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SCREENING OF MESQUITE (*PROSOPIS* spp.) FOR BIOMASS PRODUCTION AT BARREN SANDY AREAS USING HIGHLY SALINE WATER FOR IRRIGATION

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Abstract

Experiments were carried out to screen local and exotic species/accession/provenances of *Prosopis* species at germination and seedling stages under salinity conditions. Field trials were also undertaken to evaluate potential species/ accessions/provenances under salt stress. Seeds of indigenous *P. juliflora* and *P. glandulosa* showed higher germination than seeds of *P. cineraria* and the exotic species under non-saline as well as under different levels of salinity stress with EC values of NaCl solutions ranging from 0-30 $dS.m^{-1}$. There was a decrease in germination of all species with increasing salinity levels. Seedling emergence was completely inhibited above EC 10 $dS.m^{-1}$ in *P. juliflora* and *P. cineraria* and above EC 15 $dS.m^{-1}$ in *P. glandulosa*.

Growth of 3 indigenous and 2 exotic *Prosopis* species/provenances in pots containing sandy soil irrigated with dilutions of sea water adjusted at EC_{iw}: of 10, 20, 30, and 40 $dS.m^{-1}$ showed that *P. glandulosa* did not survive beyond EC_{iw}: of 20 $dS.m^{-1}$. Among the surviving plants, *P. juliflora* obtained from Brazil grew at the highest salt concentration and showed minimum biomass reduction in comparision with other species.

In a field experiment, seedlings of 12 indigenous and 8 exotic species/accessions/provenances of *Prosopis* transplanted under field conditions and irrigated with saline water (EC: 14-16 $dS.m^{-1}$) showed that the indigenous species/provenances, viz., *P. juliflora* (D.I. Khan) and *P. glandulosa* (Sujawal), and the exotic species/accessions, *P. alba* (Acc.# 0166) and 2 South American species showed better growth in terms of plant height and stem diameter under prevailing haloxeric conditions. Importance of mesquite cultivation for providing fodder, fuelwood, timber, and checking movement of sand dunes to control desertification is discussed.

Introduction

Mesquite, a woody leguminous plant grows naturally in hot semi-arid and arid regions of the world. Its fruits provide an alternative source of food for humans and feed for ruminants. Leaves of *Prosopis cineraria* are grazed by goats and sheep. Mesquite pods contain 9.6-12.5% crude protein, 1-3.4% reducing sugar, and 8.3-12.8% total sugar (Gupta *et al.*, 1984). Mesquite has provided dietary base in the United States and Mexican border areas for several thousand years (Nabhan, 1984). Almost all the *Prosopis* species produce good-quality fuelwood and charcoal. Some are capable of growing into trees that can produce wood for making wooden flooring, doors and furniture. Some multistem species have been found to control sand dunes, soil erosion and desertification. Enhanced honey production is noted in hives placed in the vicinity of mesquite forests. Apart from being able to tolerate water stress, *Prosopis* spp., can also tolerate salt stress up to a high salinity level (Rhodes & Felker, 1988; Ahmad *et al.*, 1986; Jarrell & Virginia, 1984; Felker *et al.*, 1981).

Of the 44 different *Prosopis* species of this genus distributed all over the semi-arid and arid regions of the world (Galera *et al.*, 1992; Dutton, 1992), *P. juliflora*, *P. cineraria*, and *P. glandulosa*, which differ morphologically as well as ecologicaly are found to occur naturally in Pakistan. *P. juliflora*, a deep-rooted plant varying from shrub to tree habitat was naturalized in Pakistan in the early 1950's to stabilize dunes and provide fuelwood (Mohammad, 1992). Man-made forests of *P. juliflora* have been established on the barren coastal sandy belt of Pasni, Pakistan, through irrigation with highly saline underground water (Khan *et al.*, 1986). Experiments conducted to determine the effects of irrigation frequency on biomass production have shown greater productivity in selected *Prosopis* species as compared to other tree species under high temperature/drought conditions (Felker *et al.*, 1983a). Among trees of *P. chilensis, P. alba* and *P. velutina* grown for 2½ years, *P. velutina* is reported to produce 7.2 kg dry biomass/plant as compared to other 29 species of *Prosopis* (Felker *et al.*, 1983b). Trees of dry irrigated regimes also showed the highest pod production. In the present study experiments were carried out to screen and identify the mesquite (*Prosopis*) species/accessions/provenances, including both local and exotic genome lines which are capable of growing with saline water and produce maximum biomass and fuelwood in semi-arid coastal regions of Pakistan around Karachi, where good quality water is not available.

Materials and Methods

Germination: Twenty seeds of 9 different provenances of 3 local *Prosopis* species (*P. juliflora*, *P. glandulosa* and *P. cineraria*) and one exotic species (*P. pallida*) were treated with concentrated sulphuric acid for 20 minutes, washed with running tap water and placed on filter paper in Petri dishes. The Petri dishes were incubated at 28^{o}C. The filter paper was saturated with non-saline or saline water solutions of various salinities by dissolving Analar grade of sodium chloride in distilled water to give electrical conductivity (EC) values of 5, 10, 15, 20, 25, and 30 dS.m^{-1}. Each salinity was replicated 3 times in a completely randomized design. Germination counts were recorded daily for 8 days. Seeds were considered to have germinated when the hypocotyl emerged from the seed coat.

Emergence: The seeds of each of the species used in the germination study were sown in plastic containers filled with sand and irrigated with different dilutions of NaCl with an EC_{iw} range of 5-30 dS.m^{-1}. There were 3 replicates of each treatment in a completely randomized design and observations recorded for 8 consecutive days.

Salt tolerance in *Prosopis* species/provenances: Seedlings of 2 exotic species, *P. juliflora* obtained from Brazil and *P. pallida* (supplied by Winrock), and two indigenous species *P. glandulosa* (two provenances) and *P. juliflora* (one provenance) were raised from seeds in earthen pots containing 12 kg sand. Once established, the seedlings about 1 cm in height, were irrigated with various dilutions of seawater to give EC values of 10, 20, 30 and 40 $dS.m^{-1}$. Plants irrigated with non-saline water were kept as control. Each treatment was replicated 5 times in a completely randomized design. Data on height, stem diameter and number of branches were recorded every 4 months. After 1 year the plants were harvested and separate parts of leaf, stem and roots were placed in an oven at 70°C for 48h for determination of dry weight. Soil samples from the pots were also collected, oven dried and saturated extract of soil obtained for measurement of electrical conductivity.

