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INTERACTIVE EFFECTS OF SALINITY AND WATERLOGGING ON GROWTH AND BIOMASS PRODUCTION IN *ATRIPLEX AMNICOLA* PAUL G. WILSON

**FARKHUNDA ALA, SHOAIB ISMAIL, RAFIQ AHMAD
AND HUMAIRA MARYAM**

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

Abstract

The interactive effects of different salt concentrations (EC: 0, 10 and 20 $dS.m^{-1}$) and waterlogging levels of 75, 100 and 125% water holding capacity on growth of *Atriplex amnicola* Paul G. Wilson in sandy loam and silty loam soils was studied. Plant growth in terms of shoot volume decreased in salinity treatments, with no significant differences at waterlogging treatments. There was an increase in shoot volume in silty loam soil as compared to sandy loam soil. Leaf area : weight ratio (LA:W) showed definite responses to both salinity and waterlogging treatments.

Silty loam soil produced higher biomass as compared to sandy loam soil. High salt contents of EC: 20 $dS.m^{-1}$ at 125% WHC showed adverse effects on biomass production. In sandy loam soils, different plant parts showed non-significant variation in organic matter and ash contents for salt levels, whereas, ash contents increased and organic matter decreased at waterlogging levels. Silty loam soil exhibited low percentage of organic matter than sandy loam soils. Shoot biomass productivities correlated to both soil salinity and plant volume data. Regression equations have been calculated to determine the estimated biomass over a period of time.

Introduction

Approximately 10% of the total land area of the world is affected by salinity and sodicity problem (Szabolcz, 1991) and about 20 million hectares of land deteriorates to zero production each year (Malcolm, 1993). In Pakistan, out of 20.36 million ha. of cultivated land, ca. 5.8 million ha. are salt-affected (Qureshi *et al.*, 1993) of which 3.1 million ha. occurs in the irrigated areas (Canal Commanded Areas), with Na^+ and Cl^- being the dominant ions. The salt content varies in different regions of the salt-affected areas, but at certain sites could reach up to an EC_e of 90-102 $dS.m^{-1}$ (Ahmad & Ismail, 1993 a).

Besides salinity, waterlogging is often encountered in the salt affected areas. In Pakistan, the problem of waterlogging has been primarily due to the proliferation of unlined canals and the construction of dams and water-works to reduce run off (Sabadell, 1988). In the Punjab and Sindh, which are the main agricultural areas of the country, there are approximately 1.74 m.ha. which have ground waters at 0-5 cm. and 2.81 m.ha. at 1.5-3 m depth.

Area of high salinity and sodicity do not support the growth of glycophytic species but are occasionally dominated by halophytic species. Economic uses of the halophytic species as forage/fodder for grazing animals, reclamation and use as oil crops, etc., have been extensively reviewed (Choukrallah, 1993; Jefferies & Pitman, 1986; Le Houerou, 1986).

Among the halophytes the genus *Atriplex* has been extensively studied not only for its biomass productivities, but also for its fodder value and its ability to grow on degraded saline lands; improve soil conditions (Malcolm, 1993; Davidson & Galloway, 1993; O'Leary, 1986; Barrett-Lennard *et al.,* 1986); and its nutritional values (Hanjra & Rasool, 1993; Bhattacharya, 1988). *Atriplex amnicola* is regarded as one of the most salt tolerant and productive species within the genus. It grows in highly saline areas, has good palatability and recovers from grazing (Malcolm & Swaan, 1989). Within the prevailing climatic zones of Pakistan, *A. amnicola* and *A. lentiformis* have been reported as being well adapted and productive species for both sandy and inland wasteland areas (Abdullah *et al.*, 1993; Ahmad & Ismail, 1993b; Rashid *et al.*, 1993).

The present study was carried out to evaluate the growth response and biomass production of a clone of *A. amnicola* to various degrees of salinity and waterlogging in two types of soils which are representative of the saline areas of Pakistan.

Materials and Methods

Experimental Design: Vegetative cuttings of *Atriplex amnicola* Paul G. Wilson, were obtained from Western Australian Department of Agriculture and propagated in

Table 1. Physical and chemical characteristics of the types of soil used in the experiment.

Parameters Studied	Soil Type 1	Soil Type 2
Soil Texture	Sandy Loam	Silty Loam
Water Holding Capacity (%)	20.56 ± 1.78	29.54 ± 1.39
pH	8.43 ± 0.03	8.05 ± 0.03
Electrical Conductivity ($dS.m^{-1}$)	4.98 ± 0.56	8.45 ± 1.87
Total Dissolved Solids (g/L)	3.32 ± 0.37	5.54 ± 1.26
Osmotic Potential (K.Pa)	-199	-318
Na^+ ($Meq.L^{-1}$)	16.44 ± 0.75	170.10 ± 2.76
Cl^- ($Meq.L^{-1}$)	52.23 ± 10.51	156.86 ± 5.53

Each value is the mean ± s.e. of five readings.

Table 2. Analysis of saline irrigation solution used in the experiment.

Parameters Studied	Salt Treatment 1	Salt Treatment 2	Salt Treatment 3
Electrical Conductivity ($dS. m^{-1}$)	0.34	10.00	20.00
Total Dissolved Solids (g/L)	0.22	6.68	13.31
pH	8.00	8.10	8.25
Na^+ ($Meq.L^{-1}$)	0.91	395.65	840.00
Cl^- ($Meq.L^{-1}$)	0.74	136.20	063.50

polythene bags filled with three parts of sand and one part of organic manure. Experiment was conducted in 30 cm diameter and 45 cm height undrained plastic pots. An 8-cm. layer of pebble stone was placed at the bottom of the pots to facilitate water movement beneath the soil. A 50 cm PVC pipe was placed on top of the pebble layer for irrigation. Two separate sets of pots were filled with two different types of soil (Table 1).

