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STUDIES ON GROWTH AND SALT REGULATION IN SOME HALOPHYTES AS INFLUENCED BY EDAPHIC AND CLIMATIC CONDITIONS

HUMAIRA MARYAM, SHOAIB ISMAIL, FARKHUNDA ALA AND RAFIQ AHMAD

Biosaline Research Laboratories,
Department of Botany,
University of Karachi, Karachi-75270, Pakistan.

Abstract

Variations in plant growth due to changes in edaphic and climatic conditions in two halophytic species viz., *Suaeda fruticosa* (L.) and *Tamarix indica* Willd., from the saline community at Karachi University campus are reported. Growth rates of plants and regulation of Na^+ and Cl^- salts with reference to prevailing climatic and edaphic conditions were studied from mid of July to first week of November. Soil moisture content increased with soil depth in both the species studied while electrical conductivity was high in the uppermost part of the soil profile. Maximum salt accumulation was observed in *S. fruticosa* ranging from EC: 110-130 $dS.m^{-1}$ at soil surface of 0-5 cm. Concentrations of Na^+ and Cl^- ions in the saturated soil extract significantly corresponded to the electrical conductivities observed at different time period and at different soil depths.

Stomatal conductance and transpiration rates exhibited an increase with more water availability in soil. No significant variation was evident in plant moisture content in both the species. *T. indica* exhibited comparatively higher organic matter and low ash as compared to *S. fruticosa*. Concentration of Cl^- remained unaffacted in *T. indica*. Plant volume increased with time in *S. fruticosa* exhibiting higher rate of increase in volume as compared to *T. indica*. Moisture content and soil salinity (EC_e) significantly affected growth in both *S. fruticosa* and *T. indica*, whereas, growth of *T. indica* was also influenced by Na^+ content of soil. Percentage of both Na^+ and Cl^- ions in relation to the external medium concentrations showed higher proportion of Na^+ in both the species, although *T. indica* exhibited a relatively less absorption and accumulation of both the ions as compared to external medium.

Introduction

Pakistan has 5.8 m.ha. of salt-affected land (Qureshi *et al.*, 1993) including both inland and coastal areas most of which are saline and not suitable for cultivation of conventional crops, forages, fuelwood and timber species. The salt-affected areas have natural communities but usually dominated by halophytes differing in shape, size, forms and general habit in relation to prevailing soil, water and climatic conditions. The halophytic species vary from grasses to shrubs and trees and occur in diverse environmental conditions from coastal swamps to marshes and arid plains. They also occur in irrigated areas which are turned saline due to transportation of salts. True halophytes may not necessarily be found in areas of abundant water, but are also found under drought conditions (Malcolm, 1993). The halophytes besides having sand-binding and salt absorption properties also have great economic importance for use as forage/fodder, oil crops, pulp, paper industry and fuelwood (Malcolm, 1993; Joshi & Iyengar, 1978; Chapman, 1972).

The distribution of halophytes depend mostly on edaphic factors like, soil texture, pH, moisture, mineral composition, etc., than on climatic factors (Joshi, 1982; Ungar, 1974; Gill & Abrol, 1993). Soil salinity alone or in combination with waterlogging play an important role in the distribution of halophytes. Variation in total salinity, depth of saline horizon and extent of waterlogging can greatly influence the vegetation of an area including halophytes. The effects of salinity can either be a combination of ions or response of individual ions. Likewise, waterlogging, water-table depths, salinity of underground water are other important associated factors. Different halophytic species exhibit different mechanisms of salt uptake and regulation through which they not only survive but are able to grow under different edaphic conditions. Studies of such representative plant species not only provide chances for studying the mechanism(s) of salt tolerance in these plants but also provide information which can be applied to other conventional species for increasing salt tolerance and productivity through genetic engineering and plant breeding.

The present report describes the growth and salt regulation in two halophytic species viz., *S. fruticiosa* and *T. indica* differing in growth habits and forms and to monitor changes associated with variation in climatic and edaphic factors over a period of time.

Materials and Methods

Two dominating species of halophytic community viz., *Suaeda fruticosa* (L.) Forrsk., and *Tamarix indica* Willd., were selected from the saline areas of Karachi University campus. Ten healthy plants of each species of equal size were selected and tagged in the field and monitored for a period of four months from July to mid of November to evaluate morphological and ionic variations related to climatic and edaphic factors. Out of 10 replicates of each species, 3 replicates were extensively studied alongwith their edaphic factors. The remaining replicates were monitored only for morphological variations with time.

