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Full Length Research Paper

Rate of salt excretion by salt excreting mangroves of sundarban under varying environmental conditions

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A study was conducted on six salt excretory species of mangrove plants (*Avicennia officinalis, A. alba, A. marina, Aegialitis rotundifolia, Acanthus ilicifolius, Aegiceras sp.*) for evaluating the their rate of salt ion (Na, K, Cl) excretion from leaves at various sites and times in Sundarban. A correlation was established in between the overall rate of excretion from the species studied and surface water salinity, showing insignificant values mostly, indicating to the soil salinity as the controlling factor for excretion. A relationship between Na and K excretion was also established with seasonal and temporal variations. Nature of chloride excretion was also studied. A detailed account of the excretion patterns for all the species individuals was also discussed in the current study.

Keywords: Mangrove, Salt excretion, Salt ions, Salinity, Temporal variation.

INTRODUCTION

Mangrove species continuously incorporate salts from substrate and transport them to the leaves in the transpiration stream (Ball, 1988). Salt uptake helps to maintain positive pressure potential through their contribution to osmotic adjustment of growing tissues (Downton, 1982; Suárez, 2005; 2006 and Sobrado, 2000). However, under high salinity conditions, the survival of the plant depends on its ability to regulate the internal salt concentrations and prevent ions from reaching toxic levels (Scholander et al., 1962; Atkinson et al., 1967; Ball, 1988). It has been shown that during water uptake, roots of some mangrove species exclude 80-95% of the salt in the soil solution (Scholander et al., 1962; Atkinson et al., 1967). In addition, plants may regulate shoot ion concentration and reduce salt concentration in leaf tissue by other means such as salt secretion through leaf glands, succulence, and relocation of salt to other organs (Scholander et al., 1962; Atkinson et al., 1967; Leshem and Levinson, 1972; Sobrado, 2001).

In various mangrove species, salt is secreted by salt glands in the leaves, and their activity seems to be associated with the salinity of the nutrient solution. Thus, salt secretion contributes to eliminate the excess of salt reaching the leaves (Drennan and Pammeter, 1982; Sobrado, 2001). The activity of salt glands is highly selective, secreting mostly NaCl and thus contributing to maintain a favorable K^+/Na^+ ratio in the leaf cells (Sobrado and Greaves, 2000). However, other ions such as K^+, Mg^{2+}, Ca^{2+} and SO_4^{2-} can be present in the secreted solution (Scholander et al., 1962; Atkinson et al., 1967; Boon and Allaway, 1986; Sobrado and Greaves, 2000). Thus, secretion regulates internal salt concentrations and contributes to build specific ionic ratios favorable for the maintenance of the metabolic activity of leaf cells. The quality and quantity of the salt taken up and secreted varies widely, depending on soil salinity and species (Albert and Popp, 1977). As in other mangrove species, in Avicennia spp., the leaf secretion rate increases with soil salinity.

In the numerous papers dealing with salt secretion in *Avicennia* species, several aspects have received contradictory reports: (i) succulence does not increase with salinity of the nutrient solution and has little significance for regulation of leaf salt concentrations (Tomlinson, 1986) or tends to increase, contributing with salt regulation (Suárez, 2005; Sobrado, 2001), or tends to decrease under hypersaline conditions (Sobrado, 2001); (ii) the rate of salt secretion increases with salinity (Ball, 1988) or tends

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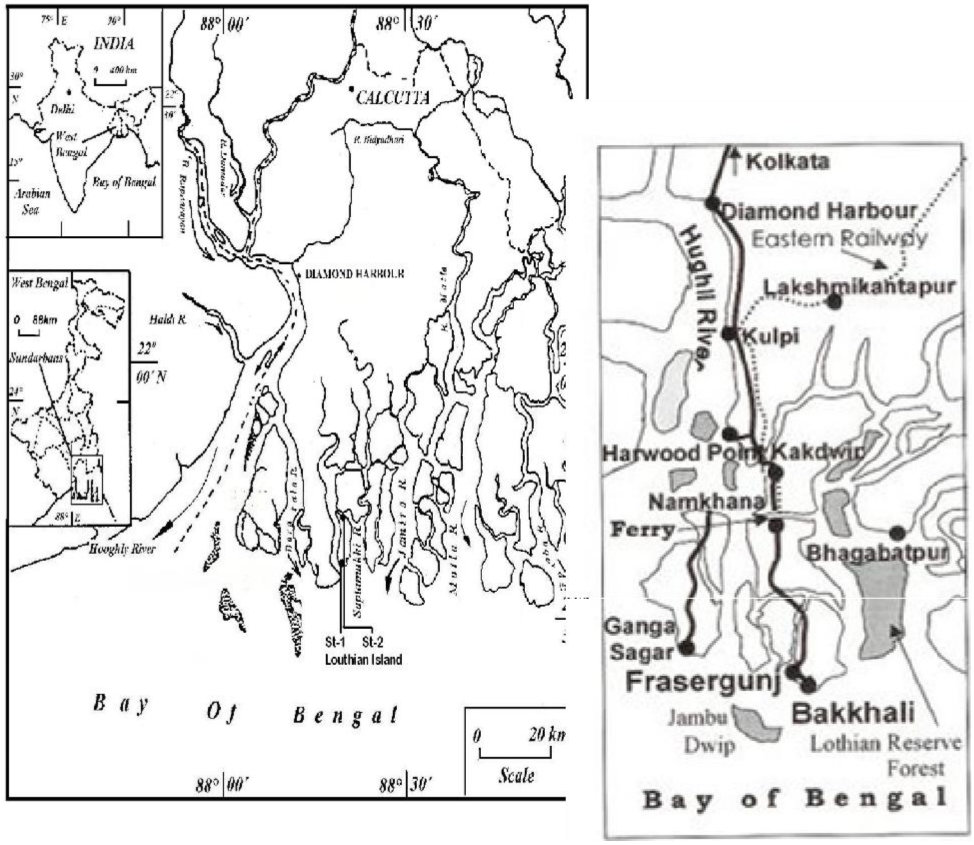