Three month old seedlings of *A. amnicola* of uniform size were transplanted in each pot (1 seedling/pot), and established for one week with tap water. Plants were then acclimatized to the saline conditions by gradually increasing the salinity of the water until they reached to the final concentration of salts at which the experiment was continued.

The experiment was conducted using a 'Completely Randomized Design' (CRD). Separate sets of pots were prepared for two different soil types. Each set comprised of three salinity treatments of EC: 0, 10 and 20 $dS.m^{-1}$, with each salt treatment further subjected to three waterlogging levels of 75, 100 and 125% water holding capacity (WHC). The WHC was calculated in both type of soil samples as described by Richards (1954). There were 3 replicates of each treatments. Levels of salinity were maintained by mixing appropriate amount of sea salt in tap water to give the desired EC_{iw}. Analyses of the salt solution used in the experiment is given in Table 2. Pots for both salinity and waterlogging treatments were randomized in the set up and replicated twice for monitoring plant growth at two different harvest periods of 4 and 8 weeks, respectively. Plants were subjected to irrigation after every third day when the moisture content at low watering (75% WHC) treatment pots decreased upto 50%. Pots of 100% and 125% waterlogging treatments received that much amount of water to attain the respective moisture levels.

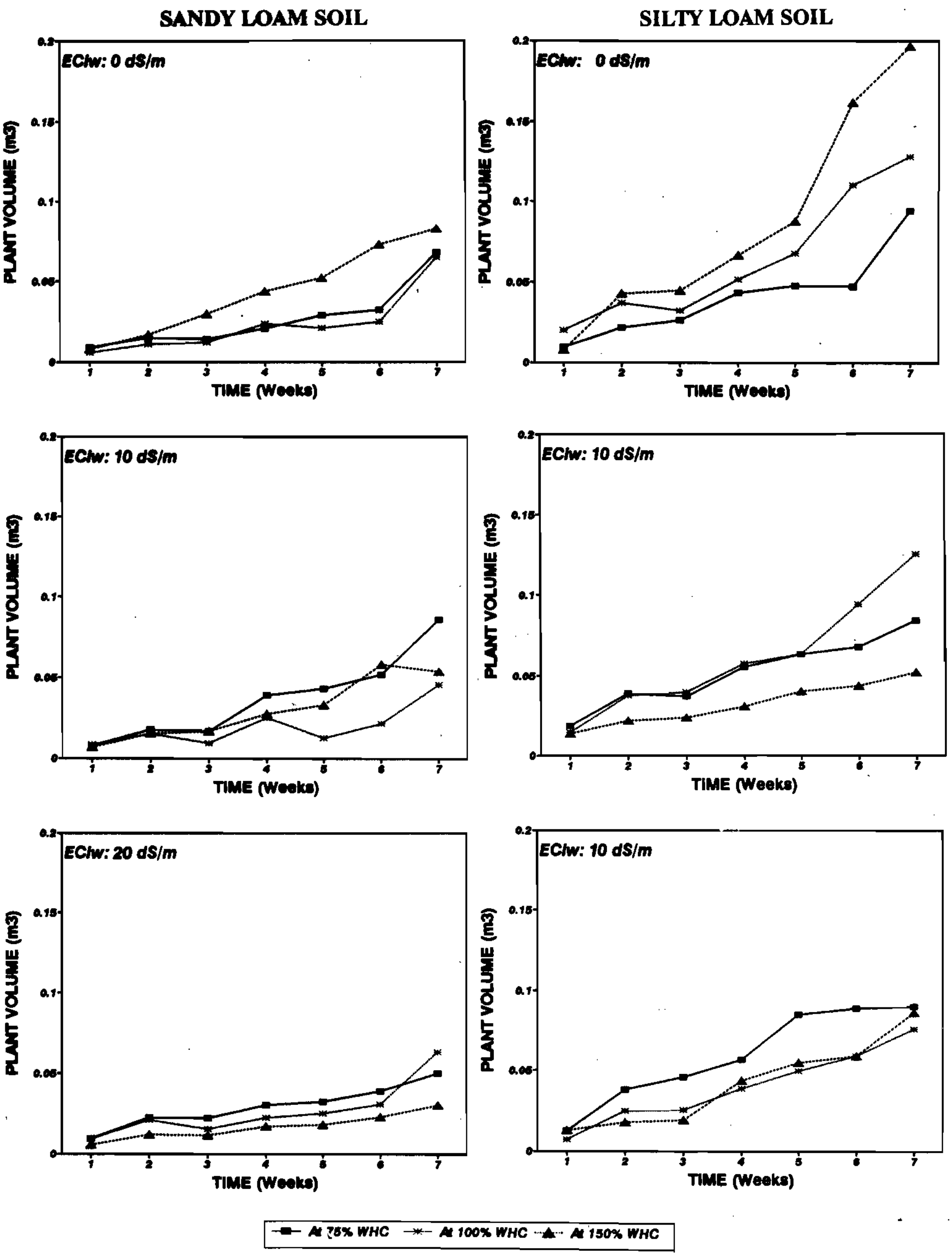

Fig.1. Variation in plant volume of *Atriplex amnicola* grown in two types of soil under different salinity and waterlogging conditions.

Morphological Studies: Plant height and diameter(s) [maximum diameter of plant designated as "d_1", and right angle to "d_1" designated as "d_2"] were recorded weekly to calculate the shoot volume. Shoot volume was calculated as described by Ward (1993) and Ismail *et al.*, (1993) for hemispheroid plant shape.

$$\text{Plant Volume: } 1/6\pi(d_1{*}d_2{*}h)$$

Plant Harvest: Pots containing both types of soil with respective salinity and waterlogging treatments were harvested after 4 weeks and 8 weeks growth period. At each harvest, plants were separated into leaf, stem and roots for fresh weight determination. Sub-samples of respective plant parts were oven dried at 70°C for dry weight. Dried samples of respective parts were further analyzed for organic matter and ash contents.