Screening of local and exotic genome of *Prosopis* under field conditions using saline water for irrigation: Seeds of 21 exotic and 13 local species/accessions were sown after acid treatment in plastic bags filled with pure sand. On the basis of better germination percentage and availability of good-sized seedlings, 20 accessions/provenances of different *Prosopis* species (8 exotic and 12 indigenous) were transplanted in different blocks in a completely randomized design. The whole experimental area was divided into 20 blocks, each randomized for a different species/accession/provenance. There were 3 rows in each block with 3 plants/row, for a total of 9 replicates of each species/accession/provenance. Plant-to-plant and row-to-row distance was kept at 3 m. Plants were irrigated twice a week during summer and once a week in winter by filling each pit with 20 L underground saline water (EC: 14-16 $dS.m^{-1}$), pumped from a 12 m deep well dug at the experimental site. Data regarding survival, plant height and number and length of branches were recorded periodically to determine the growth of the plants. Some plants which were destroyed by field rabbits during the first 2 months were replanted from the stock. Data pertaining to quantum yield, stomatal conductance, and transpiration rate were recorded using a LICOR (LI-1600) porometer. Chlorophyll and sugar contents of the plants were analyzed as described by Maclachlam & Zalik (1963) and Yemm & Willis (1956), respectively.

Results

Germination and emergence studies: Seeds of *P. juliflora* and *P. glandulosa* from Sujawal showed maximum germination under non-saline (control) conditions as compared to *Prosopis* from other sources (Fig. 1). Germination was reduced by 5-10% in all the species at EC of 5-15 $dS.m^{-1}$ as compared with the respective controls. *Prosopis* from Sujawal also showed tolerance to salt stress, with a 60% germination in a saline solution of EC: 20 $dS.m^{-1}$. The overall *Prosopis* germination response for the seed sources at EC: 20 $dS.m^{-1}$ was:

P. juliflora (Sujawal) > *P. glandulosa* (Sujawal) > *P. cineraria* (Peshawar) > *P. cineraria* (Karachi) > *P. juliflora* (Bhawani) > *P. cineraria* (Tandojam) > *P. pallida.*

The percentage of emergence in non-saline control was different in the soil than in the Petri dishes (Fig.2). Emergence of the seedlings of 3 *Prosopis* species was *P. glandulosa* (Sujawal), 80%; *P. juliflora* (Bhawani), 70%; *P. cineraria* (TandoJam), 40%. *P. juliflora* and *P. cineraria* seedlings did not establish beyond EC of 10 $dS.m^{-1}$ and *P. glandulosa* at EC: 15 $dS.m^{-1}$. Emergence at EC 10 $dS.m^{-1}$ in *P. juliflora* and *P. cineraria* was about 10% and in *P. glandulosa* at EC: 15 $dS.^{-1}$ was 5% only (Fig.2).

Salt tolerance in 2 exotic and 3 indigenous *Prosopis* species/provenances: The seedlings of the different species/provenances of *Prosopis* showed various degrees of salt

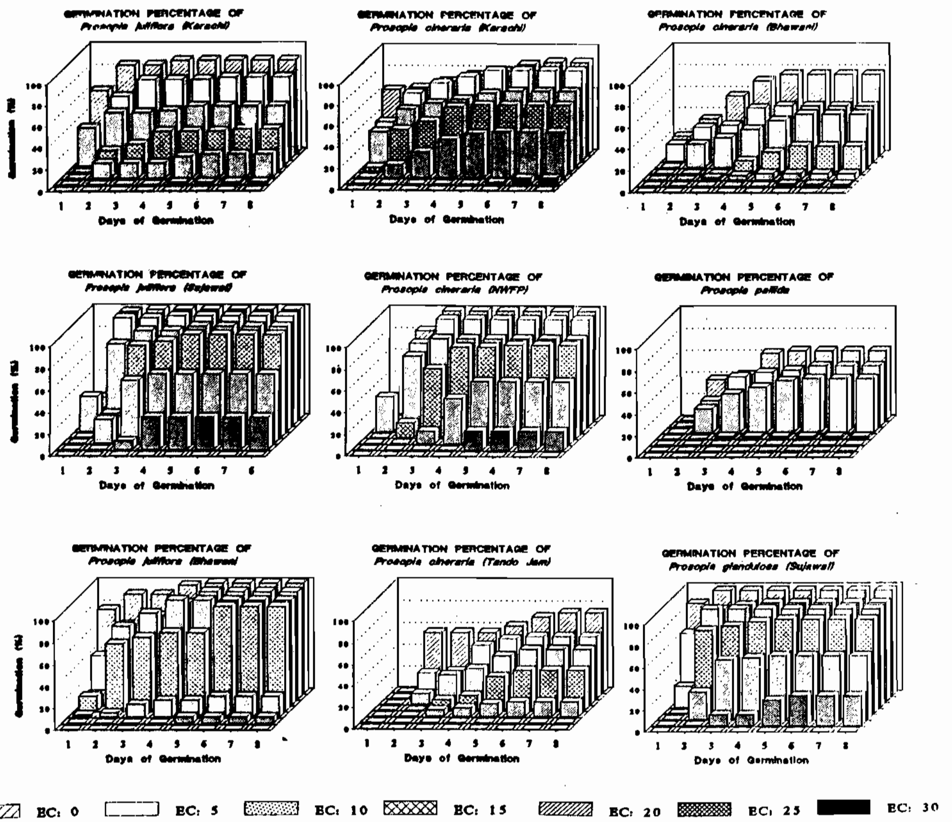

Fig.1. Effect of various salt levels on the germination of different *Prosopis* species/provenances.

tolerance when irrigated with different concentrations of saline water (Table 1). *P. glandulosa* failed to grow beyond EC_{iw} level of 20 $dS.m^{-1}$, with 35 to 40% reduction in height and about 50% reduction in stem diameter as compared to plants grown in non-saline soil. All other *Prosopis* species exhibited a marked reduction in growth only at the highest salinity level (EC_{iw}: 40 $dS.m^{-1}$). At an EC_{iw} of 20 $dS.m^{-1}$, *P. juliflora* (Bhawani) was highly tolerant with no effect on plant height, followed by 8% reduction in *P. pallida* (Winrock) and 13% reduction in *P. juliflora* (Brazil). Similarly, stem diameter was least affected in *P. juliflora* (Brazil), followed by *P. pallida* (Winrock) and *P. juliflora* (Bhawani).

