months) in an uncontrolled green house under natural temperature and light. Plants were irrigated with half strength Hoagland and Arnon solution no. 2 for 2 weeks through sub-irrigation. After 2 weeks of growth, plants were treated with five concentrations of seawater (0, 25, 50, 75, and 100%) fortified with nitrogen (Popp and Polania, 1989). Seawater dilutions were made by using salt obtained from drying of seawater. The concentration of seawater of the Arabian sea at Karachi, Pakistan is about 600 mM (58.2 dS m^{-1} or 35‰). Fresh tap water was added daily to correct for evaporation. The water in seawater treatments was completely replaced once a week to avoid built up of salinity in pots. At the initiation of the experiment, the seawater concentration of all treatments was gradually increased by 25% seawater at 2 days intervals (for 25% = 2 days; 50% = 4 days; 75% = 8 days; 100% = 8 days) to reach the maximum salinity levels of 100% seawater after 8 days (preliminary test showed that a 2 days gap was sufficient). Fresh and dry weight of plant shoots and roots, plant height, number of nodes, number of leaves, leaf area and diameter of stem at the first inter-node were measured twice at 6 month intervals (at both seedling and sapling stages) after the highest salt concentration was reached. Dry mass was determined after drying for 48 h in a forced-draft oven at 60°C.

The leaves selected from the first bottom node of the plant was designated as "old leaf" and those collected from the second node to the apex were termed "young leaf". Leaf water potential for old leaves and young leaves was measured with a Wescor HR33T Dew Point Microvoltmeter. Osmotic potential in both young and old leaves was then measured by freezing the leaf disk (5 mm diameter) in liquid nitrogen and using the same equipment. Xylem pressure potential of the stem was measured with a pressure bomb (Arimad-2, Wagtech International Limited, UK) on five shoots from each treatment. Stomatal conductance was measured using an A-4 porometer (Delta-T devices) on the adaxial surface of fully expanded young and old leaves.

For proline and ion measurements, 0.5 g of plant material was boiled in 10 ml of water for 2 h at 100°C using a dry heat bath. This hot water extract was cooled and filtered using Whatman no. 42 filter paper, and then used directly to measure proline according to Bates et al. (1973). The acid soluble, total and water soluble oxalates were measured according to Karimi and Ungar (1986). A volume of 1 ml of hot water extract was diluted with distilled water for ion analysis. Chloride ion content was measured with a Beckman specific ion electrode whereas cations of plant organs (Na^+ and K^+) were analyzed using a Perkin-Elmer model 360 atomic absorption spectrophotometer. Ca^{2+} and Mg^{2+} concentrations were assayed by flame emission atomic absorption spectrometer.

The results of growth, ion contents and water relations were analyzed using two way ANOVA and proline and oxalate contents with one way ANOVA. A Bonferroni-test was carried out to determine if significant ($P < 0.05$) differences occurred among individual treatments (SPSS, 1996).

3. Results

Seedlings and saplings of *C. tagal* had the highest biomass at 50% dilution of seawater, lower and higher dilutions resulted in less biomass (Tables 2 and 3). Compared to the effect of growth stage (seedlings versus saplings), salinity effects generally contributed substantially more to the explained variation (higher SS), although, both factors were significant (Table 1). This is confirmed by the observation that sampling has hardly increased their weight compared to seedling (Tables 2 and 3). Number of nodes and leaves in both seedlings and saplings did not change up to 50% seawater treatment but a significant ($P < 0.05$) decrease occurred with an increase in salinity (Tables 2 and 3). Stem diameter did not change up to 75% seawater and declined in the 100% salinity treatment (Tables 2 and 3). Leaf area was significantly ($P < 0.001$) higher at 50% seawater than in the other treatments (Tables 2 and 3).