Results

Plant Volume: In sandy loam soil, the over-all plant volume decreased at EC_{iw}: 20 $dS.m^{-1}$ as compared to non-saline conditions. Waterlogging (125% WHC) seemed to increase plant volume at 0 $dS.m^{-1}$ with minimum values at 20 $dS.m^{-1}$. However, differences in waterlogging treatments appeared to be non significant (Fig. 1, Table 3).

Table 3. ANOVA for plant volume in *A. amnicola* under different levels of salinity and waterlogging treatements, soil types and harvest period.

SOURCE	df	Mean	F-Value
	Square		
Salinity (S)	2	0.002	1.40
Waterlogging (W)	2	0.001	0.44
S x W	4	0.002	1.21
Soil Type (ST)	1	0.030	23.35***
S x ST	2	0.002	1.28
W x ST	2	0.001	0.43
S x W x ST	4	0.001	1.07
Harvest Period (H)	1	0.062	48.61***
S x H	2	0.004	3.06*
W x H	2	0.001	0.08
S x W x H	4	0.001	0.84
ST x H	1	0.005	4.15*
S x ST x H	2	0.002	1.88
W x ST x H	2	0.002	1.91
S x W x ST x H	4	0.003	2.44*
Erro72		0.001	
C.V.(%)		*64.14*	

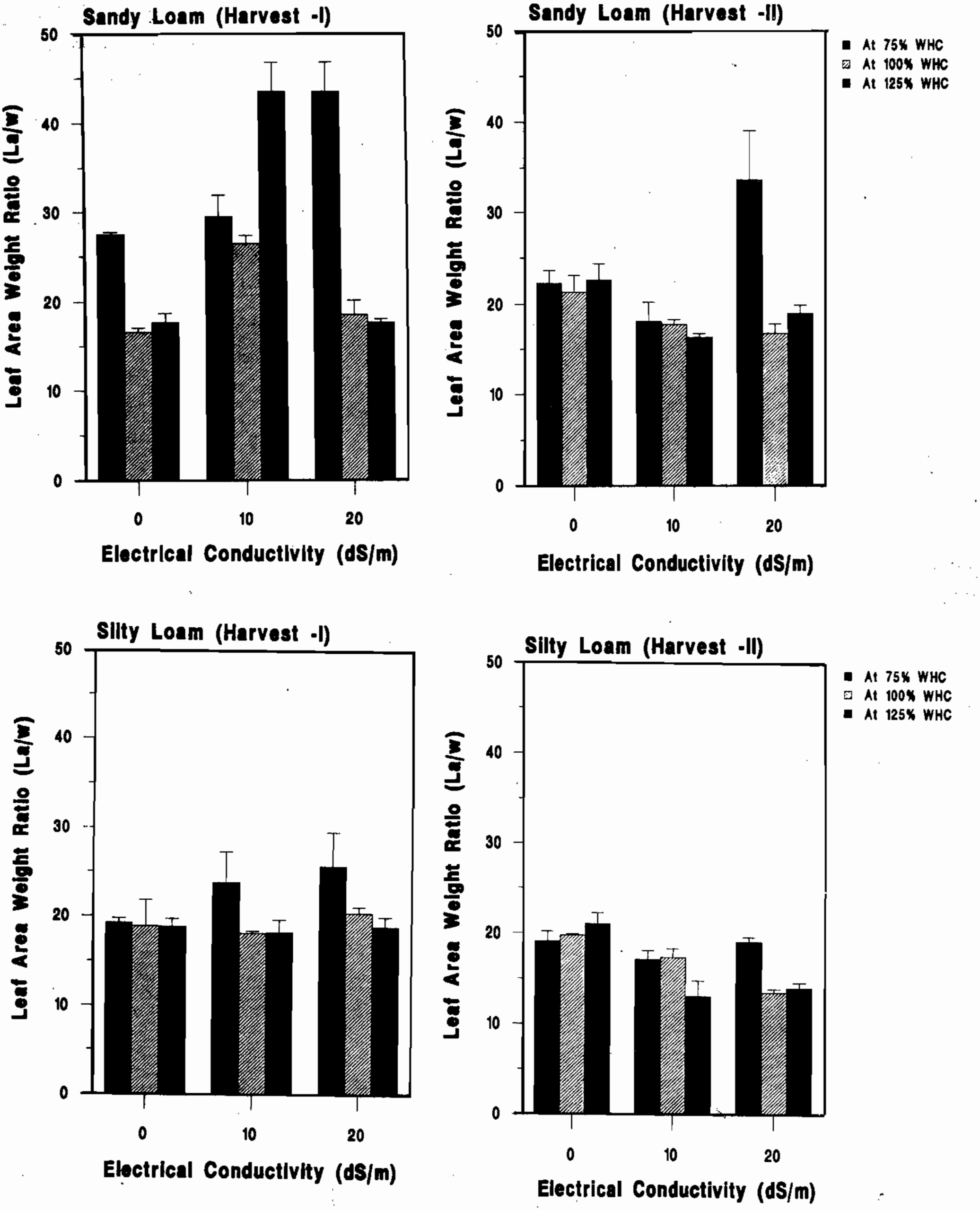

Fig.2. Variation in leaf area : weight (LA : W) ratio observed in *Atriplex amnicola* at two growth periods (after 4th and 8th weeks).

Table 4. ANOVA for biomass production in *A. amnicola* under different levels of salinity and waterlogging treatements, soil types and harvest period.

