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ALLEVIATION OF SALINITY TOLERANCE BY FERTILIZATION IN FOUR THORN FOREST SPECIES FOR THE RECLAMATION OF SALT-AFFECTED SITES

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Abstract

Salinity tolerance and the effect of salinity-fertility interaction on growth and dry matter production of four native thorn forest species viz., *Salvadora oleoides* Decne., *Prosopis cineraria* (L.) Druce., *Capparis decidua* (Forsk.) Edgew. and *Tamarix aphylla* (L.) Karsten) was assessed by conducting a pot experiment. Treatments included a combination of 5 levels of salinity (0.65, 5.8, 10.69, 20.71 and 30.4 mS cm^{-1}) and two levels of fertility (control and with addition of 100 kg N ha^{-1} and 60 kg P ha^{-1}) using a factorial design with five replications. The results showed a negative linear relationship between gain in plant height, dry matter production and increasing salinity under both low and increased fertility treatments but the effect was more pronounced under low fertility. All plant characters decreased with increasing salinity levels and were enhanced with increasing fertility. All tree species seemed to be salt tolerant to varying degrees. EC_e value at which dry matter production would be reduced to 50% as compared to un-fertilized control plants was highest for *S. oleoides* followed by *P. cineraria*, *T. aphylla* and *C. decidua* under low fertility and this sequence of decreasing salt tolerance was maintained when plants were supplemented by fertilizers. The interaction between salinity and fertility was significant for all plant parameters suggesting that addition of fertilizers can effectively be used as a restoration strategy to alleviate adverse effects of salinity and to support plant growth under saline conditions.

Introduction

Salinization of soils and ground water is a serious land degradation problem in arid and semi-arid areas and is increasing steadily in many parts of the world including Pakistan. According to conservative estimate, about 7% of total land area of the world is saline to varying degrees (Szabolcs, 1994). In Pakistan about 6.3 M ha are believed to be affected by salinity (Qureshi & Barrett-Lennard, 1998) and is caused mostly by the presence of NaCl (Mushtaq & Rafique, 1977).

For overcoming salinity problem two primary lines of action are being emphasized: reclamation by using chemical amendments or by growing salt tolerant plants (Ashraf, 1994; Flowers *et al*., 1997; Shannon & Grieve, 1999). During the past few decades scientists have emphasized the latter strategy, formally called the *biotic approach* considering it economical, feasible and efficient (Ashraf & McNeilly, 2004). For this purpose use of salt-tolerant clones of forest tree species is also suggested (Cha-um & Kirdmanee, 2008). Trees cause remediation of saline soil in terms of lowering saline water table, using underground water and decreasing evaporation rate (Barrett-Lennard, 2002). They improve physical, chemical and biological properties of soil.

The dominant climax species of plain thorn forest community, *Salvadora oleoides* Decne. and *Prosopis cineraria* (L.) Druce., are often associated with *Capparis decidua* (Forsk.) Edgew. and *Tamarix aphylla* (L.) Karsten (Parker, 1954., Champion *et al*., 1965). All the plant species of thorn forests have been identified as providers of medicine, fiber, construction material, fodder and fuel (Khan, 1996) and are reported to increase soil fertility under them by adding nutrients to the soil (Puri & Kumar, 1995; Ramoliya & Pandey, 2002; Yin, *et al*., 2009). They also contribute to the stability of the fragile desert sand dunes where little else grows (Gates & Brown 1988; Pandey & Rokad, 1992; Khan, 1994) and are salt tolerant and drought resistant (Khan & Qaiser, 2006).

The defense response of higher plants to salt stress is a complex system, which depends on a particular stage of morphological and developmental processes, salt tolerant ability and environmental effects (Ashraf & Harris, 2004). Waisel (1961) investigated the effect of saline irrigation on growth of young saplings of *T. aphylla*. The saplings died when the concentration of the solutions was raised to about 0.7*M* NaCl and growth was depressed even by irrigation with a 0.1*M* NaC1 solution. *P. cineraria* is reported to be very flexible in terms of soils, accepting highly alkaline soils with pH up to 9.8 and to salinity accepting salt concentrations up to half of sea water strength *i.e*., 18,000 mg L^{-1} or 25 mS cm^{-1} electrical conductivity (Qureshi & Barrett-Lennard, 1998). Both *S. oleoides and P. cineraria* are reported to be salt tolerant even at seedling stage, tolerating salinity up to 16.5 and 13.3 dS m^{-1} respectively (Ramoliya & Pandey, 2002; Ramoliya *et al*., 2006). On the basis of field observations *C. decidua* is reported to possess fair tolerance to salinity and alkalinity. In Cholistan Desert it was found in all the seven vegetation types, showing 100% frequency on the soils with EC values ranging from 0.8-10.70 dS m^{-1}, low organic matter (0.17 – 0.18%), 2.26 mg/100 g Na concentration and 0.0188 mg/100g Na^+/K^+ ratio. It was found on soils with moderate K and low P (Arshad *et al*., 2008).

It is difficult to study plant response to fertilizers under saline conditions due to high concentration of salts and nutritional imbalances (Esmaili *et al*., 2008). Studies showed that application of fertilizers in saline soils might result in increased, decreased or unchanged plant salt tolerance. In other words, plant response to fertilizers depends on severity of salt stress in the root zone (Maas & Grattan, 1999). Under low salinity stress, nutrient deficiency limits plant growth more than salinity and a positive interaction or an increased salt tolerance response occurs. While under moderate and high salinity, the limiting effect of salinity also affects plant growth (Grattan & Grieve, 1999).

Most investigations on salinity-fertilizer issue focused either on fertilizer influence on plant or on salinity as limiting plant growth factor. Comparatively few publications are available in the literature on interactive effects of salinity and fertilization, of which majority are being conducted on agricultural crops (Garg *et al*., 1993; Helalia *et al*., 1996; Kabir *et al*., 2005) to a lesser extent on grasses (Smart & Barko, 1980; Tawfik *et al*., 2006), shrubs (Adam, 2004; Lee *et al*., 2007) and trees (Percival & Barnes, 2005; Lovelok *et al*., 2009).