Morphological Studies: Plant height (h) and diameter[s] (maximum diameter of plant designated as "d_1", and at right angle to d_1 designated as "d_2") were recorded fortnightly to calculate the shoot volume as described by Ward (1993) and Ismail *et al.*, (1993) on the bases of plant shapes.

Equation for *Tamarix indica*: $1/6\,\pi * d_1 * d_2 * h$

" " *Suaeda fruticosa*: $d_1 * d_2 * h$

Salinity Measurements: Electrical conductivity was measured fortnightly at 0-50 and 50-100 cm depth of soil by EM-38 conductivity measurements (EM-38 Ground Conductivity Meter, Geonics Ltd., Canada). For EC_e measurements, samples of soil were taken at 0-5, 5-50 and 50-100 cm depth in the rhizosphere of the plants. Moisture content of soil samples was determined by the difference of moist and oven dried soil.

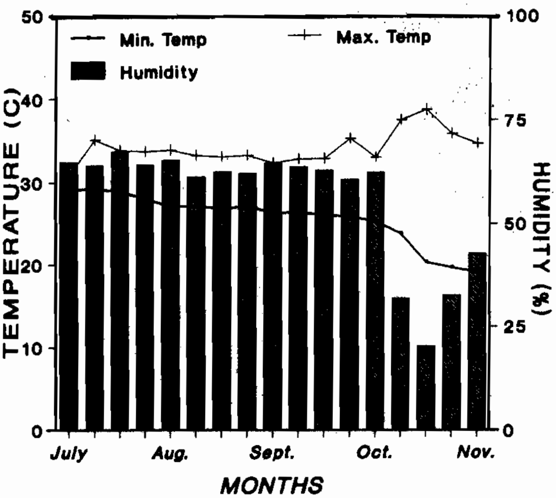

Fig.1. Ombrothermic diagram of the study site at Karachi University campus.

Plant Measurements: Samplings were done fortnightly on selected replicates of both the species. Randomly collected fresh plant samples were weighed and oven dried at 70°C for 48 h for dry weight measurements. Oven dried plant samples were then ashed in a furnace at 500°C for 6 h. and used for ionic estimations as described by Karimi & Ungar (1986). Sodium ions were determined by atomic absorption spectrophotometry (Jarrell Ash AA-782A), whereas, chloride were determined by chloridometer (Haake Buchler Instruments).

Stomatal conductance, transpiration rate and quantum yield of plants under dry and wet soil conditions was also determined in all the replicate plants. Measurements were recorded when the soil was dry (7% moisture), which was then watered till the soil profile was moistened upto 50 cm depth. Measurements were then made on the following day. Final measurements were taken on dry soil (12% moisture), five days after the soil was moistened. Measurements were made with a LICOR (LI-600) porometer.

Results

The seasonal changes with time and their effects on physical and chemical properties in two halophytic species viz., *Suaeda fruticosa* and *Tamarix indica* for four months from mid of July to mid of November is presented. Ombrothermic diagram for climatic changes at the experimental area is presented in Figure 1. Humidity remained low during the period of November with minimum and maximum temperature exhibiting maximum variation. Maximum temperature ranged between 32-35°C and minimum between 25-30°C from July to October.

Changes in Soil Characteristics: Both *S. fruticosa* and *T. indica* occurred mostly in silty loam soil profile which had sandy-loam and loamy-sand types at 5-50 and 50-100 cm soil depths, respectively. In the rhizosphere of *S. fruticosa* plants, moisture content of soil increased at lower soil depths. The upper 5 cm soil profile showed an increase in