FRESH WEIGHT

SOURCE	df	LEAF WEIGHT Mean Square	LEAF WEIGHT F-Value	STEM WEIGHT Mean Square	STEM WEIGHT F-Value	ROOT WEIGHT Mean Square	ROOT WEIGHT F-Value
Salinity (S)	2	74.88	0.60	192.24	3.50**	6.26	3.38
Waterlogging (W)	2	94.42	0.76	124.54	2.26	10.22	5.51**
S x W	4	73.78	0.59	135.66	2.47	2.19	1.18
Soil Type (ST)	1	3786.49	30.33***	2626.31	47.76***	0.56	0.30
S x ST	2	97.84	0.78	48.35	0.88	0.64	0.35
W xST	2	56.77	0.45	128.64	2.34	5.05	2.72
S x W x ST	4	47.04	0.38	48.84	0.89	4.57	2.47**
Harvest Period (H)	1	1294.84	10.37***	6363.04	115.72***	15.69	8.47***
S x H	2	66.88	0.54	412.91	7.51***	0.47	0.25
W x H	2	807.19	6.47**	78.22	1.42	1.02	0.55
S x W x H	4	39.30	0.31	64.89	1.18	1.49	0.81
ST x H	1	176.47	1.41	367.26	6.68**	9.86	5.32*
S x ST x H	2	33.74	0.27	55.55	1.01	3.98	2.15
W x ST x H	2	172.35	1.38	6.72	0.12	5.17	2.79
S x W x ST x H	4	82.51	0.66	176.96	3.22**	4.08	2.20
Error	72	124.85		54.98		1.86	
C.V.(%)		*36.95*		*29.41*		*36.29*	

DRY WEIGHT

Salinity (S)	2	4.81	0.34	79.49	6.16**	1.73	5.94**
Waterlogging (W)	2	9.69	0.69	50.18	3.89*	1.34	4.61**
S x W	4	13.52	0.96	61.66	4.78***	0.15	0.52
Soil Type (ST)	1	490.94	34.82***	968.94	75.04***	1.43	4.94**
S x ST	2	9.55	0.68	26.30	2.04	0.43	1.48
W x ST	2	1.21	0.09	28.87	2.24	0.81	2.79
S x W x ST	4	4.63	0.33	32.66	2.53	0.51	1.74
Harvest Period (H)	1	536.33	38.04***	2887.65	223.63***	7.89	27.16***
S x H	2	22.48	1.59	159.97	12.39***	0.84	2.88
W x H	2	51.45	3.65*	31.84	2.47	0.06	0.21
S x W x H	4	7.17	0.51	29.19	2.26	0.24	0.82
ST x H	1	60.54	2.88	130.79	10.13**	1.91	6.58**
S x ST x H	2	0.65	0.65	23.43	1.81	0.71	2.45
W x ST x H	2	10.54	0.75	6.21	0.48	0.74	2.56
S x W x ST x H	2	13.36	0.95	64.39	4.99***	0.54	1.85
Error	72	14.10		12.91		0.29	
C.V.(%)		*42.26*		*25.37*		*38.05*	

Silty loam soil exhibited better plant volume as compared to sandy loam soils and exhibited higher plant volumes at 0 $dS.m^{-1}$ and 125% WHC. Increase in salinity showed a reduction in plant volume at 125% WHC. Plants at 20 $dS.m^{-1}$ exhibited greater reduction in the plant volume as compared to other salinity treatments though statistically non-significant differences were evident for different waterlogging levels.

Leaf Area: Weight Response: As compared to sandy loam soil, silty loam soil (at Harvest -I period) exhibited non-significant variation at 100 and 125% WHC at all the salt levels (EC: 0-20 $dS.m^{-1}$). A slightly higher value was evident at 75% WHC. At Harvest -II, the ratio decreased with increase in salinity and waterlogging levels (Fig. 2). Sandy loam soils in general also exhibited a decrease in this ratio with increase in salinity and waterlogging levels. However, there appeared an exception at 10 $dS.m^{-1}$ (Harvest -I) when the ratio was very high at high waterlogging levels (125% WHC). At 20 $dS.m^{-1}$, significant variation was evident at 75% WHC as compared to 100 and 125% WHC, at both the harvest periods.

Biomass Productivities: At first harvest, fresh weight of stem in sandy loam soil did not exhibit any significant variation to both salinity and waterlogging treatments, whereas, in silty loam soil, it showed reduction to increased levels of water (Fig. 3). Salinity in silty loam showed a maximum increase in stem biomass at 20 $dS.m^{-1}$. Leaf biomass in general did not show any variation to both salinity and waterlogging treatments (Table 4). Root biomass was not affected by salinity treatments but showed a reduction with increased waterlogging (Fig. 3). At first harvest, dry biomass and ash-free dry biomass again showed non-significant variation for stem component in sandy loam soil. Except under non-saline condition, all component parts exhibited a decrease in waterlogging treatments. In silty loam soil, stem showed higher biomass at 20 $dS.m^{-1}$ salinity in 100% WHC-waterlogging treatment (Fig. 3). Both salinity and waterlogging treatments showed a significant variation in dry weight in stem and root components (Table 4).

At second harvest, fresh weight of above ground biomass increased in both salinity and waterlogging treatments of sandy loam soils (Fig. 4), however, dry weight and ash-free dry weight showed lower productivities at higher salinity level (20 $dS.m^{-1}$), as well as in waterlogging levels. Leaf biomass was less affected by salinity but showed higher differences in waterlogging treatments. In silty loam soils, an increase in moisture levels of growing medium significantly increased the above ground productivity, especially of the stem component of fresh, dry and ash-free dry weights. Higher salinity (20 $dS.m^{-1}$) although showed relatively less differences to the other salt treatments for fresh and dry weight, exhibited significant variation when compared for the ash-free dry weight. Dry and ash-free dry biomass showed a very significant effect in both the harvest periods (Fig. 4, Table 4). Analyses of variance for both fresh and dry biomass of *A. amnicola* plants showed significant variation for soil types, harvest periods and interactions between salinity and harvest; and soil types and harvest (Table 4). Productivities of stem (both fresh and dry) was affected by salinity, waterlogging, soil types and harvest periods.