Water potential in seedlings and saplings increased with an increase in salinity (Fig. 1A). There was no significant ($P < 0.05$) difference in water potentials between seedlings and saplings (Table 1). Water and osmotic potential in both seedlings and saplings was positively

Table 1
Two way ANOVAS of the effect of plant stage (seedling and sapling), salinity (0–100% seawater) on a number of plant response parameters[a]

Independent variable	Plant stage			Salinity			Interaction			Residual		Total	
	SS	d.f.	P	SS	d.f.	P	SS	d.f.	P	SS	d.f.	SS	d.f.
Fresh weight	0.73	1	00.05	41.20	8	0.001	0.18	8	0.01	0.92	40	43.60	49
Dry weight	0.06	1	00.01	37.60	8	0.001	0.04	8	0.001	0.53	40	39.30	49
Leaf area	21.2	1	0.001	44.30	8	0.001	0.32	8	0.001	0.45	40	48.20	49
Xylem tension	0.03	1	NS	00.95	8	0.001	0.13	8	00.01	0.35	40	154.6	49
Osmotic potential	0.61	1	00.01	40.23	8	0.001	0.02	8	NS	2.01	40	43.7	49
Water potential	0.0006	1	NS	40.42	8	0.001	0.15	8	NS	0.85	40	42.20	49
Stomatal conductance	1012	1	0.001	2109	8	0.001	264	8	0.001	407	40	37749	49

[a] Presented are the factors: residual and total sum of squares (SS), their degrees of freedom (d.f.) and levels of significance (*P*).

Table 2
Given are means ± S.E. ($n = 5$) of fresh weight, dry weight, plant height, number of nodes, stem diameter, number of leaves and leaf area after 6 months culture (seedlings) of *Ceriops tagal* in different seawater dilutions

Growth parameters	Seawater (%)				
	0	25	50	75	100
Fresh weight (g)	$35.0^{a} \pm 1.5$	$43.5^{b} \pm 0.98$	$63.0^{c} \pm 1.60$	$39.1^{ab} \pm 2.10$	$35.0^{a} \pm 0.98$
Dry weight (g)	$3.50^{a} \pm 0.12$	$4.20^{b} \pm 0.21$	$5.20^{c} \pm 0.09$	$3.20^{d} \pm 0.10$	$3.10^{d} \pm 0.09$
Plant height (cm)	$45.8^{b} \pm 1.2$	$43.5^{b} \pm 2.3$	$49.8^{c} \pm 2.8$	$39.1^{a} \pm 3.3$	$41.2^{a} \pm 1.2$
Number of nodes	$6.3^{b} \pm 0.9$	$6.0^{b} \pm 0.8$	$6.0^{b} \pm 1.2$	$4.0^{a} \pm 0.7$	$4.6^{a} \pm 0.6$
Stem diameter (cm)	$0.6^{a} \pm 0.03$	$0.6^{a} \pm 0.04$	$0.7^{b} \pm 0.03$	$0.6^{a} \pm 0.02$	$0.5^{b} \pm 0.02$
Number of leaves	$9.6^{b} \pm 1.2$	$9.3^{b} \pm 1.8$	$9.6^{b} \pm 2.9$	$7.6^{a} \pm 1.3$	$7.6^{a} \pm 1.7$
Leaf area per plant (cm^2)	$33.7^{b} \pm 0.9$	$30.7^{a} \pm 1.3$	$61.2^{c} \pm 1.62$	$29.5^{a} \pm 1.3$	$28.4^{a} \pm 0.7$

Mean values in rows for each parameter having the different letters are significantly different at $P < 0.05$ level by Bonferroni-test.

Table 3
Given are means ± S.E. ($n = 5$) of fresh weight, dry weight, plant height, number of nodes, stem diameter, number of leaves and leaf area after 12 months culture (saplings) of *Ceriops tagal* in different seawater dilutions