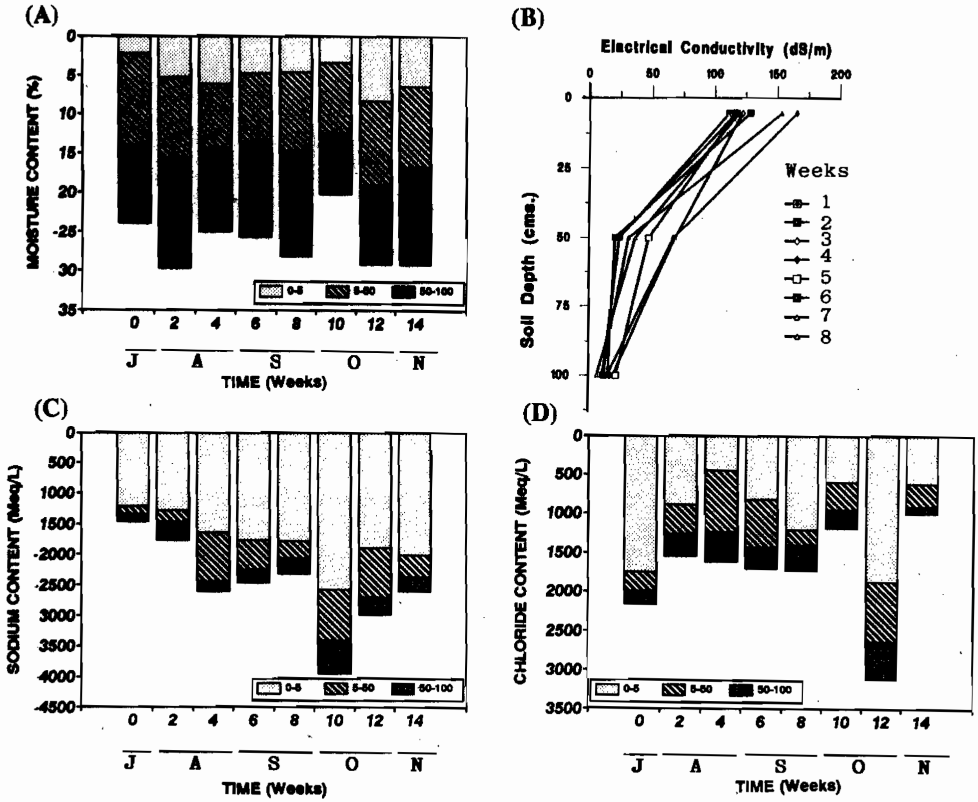

Fig.2. Variation in soil moisture, salinity, sodium and chloride content in *S. fruticosa* community.

moisture content when the temperature started decreasing, whereas, low moisture was observed in the upper part of the soil profile during mid July and late October (Fig. 2 A). Electrical conductivity showed a reduction with increase in soil depth with values ranging between 100-170 $dS.m^{-1}$ at 0-5 cm soil depth, 20-80 $dS.m^{-1}$ at 5-50 cm and 10-35 $dS.m^{-1}$ at 50-100 cm (Fig. 2 B). Both Na^+ and Cl^- concentrations were significantly high at the surface soil and decreased to even less than half at subsequent soil depths (Figs. 2 C and D). The highest concentration of Na^+ in the upper soil (0-5 cm) was evident on the 10th week (October), whereas, high Cl^- content at this soil depth was evident at 0 week (July) and 12th week (October). ANOVA showed significant differences in *S. fruticosa* for moisture content, electrical conductivity, sodium and chloride contents with reference to soil depth, while differences with respect to time was evident for sodium content only (Table 1).

Moisture content in *T. indica* showed non-significant differences with increase in soil depths except on 8^{th} and 12^{th} week (September-October). Apparently moisture seemed to increase generally at lower depths (5-50 and 50-100 cm.) of soil profile except on 6th week (August) when ca. 20% moisture was present in the upper soil (Fig. 3 A). Electrical conductivity exhibited a significant decrease with increase in soil depth except at the end of August when EC_e decreased by 29% only at 0-5 cm soil depth

Table 1. ANOVA for soil moisture, salinity, Na^+ and Cl^- ions in respect to soil depths and time (in weeks) in *S. fruticosa*.

		MOISTURE CONTENT			ELECTRICAL CONDUCTTIVITY		
SOURCE	df	MS	F-Value	Prob.	MS	F-Value	Prob.
Soil Depth (S)	2	248.76	14.57	P<0.001	76164.17	72.88	P<0.001
Time (T)	7	10.90	0.639	N.S.	1636.25	1.565	N.S.
S x T	14	7.85	0.460	N.S.	356.10	0.340	N.S.
Error	43	17.06			1044.94		
Total	66						