Figure 1. A geographical map and a transport map showing the study sites at Sundarban.

to saturate following a sigmoid pattern in plants grown under hypersaline conditions (Sobrado, 2001); and (iii) the rate of salt secretion appears to be nearly constant (Scholander et al., 1962; Sobrado, 2001) or to vary diurnally (Drennan and Pammeter, 1982).

In the present study we, therefore, re-evaluate previous findings by performing a full assessment of the effect of salinity on the rate and ionic composition of leaf secretion in plants of salt excretory mangrove species growing in the Sundarban deltaic region (30º24'-30º28'N to 77º40'-77º44'E). The importance and physiological relevance of the secretion for the maintenance of the internal concentrations of leaf ions, as well as the role of selective ion secretion on leaf ion ratios were examined.

MATERIALS AND METHODS

At the initial phase of the study large number of leaf samples of mangrove species (*Avicennia marina, A. alba, A. officinalis, Aegialitis rotundifolia, Acanthus ilicifolius and Aegiceras sp*.) from different study areas at Sundarbans (Bhagabatpur (20º39.1'N to 88º7.34'E), Chandanpiri (21º40.49'N to 88º7.34'E) and Sagar Island (Chemaguri) (21º39.52'N to 88º17.37'E)) were chosen for the study (figure 1).

Determination of the rate of salt excretion

At first, about 30 leaves from each of the mangroves species under consideration were washed clean with distilled water to remove the existing salt crystals and were covered with clean and transparent polythene bag in order to minimize contaminations from dirt particles and other external salt sources. The bags were kept on for a period of ten hours. Sampling involved rinsing the leaves with 25 ml of distilled water to dissolve the salt crystals present on the leaf surface while still attached to the plant to minimize collection error. The solutions were collected in 50 ml plastic (TARSON) containers and were further analyzed for the estimation of different ions (Na, K, and Cl). The flame photometer (Systronics Digital Flame Photometer-125, Serial No.-1473) was employed to estimate the sodium and potassium ion contents in these solutions and for the estimation of chloride ions standard gravimetric method was applied (Scholander *et al,* 1962). After the series, the leaves were detached from the bush and later traced on a millimeter graph paper to determine the leaf area.

RESULT AND DISCUSSION

The six species of salt excreting mangroves of the Sundarban studied showed considerable variations in the rates of excretion of sodium, potassium and chlorine ion excretion, over spatial and temporal changes. The following graphical representations reflect the observations made:

Species wise spatio-temporal variations (Figure 2-7)

As evidenced from the figure, during premonsoon period, at Lothian Is. (Stn.1), all the salt excreting mangroves exhibited a similar trend in excretion as rates were higher in leaves covered with a black polythene plastic sheet compared to the rates from the leaves left uncovered. This can be explained by the fact that leaves covered with the plastic sheet absorbed more sunrays and consequently raised the temperature to facilitate optimum transpiration in case of *Avicennia spp.* (Tomlinson, 1996; Scholander, 1962). The exception was found in case of *Aegialitis rotundifolia,* where rate of chloride ion excretion actually was found to be lower in covered samples than in uncovered ones (Joshi and Ghosh, 2003). *Acanthus ilicifolius* showed a very high rate of excretion for all the three ions examined, as it normally grows in high saline conditions and shows a higher metabolic activity than larger woody plants (Joshi and Ghosh, 2003). *Avicennia officinalis* showed a relatively lower rate of excretion of the ions as it has a diurnal variation in the rate of excretion of salts (Gordon and Duminsky, 1993) and might have encountered a primary stomatal closure followed by a reduced transpiration rate (Drennan and Pammentar, 1982).