Phosphorus nutrition has been implicated in modifying the effects of saline conditions upon the growth of glycophytic plants (Champagnol, 1979; Feigin, 1985). However, the evidence is contradictory. Phosphorus/salinity interactions reported range from an induced enhancement of salinity tolerance by phosphorus (Ravikovitch & Yoles, 1971; Garg *et al*., 2005) to antagonism between phosphorus fertilization and salinity (Nieman & Clark, 1976; Cerda *et al*., 1977). Other studies report no interactions (Khalil *et al*., 1967; Termaat & Munns, 1986). Similar types of reports have been found for salinity and Nitrogen interaction with an improved salt tolerance with N (Choi *et al*., 2004; Al-Harbi *et al*., 2008), reduced salt tolerance with N (Khalil *et al*., 1967; Peters, 1983) and no effect (Selassie & Wagenet, 1981; Drenovsky & Richards, 2003).

The objective of this study was to determine the salt tolerance of the four species and the response of these species to fertilization under saline conditions. Plain thorn forest community is described as threatened (Khan, 1994) and archaeological site of Harappa was identified as the only site in Punjab which has remnants of this community (Khan & Sharif, 2004). There is a barren salt-affected area of 36 acres at Harappa mound which is available for augmenting the population of thorn forest community. *In-situ* conservation and rehabilitation of this community will not only protect this biological wealth but will also provide an ideal site for the students of ecology to study native vegetation in its natural habitat (Sharif & Khan, 2006). No study in the literature was found on the salinity-fertility interaction of the four thorn forest species, so this study will facilitate the rehabilitation of this community at Harappa mound. Moreover information thus gathered will also be helpful in the bio-reclamation of other saline wastelands.

Materials and Methods: The present study was conducted at GC University Botanic Garden (GCBG), Lahore (lat 31°32´59˝ long 74°20´37˝ elevation 217m). Mean percentage relative humidity was 59.4 ± 17.33% and mean maximum and minimum temperatures were 36.42 ± 2.2ºC and 26.28 ± 2.03ºC respectively during the study period (April, 15^{th} to August, 30^{th}, 2006).

Salinity treatments provided were in mS cm^{-1} of the soil saturation extract. Experiment comprised of five replicates of NaCl salinity treatments i.e., S_0 - S_4 from 0 - 30 mS cm^{-1} soil salinity and two levels of fertility with no addition of N and P (F_0) representing low fertility and with addition of N and P @ of 100 and 60 kg ha^{-1} respectively i.e increased fertility (F_1) in factorial design. Soil used for this experiment was sandy loam containing 56.2% sand, 27.1% silt and 16.7% clay. pH of the soil was 7.5 and the EC_e mS cm^{-1} was 0.65. Soil fertility was low with respect to nitrogen (0.05%) and phosphorus (0.01%). Soil with low N and P was used in the experiment because soils of natural habitat of thorn forest community are naturally low in organic matter and deficient in plant available nutrients, especially P (Muhammad *et al*., 2008). Four lots of soil, 100 Kg each, were separately spread over a 50 mm thick polyethylene sheet after air drying and sieving. To achieve various salinity grades 292.5, 585, 1170 and 1755 g NaCl was mixed in respective soil lots. The fifth lot was maintained as control. Saturation extracts were made from control and these salinized soil samples and their electrical conductivity was measured with "Sesmo-Direct Con200" conductivity meter and was found to be 0.65, 5.8, 10.69, 20.71 and 30.4 mS cm^{-1} respectively.

Thoroughly cleaned earthen pots of 30cm diameter were used in this experiment. Pots were lined with polyethylene and were filled with 10 Kg of respective salinized soil. Six months old plants (*T. aphylla* raised from stem cuttings) and ten months old plants (*Capparis decidua*, *Prosopis cineraria*, *Salvadora oleoides*, propagated from seeds) of almost equal height were selected and their shoot lengths were noted. One plant of each species was transplanted in a pot under each treatment. Fertilizer provided was in the form of Urea and DAP. Pots were labeled according to their respective treatment and were kept in a fenced enclosure in natural light for four and a half months. The top of the enclosure was covered by a thick and transparent plastic sheet. As all the four species are characteristic of arid and semi-arid environments so the seedlings were watered when required. During the entire period weeds were removed by hand and plants were monitored regularly for taking plant height.

Plant height and dry weights (shoot, root and total plant biomass) were used as growth indices. Final shoot lengths were noted at the time of harvest. Gain in plant height was determined by subtracting their initial reading from final reading. After harvesting plant tissues (roots and shoots) from all treatments were dried in an oven at 65°C for 48h. Dry weight of roots and shoots were noted and leaves were separated from shoots. Percent relative weight of tissues of plants compared to those of un-fertilized control plants were computed as (total plant tissue dry weight/un-fertilized control dry weight) x 100. Data recorded were subjected to ANOVA using a full factorial design to see the effect of fertility, salinity and fertility*salinity interaction on height and dry weights of plants using the SPSS software version 16 (SPSS for Windows, SPSS Inc. USA). For assessing the effect of increasing soil salinity under low (F_0) and increased (F_1) fertility, treatment means were compared with their respective controls (S_0F_0 and S_0F_1) by applying Tukey test. The Correlations between growth parameters and salt concentrations were evaluated by Pearson's correlation coefficients for both low and increased fertility treatments. Salt concentration at which total plant biomass was reduced by 50% (DW_{50}) as compared to un-fertilized control (S_0F_0) under both low and increased fertility was determined by fitting a straight line relationship between the response and salt concentration.

Results

The alleviation of adverse effects of salinity by increasing fertility on growth and dry matter production of the four thorn forest species are described below.

I. *Capparis decidua*: All plant characteristics except root/shoot dry weight ratio were significantly decreased ($p<0.01$) with increasing salinity levels under both low and enhanced fertility (Fig. 1 and Table 1). However the effect of salinity was more pronounced under low fertility treatment and increasing soil fertility had a significantly positive effect ($p<0.01$) on plants (Table 1). There was a negative linear relationship (r = -0.912 and -0.908 $p<0.01$) between increase in plant height, (r = -0.955 and -0.878 $p<0.01$) shoot dry weight, (r = -0.941 and -0.862 $p<0.01$) root dry weight, (r = -0.950 and -0.872 $p<0.01$) total plant biomass and increasing salt concentration under increased and low fertility treatments, respectively. Plants grew and survived at 20.71 mS cm^{-1} soil salinity indicating that this is a salt tolerant species.