		SODIUM CONTENT			CHLORIDE CONTENT		
SOURCE	df	MS	F-Value	Prob.	MS	F-Value	Prob.
Soil Depth (S)	2	10435176.14	34.16	P<0.001	3079448.29	4.234	P<0.05
Time (T)	7	731592.29	2.39	P<0.05	1407024.83	1.934	N.S.
S x T	14	517870.38	1.69	N.S.	415375.24	0.571	N.S.
Error	43	305397.11			60983.76		
Total	66						

compared to 5-50 cm depth (Fig. 3 B). Moisture content during this period was also high in the upper soil. The EC_e varied between 23-141 $dS.m^{-1}$ at 0-5 cm soil, between 15-37 $dS.m^{-1}$ at 5-50 cm and between 10-40 $dS.m^{-1}$ at 50-100 cm. Ion concentration (both Na^+ and Cl^- ions) decreased with increase in soil depth which correlated with the EC_e and exhibited a significantly high concentration of sodium ions at soil surface (Figs. 3 C and D). Chloride ions showed accumulation on 2nd and 10th week at the upper soil surface. ANOVA for soil characteristics associated with *T. indica* exhibited non-significant differences in moisture content for both soil depths and time (Table 2), whereas, electrical conductivity, sodium and chloride concentrations showed significant variation with soil depth only. EC_e also exhibited significant effect for time also.

Plant Response to Edaphic Conditions: Physiological processes of plants were significantly affected by the moisture content of soil. Stomatal conductance in both species ranged between 10-15 $m.mol.m^{-2}.s^{-1}$ at initial dry period (which prevailed in the area), decreased to 7-11 $m.mol.m^{-2}.s^{-1}$ at wet period (one day after the soil was moistened) and then increased 3-fold again on subsequent dry period (Table 3). Transpiration rate also exhibited similar response, whereas, quantum yield showed significant effect to moisture present in the rhizosphere of *T. indica*.

Proportion of moisture, organic matter and ash in relation to the total fresh weight showed that moisture content ranged between 60-80% in *S. fruticosa* while *T. indica* had relatively low moisture content ranging between 40-60% (Fig. 4). Organic matter was approximately 20% in *S. fruticosa* while ash content varied between 8-10% except in August, when organic matter decreased to 10% and ash content increased 2-fold. *T. indica* had relatively more organic matter (25-40%) and less ash (10-15%) contents as compared to *S. fruticosa* except in samples collected on the 4th week when ash was 40% and organic content was 15% only.

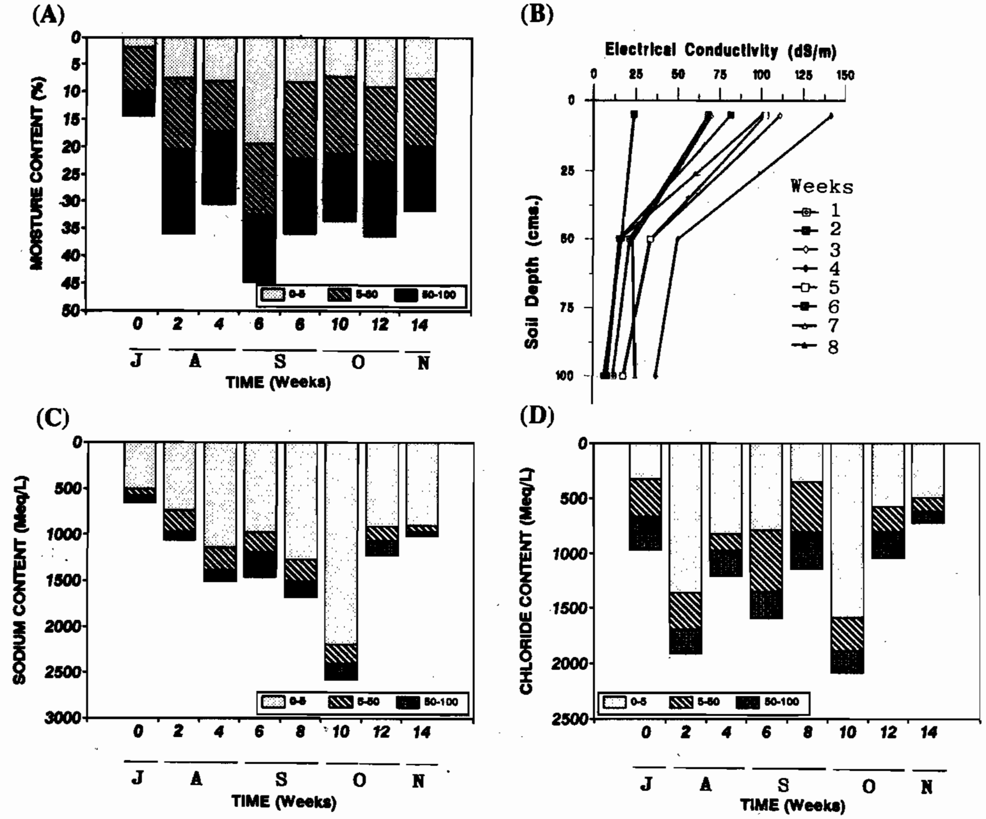

Fig.3. Variation in soil moisture, salinity, sodium and chloride content in *T. indica* community.