At Chandanpiri (Stn.2), a similar pattern of excretion was observed among all the plants but in *A. officinalis*, the rates were lower in general which could be explicable by the fact of reduced stomatal activity and transpiration at noon (Drennan and Pammeter, 1982), and the temperature inside the cover might have crossed 39ºC, considered to be optimum for the stomatal functioning (Tomlinson, 1986). Here, another interesting finding is the increased rate of chloride exclusion by *A. rotundifolia* in the covered leaves as compared to the uncovered leaves. As these trees were situated under the much larger black mangroves the raised temperature inside the cover might have reached optimum stomatal efficiency (Dschida et. al., 1992) and also they were much closer to the shore line than normally encountered and the proximity towards a regular source inundation might have triggered higher rates (Joshi and Ghosh, 2003).

At Sagar Is.(Stn.3), the plants showed a pattern comparable to the other sites, but *Aegialitis rotundifolia* showed a pattern somewhat similar to the one observed at Lothian Is. despite the pronounced salinity difference in surface water between the two sites (20.9 psu at Lothian while 10.3 psu at Sagar Is.) indicating that surface water salinity is not the sole influencing parameter in terms of excretion of excess salts by mangroves (Scholander et al., 1962). *A. ilicifolius* owing to its high saline habitat excreted very high amounts of salt ions (Joshi and Ghosh, 2003)rate of ions, more from the uncovered leaves than the covered leaves, might have been subjected to heat stress induced stomatal closure and transpiration drop. *Aegiceras sp.,* otherwise showing a constant trend irrespective to changes in salinity showed a drop in sodium ion excreted from the covered leaves while chloride exclusion followed the usual pattern. The reason is not clear so far but due to heat stress of covered leaves along with higher concentration of chloride ion in leaf sap than the ambient medium due to higher dilution by fresh water at Sagar Is. (Scholander, 1962).

The scenario changed completely during the monsoon season as the focus shifted mainly to the chloride ion concentration in the leaves and consequent secretion by transpiration pull.

Both at Lothian and Chandanpiri, the rates of chloride excretion were higher considerably compared to the sodium ions. This explains and supports the view of increased chloride ion concentration in the leaves through the uptake of greater amounts of by the roots of *Avicennia spp*. and other salt excreting mangroves in order to maintain a steady osmotic pressure (Morrow and Nickerson, 1973). The only exception was the *A. rotundifolia* in which the rates were not exceedingly high as suggested by the distance from the shore (only reached by a very high tide) and therefore a comparatively lower dilution of the ambient salt content by fresh water incursion (Joshi and Ghosh, 2003). In most of the cases the rates were higher in uncovered leaves as the increased temperature and humidity inside the covers might have caused a reduced transpiration pull and consequent rate of excretion of ions (Dschida et. al., 1992).

At Sagar Island, the pattern of excretion followed a similar trend as was observed during premonsoon season in both the covered and uncovered leaves, with higher rate of excretion from the covered leave in general. Sodium ion excretion from *A. officinalis* was found to be very low compared to the chloride ion excretion in general which can be explained as the combined effect of its diurnal variation in excretion (Boon and Allaway, 1982) and increased concentrations of chloride ion in the plants due to higher rates of dilution by fresh water, which in turn could be explained by the almost similar rate of excretion of chloride ions from all