Multiple comparisons ($p< 0.01$ or $p<0.05$) for increasing salinity from 0.65 to 5.8 mS cm^{-1} showed significant decline in all the parameters under investigation for both low (un-fertilized) and increased fertility (100 kg N ha^{-1} and 60 kg P ha^{-1}) treatments (Fig. 1). Soil salinity levels of 10. 69 to 20.71 mS cm^{-1} significantly affected ($p< 0.01$) all growth and dry weight parameters with or without fertilizer addition as compared to their controls.

Significant fertility*salinity interaction ($p<0.05$) was shown by dry weights of shoot, root and total plant biomass (R^2_{Adj} = 0.903, 0.879 and 0.894 respectively). While plant height (p= 0.461) and root/shoot dry weight ratios (p=0.708) did not show any significant fertility*salinity interaction (Table 1). Percentage relative tissue dry weights as compared to un-fertilized control plants remained higher for increased fertility treatment at all salinity levels (Fig. 5). The salt concentrations at which total plant dry weights would be reduced to 50% of un-fertilized control plants (DW_{50}) were 12.85 mS cm^{-1} for low (y %age relative tissue dry weight = 97.185 – 3.6734x, R^2_{Adj} = 0.948) and 19.26 mS cm^{-1} for increased fertility treatment (y %age relative tissue dry weight = 134.15 – 4.3696x, R^2_{Adj} = 0.850), respectively.

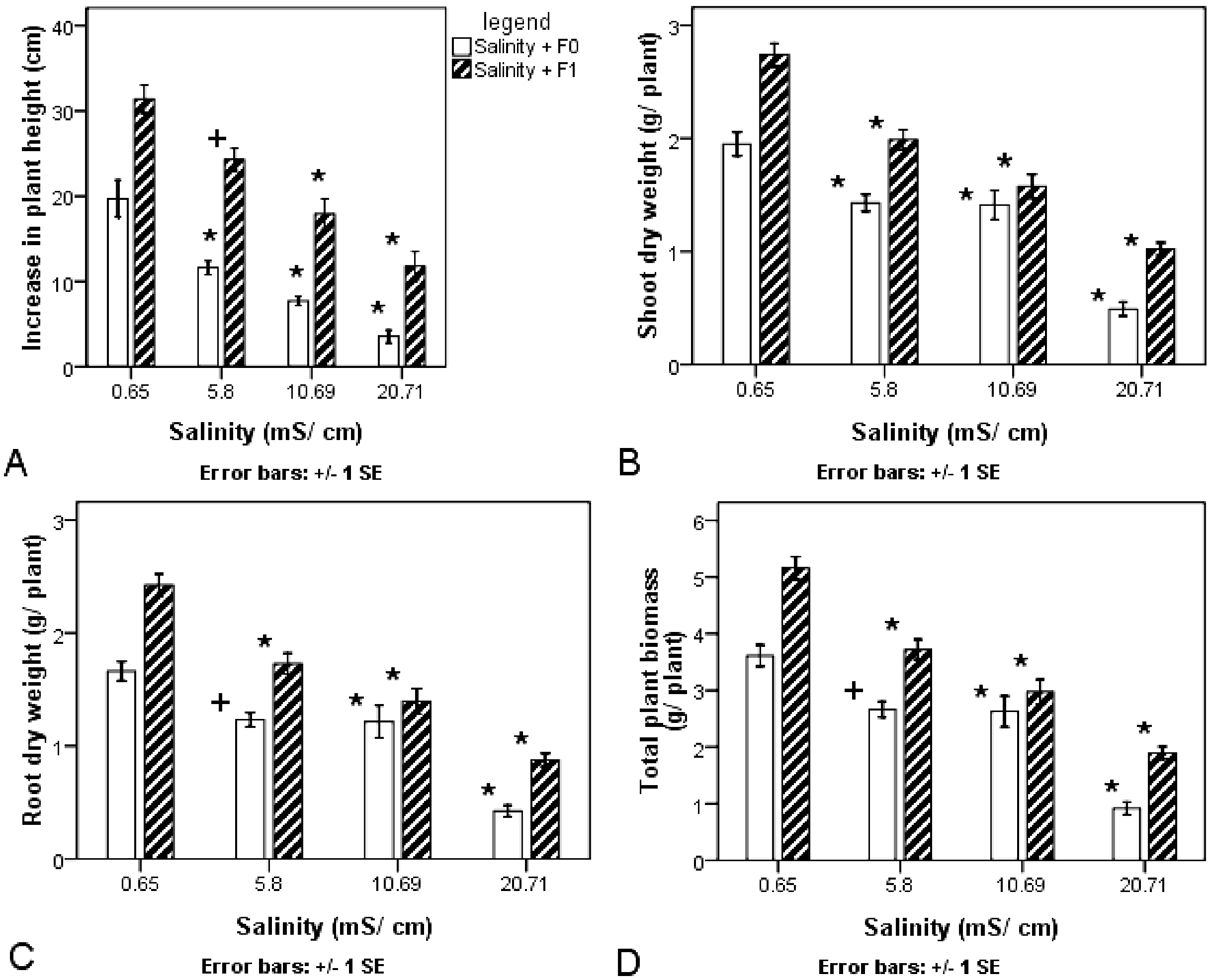

Fig. 1. Effect of salinization of soil under low (un-fertilized) and increased (100 kg N ha^{-1} and 60 kg P ha^{-1}) fertility treatments on (A) plant height (cm); (B) shoot dry weight (g plant^{-1}); (C) root dry weight (g plant^{-1}) and (D) total plant biomass (g plant^{-1}) of *Capparis decidua* plants. Results of one-way ANOVA are given *, treatment means significantly different at $p<0.01$ from their controls; +, treatment means significantly different at $p<0.05$ from their controls; ns, non-significant at $p>0.05$ (Tukey test).