S. fruticosa exhibited a higher growth rate with plant volume varying from 0.76 m^3 to 2.30 m^3 during the 4 months growth period. *T. indica* exhibited a lower plant volume due to the nature of the species. A 200% increase in plant volume was observed in *T. indica* from 1st to 8th week (July-September), whereas, in *S. fruticosa* this increase was 225% from initial observations. *S. fruticosa* exhibited higher rates for the first twelve weeks (July-October), after which very little variation was evident (Fig. 5), whereas, *T. indica*, showed little variation during the first nine weeks followed by significant variation with time. Plant growth as influenced by soil moisture content and salinity (EC_e) was studied in reference to variation in plant volume. Soil moisture content exhibited a significant relationship to plant volume in *S. fruticosa* and *T. indica* with 2nd and 3rd degree polynomials, respectively (Fig. 6). Relationship between the estimated EC_e and plant volume also exhibited significant relationships for both the species. *S. fruticosa* exhibited a 2nd degree polynomial curve indicating maximum plant volume to moderate salt level of 10-15 $dS.m^{-1}$. Both species tended to show a decline in plant volume after 20 $dS.m^{-1}$.

Table 2. ANOVA for soil moisture, salinity, Na^+ and Cl^- ions in respect to soil depths and time (in weeks) in *T. indica*.

SOURCE	df	MOISTURE CONTENT MS	F-Value	Prob.	ELECTRICAL CONDUCTTIVITY MS	F-Value	Prob.
Soil Depth (S)	2	97.02	1.922	N.S.	30274.67	47.71	P<0.001
Time (T)	7	67.85	1.344	N.S.	2435.62	03.84	P<0.01
S x T	14	20.37	0.403	N.S.	635.18	01.00	N.S.
Error	38	50.47			634.56		
Total	61						

SOURCE	df	SODIUM CONTENT MS	F-Value	Prob.	CHLORIDE CONTENT MS	F-Value	Prob.
Soil Depth (S)	2	5321450.59	38.30	P<0.001	1547611.83	8.846	P<0.001
Time (T)	7	313415.18	02.27	N.S.	243072.11	1.389	N.S.
S x T	14	149913.91	01.08	N.S.	192614.69	1.101	N.S.
Error	18	138918.75			60983.76		
Total	41						

Table 3. Some physiological measurements in the halophytic plants studied with reference to varying moisture content of soil.

Plant Species	Analysis Period	Moisture Content of Soil (%) [0-5 cms.]	Stomatal Conductance ($mmol.m^{-2}s^{-1}$)	Transpiration Rate ($mmol.m^{-2}s^{-1}$)	Quantum Yield ($\mu mols^{-1}m^{-2}$)
Suaeda fruticosa	Dry	9.182	10.00	0.863	1521
		±0.634	±0.59	±0.065	±195
	Wet*	10.872	7.23	0.668	1483
		±0.938	±1.63	±0.149	±196
	Dry**	10.465	42.10	2.379	1465
		±1.271	±7.39	±0.503	±200
$LSD_{0.05}$		n.s.	13.20	0.919	n.s.
Tamarix indica	Dry	14.284	15.28	1.124	1616
		±1.875	±1.07	±0.107	±155
	Wet	15.456	11.32	0.919	1466
		±2.732	±2.24	±0.147	±83
	Dry	12.547	38.43	1.717	1566
		±0.408	±4.70	±0.174	±102
	$LSD_{0.05}$	n.s.	9.59	0.442	331

*Wet period indicates observations recorded 1-day after the area was watered.