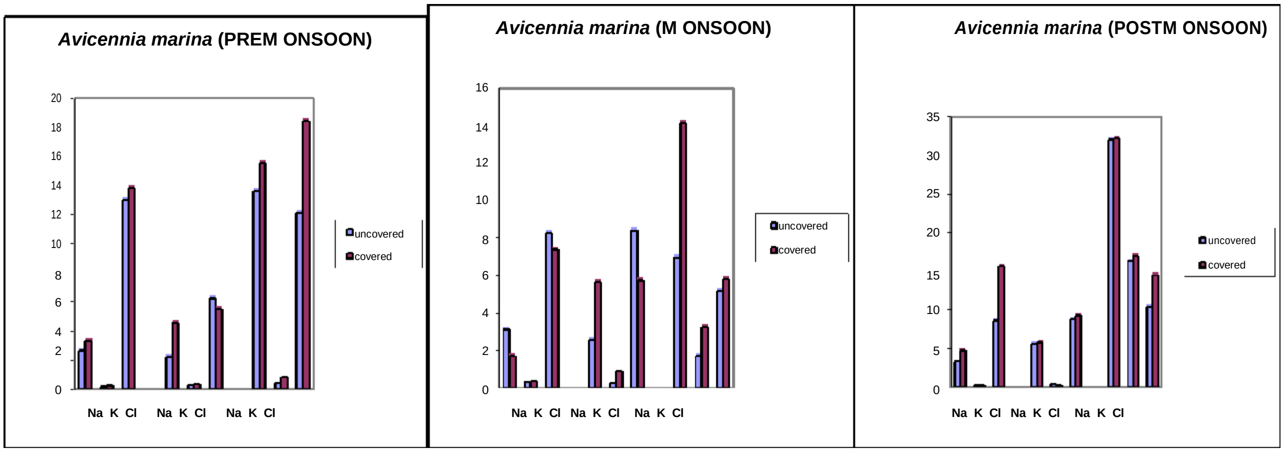

Figure 2. Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3

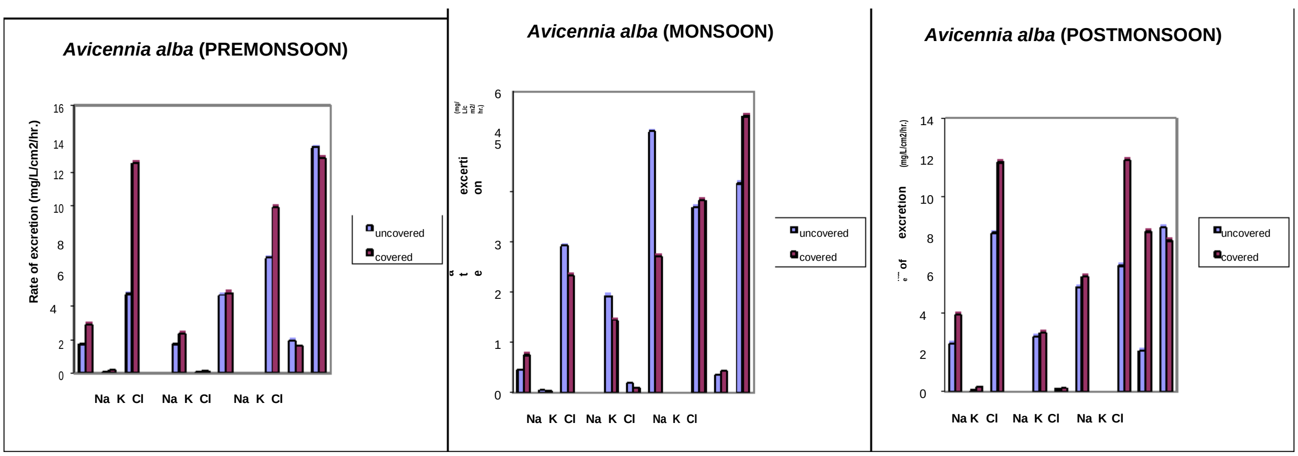

Figure 3. Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3

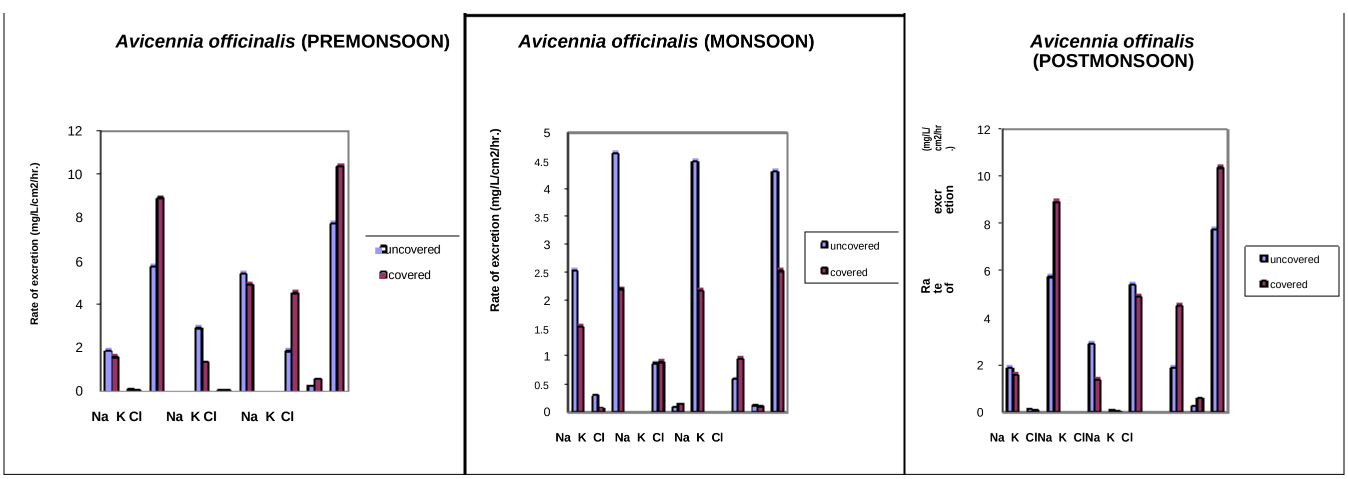

Figure 4. Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3

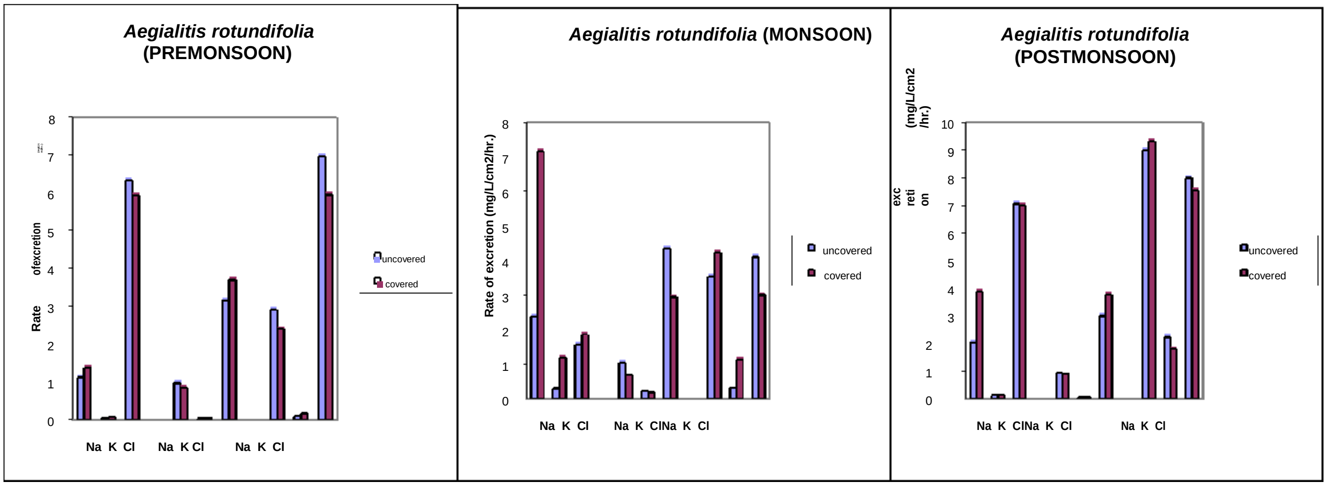

Figure 5. Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3

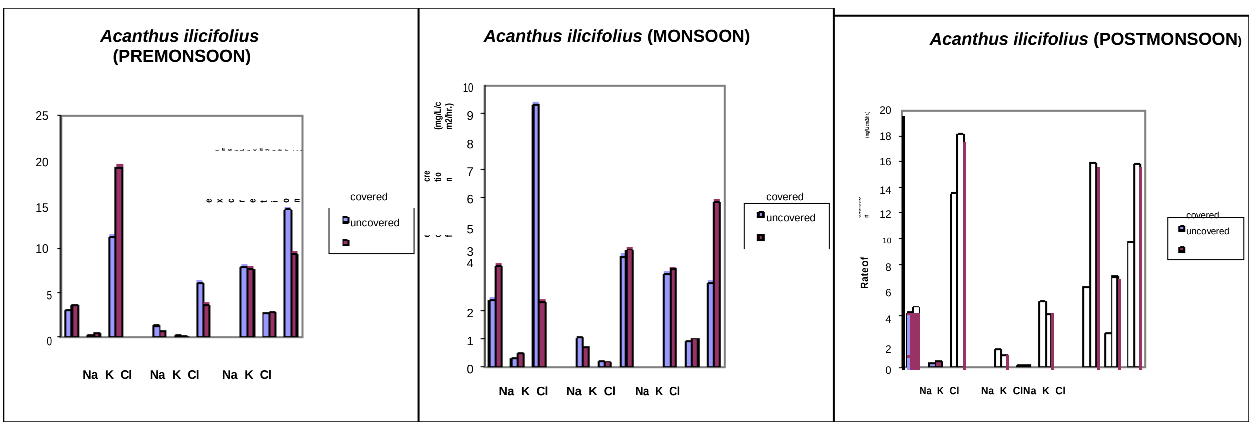

Figure 6. Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3

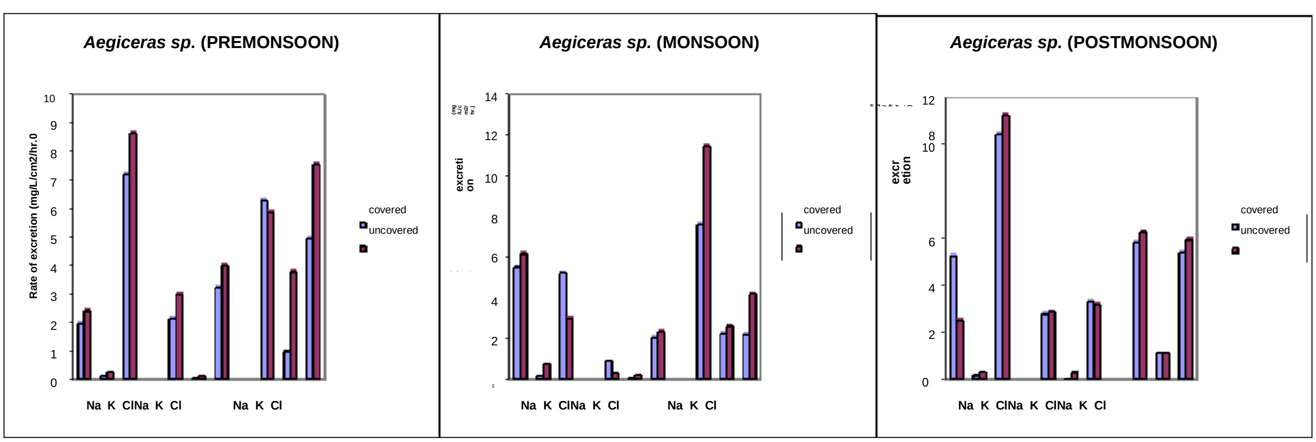

Figure 7. Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3 Stn.1 Stn.2 Stn.3

Figure 2-7. The charts represent the changes in the excretion rate of ions from the six mangrove species studied at various sites in three different seasons.

three stations (Boon and Allaway, 1986). However, *Aegiceras sp.* hardly showed any variations with changes in temperature, salinity or distance from the coast (Joshi and Ghosh, 2003).

During the post monsoon period at Lothian Is. when the salinity of the surface drastically increased due to less humidity in the air and higher rates of evaporation, the rates of excretion of ions from the salt excretory mangroves species studied showed changes from their monsoonal trends as well. All the species in general exhibited a pattern similar to the premonsoon trend with specific exceptions. *Aegialitis rotundifolia* exhibited a trend more or less similar to others but rate of chloride ion concentration from both the uncovered and covered leaves were almost similar. It might be due to the decrease in temperature (21ºC) that did not increase the temperature even inside the covers (25ºC) and no heat stress occurred. This could also vindicate the concept of chloride ion increase in plants due to salt dilution in monsoon. *A. ilicifolius* followed its similar pattern of high excretion rates due to its high saline habitat. However, *Aegiceras sp.