Growth parameters	Seawater (%)				
	0	25	50	75	100
Fresh weight (g)	$47.1^{a} \pm 2.30$	$44.8^{a} \pm 1.90$	$59.0^{b} \pm 0.96$	$42.9^{a} \pm 2.10$	$40.5^{a} \pm 1.53$
Dry weight (g)	$03.8^{a} \pm 0.30$	$04.3^{a} \pm 0.09$	$05.5^{b} \pm 0.14$	$03.4^{c} \pm 0.24$	$03.3^{c} \pm 0.14$
Plant height (cm)	$47.1^{b} \pm 1.2$	$44.8^{b} \pm 1.3$	$52.4^{c} \pm 2.8$	$42.9^{a} \pm 3.3$	$41.2^{a} \pm 1.2$
Number of nodes	$6.3^{b} \pm 0.9$	$6.0^{b} \pm 0.8$	$7.3^{c} \pm 1.2$	$5.0^{a} \pm 0.7$	$4.6^{a} \pm 0.6$
Stem diameter	$0.7^{b} \pm 0.03$	$0.7^{b} \pm 0.04$	$0.8^{c} \pm 0.03$	$0.6^{a} \pm 0.02$	$0.5^{a} \pm 0.02$
Number of leaves	$9.6^{b} \pm 1.3$	$9.3^{b} \pm 1.8$	$9.6^{b} \pm 2.9$	$8.0^{a} \pm 1.3$	$7.3^{a} \pm 1.7$
Leaf area per plant (cm^2)	$36.7^{b} \pm 0.9$	$39.8^{b} \pm 1.3$	$76.2^{c} \pm 1.62$	$32.5^{a} \pm 1.3$	$31.9^{a} \pm 0.7$

Mean values in rows for each parameter having the different letters are significantly different at $P < 0.05$ level by Bonferroni-test.

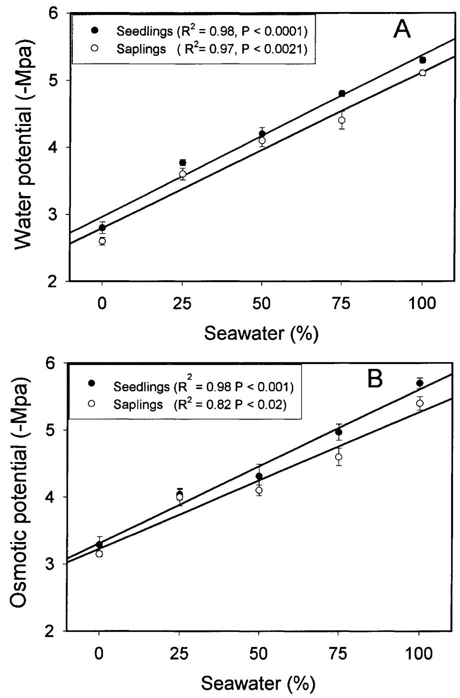

Fig. 1. Effect of NaCl (0, 25, 50, 75 and 100% seawater) on the (A) water potential and (B) osmotic potential of *Ceriops tagal* seedlings and saplings. A linear regression, means and standard errors are represented.

correlated with the concentration of seawater. Osmotic potential in seedlings and saplings became increasingly more negative ($P < 0.0001$) with increase in seawater concentration (Fig. 1B, Table 1). Stomatal conductance decreased significantly ($P < 0.001$) with increase in salinity (Fig. 2, Table 1). Stomatal conductance was significantly higher in older leaves and saplings. There was a negative relationship ($r = -0.96$) between stomatal conductance and salinity.

The xylem tension increased with the increase in salinity (Fig. 3, Table 1), however, xylem tension of seedlings was similar to that of saplings. There was a positive relationship ($r = -0.96$) between xylem tension and salinity.

Total concentrations of cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) and the anion (Cl^-) increased with increase in salinity (Table 4). At all seawater dilutions the increase in total inorganic ions resulted from increased Na^+ and Cl^-. Calcium, K^+, and Mg^{2+} concentration decreased with an increase in salinity.

In young leaves, proline concentration substantially increased at low salinity and peaked at 50% seawater a further increase in salinity had no affect on proline content (Fig. 4). Old leaves followed the same pattern but concentration of proline was significantly lower than young leaves (Fig. 4). All three types of oxalate production significantly ($P < 0.001$) decreased with an increase in seawater concentration (Fig. 5).