**Dry period indicates observations recorded 5-days after soil wetting.

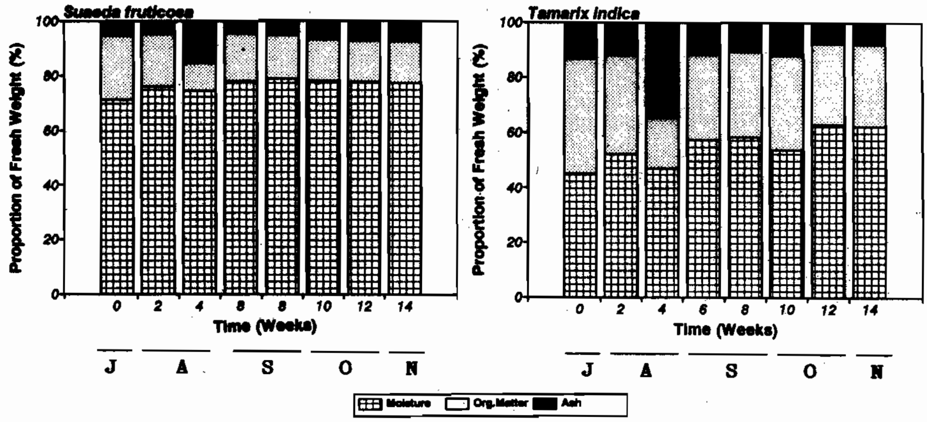

Fig.4. Contribution of moisture content, organic matter and ash content (as percentage of fresh weight) in *S. fruticosa* and *T. indica*.

Variation in concentration of Na^+ and Cl^- in leaves of *S. fruticosa* over a period of time showed non-significant variations in uptake of sodium and chloride ions till September (Fig. 7), followed by higher concentration of sodium as compared to chloride ions. *T. indica* showed more or less equal amounts of Na^+ and Cl^- ions concentration throughout the present study period.

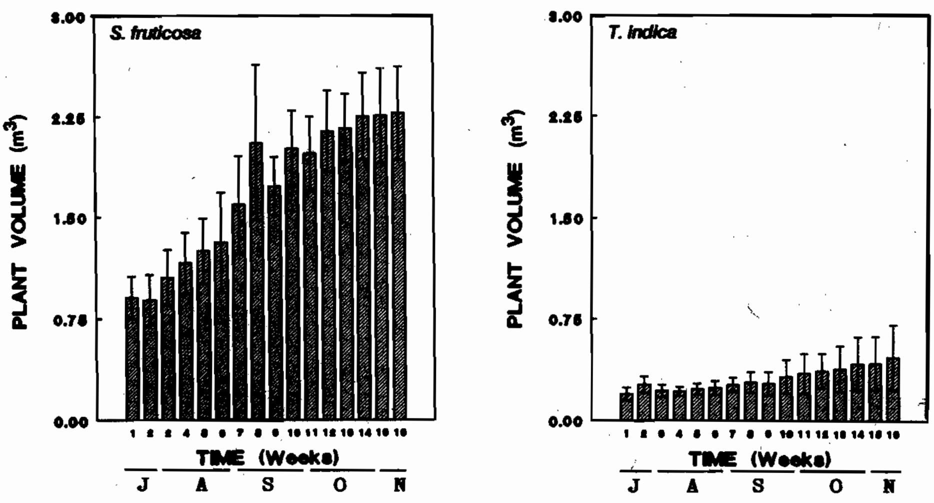

Fig.5. Variation in plant volume in *S. fruticosa* and *T. indica* over period of time.