II. *Tamarix aphylla*: The low fertility and increasing salt concentration both significantly reduced ($p<0.01$) plant height, shoot dry weight, root dry weight and total plant biomass (Table 1 and Fig. 2), while root/shoot dry weight ratios remained un-affected by both factors ($p>0.05$). There was a significant negative linear relationship (r = -0. 946 and -0.944 $p<0.01$) between increase in plant height, (r = -0.954 and -0.957 $p<0.01$) shoot dry weight, (r = -0.957 and -0.963 $p<0.01$) root dry weight, (r = -0.958 and -0.961 $p<0.01$) total plant biomass and increasing salt concentration under increased and low fertility treatments, respectively.

Multiple comparisons ($p<0.01$ or $p<0.05$) for increasing salinity from 0.65 to 5.8 mS cm^{-1} showed significant decline in root and total plant dry weights under both low (un-fertilized) and increased fertility (100 kg N ha^{-1} and 60 kg P ha^{-1}) treatments (Fig. 2). Decrease in plant height was however non-significant (p= 0.071) for low fertility and shoot dry weight was non-significant (p= 0.063) for fertilizer treated plants as compared to their respective counterparts. Although difference in plant height was significant for increased fertility plants but even then they gained 7.88% and 30.82% more height as compared to un-fertilized control and plants grown under same salinity level (5.8 mS cm^{-1}), respectively.

Table 1. Analysis of variance for growth and dry matter characters of the plants of four tree species grown under different salinity and fertility levels.

Plant species	Sources of variance	Df	Mean squares				
			Increase in height	Shoot dry weight	Root dry weight	Total plant biomass	Root/shoot dry weight ratio
C. decidua	Fertility	1	1149.184**	2.604**	2.227**	9.646**	0.002
	Salinity	3	583.779**	4.286**	3.292**	15.088**	6.34E-05
	Fertility * salinity	3	9.254	0.166†	0.142†	0.611†	0.001
	Error	32	10.502	0.043	0.043	0.168	0.002
T. aphylla	Fertility	1	788.045**	813.061**	240.704**	1938.540**	0.008
	Salinity	4	1512.595**	1356.985**	521.114**	3558.858**	0.001
	Fertility* salinity	4	27.620 †	39.141†	12.415†	92.301†	0.006
	Error	40	12.985	13.26	4.455	31.241	0.002
P. cineraria	Fertility	1	1102.621**	14.344**	11.452**	51.436**	0.000
	Salinity	4	1329.356**	11.579**	9.106**	41.557**	0.001
	Fertility* salinity	4	32.888†	0.655†	0.485†	2.265†	0.001
	Error	40	11.12	0.175	0.13	0.599	0.001
S. oleoides	Fertility	1	1635.920**	10.859**	8.756**	39.119**	0.000
	Salinity	4	1935.132**	8.652**	6.866**	30.933**	0.001
	Fertility* salinity	4	31.757†	0.645†	0.585†	2.456†	0.001
	Error	40	10.422	0.236	0.185	0.822	0.002