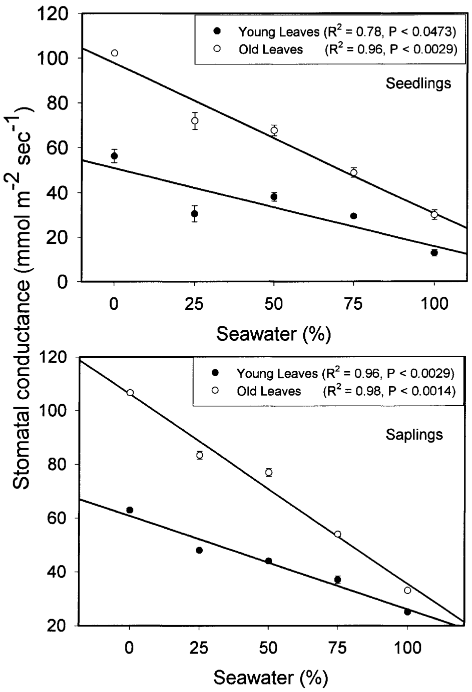

Fig. 2. Effect of NaCl (0, 25, 50, 75 and 100% seawater) on the stomatal conductance in *Ceriops tagal* seedlings and saplings. A linear regression, means and standard errors are represented.

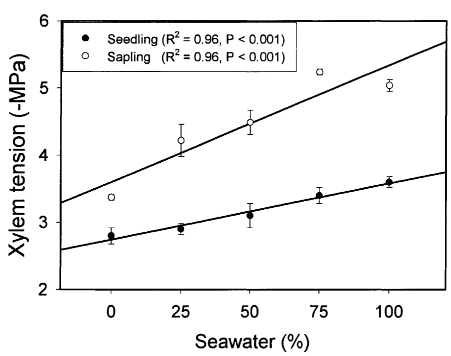

Fig. 3. Effect of NaCl (0, 25, 50, 75 and 100% seawater) on the xylem tension in *Ceriops tagal* seedlings and saplings. A linear regression, means and standard errors are represented.

Table 4
Ion concentration (μmol g^{-1} dry weight) in the *Ceriops tagal* saplings harvested 12 months after the highest salinity reached

Ions	Seawater (%)				
	0	25	50	75	100
Sodium	$284^{a} \pm 1.8$	$290^{a} \pm 4.5$	$323^{b} \pm 6.5$	$421^{c} \pm 9.8$	$848^{d} \pm 7.31$
Potassium	$84^{a} \pm 2.3$	$94^{a} \pm 9.8$	$70^{a} \pm 3.4$	$57^{c} \pm 2.1$	$37^{c} \pm 3.9$
Calcium	$63^{a} \pm 1.2$	$60^{a} \pm 3.2$	$75^{b} \pm 9.9$	$56^{c} \pm 3.3$	$44^{d} \pm 3.6$
Magnesium	$71^{a} \pm 3.4$	$85^{b} \pm 4.9$	$93^{b} \pm 10.5$	$60^{c} \pm 6.7$	$84^{d} \pm 8.7$
Chloride	$286^{a} \pm 9.8$	$270^{a} \pm 3.4$	$340^{b} \pm 6.5$	$466^{c} \pm 7.8$	$973^{d} \pm 6.9$

Values in each column having the same letter are not significantly different at $P < 0.05$, Bonferroni-test.

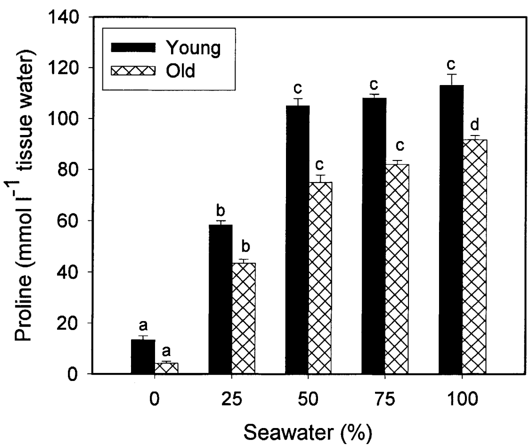

Fig. 4. Effect of NaCl (0, 25, 50, 75 and 100% seawater) on the proline content in *Ceriops tagal*. Bar represent means ± standard errors. Different letter above bars represent significant differences ($P < 0.05$) between treatments.