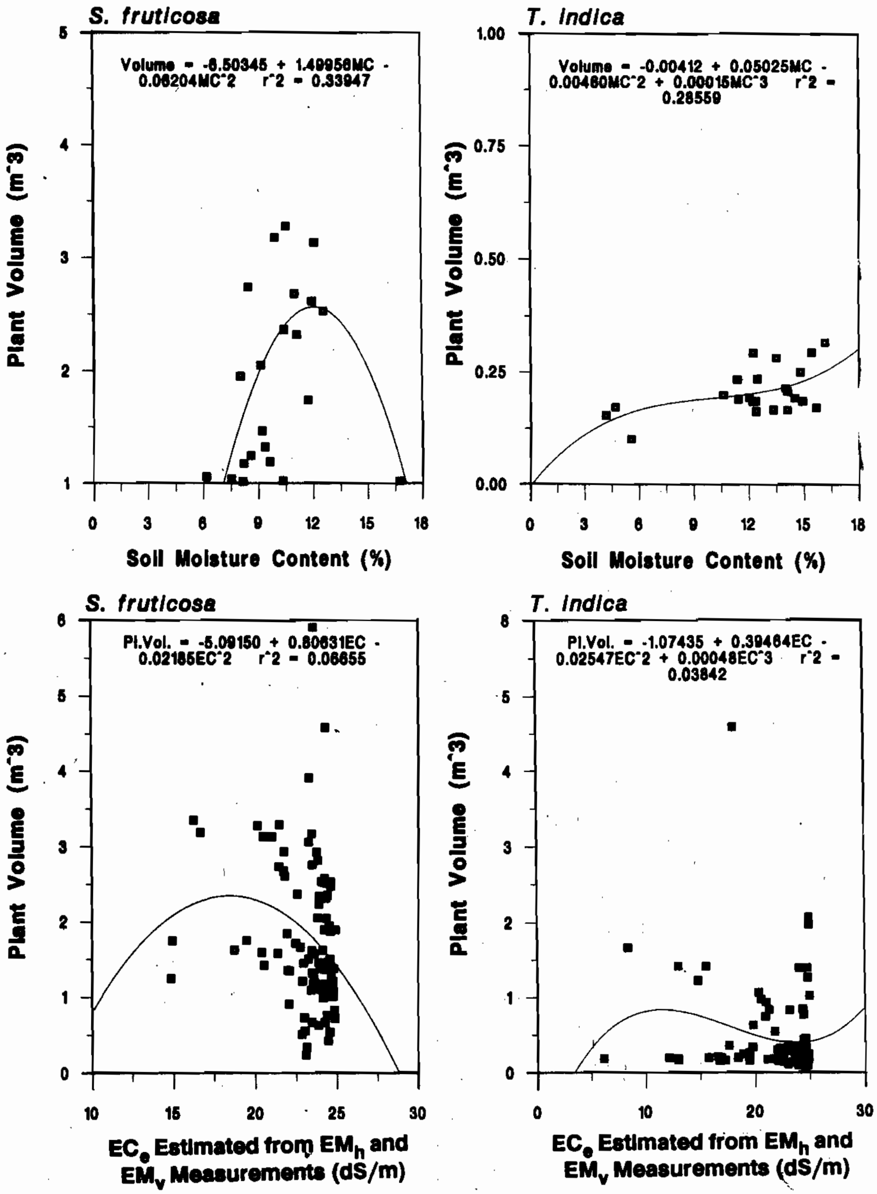

Fig.6. Relationships between soil moisture and salinity (EC_e) as factors contributing towards the variation in plant volume over a period of time.

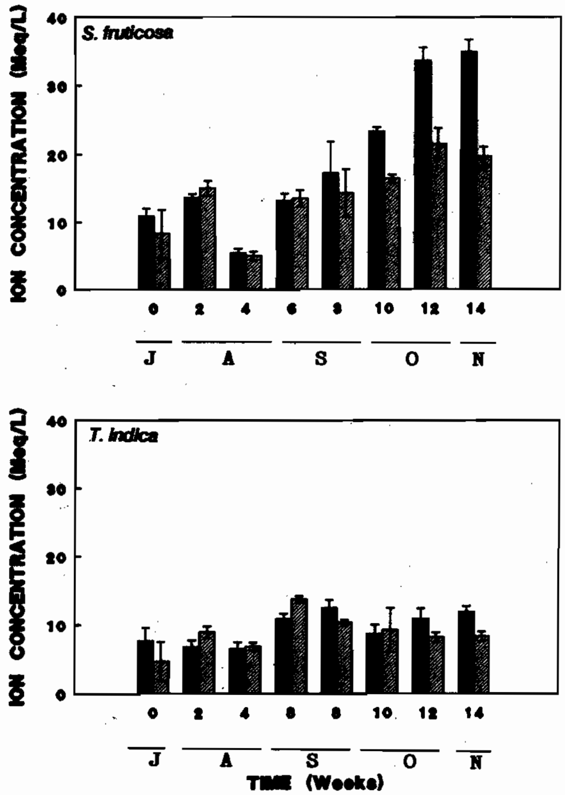

Fig.7. Variation in concentration of sodium and chloride ions over time period.

Discussion

Vegetation of an area as a function of plant cover in that area is influenced by climate, soil and water. Soil moisture governs plant growth through water influx by the root system controlling the metabolic pathways within the plant cell and consequently growth. In addition, soil having a high proportion of soluble salts have a very high negative osmotic potential (Saurez & Lebron, 1993) which affects the water influx to the plant. Plants under such conditions either avoid the presence of salts (by lowering the osmotic potential of cells), or tolerate the salts through different mechanisms (Flowers, 1985; Flowers *et al.*, 1977) including accumulation and secretion (Schirmer & Breckle, 1982).

The increase in moisture content in soils of *S. fruticosa* with increase in soil depth could be due to (i) presence of a shallow water-table; or (ii) presence of shallow root system in these plants which depletes the soil moisture at the upper soil profile. On the other hand, *T. indica* with well developed vertical roots absorb moisture at a very high rate which exhibits moisture variation in different soil profile.