** Highly significant at 0.01 level, ANOVA

† Significant at 0.05 level, ANOVA

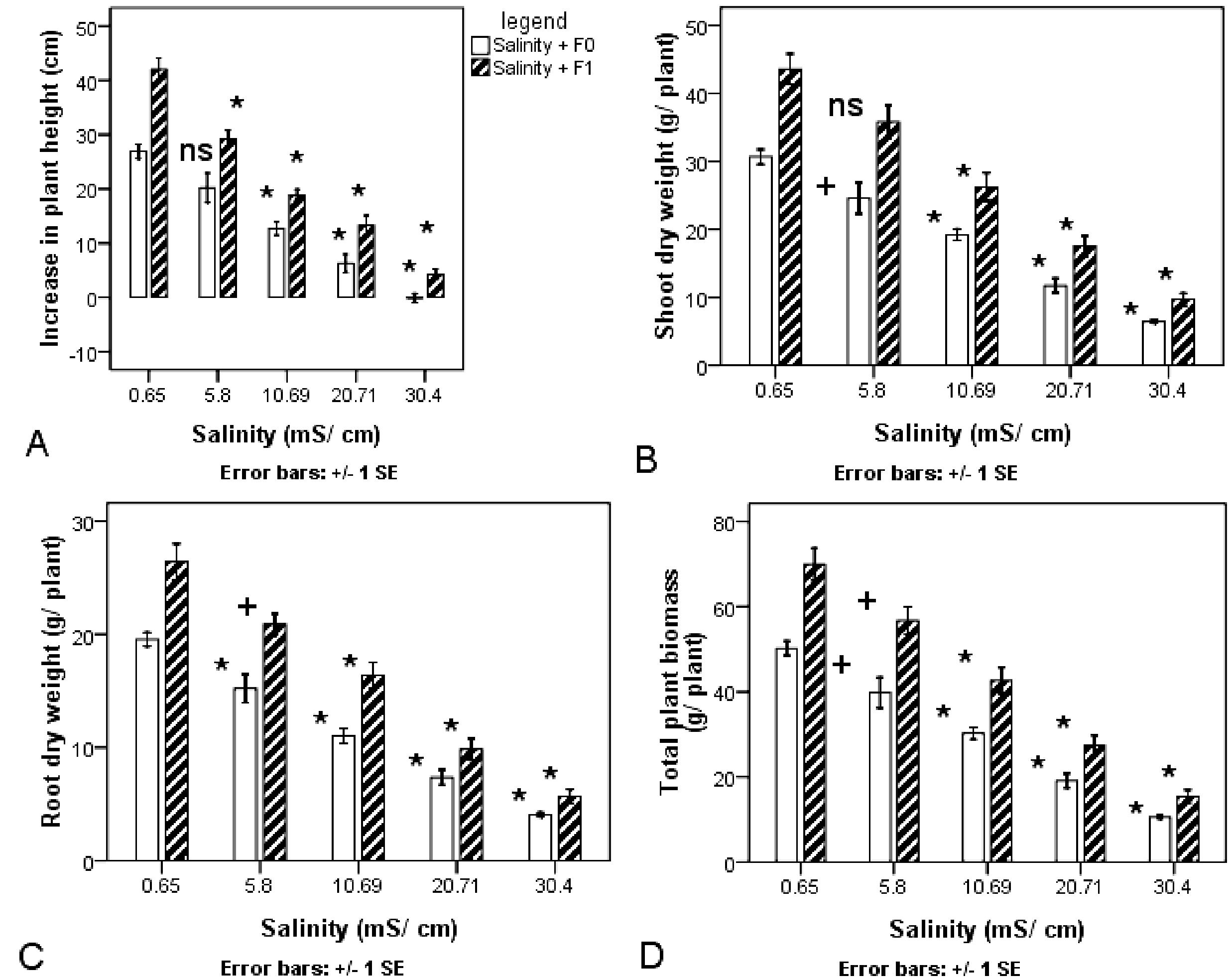

Fig. 2. Effect of salinization of soil under low (un-fertilized) and increased (100 kg N ha^{-1} and 60 kg P ha^{-1}) fertility treatments on (A) plant height (cm); (B) shoot dry weight (g $plant^{-1}$); (C) root dry weight (g $plant^{-1}$) and (D) total plant biomass (g $plant^{-1}$) of *Tamarix aphylla* plants. Results of one-way ANOVA are given; *, treatment means significantly different at $p<0.01$ from their controls; +, treatment means significantly different at $P < 0.05$ from their controls; ns, non-significant at $p>0.05$ (Tukey test).

Soil salinity levels of 10. 69 to 30.4 mS cm^{-1} significantly affected ($p<0.01$) all above mentioned parameters with or without fertilizer addition. Growth completely stopped at 30.4 mS cm^{-1} with no further gain in plant height under low fertility. But plants growing under same salinity level gained 4.3 cm height when supplemented with fertilizers.

Significant fertility*salinity interaction ($p<0.05$) was shown for plant height, shoot dry weight, root dry weight and total plant biomass with values of R^2_{Adj} = 0.915, 0.906, 0.914 and 0.914, respectively (Table 1). Percentage relative tissue dry weights as compared to un-fertilized control plants remained higher for increased fertility treatment at all salinity levels (Fig. 5). The salt concentrations at which total plant dry weights would be reduced to 50% of un-fertilized control plants (DW_{50}) were 17.38 mS cm^{-1} for low (y %age relative tissue dry weight = 95.202 – 2.6008x, R^2_{Adj} = 0.957) and 23.23 mS cm^{-1} for increased fertility treatment (y %age relative tissue dry weight = 133.56 – 3.5982x, R^2_{Adj} = 0.960), respectively.

III. *Prosopis cineraria*: Plants survived and grew up to soil salinity of 30.4 mS cm^{-1}, which suggests that *P. cineraria* is a highly salt-tolerant plant species. The increasing concentration of salt in soil under both low and increased fertility treatments retarded the elongation of stem and accumulation of shoot, root and total plant biomass ($p<0.01$), as compared to those in control soil (Table 1 and Fig. 3). But this effect was more pronounced under low fertility as fertilizer addition significantly enhanced plant growth and dry weight production ($p < 0.01$) as compared to un-fertilized plants (Table 1). There was a significant negative linear relationship (r = -0. 965 and -0.934 $p<0.01$) between increase in plant height, (r = -0.936 and -0.885 $p<0.01$) shoot dry weight, (r = -0.941 and -0.885 $p<0.01$) root dry weight, (r = -0.939 and -0.886 $p<0.01$) total plant biomass and increasing salt concentration under increased and low fertility treatments, respectively.

No significant decrease ($p>0.05$) in shoot dry weight, root dry weight and total plant biomass was found as compared to control (0.65 mS cm^{-1}), when plants were subjected to slight salinity (5.8 mS cm^{-1}) under both low and increased fertility treatments (Fig. 3). While there was a significant decline ($p<0.01$) in gain in plant height as compared to their controls (0.65 mS cm^{-1}) under both fertility treatments. Soil salinity levels of 10. 69 to 30.4 mS cm^{-1} significantly affected all the above mentioned parameters ($p<0.01$) with or without fertilizer addition as compared to their controls.

Significant fertility*salinity interaction ($p<0.05$) was shown by plant height, shoot dry weight, root dry weight and total plant biomass with values of R^2_{Adj} = 0.922, 0.879, 0.884, 0.883, respectively (Table 1). Percentage relative tissue dry weights as compared to un-fertilized control plants remained higher for increased fertility treatment at all salinity levels (Fig. 5). The salt concentrations at which total plant dry weights would be reduced to 50% of un-fertilized control plants (DW_{50}) were 24.25 mS cm^{-1} for low (y %age relative tissue dry weight = 97.377 – 1.9539x, R^2_{Adj} = 0.943) and 30.46 mS cm^{-1} for increased fertility treatment (y %age relative tissue dry weight = 141.66 – 3.0088x, R^2_{Adj} = 0.953), respectively.

IV. *Salvadora oleoides*: Both low fertility and increasing salt concentration significantly ($p<0.01$) reduced plant height, dry weights of shoot and root and total plant biomass (Table 1 and Fig. 4). While root/shoot dry weight ratios remained un-affected by both factors ($p>0.05$). There was a significant negative linear relationship (r = -0.967 and -0.949 $p<0.01$) between increase in plant height, (r = -0.931 and -0.770 $p<0.01$) shoot dry weight, (r = -0.931 and -0.768 $p<0.01$) root dry weight, (r = -0.933 and -0.771 $p<0.01$) total plant biomass and increasing salt concentration under increased and low fertility treatments, respectively.

Multiple comparisons show no significant decrease ($p>0.05$) in shoot dry weight, root dry weight and total plant biomass as compared to control (0.65 mS cm^{-1}), when plants were subjected to slight salinity (5.8 mS cm^{-1}) under both low and increased fertility treatments (Fig. 4). There was a non-significant decrease in shoot length (P = 0.073) under low fertility while this decline was significant ($p<0.01$) for fertilizer supplemented plants under 5.8 mS cm^{-1} soil salinity level. Even then in fertilizer treated plants, gain in plant height was 21.43% and 39% more as compared to un-fertilized control and plants grown at same salinity (5.8 mS cm^{-1}) but low fertility level, respectively.