Biomass production of *Prosopis* leaf, stem and roots irrigated with water ranging from 0 to 40 $dS.m^{-1}$ is presented in Table 2. Among the five species/provenances studied, *P. juliflora* (Bhawani) produced the highest amount of both fresh and dry biomass in all the plant parts under non-saline (control) conditions. In general, root biomass was greater in all the plants followed by stem and leaf. At 20 $dS.m^{-1}$ level, *P.juliflora* (Brazil) exhibited less reduction in biomass which was still about 50% in both leaf and stem. This compared with reductions in leaf and stem, respectively, of

Table 1. Growth responses of *Prosopis* species/provenances under saline water irrigation.

Plant Species/ Accesssions	Salinity Levels ($dS.m^{-1}$)	Growth Period (Months) 4		8		12	
		Plant Height (cms)	Stem Diam.	Plant Height	Stem Diam.	Plant Height	Stem Diam.
P. juliflora	0	102.00	0.78	133.00	1.30	139.33	2.30
(Bhawani)		±11.25	±0.04	±23.38	±0.11	±25.82	±0.17
	10	61.00	0.74	110.00	1.12	136.60	1.50
		±4.04	±0.02	±14.60	±0.01	±9.20	±0.09
	20	44.33	0.70	86.66	0.93	138.33	1.36
		±5.54	±0.05	±14.80	±0.09	±1.66	±0.12
	30	48.00	0.65	64.00	0.65	72.00	1.26
		±6.80	±0.02	±18.14	±0.03	±3.78	±0.16
	40	40.33	0.55	49.00	0.66	68.33	1.13
		±2.40	±0.08	±5.13	±0.09	±4.60	±0.16
P.juliflora	0	102.66	0.83	106.33	1.26	113.33	1.81
(Brazil)		±5.89	±0.07	±7.31	±0.08	±49.69	±6.00
	10	69.50	0.62	110.66	1.16	140.00	1.63
		±4.76	±0.01	±16.89	±0.03	±22.90	±0.66
	20	58.33	0.60	79.00	0.85	98.66	1.36
		±7.83	±0.00	±12.01	±0.10	±23.90	±0.14
	30	56.00	0.55	74.33	0.56	97.33	1.06
		±3.78	±0.03	±5.36	±0.0	±2.66	±0.06
	40	47.00	0.43	54.66	0.46	60.66	0.86
		±2.88	±0.03	±5.36	±0.03	±20.46	±0.10
P. pallida	0	85.00	0.76	144.00	1.46	136.60	2.33
(Winrock)		±11.70	±0.04	±11.59	±0.18	±23.33	±0.17
	10	60.00	0.54	118.66	1.03	143.33	1.66
		±4.04	±0.02	±7.69	±0.03	±11.66	±0.14
	20	45.00	0.55	99.33	0.83	126.33	1.50
		±3.60	±0.02	±5.66	±0.06	±13.50	±0.09
	30	41.00	0.55	66.00	0.66	100.30	1.06
		±7.55	±0.07	±19.52	±0.03	±12.25	±0.16
	40	40.33	0.45	54.33	0.46	60.30	1.01
		±5.69	±0.06	±9.26	±0.03	±5.33	±0.04

Table 1 (Cont'd)

Plant Species/ Accessions	Salinity Levels ($dS.m^{-1}$)	Growth Period (Months) 4		8		12	
		Plant Height	Stem Diam.	Plant Height	Stem Diam.	Plant Height	Stem Diam.
		(cms)					
P. glandulosa	0	16.16	0.43	107.66	1.50	109.00	2.26
(Sujawal)		±1.96	±0.02	±8.95	±0.21	±16.46	±0.17
	10	14.33	0.53	54.33	0.96	66.00	1.70
		±0.33	±0.03	±2.85	±0.05	±3.03	±0.05
	20	19.00	0.48	51.66	0.83	71.33	1.23
		±3.21	±0.06	±4.33	±0.06	±5.33	±0.08
	30	15.66	0.40	35.00	0.50	---	---
		±2.33	±0.00	±0.00	±0.00	---	---
	40	16.66	0.45	---	---	---	---
		±2.60	±0.08	---	---	---	---
P. glandulosa	0	30.50	0.38	125.00	1.36	120.00	2.16
(Karachi)		± 5.00	±0.02	±14.84	±0.08	±5.70	±0.03
	10	11.66	0.44	69.00	0.94	88.33	1.43
		±2.72	±0.04	±8.86	±0.04	±6.00	±0.14
	20	11.66	0.43	59.66	0.70	71.33	1.06
		±2.72	±0.03	±18.98	±0.10	±14.43	±0.27
	30	11.33	0.40	30.00	0.50	---	---
		±3.93	±0.00	±0.00	±0.00	---	---
	40	9.66	0.38	---	---	---	---
		±1.95	±0.02	---	---	---	---

Dashes indicate the dead plants.

53 and 61% in *P. pallida* (Winrock), 40 and 62% in *P. glandulosa* (Sujawal), 70 and 85% in *P. glandulosa* (Karachi) and 85 and 73% in *P. juliflora* (Bhawani). *P. glandulosa* did not tolerate high salinities and failed to grow when given irrigation water with an EC of 20 dS. m^{-1}. At the highest salinity level (EC: 40 $dS.m^{-1}$), biomass reduction reached about 85 to 92% in the surviving 3 species/provenances.