Fresh weight : dry weight ratio in leaves and roots of plants grown on sandy loam soils were less effected by waterlogging treatments but decreased with increasing salinity levels (Table 5). These ratios were, however, significantly different for both

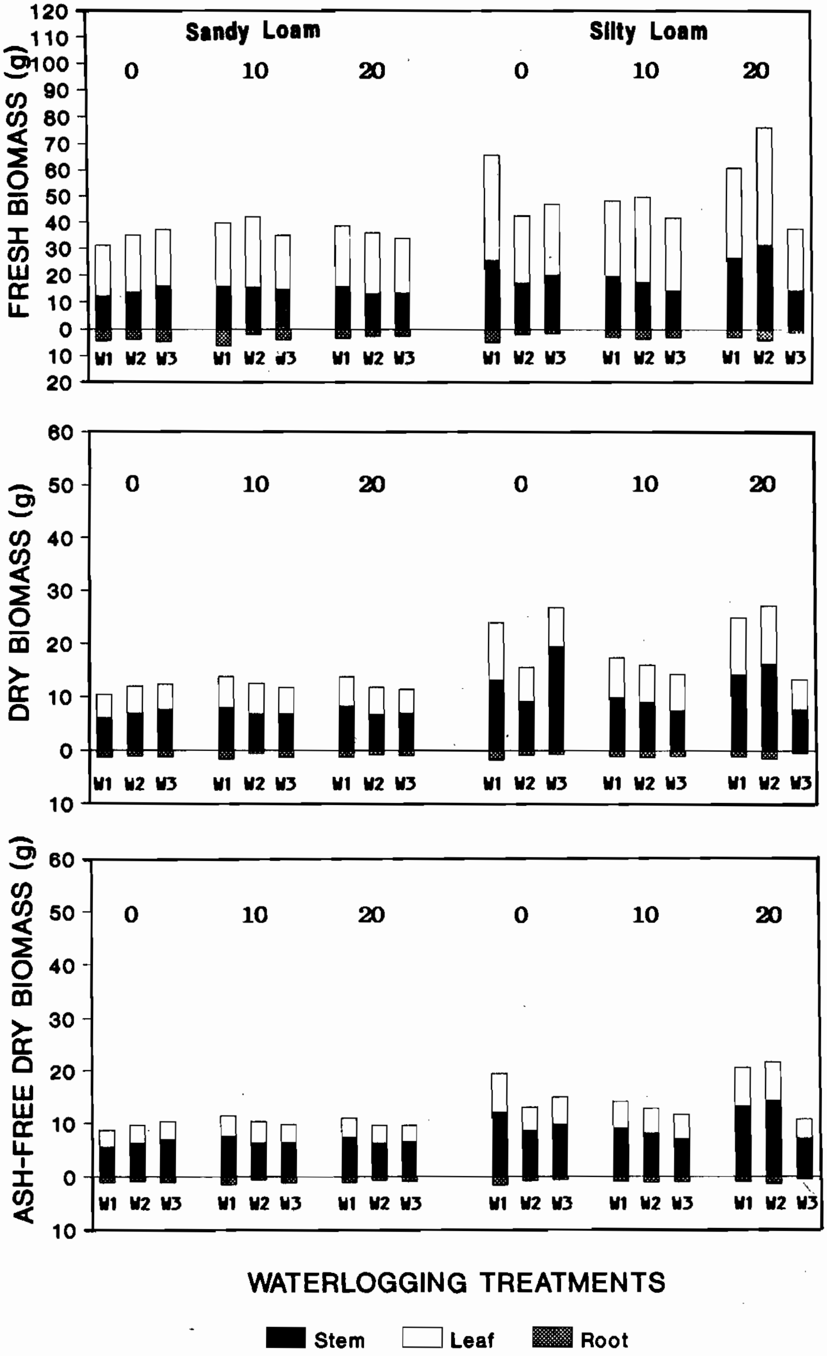

Fig.3. Variation in biomass productivity as affected by salinity and waterlogging treatments after 4 weeks growth

Figures above the bars indicate the electrical conductivity of irrigation water, whereas, those below the bars (W1, W2, and W3) represent waterlogging treatments at 75, 100 and 125% WHC.

Table 5. Some ratios related to biomass productivity of *A. amnicola* subjected to various degrees of salinity and waterlogging treatments.

PARAMETERS STUDIED	WATERLOGGING LEVELS (% OF WHC)	SALINITY LEVELS (EC_{iw} in $dS.m^{-1}$)					
		0		10		20	
		Harvest I	Harvest II	Harvest I	Harvest II	Harvest I	Harvest II
				SANDY LOAM SOIL			
LEAF FW/DW Ratio	75	4.46	2.93	4.17	3.11	4.08	3.67
	100	4.20	2.82	4.60	3.11	4.39	3.11
	125	4.42	3.05	4.06	3.11	4.88	3.81
STEM FW/DW Ratio	75	2.04	1.74	1.95	1.05	1.91	3.54
	100	1.96	1.51	2.28	1.90	1.97	3.03
	125	2.09	1.58	2.12	1.15	1.92	5.46
ROOT FW/DW Ratio	75	3.31	2.68	3.72	2.77	2.73	2.98
	100	3.45	2.56	2.92	2.42	3.13	2.89
	125	3.66	2.72	2.97	2.59	2.66	3.03
Shoot/Root Ratio (Fresh Weight)	75	7.24	13.55	6.36	12.15	11.17	20.59
	100	9.48	10.63	21.74	11.88	13.34	14.44
	125	7.84	16.87	8.86	11.79	12.59	27.15
Shoot/Root Ratio (Dry Weight)	75	8.00	17.14	8.19	18.60	10.90	17.09
	100	11.20	14.00	19.00	12.47	13.82	13.63
	125	9.58	21.51	8.87	16.00	11.59	19.08
				SILTY LOAM SOIL			
LEAF FW/DW Ratio	75	3.96	2.66	3.79	2.61	3.19	2.70
	100	3.96	2.84	4.55	2.78	4.01	3.53
	125	3.67	2.35	4.00	3.69	4.05	3.60
STEM FW/DW Ratio	75	1.93	1.68	1.95	1.68	1.84	1.66
	100	1.84	1.72	1.91	1.77	1.92	1.76
	125	1.85	1.51	1.88	1.79	1.87	1.82
ROOT FW/DW Ratio	75	2.73	2.06	7.35	2.29	2.79	2.41
	100	2.31	2.11	2.75	2.12	2.76	3.080
	125	2.25	1.89	2.68	2.61	2.35	2.645
Shoot/Root Ratio (Fresh Weight)	75	13.52	10.89	44.25	17.89	19.76	17.30
	100	21.04	16.50	14.09	16.73	17.84	24.06
	125	29.78	23.17	13.82	27.20	28.70	22.07
Shoot/Root Ratio (Dry Weight)	75	13.50	11.25	16.09	20.65	22.76	20.70
	100	17.92	16.73	12.60	16.38	17.79	29.01
	125	25.82	24.18	12.84	26.73	24.12	22.07