Significant fertility*salinity interaction ($p<0.05$) was shown by all plant parameters under investigation (Table 1) with values of R^2_{Adj} = 0.949, 0.799, 0.802 and 0.804 for gain in plant height, shoot dry weight, root dry weight and total plant biomass respectively. Percentage relative tissue dry weights as compared to un-fertilized control plants remained higher for increased fertility treatment at all salinity levels (Fig. 5). The salt concentrations at which total plant dry weights would be reduced to 50% of un-fertilized control plants (DW_{50}) were 28.55 mS cm^{-1} for low (y %age relative tissue dry weight = 100.10 – 1.786x, R^2_{Adj} = 0.996) and 32.93 mS cm^{-1} for increased fertility treatment (y %age relative tissue dry weight = 148.52 – 2.992x, R^2_{Adj} = 0.994) respectively.

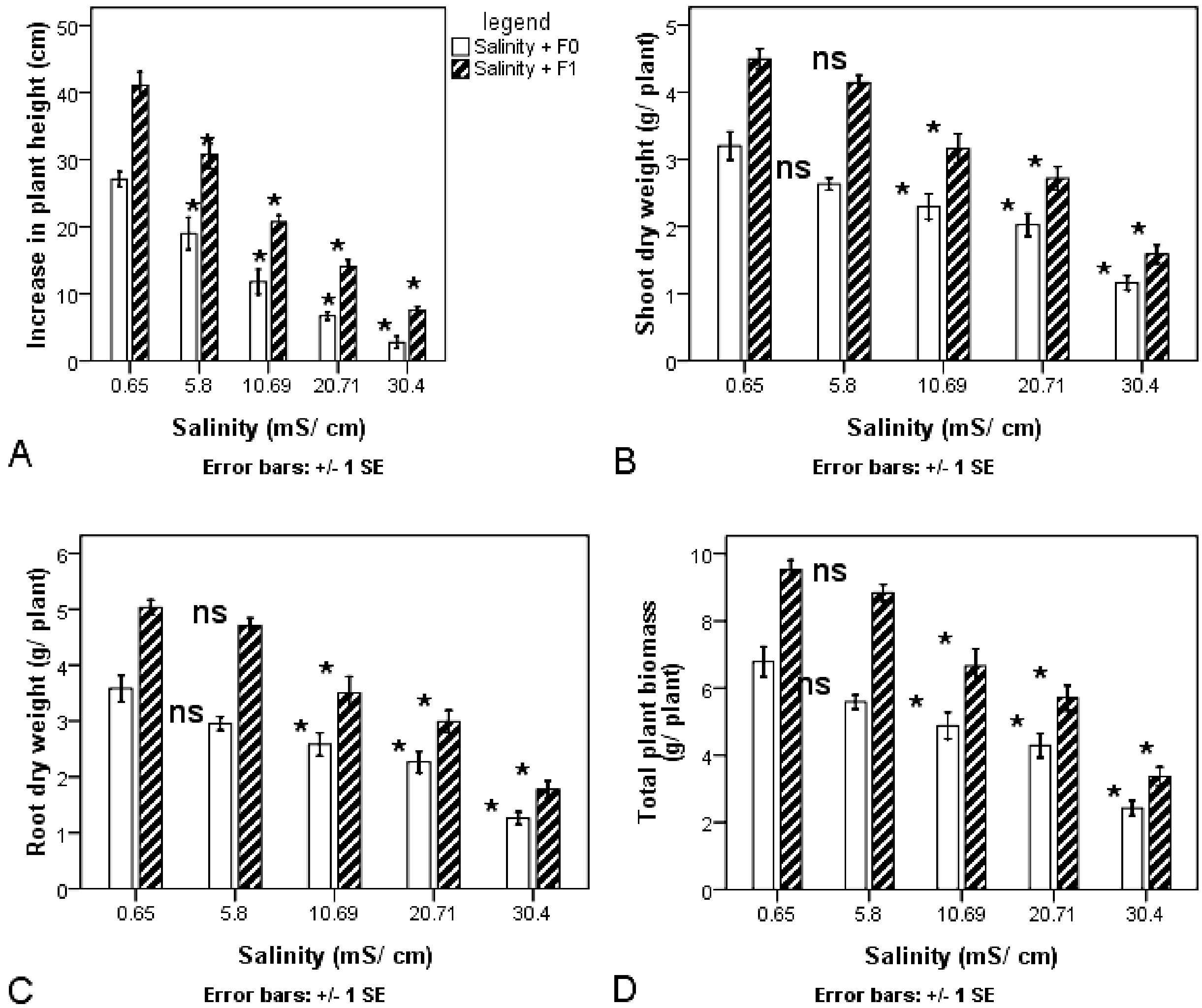

Fig. 3. Effect of salinization of soil under low (un-fertilized) and increased (100 kg N ha^{-1} and 60 kg P ha^{-1}) fertility treatments on (A) plant height (cm); (B) shoot dry weight (g $plant^{-1}$); (C) root dry weight (g $plant^{-1}$) and (D) total plant biomass (g $plant^{-1}$) of *Prosopis cineraria* plants. Results of one-way ANOVA are given; *, treatment means significantly different at $p<0.01$ from their controls; +, treatment means significantly different at $p<0.05$ from their controls; ns, non-significant at $p>0.05$ (Tukey test).

Discussion

Salinity significantly reduced plant height of all the four tree species under both low and increased fertility treatments. However growth was significantly promoted under increased fertility conditions. Maximum decline in plant height as compared to control (0.69 mS cm^{-1}) at the highest salinity level (20.71 mS cm^{-1} for *C. decidua* and 30.4 mS cm^{-1} for rest three species) was more than 100% for *T. aphylla* followed by 89.7% for *P. cineraria*, 82.7% for *S. oleoides* and 82.23% for *C. decidua*.