Root biomass was less affected than shoots at all salinity levels. The root biomass of *P. juliflora* (Bhawani) was greatest among the species/provenances studied. Moisture content in the shoots of control plants varied from about 36-50%. The percentage of moisture in some of the plants irrigated with saline water increased up to 67% at the highest salinity level of irrigation water.

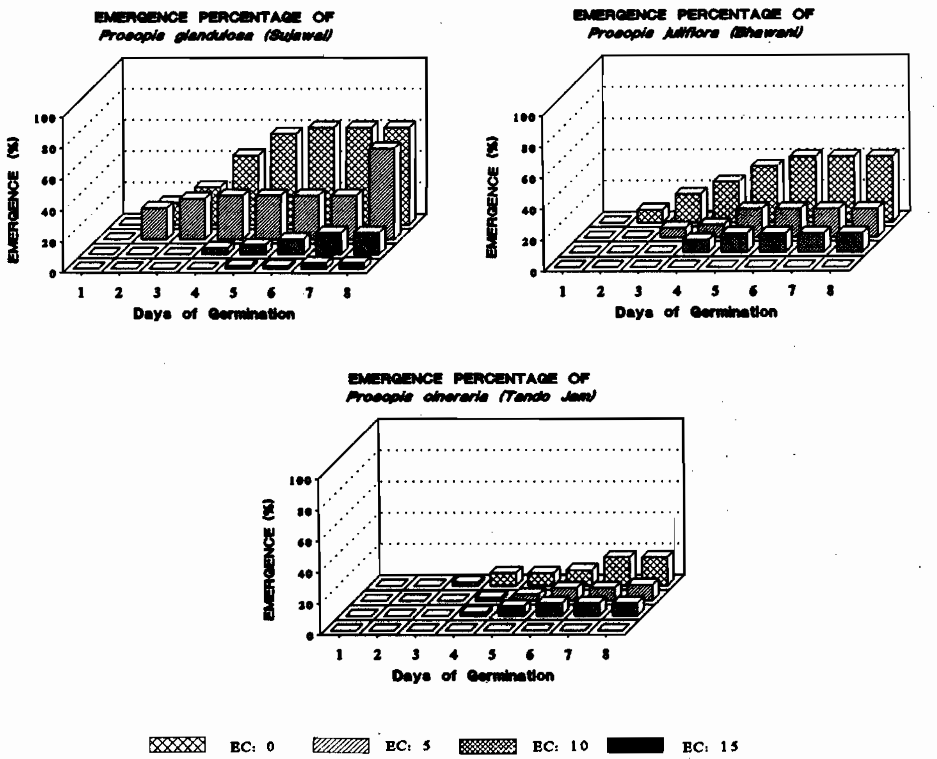

Fig.2. Effect of various salt levels on the emergence of different *Prosopis* species/provenances.

Shoot biomass under non-saline control conditions was in the order of: *P. juliflora* (Bhawani) > *P. pallida* (Winrock)> *P. glandulosa* (Karachi) > *P. glandulosa* (Sujawal) > *P. juliflora* (Brazil), and where, irrigation water of 20 $dS.m^{-1}$ was used *P. juliflora* (Brazil) > *P. pallida* (Winrock) > *P. juliflora* (Bhawani) > *P. glandulosa* (Sujawal) > *P. glandulosa* (Karachi). There was some accumulation of salts in the soil even at low levels (0 & 10 $dS.m^{-1}$) of salinity in the irrigation water as a result of partial leaching during watering, whereas, at higher salinity level (40 $dS.m^{-1}$), the EC_e was less than the EC of the irrigation water.

Screening of local and exotic genomes of *Prosopis* under field conditions using saline water for irrigation: Different *Prosopis* species exhibited different growth responses depending on their habitat and growth vigour. The height of *P. juliflora* (D. I. Khan), *P. glandulosa* (Sujawal) and *P. julifora* (Sujawal-2) ranged from 61.1 to 92.4 cm. The first two species exhibited better performance with regard to both number and cumulative length of the branches. The height of *P. alba* (Acc. # 0166), *Prosopis* sp. (Peru), and *P. juliflora* (Brazil) ranged from 75.9 to 96.4 cm. With respect to the number of branches, *Prosopis* sp. (Peru), *P. chilensis* (Acc. #0009) and *P. articulata* (Acc. #0598), ranked first, second and third, respectively. With reference to the

Table 2. Biomass production of some *Prosopis* species/provenances grown with different concentrations of saline water.

Plant Species	Parameters Studies	Control	EC:10	EC:20	EC:30	EC:40	F-Value	$LSD_{0.05}$
		$dS.m^{-1}$						
Prosopis juliflora (Bhawani)								
Leaf	Fresh Weight (g)	150.00 ±67.10	45.83 ±5.67	22.30 ±11.30	18.66 ±2.30	11.66 ±1.20	3.54*	96.30
	Dry Weight (g)	67.16 ±34.29	17.00 ±1.52	6.66 ±0.66	7.33 ±1.45	4.00 ±1.00	2.99	n.s
Stem	Fresh Weight (g)	209.33 ±41.47	95.16 ±13.58	54.50 ±22.00	39.83 ±10.52	26.00 ±4.00	10.92*	70.7
	Dry Weight (g)	116.00 ±25.32	65.33 ±10.49	34.50 ±13.40	20.66 ±5.54	14.33 ±1.45	9.02*	45.5
Root	Fresh Weight (g)	268.60 ±6.64	111.66 ±5.54	114.33 ±18.20	51.00 ±13.70	28.10 ±8.54	65.8*	36.4
	Dry Weight (g)	106.66 ±7.79	32.00 ±1.52	29.00 ±3.78	12.66 ±2.40	7.33 ±2.20	91.79***	12.8
	EC_e ($dS.m^{-1}$)	0.94 ±0.02	18.53 ±1.18	28.80 ±5.87	33.26 ±4.39	35.10 ±0.59		
Prosopis juliflora (Brazil)								
Leaf	Fresh Weight (g)	80.20 ±22.69	66.33 ±2.90	69.66 ±5.36	27.00 ±4.35	13.00 ±2.08	16.69*	20.12
	Dry Weight (G)	25.66 ±10.08	29.00 ±0.57	25.00 ±1.15	9.00 ±1.15	3.66 ±0.33	6.13*	14.42
Stem	Fresh Weight (g)	153.30 ±62.00	135.00 ±17.00	72.16 ±16.88	39.60 ±6.93	22.66 ±0.88	3.70*	94.30
	Dry Weight (g)	126.33 ±23.34	77.33 ±6.69	36.66 ±8.83	26.00 ±5.03	8.66 ±1.85	15.90*	37.18
Root	Fresh Weight (g)	104.66 ±19.06	42.66 ±6.83	21.00 ±2.88	12.33 ±0.33	7.66 ±0.88	18.87*	28.85
	Dry Weight (g)	50.33 ±9.49	16.66 ±0.33	8.66 ±1.45	5.00 ±0.57	2.33 ±0.33	20.77*	1.65
	EC_e ($dS.m^{-1}$)	1.05 ±0.04	25.36 ±2.42	31.8 ±0.05	32.75 ±2.57	34.80 ±0.83		