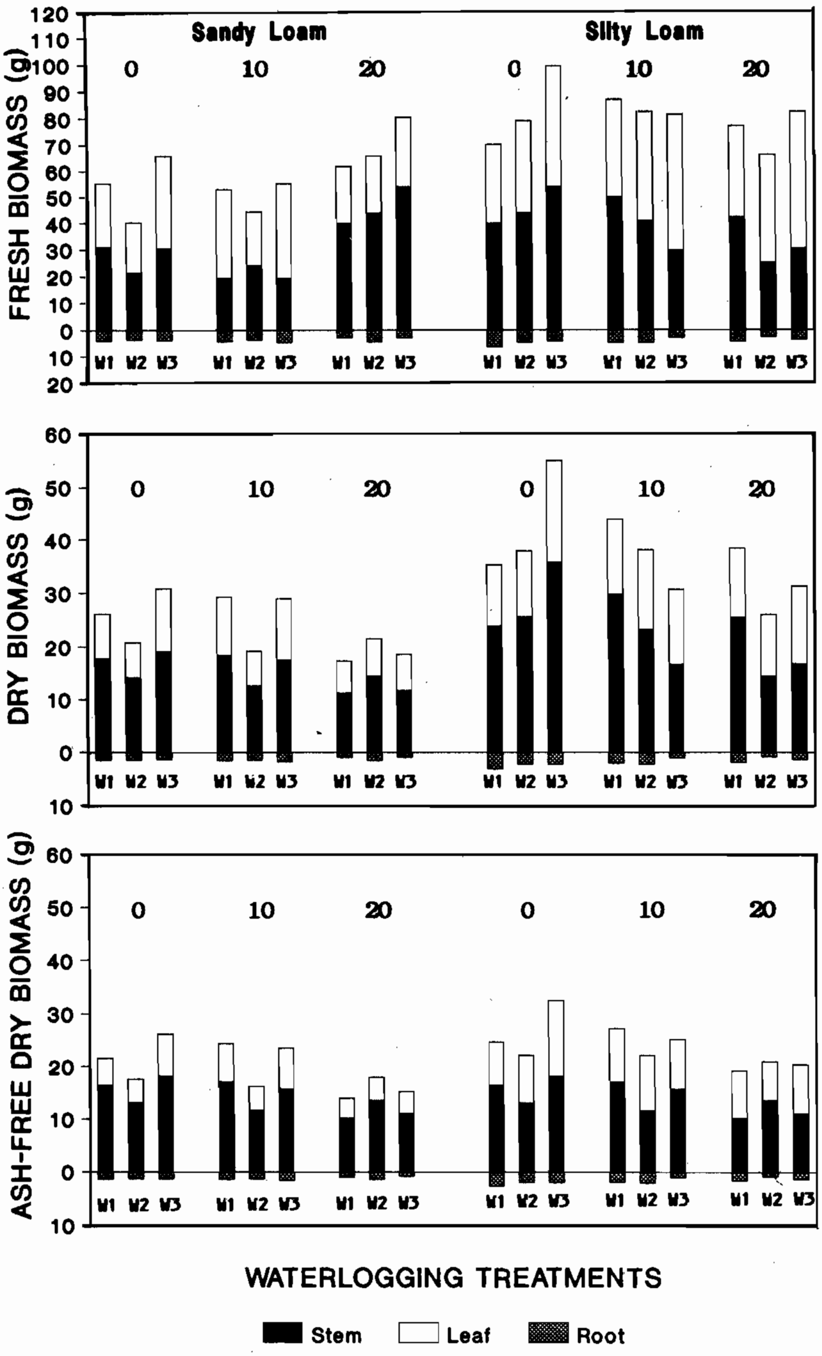

Fig.4. Variation in biomass productivity as affected by salinity and waterlogging treatments after 8 weeks growth.

Figures above the bars indicate the electrical conductivity of irrigation water, whereas, those below the bars (W1, W2, and W3) represent waterlogging treatments at 75,100 and 125% WHC.