Dry weight production of shoots, roots and total plant biomass were also significantly reduced by salinity in all the four species under low and increased fertility treatments. However increased fertility significantly enhanced dry matter production in all plants. Different plant parts were not equally affected by salinity, the growth of shoots was more suppressed than that of roots. Although not statistically significant but increase in root/shoot dry weight ratios as compared to their controls with increasing salinity

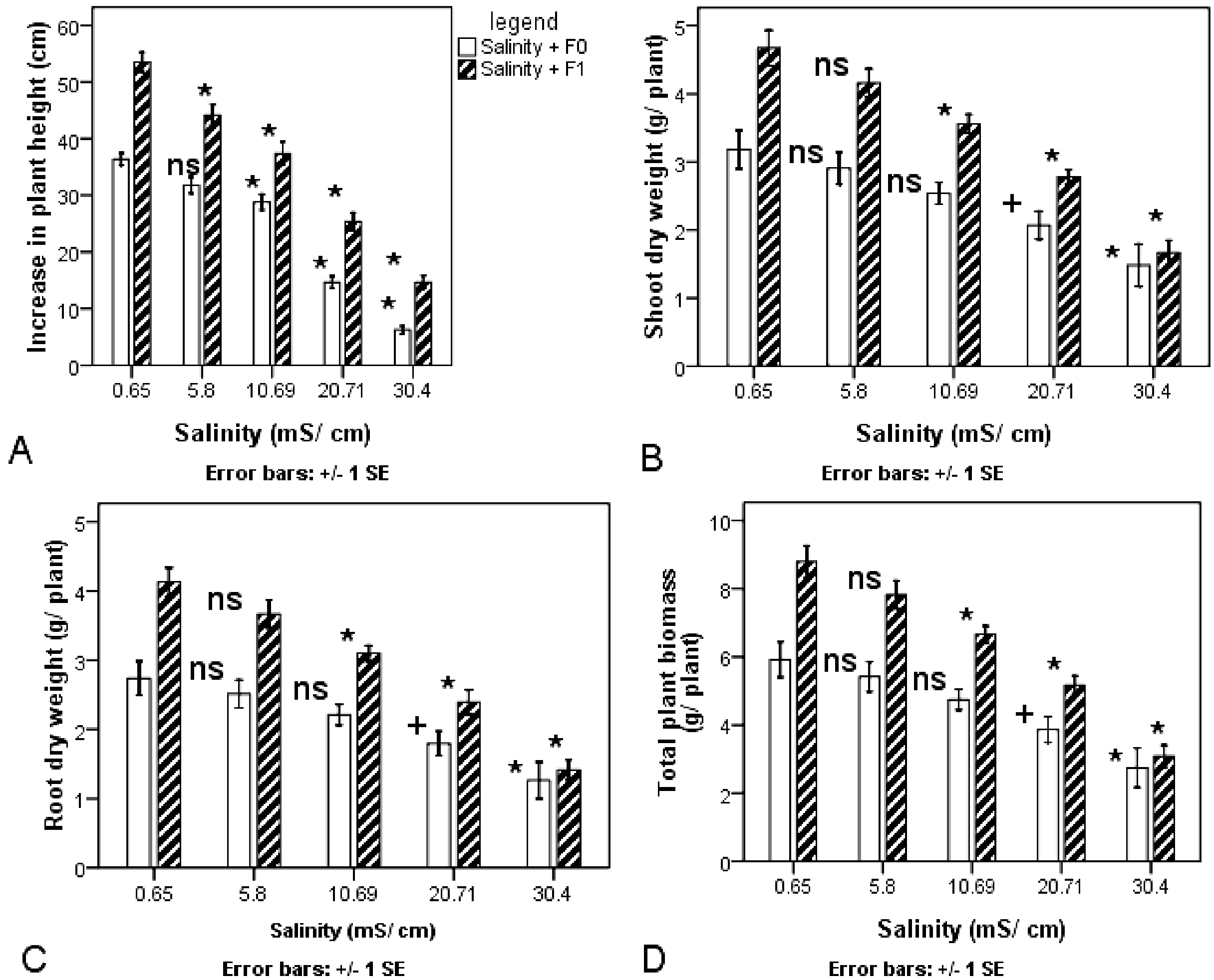

Fig. 4. Effect of salinization of soil under low (un-fertilized) and increased (100 kg N ha^{-1} and 60 kg P ha^{-1}) fertility treatments on (A) plant height (cm); (B) shoot dry weight (g $plant^{-1}$); (C) root dry weight (g $plant^{-1}$) and (D) total plant biomass (g $plant^{-1}$) of *Salvadora oleoides* plants. Results of one-way ANOVA are given; *, treatment means significantly different at $p<0.01$ from their controls; +, treatment means significantly different at $p<0.05$ from their controls; ns, non-significant at $p>0.05$ (Tukey test).

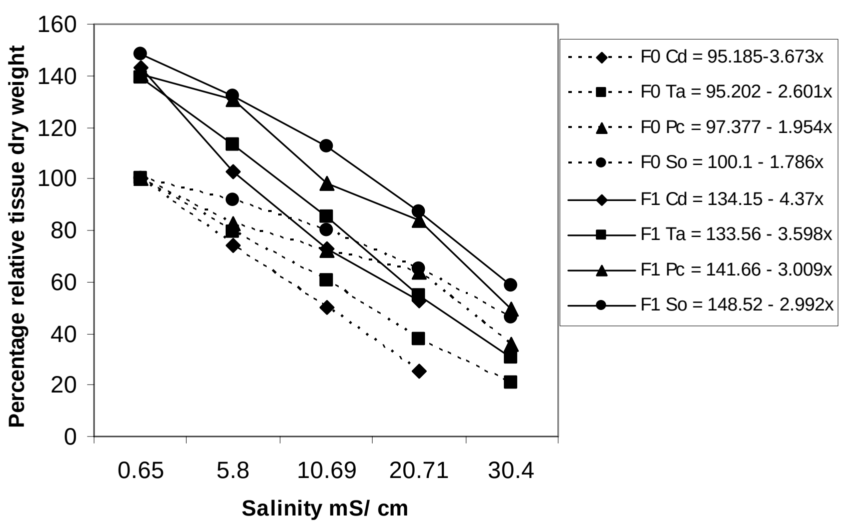

Fig. 5. Regression of salinity on percentage relative tissue dry weights of plants as compared to their un-fertilized controls under low (F_0) and increased (F_1) fertility treatments (see text for values of R^2_{Adj}). **Cd**, *Capparis decidua*; **Ta**, *Tamarix aphylla*; **Pc**, *Prosopis cineraria*; **So**, *Salvadora oleoides.*

under low fertility treatment reaching from 0.89 to 0.92 in *P. cineraria* and from 0.85 to 0.87 in *C. decidua* at highest salinity level shows that shoot biomass accumulation is more retarded as compared to roots in response to increasing salinity. This trend was reversed in fertilized plants and there was a decrease in root/shoot dry weight ratios as compared to control with increasing salinity levels. Decrease in root/shoot dry weight ratio of fertilized *C. decidua* (0.89 – 0.86), *T. aphylla* (0.60 to 0.58) and *S. oleoides* (0.89 to 0.85) plants suggest that fertilizer application has supported shoot growth more than root growth even under highly saline conditions.