Table 2 (Cont'd)

Plant Species	Parameters Studies	Control	EC:10	EC:20	EC:30	EC:40	F-Value	$LSD_{0.05}$
		$dS.m^{-1}$						
Prosopis pallida (Winrock)								
Leaf	Fresh Weight (g)	134.33	89.30	63.16	18.33	10.66	8.30*	55.89
		±39.10	±1.20	±3.34	±4.09	±3.10		
	Dry Weight (g)	56.66	29.66	21.66	7.30	3.60	11.06*	20.07
		±13.90	±0.88	±2.02	±2.02	±0.66		
Stem	Fresh Weight (g)	180.00	106.33	70.33	39.66	13.66	2.81	n.s
		±83.30	±16.85	±2.77	±6.93	±1.70		
	Dry Weight (g)	96.33	64.66	40.33	18.66	5.30	3.18	n.s
		±44.40	±9.17	±3.66	±2.60	±0.60		
Root	Fresh Weight (g)	138.00	42.30	34.33	24.66	5.00	32.80*	28.42
		±14.50	±5.48	±6.43	±10.90	±2.00		
	Dry Weight (g)	79.66	17.00	13.00	6.66	2.33	24.10*	20.38
		±13.80	±2.60	±2.08	±2.40	±0.33		
	EC_e ($dS.m^{-1}$)	1.70	24.10	32.73	26.23	33.90		
		±0.23	±2.37	±3.10	±0.75	±0.46		
Prosopis glandulosa (Sujawal)								
Leaf	Fresh Weight (g)	63.66	22.83	38.00	—	—	28.20*	n.s.
		±7.85	±2.40	±3.60	—	—	15.59	n.s.
	Dry Weight (g)	31.00	9.33	10.66	—	—	20.52	n.s
		±4.58	±0.30	±0.66				
Stem	Fresh Weight (g)	114.60	32.50	43.83	—	—	6.57*	59.41
		±35.10	±4.80	±6.64				
	Dry Weight (g)	104.00	28.66	24.00	—	—	71.06*	18.43
		±7.20	±4.80	±3.05				
Root	Fresh Weight (g)	117.00	94.33	60.00	—	—	9.07*	55.71
		±30.13	±12.25	±18.55				
	Dry Weight (g)	62.33	29.66	15.00	—	—	6.79*	32.16
		±14.80	±4.09	±4.50				
	EC_e ($dS.m^{-1}$)	1.71	18.92	24.90	33.20	34.64		
		±0.29	±0.86	±2.77	±0.00	±0.28		

Table 2 (Cont'd)

Plant Species	Parameters Studies	Control	EC:10	EC:20	EC:30	EC:40	F-Value	$LSD_{0.05}$
		dS.m^{-1}						
Prosopis glandulosa (Karachi)								
Leaf	Fresh Weight (g)	65.66	29.16	20.33	—	—	4.70*	38.33
		±19.00	±1.58	±0.88				
	Dry Weight (g)	31.00	11.33	7.00	—	—	6.99*	16.72
		±8.30	±0.66	±0.57				
Stem	Fresh Weight (g)	182.33	63.16	21.50	—	—	65.17*	35.78
		±16.60	±4.34	±4.80				
	Dry Weight (g)	126.66	36.33	16.33	—	—	52.26*	28.13
		±13.67	±2.66	±2.02				
Root	Fresh Weight (g)	151.66	136.66	31.33	—	—	17.26*	54.61
		±17.50	±18.66	±9.49				
	Dry Weight (g)	81.33	35.36	9.66	—	—	46.30*	18.45
		±8.11	±3.75	±2.33				
EC_e (dS.m^{-1})		0.94	19.40	22.85	30.50	35.64		
		±0.10	±1.66	±0.39	±0.00	±0.24		

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

cumulative length of branches, *P. articulata* (Acc. #0598), *P. alba* (Acc. #0166) and *Prosopis* species (Peru) were the three best exotic species/accesssions. The differences among these 6 species/accessions, irrespective of origin, for various parameters were significant ($P < 0.05$) as compared with the rest of the species/accessions/provenances. *P. alba* proved to be the best with respect to height, number and cumulative length of the branches. *P. alba* also appeared to have a greater tendency to become monostemic as compared with *Prosopis* from local sources.

P. cineraria was the only palatable species among the various species/accessions/provenances used in this experiment. It is generally monostemic and makes a shady crown. *P. cineraria* (Tando Jam), though not as high as *P. juliflora* (D.I. Khan) or *P. alba* (Acc. #0116), is still a good choice because of its grazing value.

There appeared to be salt accumulation in the soil due to saline water irrigation over a period of time and insufficient leaching of the saline water through the root zone (Table 3). This could be attributed to differences in soil texture in different areas of the experimental field. The salt accumulation in the root zone varied from 5 to 14 dS.m^{-1}, and could be one of the factors affecting rooting and growth pattern.

Data on some physiological parameters for the plants grown with saline water are presented in Table 4. *P. articulata* (Acc. #0598), an exotic species, showed the highest quantum yield, followed by *P. glandulosa* (Sujawal), an indigenous species. The lowest quantum yield was observed for *P. juliflora* (D.I. Khan), which had a significantly

Table 3. Some morphological characters in different *Prosopis* species/accessions/provenances as influenced by saline water irrigation.