* showed an increase in sodium ion excretion rate from the uncovered leaves, which can be explained by the age difference of the leaves (larger leaves were selected for the cover), as it generally did not show any significant changes in its excretion pattern with changes in the physico-chemical parameters of the environment (Sobrado, 2001).

At Chandanpiri and Sagar Is. Apart from little specific exceptional excretory behaviour more or less the plants followed a similar path to the Lothian Is. excretion pattern. At Chandanpiri, *A. rotundifolia* might have encountered heat stress related reduced excretion from covered leaves (Albert and Popp, 1977; Sobrado, 2001). In case of *Aegiceras sp*. the uncovered and covered leaves exhibited insignificant changes in rates of excretion, suggesting once again that when the leaves are of similar age the plant hardly shows any drastic changes in its excretion patterns for the three ions over a change in salinity or temperature (Sobrado, 2001; Scholander, 1962). At Sagar Is. in case of *A. marina,* the excretion rates of both sodium and potassium were exceedingly high compared to the previous values and chloride rate of excretion. Physiologically it is hard to assume sodium and potassium pollution increasing their amount in the soil and water without a rise in chloride content given the fact that they form salts readily or this might have been a case of physiological dysfunctionality where the plant failed to utilize sodium and potassium ions. This needs future studies in order to make any comment on it.