Electrical conductivity which was high at the soil surface and gradually decreased with soil depth was presumably due to low moisture content at the soil surface. High temperature and low moisture of the environment (humidity) results in high evaporation rates at soil surface resulting in salt accumulation at the upper soil surface. Deeper soil layers have less evaporation demand and as such exhibit higher moisture content particularly at sites with watertable varying at 1 or 1.5 m.

Both *S. fruticosa* and *T. indica* showed a general increase in EC_e with time. Temperature and humidity during the period remained high between 30-40°C and 60-70 %, respectively. A decrease in EC_e for both the species was observed in mid of October as the plants were watered for physiological studies. After this period, it again exhibited an increase in EC_e due to rapid evaporation of moisture from the soil surface leaving the salts behind on the top soil horizon. Both Na^+ and Cl^- ions were present in greater amount on the top soil surface than at deeper soil depths. Na^+ ion content being in much higher quantity than Cl^-, thus exhibiting sodicity conditions.

Both the species studied in reference to growth under saline conditions could be classified into two groups; (i) *T. indica* that had lower growth rate; and (ii) *S. fruticosa* exhibiting higher growth rate. This higher growth rate in the latter species could be attributed to its ability to accumulate high ion concentration to maintain turgor and use the energy produced by cell for normal growth processes. Such high growth rates due to high salt uptake has been reported (Ala *et al.*, 1994; Jefferies & Rudmik, 1991; Yeo, 1983). Plant volume of *S. fruticosa* increased gradually till the mid of September (8 weeks) after which the shoot volume became more or less constant as during this period the plants entered into the reproductive phase and hence exhibited no variation in growth rate of vegetative parts.

There was significant relationship between plant volume and EC_e estimated from EM_h and EM_v. Correlations/regressions obtained from these results were better than those between plant volume and EC_e of the composite soil sample at 0-100 cm depth. Significant relationships were also found between plant volume and soil moisture content, which indicate that availability of moisture and its influx to the plant significantly affects plant growth.

Responses of transpiration to soil water status is reported to be modified by transpiration demand, as influenced by air humidity and temperature (Eshel & Waisel, 1984). Transpiration rate and stomatal conductance are related to each other as they both depend on the opening/closing of stomates. In the present study, there were non-significant differences between initial dry and subsequent wet conditions with respect to these parameters. It would suggest that after one day of moisture application the root system of plants did not absorb moisture in amount to cause an appreciable increase in stomatal opening and consequently increase in transpiration rate and stomatal conductance were not evident. After 5 days interval, moisture application in soil was able to increase the transpiration pull and thus exhibited higher transpiration rate and stomatal conductance. Increase in transpiration rates is usually accompanied by a high electrolyte concentration both in non-halophytes and halophytes (Greenway, 1965).

Plants regulate their internal osmotic balance by varying their water relation and accumulation of organic compounds. Halophytic plants also have an advantage of accumulating ions (mainly Na^+ and Cl^-) for maintaining their osmotic potential. Majority of the transported salts are accumulated in the vacuole for turgor maintenance, particularly in *Salicornia* and *Suaeda* species, which have leaves composed of enlarged cells in which the vacuoles occupy most of the cell volume (Gorham, 1993). Upto 90% of the total ions absorbed by roots is transported to shoot, 95% of which is localized in the vacuole (Flowers *et al.*, 1986). Increased salt acccumlation in cells with age may lead to saturation of vacuole and consequently localization in cytoplasm also, leading to senescence and death of the plant parts.

The halophytic plants are known to absorb salts to balance the negative osmotic potential of soil. Some plants accumulate more cations (Na^+) whereas, other accumulate anions (Cl^-) to balance the osmotic gradient, while some plants absorb equal amounts of these ions. As compared to *S. fruticosa*, *T. indica* exhibited lower concentrations of Na^+ in plants, but had higher quantities of Cl^- ions. High Cl^- concentrations can also be attributed to the fact that in addition to other parts of leaf, Cl^- has been reported to be present in additional sites of *Tamarix aphylla*, including the apoplast (walls) of the mesophyll cells and the walls of the transfusion zone (Campbell & Thomson, 1975). Though it is still debatable as to which ion is more toxic (Gorham, 1993), yet in monocots, Na^+ is reported to be more toxic than Cl^- ions (Kingsbury & Epstein, 1986). *Tamarix* species are also reported to `avoid' salt stress by extracting water from less saline soil profile (where less saline solution is present).

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