Name of Species	Height of Main Stem (cm)	Number of Branches	Length of Branches (cm)	Salinity of Root Zone ($dS.m^{-1}$)
P. juliflora (Karachi)	16.75 ± 0.80 g	1.50 ± 0.09 b	20.5 ± 1.59 h	11.53 ± 1.08
P. juliflora (Sujawal -1)	30.00 ± 2.40 defg	3.25 ± 0.23 b	61.75 ± 7.20 fgh	15.90 ± 9.28
P. juliflora (Sujawal -2)	61.14 ± 2.47 bcd	4.71 ± 0.46 b	213.14 ± 19.40 cd	11.13 ± 1.58
P. juliflora (D.I.Khan)	92.44 ± 3.10 a	8.44 ± 0.25 a	516.88 ± 16.40 a	8.50 ± 1.78
P. juliflora (Faisalabad)	33.66 ± 4.10 defg	4.33 ± 0.29 b	187.00 ± 12.40 de	13.65 ± 0.10
P. juliflora (Bhawani)	21.40 ± 2.60 fg	1.50 ± 0.14 b	34.25 ± 2.60 gh	8.53 ± 1.07
P. glandulosa (Sujawal)	75.11 ± 4.09 bcd	4.87 ± 0.25 b	164.25 ± 18.03 def	7.70 ± 0.00
P. glandulosa (Sujawal)[Thornless]	40.66 ± 2.80 defg	3.40 ± 0.33 b	136.4 ± 13.16 defg	10.80 ± 2.17
P. glandulosa (N.W.F.P.)	45.50 ± 2.70 cdefg	1.37 ± 0.09 b	36.12 ± 3.52 gh	8.36 ± 0.73
P. cineraria (Tando Jam)	45.37 ± 2.61 cdefg	3.25 ± 0.27 b	134.62 ± 13.10 defg	7.60 ± 0.00
P. cineraria (Karachi)	37.00 ± 1.55 defg	2.14 ± 0.15 b	76.00 ± 11.43 fgh	5.70 ± 0.00
P. cineraria (N.W.F.P.)	23.11 ± 1.29 efg	4.00 ± 0.26 b	100.33 ± 7.97 efgh	5.00 ± 0.00
P. nigra (Acc # 1117)	48.33 ± 3.05 cdefg	2.33 ± 0.13 b	72.00 ± 6.18 fgh	8.70 ± 2.57
P. articulata (Acc # 0598)	75.11 ± 4.09 abc	4.87 ± 0.25 b	347.00 ± 19.05 b	12.83 ± 3.16
P. chilensis (Acc # 0009)	35.20 ± 3.11 defg	5.00 ± 0.67 b	81.2 ± 11.40 efgh	11.16 ± 0.94
P. alba (Acc # 0591)	55.75 ± 4.50 bcde	3.33 ± 0.17 b	123.00 ± 8.01 defgh	11.86 ± 2.26
P. alba (Acc # 0166)	96.44 ± 5.94 a	4.60±6.20 b	325.33 ± 15.79 b	6.36 ± 0.49

Table 3 (cont'd)

Name of Species	Height of Main Stem (cm)	Number of Branches	Length of Branches (cm)	Salinity of Root Zone ($dS.m^{-1}$)
Prosopis Spp. (Peru)	83.44 ± 3.70 ab	5.33 ± 0.34 b	295.66 ± 13.4 bc	8.00 ± 0.87
P. pallida (Winrock)	40.80 ± 5.97 defg	1.20 ± 0.12 b	43.25 ± 10.70 gh	13.53 ± 1.76
P. juliflora (Brazil)	75.85 ± 7.39 abc	4.28 ± 0.25 b	92.28 ± 13.9 efgh	7.10 ± 1.61
MS (Species)	4355.18	22.44	130246.800	
df	19	19	19	
F - Value	5.04^{*}	5.67^{***}	13.184^{**}	
$LSD_{0.05}$	27.40	1.85	92.78	

Means in columns followed by same letters are not significantly different as calculated by Duncan Multiple Range Test at $P < 0.05$.

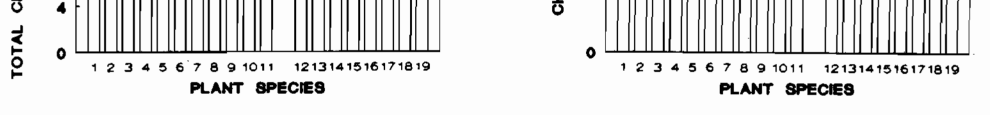

Fig.3. Concentration of chlorophyll content in local and exotic species/accessions/provenances of *Prosopis* under saline water irrigation.

Key to the Species: 1. *P. juliflora* (Karachi), 2. *P. juliflora* (Sujawal-1), 3. *P. juliflora* (Sujawal-2), 4. *P. juliflora* (D.I. Khan), 5. *P. juliflora* (Faisalabad), 6. *P. juliflora* (Bhawani), 7. *P. glandulosa* (Sujawal), 8. *P. glandulosa* (Sujawal, Thornless), 9. *P. glandulosa* (N.W.F.P), 10. *P. cineraria* (Tando Jam), 11. *P. cineraria* (Karachi), 12. *P. nigra* (Acc. # 1117), 13. *P. articulata* (Acc. # 0598), 14. *P. chilensis* (Acc. # 0009), 15. *P. alba* (Acc. # 0591), 16. *P. alba* (Acc. # 0166), 17. *Prospis* sp. (Peru), 18. *P. pallida* (Winrock), 19. *P. juliflora* (Brazil).

lower yield than many of the other species. Differences among the remaining species/accessions/ provenances in quantum yield were non-significant (P < 0.05). With regard to stomatal conductance, 7 species/accessions/provenances exhibited significantly higher values as compared with the rest of the species/accessions/provenances. *P. alba* (Acc. #0591), an exotic species, ranked highest and *P. juliflora* (Brazil), lowest. The transpiration rate corresponded more or less with the stomatal conductance of the individual species/accessions/provenances. *P. alba* (Acc. #0591) exhibited a higher stomatal conductance value as well as maximum values for transpiration rate. These species/accessions/provenances ranking high with regard to transpiration rate were found to be statistically different (P < 0.05) *P. juliflora*, (Bhawani).