There is another very important feature and it is the relation between sodium and potassium ion excreted by the salt excreting mangroves. Strikingly the rate of excretion of these two ions showed a very similar curve with little exceptions at various species and sites, which only strengthen the assumption (Suárez and Medina, 2006). It in actuality reflects the metabolic need of these two ions as in stomatal opening and closure and transmembrane of salt ions through the Na-K pump, both of which are relevant to salt excretion process (Suárez and Medina, 2005; 06; Gierth and Mäser, 2007).

Overall comparison in variations in salt excretion by the mangroves (Tables 1-3)

The following charts represent the trend in variation in excretion of individual ions across various sites at different seasons. The rate of excretion of sodium ions from the covered leaves was found to be higher than that from the uncovered leaves at Lothian Island, irrespective to the change in surface water salinity. Although the patterns were more or less similar during premonsoon and post monsoon periods, the pattern produced during monsoon almost reverted itself due to the addition of large amount of fresh water. The excretion curve for sodium ion was similar to that of the potassium ion (Sobrado and Greaves, 2000). Excretion of chloride ions followed its own path where the pre and post monsoon curve showed almost a similar pattern of ebbs and tides; interestingly here also the monsoon curve showed a complete change in character. Apart from *A. marina* all the other species showed a constant rate of excretion from the covered leaves and it was lower than that from the uncovered leaves. It might be due to high concentration of chloride ions in the plant, the excretion rate of which could have been hindered by heat stress related reduction in the transpiration (Suárez and Medina, 2005; 2006).