All plant parameters showed significantly positive salinity-fertility interaction, which means that fertility helps in alleviating the toxic effects of soil salinity. Increase in shoot height showed positive salinity-fertility interaction in all plants except for *C. decidua*. Production of shoot, root and total plant dry weights were more persistent characteristics and showed positive salinity-fertility interaction for all plant species. Although there was not much variation among the four plant species in percentage relative dry tissue weight production as compared to un-fertilized controls, under increased fertility (being highest 148.44% for *S. oleoides* and lowest 139.2% for *T. aphylla*) under non-saline conditions, but the difference in their response under higher salinity treatments characterized the plants on the basis of their salt tolerance (Fig. 5). As the definition of salt tolerance is usually the percent biomass production in saline soil relative to plants in non-saline soil, after growth for an extended period of time (Munns, 2002). EC_e values at which dry matter production would be reduced to 50% of the un-fertilized control plants was highest for *S. oleoides* (28.55 mS cm^{-1}) followed by *P. cineraria* (24.25 mS cm^{-1}), *T. aphylla* (17.38 mS cm^{-1}) and *C. decidua* (12.85 mS cm^{-1}) under low fertility and this sequence of decreasing salt tolerance was maintained when plants were supplemented by fertilizers and the EC_e values were increased to 32.93, 30.46, 23.23 and 19.26 mS cm^{-1} respectively. It showed that in all the four plant species salt tolerance was increased under high fertility.

Above mentioned results show that all the plants under investigation are salt tolerant to varying degrees with *C. decidua* being the most sensitive for which percentage survival was low at 30.4 mS cm^{-1} under both high and low fertility treatments which led to cessation of experiment at this salinity level. There was no gain in height (rather it decreased slightly as compared to its initial value) in *T. aphylla* plants grown under low fertility indicating that growth totally ceased at this salinity level. These results are in accordance with Waisel (1960), who found no increase in weight of *T. aphylla* seedlings when irrigated with 0.3 *M* NaCl solution.

S. oleoides and *P. cineraria* were found to be most salt tolerant species with 50% dry weight reduction at 28.55 and 24.25 mS cm^{-1} salinity levels respectively, under low fertility conditions. Earlier studies on these species by Ramoliya & Pandey (2002) and Ramoliya *et al*., (2006) described this limit to be around 18, 20, 15 and 26.5 dS m^{-1} for leaf, stem, upper root and lower root tissues respectively for *S. oleoides* and 11.6, 12.5, 11.8 and 14.3 dS m^{-1} for leaf, stem, upper root and lower root tissues respectively for *P. cineraria*. This difference in salt tolerance of both plant species with the current study can be accounted to the age of the seedlings used in the study. Very young seedlings just after emergence were used in the above mentioned studies and in the current study 9-10 months old plants were used. As mentioned earlier that response to salinity varies appreciably with many environmental factors (e.g., soil fertility, soil physical conditions, irrigation methods and climate) and plant factors (e.g., growth stages, variety and rootstock) (Ghassemi *et al*., 1995). Higher root/shoot dry weight ratios i.e. 0.46 in previous study and 0.89 in the preset study for *P. cineraria* and 0.20 in previous study and 0.86 in the current study for *S. oleoides* indicate that both plants accumulate greater rootstocks with age, which enabled them to withstand high soil salinity levels. Moreover other studies also indicate the sensitivity of young seedlings to soil salinity (Zeng & Shannon, 2000).

Bernstein *et al*., (1974) described three possible types of salinity-fertility relationships. In the first case (type A), the salinity and the fertility impacts at the optimum and sub-optimum fertility levels are independent, since the relative yield (considering the yields in the non-saline treatment as 100%) is the same for the two conditions. The second case (type B) represents decreased salt tolerance at the suboptimal fertility level, while the third case (type C) represents increased salt tolerance under low fertility. All the four plant species in this study show Bernstein's type B salinity-fertility interaction where salt tolerance of plants is decreased at low fertility.

Maximum effect of fertilization was achieved under non-saline conditions in all plants and as salinity increased the difference among the percentage relative dry tissue weights of low and high fertility treated plants was reduced (Fig. 5). It showed that the supplementary effects of fertilizers are dominated by toxic effects of salinity at higher salinity levels and there is a possibility that even higher doses of fertilizers might be required to overcome this effect and to support plant growth. Bernstein *et al*., (1974) explained this as, that the correction of either salinity or fertility limits is more effective when only one of these factors is the main limiting factor. When the limiting effect of both of the above-mentioned factors is severe, the response obtained by the elimination of the other factor will be relatively small; maximal effects of salinity correction and fertilization will be achieved when both factors become non-limiting.

Salinity often upsets the nutritional balance of plants and in addition to interacting with N nutrition, salinity reduces K, Ca and Mg uptake in both glycophytic and halophytic plant species which ultimately reduces plant growth (Rozema *et al*., 1983; Zhong & Läuchli, 1994). Results of present study clearly indicate the role supplemental fertilizers can play in the restoration of thorn forest community at Harappa where saplings of same age and size are translocated to the site. Addition of fertilizers to the plants along with other amendments like soil replacement and gypsum addition would give a jumpstart to the plants and will help them in achieving enough size, vigour and tolerance by the time salinity of the surrounding soil starts impacting on them.

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