Chlorophyll content in the exotic species/accessions/provenances was higher than in the indigenous ones. The amount of total chlorophyll in *P. alba* (Acc. #0166) and *P. nigra* (Acc. #1117) was statistically different (P < 0.05) from that in the rest of the species, whereas, it did not differ among the others. The concentration of chlorophyll 'a' was lower than that of chlorophyll 'b,' except in *P. juliflora* (Karachi), and *P: cineraria* (Karachi) where it was nearly equal (Fig.3). However, in *P. cineraria* (Tando Jam), the concentration of chlorophyll 'a' was higher than that of chlorophyll 'b'. The indigenous plants, *P. glandulosa* (Sujawal), *P. glandulosa* (Sujawal, thornless), and *P. juliflora* (D.I. Khan), contained more sugar (Fig.4) than the three species/accessions of the exotic group (i.e., *P. alba*, Acc. #0166; *P. pallida* (Winrock) and *P. juliflora* (Brazil). These exotic species occupied the same ranks with respect to total chlorophyll content as well. Among the indigenous species, *P. glandulosa* contained the highest amounts of chlorophyll and sugar. *P. juliflora* (Sujawal) exhibited the highest concentration of proline (Fig.4) as compared to *P. alba* (Acc. #0166), which showed maximum concentration among the exotic species.

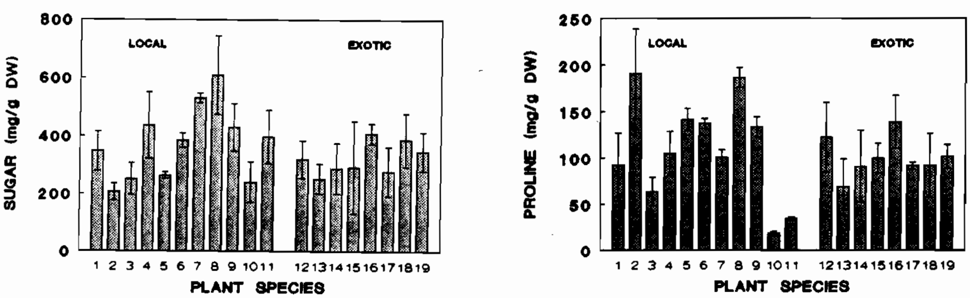

Fig.4. Concentration of sugar and proline content in local and exotic species/accessions/provenances of *Prosopis* under saline water irrigation.

Key to the Species: 1. *P. juliflora* (Karachi), 2. *P. juliflora* (Sujawal-1), 3. *P. juliflora* (Sujawal-2), 4. *P. juliflora* (D.I. Khan), 5. *P. juliflora* (Faisalabad), 6. *P. juliflora* (Bhawani),
7. *P. glandulosa* (Sujawal), 8. *P. glandulosa* (Sujawal, Thornless), 9. *P. glandulosa* (N.W.F.P), 10. *P. cineraria* (Tando Jam), 11. *P. cineraria* (Karachi), 12. *P. nigra* (Acc. # 1117), 13. *P. articulata* (Acc. # 0598), 14. *P. chilensis* (Acc. # 0009), 15. *P. alba* (Acc. # 0591), 16. *P. alba* (Acc. # 0166), 17. *Prospis* sp. (Peru), 18. *P. pallida* (Winrock), 19. *P. juliflora* (Brazil).

Table 4. Physiological measurements of different *Prosopis* species grown with saline water irrigation.

Name of Species	Stomatal Conductance (m.mol.m^2 S^{-1})	Transpiration Rate (m.mol.m^2S^{-1})	Quantum Yield (umol.$S^{-1}m^2$)
P. juliflora (Karachi)	20.23 ± 2.14 ab	1.09 ± 0.15 abc	1650 ± 195.11 abc
P. juliflora (Sujawal -1)	12.98 ± 1.68 def	0.88 ± 0.14 bcd	1688 ± 67.28 abc
P. juliflora (Sujawal -2)	15.72 ± 1.86 bcd	0.89 ± 0.12 bcd	1760 ± 66.95 abc
P. juliflora (D.I.Khan)	13.30 ± 0.83 def	0.77 ± 0.05 bcd	1415 ± 177.39 c
P. juliflora (Faisalabad)	12.98 ± 1.83 def	1.06 ± 0.15 abc	1575 ± 155.52 abc
P. juliflora (Bhawani)	9.35 ± 1.49 ef	0.49 ± 0.12 d	1700 ± 49.30 abc
P. glandulosa (Sujawal)	16.12 ± 2.93 bcd	0.99 ± 0.16 abc	1582 ± 92.40 abc
P. glandulosa (Sujawal) [Thornless]	14.74 ± 1.71 cde	1.16 ± 0.13 ab	1775 ± 31.91 ab
P. glandulosa (N.W.F.P.)	19.04 ± 1.31 abc	1.20 ± 0.05 ab	1659 ± 75.60 abc
P. cineraria (Tandojam)	11.22 ± 1.03 def	0.65 ± 0.13 cd	1556 ± 120.18 abc
P. cineraria (Karachi)	14.20 ± 1.30 cdef	1.07 ± 0.00 abc	1650 ± 195.11 abc
P. cineraria (N.W.F.P.)	11.73 ± 4.26 def	0.76 ± 0.07 bcd	1587 ± 89.04 abc
P. nigra (Acc # 1117)	8.76 ± 1.95 f	1.02 ± 0.08 abc	1721 ± 45.41 abc
P. articulata (Acc # 0598)	12.60 ± 1.28 def	0.66 ± 0.63 cd	1840 ± 70.23 a
P. chilensis (Acc # 0009)	9.03 ± 1.64 f	0.82 ± 0.87 bcd	1504 ± 113.32 abc
P. alba (Acc # 0591)	23.6 ± 5.30 a	1.42 ± 0.17 a	657 ± 204.84 d
P. alba (Acc # 0166)	9.26 ± 1.34 ef	0.66 ± 0.10 cd	1470 ± 97.88 bc
Prosopis spp. (Peru)	13.53 ± 1.39 def	0.76 ± 0.08 bcd	1587 ± 89.04 abc