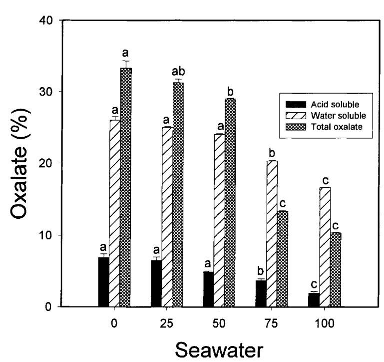

Fig. 5. Effect of NaCl (0, 25, 50, 75 and 100% seawater) on the oxalate content in *Ceriops tagal* plants. Bar represent means ± standard errors. Different letter above bars represent significant differences ($P < 0.05$) between treatments.

4. Discussion

Among the seawater treatments the greatest increase in most of the growth parameters was observed in plants irrigated with 50% seawater. These results do not agree with some other studies in which mangrove species showed their best growth at 25% seawater concentration (Burchett et al., 1989; Downton, 1982; Clough, 1984; Naidoo, 1987). However, Karim and Karim (1993) reported that best growth for *Avicennia marina* from Bangladeshi coast was obtained at 50% seawater. The coast of Karachi is regarded as one of the most arid coasts in the world and it may be that mangrove populations growing in this region have adapted to these condition by developing higher salt tolerance in comparison to the mangroves from more mesic regions in Australia and South Africa.

Osmoregulation is generally regarded as the most important adaptation against higher media salinity (Jefferies, 1980). Halophytes usually employ different mechanisms of salt tolerance. Some halophytes (e.g. *Salicornia europaea*) when exposed to salinity develop a more negative water and osmotic potential. Small perturbations in salinity have little effect on them (osmoregulators) (Karim, 1984). However, other halophytes like *Atriplex triangularis* progressively make their water and osmotic potential more negative with an increase in salinity (osmoconformers) (Karim, 1984; Khan et al., 1999 Khan et al., 2000a,b). *C. tagal* showed a progressive increase in tissue water and osmotic potentials with increase in salinity of the medium indicating that it follows an osmoconformer strategy to maintain its osmotic balance.

Salt tolerant species showed a low stomatal conductance and high water use efficiency under high drought and salinity stress (Sharma, 1977; Werner and Stelzer, 1990; Gordon, 1993). This low stomatal conductance decreases the rate of CO_2 accumulation and uptake, rate of transpiration and increase in xylem tension (Ball and Farquhar, 1984). *C. tagal* in this study also substantially reduced the stomatal conductance along with the increase in xylem tension.

The non-salt secreting species *C. tagal* had internal salt concentrations not much different from co-occurring *Avicennia marina* under hypersaline conditions (Gordon, 1993). The means by which non-secretors avoid salt damage may include efficient sequestering of ions to the vacuoles in the leaf (Stewart and Ahmed, 1983), translocation outside the leaf, possible cuticular transpiration (Tomlinson, 1986) and efficient leaf turnover to facilitate salt shedding. *C. tagal* is a salt tolerant mangrove with the competitive ability to grow in highly saline and poorly inundated locations (Ball, 1988; Gordon, 1993). High internal salt concentrations provide potential benefits to plants growing under conditions where soil osmotic potential is far lower than that of seawater on account of high soil salinity (Ungar, 1991) by contributing to the low internal potential required to permit water uptake. Our study showed that *C. tagal* maintained a high concentration of sodium and chloride, which increased with salinity.

Organic solutes, which cause a minimum amount of perturbation to macromolecular stability and cytoplasmic enzyme function, accumulate in eukaryotic cells as they adjust to low osmotic potentials (Stoery et al., 1977). *C. tagal* accumulates a lot of sodium and chloride ions and the amount of proline significantly increased with salinity, however, this increase is not sufficient to balance a large amount of salt present in vacuoles. Soluble oxalate concentrations decreased with increase in salinity, indicating no role in osmoregulation.

Popp and Albert (1995) reported that *C. tagal* accumulates cyclitols along with Na^{+} and Cl^{-} to maintain osmotic balance.

It appears from our data that if sufficient amounts of Indus river water are continuously mixed with seawater optimal conditions would prevail for the growth of *C. tagal*. The individuals of *C. tagal* accumulate a large amount of sodium and chloride to maintain osmotic balance in their tissues. *C. tagal* is a highly salt tolerant plant and could be grown at the sea front where it would receive diurnal inundation with little changes in soil salinity.

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