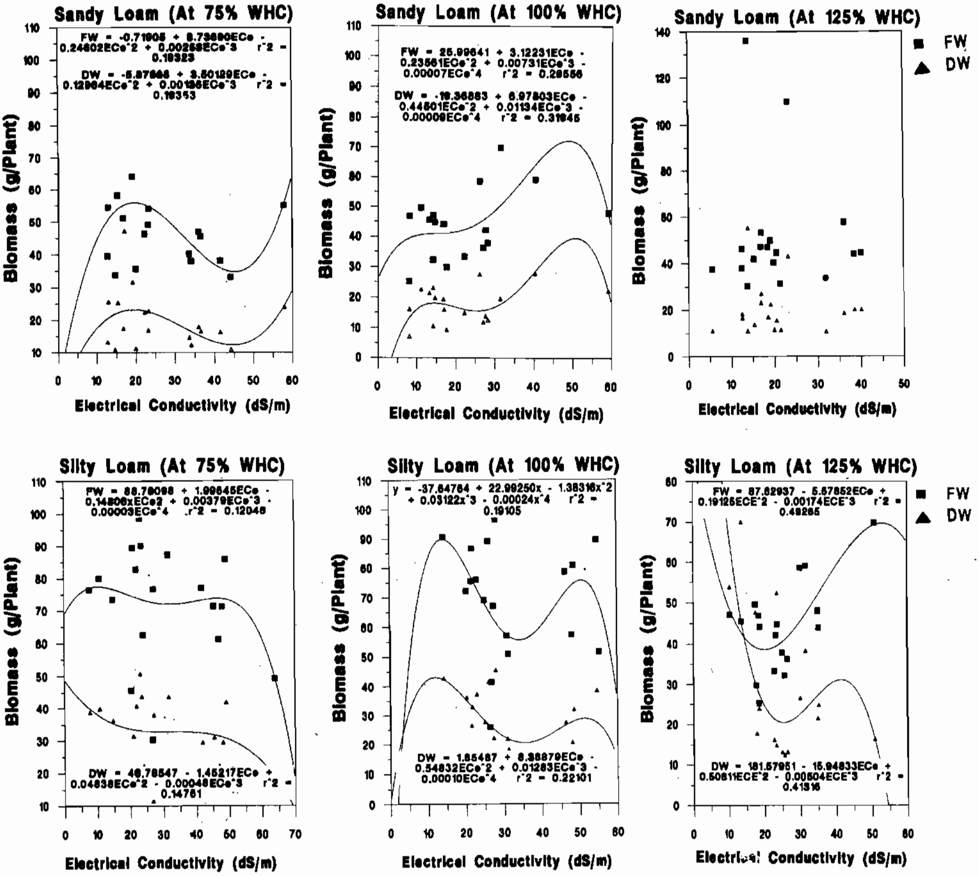

Fig.5. Relationship between soil salinity (EC_e) and shoot biomass productivity (fresh and dry weight) in *Atriplex amnicola* as influenced by salinity and waterlogging treatments.

salinity and waterlogging treatments at Harvest -II. Shoot : root ratio on fresh and dry weight bases increased in both waterlogging and salt treatments. Silty loam soil also showed similar response, however, plants grown in sandy loam soils were much affected as compared to silty loam soil. In addition, plants grown in silty loam soil showed higher shoot : root ratio signifying better availability of shoot material for forage/fodder.

Attempts made to find any possible relationship between soil and plant parameters related to plant biomass productivities in both sandy loam and silty loam soil with reference to salinity and waterlogging treatments, showed that except at high waterlogging treatment (125% of WHC) in sandy loam soil, all other waterlogging treatments exhibited a significant correlation between electrical conductivity of soil (EC_e) and total plant biomass (Fig. 5). Depending upon the effect of salts, a 3-4 degree polynomial curves were obtained between these two parameters. Shoot volume on the other hand showed a definite relationship only at low and moderate waterlogging levels in both types of soils (Fig. 6). No definite relationship were evident at high waterlogging levels.

Discussion

Low salinity (EC: 10 dS.m^{-1}) and low to moderate waterlogging levels (75 and 100% WHC), showed little effect on plant volume, whereas, high salt level (EC: 20 dS.m^{-1}) reduced plant volume as compared to non-saline conditions. Waterlogging alone showed little effect on plant volume, whereas, waterlogging x salinity significantly reduced total volume of the plant. Silty loam soil was more productive in increasing plant volume as compared to sandy loam soil, may presumably be due to better availability of moisture to the plants. Since high temperature and solar radiation increase moisture loss from soil surface, thus moisture level in the soil is reduced with little

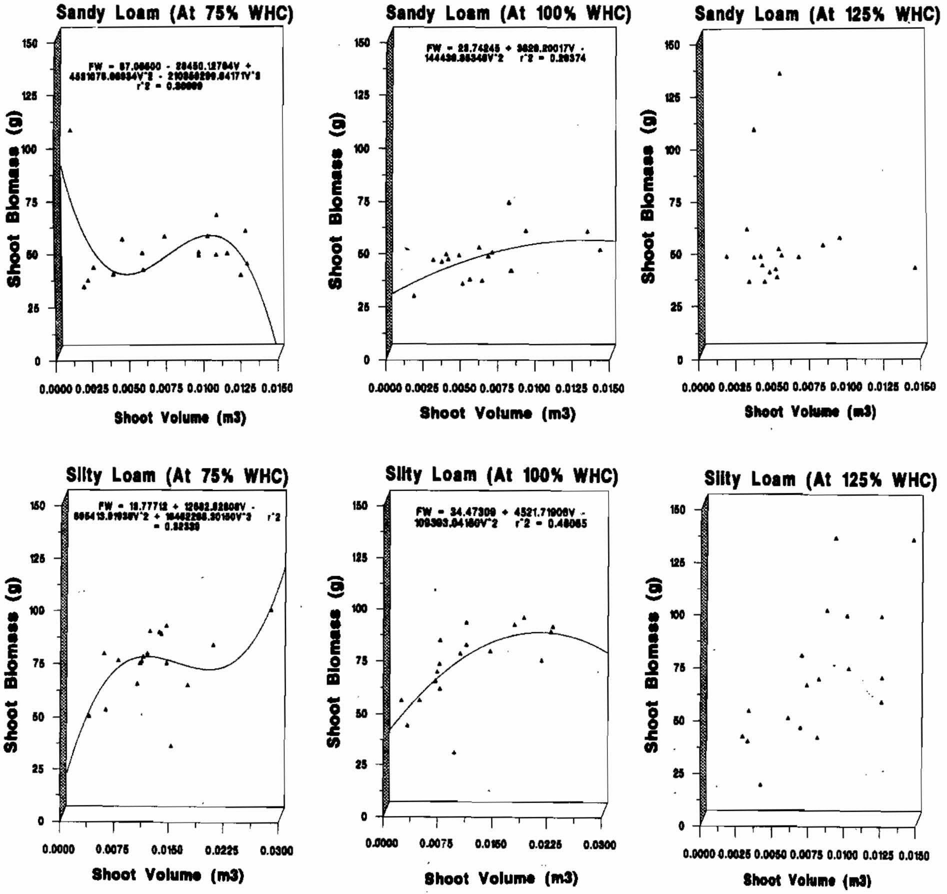

Fig.6. Relationship between shoot volume and biomass productivity (fresh and dry weight) in *Atriplex amnicola* as influenced by salinity and waterlogging treatments.

waterlogging effects. Plants irrigated with non-saline water and kept at 125% WHC showed higher plant volume as compared to plants exposed to high salt stress. Varied levels of salinity (200 and 400 mol.m^{-3} NaCl) without waterlogging have been reported to show no effect on growth, whereas, low level of oxygen (waterlogging), reduced the RGR by 80 and 86%, respectively, at the two salt levels (Galloway & Davidson, 1993).