At Chandanpiri, the curves of excretion of both sodium and potassium ions by the salt excreting mangroves were similar in character, with monsoon curve showing reversal from the pre and post monsoon curves. Here too, chloride excretion curve had its own nature and following the same pattern as shown at Lothian with higher values from uncovered leaves. At Sagar Is. also the patterns of sodium and potassium ion excretion were similar. The nature of the curves of pre and post monsoon periods showed close resemblances. Here. Chloride ion excretion curve for all three seasons reflected that values of excreted ion were higher throughout the year as Sagar Is. normally receives a huge load of river run off, consequently diluting the salt content in the ambient media and leading to an increase in chlorine content of the plants (Tomlinson et. al., 1986; Jennings, 1976).

A very interesting observation was made from all these afore-charted figures which states that the rate of excretion of all three ions from both covered and uncovered leaves reflected a species specific pattern where the lowest rate came from *Avicennia alba* mostly, in spite of its proximity towards the shore line and high chance of submergence of its roots and the highest rate

Table 1. Premonsoonal rate of excretion of salt ions from leaves of mangroves at three stations

Species (Premonsoon)	Leaf area (cm2)	Rate of excretion (mg/L/cm2/hr.) [Lothian Is.]			Leaf area (cm2)	Rate of excretion (mg/L/cm2/hr.) [Chandanpiri]			Leaf area (cm2)	Rate of excretion (mg/L/cm2/hr.) [Sagar Is.]		
		Na	K	Cl		Na	K	Cl		Na	K	Cl
Avicennia marina												
UC	17.93	2.6302	0.1621	13.0151	19.46	2.2261	0.2922	6.2612	14.29	13.6342	0.4102	12.0992
C	16.03	3.2985	0.2651	13.8412	17.03	4.5610	0.3479	5.4719	10.80	15.5625	0.8263	18.4837
Avicennia alba												
UC	25.03	1.7426	0.0728	9.7170	25.51	1.7185	0.0745	4.6350	14.75	6.8852	1.9359	13.9767
C	17.67	2.8720	0.1513	12.5565	19.56	2.3453	0.1236	4.7641	13.9	9.9076	1.6304	12.8623
Avicennia officinalis												
UC	32.97	1.6362	0.1008	8.5326	32.28	1.7371	0.0277	5.4127	28.81	1.3833	0.2486	6.4532
C	34.28	0.7526	0.0299	3.8864	30.33	0.8407	0.0422	2.1946	20.60	3.8834	0.5097	10.7706
Aegialitis rotundifolia												
UC	41.85	1.1209	0.0482	6.3313	42.89	0.9651	0.0288	3.1576	39.93	2.9066	0.0951	6.9635
C	33.65	1.3670	0.0750	5.9342	36.02	0.8377	0.0351	3.6975	33.56	2.3979	0.1609	5.9501
Acanthus ilicifolius												
UC	14.10	3.0393	0.2133	11.3107	14.11	1.2666	0.1659	6.1128	14.70	7.8910	2.7059	14.4234
C	17.40	3.6278	0.3864	19.1271	18.50	0.5997	0.1245	3.5979	18.90	7.6798	2.8267	9.3915
Aegiceras corniculatum												
UC	25.08	1.9670	0.1360	7.1919	23.40	2.1378	0.0761	3.2316	25.25	6.2824	0.9964	4.9393
C	20.57	2.4124	0.2613	8.6290	16.72	2.9814	0.1285	3.9810	19.34	5.8557	1.2874	7.5458

Table 2. Monsoonal rate of excretion of salt ions from leaves of mangroves at three stations

Species (Monsoon)	Leaf area (cm2)	Rate of excretion (mg/L/cm2/hr.) (Lothian Is.)			Leaf area (cm2)	Rate of excretion (mg/L/cm2/hr.) (Chandanpiri)			Leaf area (cm2)	Rate of excretion (mg/L/cm2/hr.) (Sagar Is.)		
		Na	K	Cl		Na	K	Cl		Na	K	Cl
Avicennia marina												
UC	17.63	3.1161	0.3021	8.2622	13.59	2.5504	0.2441	8.3783	13.93	6.9560	1.6897	5.1535
C	16.93	1.6981	0.3691	7.3632	9.30	5.6451	0.8840	5.7258	9.18	14.1612	3.2679	5.8006
Avicennia alba												
UC	37.36	0.4691	0.0680	2.9298	15.77	1.9280	0.2144	5.1994	14.55	3.6856	0.3632	4.1648
C	40.00	0.7500	0.0986	2.3296	14.70	1.4455	0.1020	2.7168	14.00	3.8392	0.4464	5.7053
Avicennia officinalis												
UC	32.40	2.5334	0.3030	4.6249	23.68	0.8683	0.0929	4.4795	29.91	0.5917	0.1224	4.3017
C	36.22	1.5184	0.0828	2.2064	24.50	0.8877	0.1530	2.1734	21.05	0.9501	0.1068	2.5296
Aegialitis rotundifolia												
UC	42.15	2.3715	0.2983	1.5683	35.15	1.1999	0.2285	4.3406	30.57	3.5315	0.3104	4.1068
C	35.60	7.1629	1.1938	1.8697	36.30	0.6818	0.0826	2.9338	31.25	4.2400	1.1200	2.9820
Acanthus ilicifolius												
UC	13.63	2.3719	0.3194	9.3140	16.85	1.0422	0.2105	3.9306	23.25	3.3032	0.9217	2.9871
C	17.40	3.5919	0.5028	2.2952	16.00	0.6818	0.1875	4.1601	15.90	3.4591	1.0220	5.8608
Aegiceras corniculatum												
UC	20.77	5.5119	0.1791	5.2417	25.29	0.9375	0.0805	2.0519	24.87	7.6266	2.2482	2.1425
C	17.80	6.1797	0.7724	2.9915	22.70	2.3230	0.2433	2.3561	19.03	11.4293	2.6142	4.1973