Table 4 (Cont'd)

Name of Species	Stomatal Conductance ($m.mol.m^2 S^{-1}$)	Transpiration Rate ($m.mol.m^2 S^{-1}$)	Quantum Yield ($umol.S^{-1} m^2$)
P. pallida (Winrock)	13.63 ± 0.96 def	0.89 ± 0.07 bcd	1528 ± 137.18 abc
P. juliflora (Brazil)	8.76 ± 1.95 f	0.80 ± 0.16 bcd	1585 ± 20.44 abc
MS Treatment (Species) (df = 19)	80.80	0.29	219757.00
MS Error (df = 108)	24.24	0.15	94561.00
F - Value	3.33***	1.92*	2.32**
$LSD_{0.05}$	4.60	0.36	287.30

Means in columns followed by same alphabets indicate non-significant differences as determined by Duncan Multiple Range Test at $P < 0.05$.

Discussion

Prosopis seeds exhibited differences in salt tolerance across the seed sources evaluated. This may have been due to better seed production and greater adaptation under prevailing saline conditions among the more tolerant spécies. Reduction in the percentage of germination with increasing salinity levels has been reported (Khan *et al.*, 1987). Local *Prosopis* species growing naturally in Sujawal produces seeds that could tolerate salts during germination with a minimum reduction in seed germination at low salinity levels (EC: 5-10 $dS.m^{-1}$) and could germinate at salinity level of up to EC: 25 $dS.m^{-1}$. As the site from where the seeds were collected is situated by the side of the river Indus although has saline soil but good-quality water is available which reduces the salt toxicity and allows *Prosopis* species to grow luxuriantly in that area. Seeds produced on plants with greater vigour could be the reason for their better salt tolerance during germination.

During seed germination the newly formed cells of the radicle come in direct contact with the saline soil and face osmotic and ionic shocks. Some of the seedlings were unable to survive, and only those seedlings (*P. glandulosa*, Sujawal) which were salt tolerant emerged out of the saline soil.

Difference in growth of *Prosopis* species under different salinity regimes could be due to genetic differences. Variations among the accessions/provenances of the same species may be due to the habitat where they grow and from where the seeds have been collected. When grown under the same environmental conditions in pots, differences in their genetic variability were evident. *P. juliflora* appeared to be a more adapted species in terms of survival and biomass productivity as compared to other species. Only *P. juliflora* (Bhawani), *P. juliflora* (Brazil), and *P. pallida* (Winrock) survived at highest salinity level of EC_{iw}: 40 $dS.m^{-1}$ with their root systems comparatively well developed.

Prosopis juliflora and *P. glandulosa* which were introduced in Pakistan during the last 50 years have since become well established as indigenous species. *P. juliflora* grows luxuriantly along the coastline near Karachi and Sonmiami and is threatening to become weed on fertile land. It is generally multistemic in nature, but pruning of branches gives it a monostemic character. It is very hardy and grows under halo-xeric conditions. Under optimum growth conditions a biomass of 52.3 tons/ha even in the alkali soil after 6 years has been reported (Singh & Singh, 1993). *P. glandulosa*, which did not grow under higher salinity in the pot culture, showed reasonably good growth when irrigated with well water with 14-16 $dS.m^{-1}$. It is comparatively less salt-tolerant, requires more water than *P. juliflora* and has been found to grow luxuriantly on saline land along the canal sides and rivers. Its biomass production varies greatly depending on the accessions (Felker *et al.*, 1983b). *Prosopis* raised from the seeds collected from D.I. Khan and Sujawal was far superior to that collected from other places in Pakistan. Although the soil is saline, but since water remains available the plants exhibit good growth and with well developed seeds, the plants seems to have the vigour for stress tolerance. Among the exotic species obtained from South America, *P. alba*, *P. articulata*, *P. nigra* and *P. pallida* exhibited better growth under the prevailing halo-xeric conditions. There are reports that some accessions of these species produce better biomass than others, where *P. alba* (Acc. #0166) showed highest biomass producion with an oven-dry mean biomass value reaching 36.8 kg/plant after 2 years of growth (Felker *et al.*, 1983 a&b).

Differences in the chlorophyll and sugar content in leaves of plants of various species/accessions/provenances were not statistically significant ($P > 0.05$), however, species like *P. alba* (0166), *P. nigra* (1117), *P. juliflora* (D.I. Khan), and *P. glandulosa* (Sujawal), showed better performance in growth, and were rated high on these parameters when compared with other species/accessions/provenances. A high correlation of chlorophyll and sugar with high quantum yield suggests better photosynthetic efficiency of these species even under saline conditions. An increased concentration of chlorophyll content has been linked with greater amounts of photosynthetic apparatus per leaf (Terry & Waldron, 1984). Similarly a relationship has been suggested between accumulation of sugar in plants under salt stress and respiration rate and allocation of carbon for synthesis of organic solutes which serve as cell osmoticum (Shannon, 1984; Jefferies *et al.*, 1979). The presence of other organic compounds is required to balance the osmotic gradient between internal and external cell potential where proline, a water soluble amino acid, is considered to have an osmo-regulatory function (Treichel, 1975).

The availability of soil moisture and the associated osmotic potential of the soil solution influences water uptake and related processes. Transpiration rate is known to be influenced by external factors such as ambient air humidity and temperature (Eshel & Waisel, 1984) and internal factors such as anatomical features of the plant. Plants with high transpiration demand also exhibit higher stomatal conductance. In the present study, *P. alba* showed maximum values of both stomatal conductance and transpiration. Among the local genomes, all provenances of *P. glandulosa* which exhibited maximum stomatal conductance and transpiration values could be attributed to the shape of the leaflets, which are broader and have less cuticle as compared with other species. Lower values of stomatal conductance in other species/accessions/ provenances may not be due to stress but to partial closure of stomates or reduced size and density of stomates per unit area (Warne *et al.,* 1990).

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