Plants are reported to show variation either in leaf expansion or accumulation of photosynthate (dry weight) under salinity condition. Leaf area-to-weight ratio (LA:W), an indicator of a plant response to stress in reference to increase/decrease in leaf area (turgor balance) or weight (metabolic adjustment) exhibited varied response to soil types, salinity and waterlogging.

Since plant weight is dependent upon the accumulation of carbon products in photosynthesis, it is determined by (i) rate of photosynthesis per leaf area, and (ii) the area of leaf surface (Terry & Waldron, 1984). Leaf area expansion was affected during early period of salinity/waterlogging treatments and thereafter adapted to these stresses signifies that growth in terms of leaf expansion may cease due to stress (particularly in reference to salinity). The thickening of the leaves may be due to increase in photosynthates. Such a response has been reported by Terry & Waldron (1984) and Aspinall (1986). Alternatively, an increase in water content and a concurrent increase in leaf volume is also possible for leaf expansion and has been reported for the halophytes (Flowers *et al.,* 1986; Handley & Jennings, 1977). Leaf expansion could thus be a function of water influx or accumulation of ions and organic solutes. Munns & Termaat (1986) have suggested that water stress of the root actually regulates leaf expansion, and as such moisture absorption by roots from the soil would govern the process of leaf expansion.

Reduction of forage/fodder is related to growth rate and consequently biomass productivity (particularly aerial biomass for perennials). Results of the present studies showed that production of biomass is controlled to some extent by moisture levels of soil, however, presence of salt with excess water affected the biomass. The productivities was at least 25% higher in silty loam soil at all the waterlogging levels as compared to sandy loam soils. As the capacity of moisture retention is much higher in such soil, availability to the plants is ensured without the expense of energy to extract water of low potential. This energy is thus used in conversion of biomass, though a part of it is still required in adjustment to salt stress.

During the early growth period of 4-weeks, the leaf growth was maximum as compared to stem in sandy- and silty-loam soils and after 8-weeks, a shift of biomass allocation towards the stem was observed. Salinity appeared to promote leaf productivity at low EC (10 dS.m^{-1}), whereas, at higher EC (20 dS.m^{-1}), leaf weight decreased with an increase in stem weight in both types of soil. This however does not affect the overall productivities in the sense that both leaves and stem of *A. amnicola* are heavily grazed. Similar response have been reported in *A. lentiformis* where increase in dry matter production appears to be related to a corresponding accumulation of stem components and enhanced by the reproductive phase (Watson *et al.,* 1987). Both salinity and waterlogging did not show any variation in the productivity of roots in both sandy loam and silty loam soil. Both fresh and dry weight of root was low in contrast to those reported by Mahmood & Malik (1987) at the salinity levels which suggests a reduction due to waterlogging only.

Though fresh and dry biomass gives an indication of productivities, but due consideration should be given when evaluating biomass due to high contents of moisture and ash (Glenn & O'Leary, 1984), and thus ash-free dry weight (AFDW) is considered better for comparison as far as total organic matter production is concerned. In the present study salinity showed little effect on the ash-free dry weight in sandy- and silty-loam soil types, with waterlogging being the major factor for reduction in biomass. Ash-free dry weight was high in silty loam soil as compared to sandy loam soil. This does not under-estimate the growth of *A. amnicola* in light textured soils, as they provide a very good medium of salt infiltration thus reducing chances of salt accumulation. A number of halophytic species have been grown on sandy wastelands with different concentration of sea water and even pure sea water (Glenn & O'Leary, 1985; Gallagher, 1985).

Variation in moisture content is the key factor to determine the FW/DW ratio. All the plants showed reduction in FW/DW ratio in leaf, stem and roots under different salinity levels as well as growth period. This probably indicates adaptibility of plant parts to salinity at early stages of growth. Shoot to root ratio appeared to be quite high as compared to those reported for other halophytes (Cooper, 1982). Both salinity and waterlogging either increased or did not alter the shoot : root ratios, however, the growth period and soil types did affect the ratio. An increase in shoot : root ratio has also been reported for other halophytic species (Okusanya & Ungar, 1984).

Presence of salts in irrigation water associated with high moisture levels results in high soil salt-contents thus adversely affecting productivities. Attempts to correlate plant biomass with soil salinity (EC_e) indicated that biomass was directly affected by the presence of total soluble salts which resulted in different growth curves at different moisture levels. This presumably is due to overall salt distribution at high moisture levels (125% WHC), whereas, at low moisture content, salt distribution was usually concentrated on the soil surface, which is reported to be the rooting zone in *A. amnicola* (Galloway & Davidson, 1993). A decrease in root growth of plants having shallower root systems have been reported (Ahmad & Ismail, 1993a; Drew & Lynch, 1980).

Growth in terms of plant volume widely used for non-destructive estimations of plant biomass (Ward, 1993; Ahmad & Ismail, 1993b; Barrett-Lennard, 1993), has been found to be useful in providing shoot biomass estimations. Correlations between plant volume and biomass productivities showed significant r-values at 75 and 100% WHC. High water levels in soils appeared to have varied response to the plants in association with salinity. Presumably plants behave differently to overcome waterlogging stress at various salt concentrations.

The present investigation shows that this provenance of *A. amnicola* can withstand both salinity and waterlogging and there is need to evaulate its cultivation on long term bases under field conditions.

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