Table 3. Post monsoonal rate of excretion of salt ions from leaves of mangroves at three stations

Species (Post monsoon)	**Leaf area (cm2)**	**Rate of excretion (mg/L/cm2/hr.) [Lothian Is.]**			**Leaf area (cm2)**	**Rate of excretion (mg/L/cm2/hr.) [Chandanpiri]**			**Leaf area (cm2)**	**Rate of excretion (mg/L/cm2/hr.) [Sagar Is.]**		
		Na	K	Cl		Na	K	Cl		Na	K	Cl
Avicennia marina												
UC	17.93	3.3454	0.2836	8.6555	12.06	5.5841	0.4684	8.8308	12.88	32.1028	16.4099	10.3738
C	16.92	4.6823	0.2260	15.7358	8.60	5.8226	0.2877	9.2877	7.65	32.3529	16.9934	14.5016
Avicennia alba												
UC	24.53	2.4805	0.0937	8.1162	16.50	2.8203	0.1540	5.3487	14.925	6.4404	2.0893	8.4084
C	18.90	3.9550	0.2500	11.7394	11.20	3.0513	0.1953	5.9166	12.06	11.8366	8.1882	7.7114
Avicennia officinalis												
UC	31.07	1.8547	0.1194	5.7420	20.90	2.9043	0.0821	5.4140	24.55	1.8529	0.2748	7.7436
C	31.89	1.5169	0.0744	8.9029	20.40	1.3639	0.0531	4.8943	17.12	4.5268	0.5987	10.3679
Aegialitis rotundifolia												
UC	42.55	2.0262	0.1337	7.0602	5.26	0.9254	0.0454	2.9879	27.61	8.9935	2.2324	7.9767
C	31.74	3.8828	0.1189	6.9903	4.87	0.9079	0.0528	3.7572	26.50	9.3113	1.7924	7.5353
Acanthus ilicifolius												
UC	14.75	4.2608	0.3369	13.5294	22.03	1.3765	0.1202	5.1364	22.87	6.2740	2.6153	9.7489
C	18.30	4.6803	0.4603	18.1864	16.09	0.9154	0.1443	4.1368	14.03	15.8766	7.0384	15.8143
Aegiceras corniculatum												
UC	23.68	5.2627	0.1846	10.4452	20.20	2.7599	0.1153	3.2952	25.46	5.8424	1.1314	5.3947
C	23.69	2.4957	0.3345	5.6194	16.62	2.8715	0.2993	3.2039	18.60	6.2768	1.1693	5.9643

of excretion was observed in *A. marina,* with *A. ilicifolius* being the second highest salt excretory species, owing naturally to its high saline habitat. *Avicennia officinalis* exhibited a varied pattern depending on salinity changes, temperature and its diurnal variation in transpiration rates (Boon and Allaway, 1982; 1986). *Aegiceras sp.* however, reflected no significant variation in the rate of excretion with changes in the sites and other physico-chemical parameters (Ball, 1988).

CONCLUSION

A study has been made to understand the effect of chemical parameter such as surface water salinity on the amount and consequently the rate of excretion of salt ions (mainly sodium, potassium and chloride). In general the premonsoon and postmonsoon trend of excretion showed similarities being times of the year when salinity increases. Monsoon showed comparative high rates of chlorine excretion from the leaves. Covered leaves of many species including *Avicennia officinalis, Aegialitis rotundifolia* etc. showed lower rates of excretion of ions during premonsoon and monsoon periods mainly, due to heat-induced stomatal closure followed by lowered transpiration rate. However, plants like *Aegiceras sp.* hardly showed any significant change in the rates of excretion of the ions with changes in sites, seasons, salinity gradient or even the distance from shoreline. Amongst the ions excreted, sodium and potassium exhibited a pattern of excretion resembling each other. It might indicate their similar degree of utilization in metabolic processes

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