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Jojoba (*Simmondsia chinesis* (Link) Schneider): A Potential Shrub in the Arabian Desert: III. Effect of Saline Irrigation on Vegetative Growth, Nutritive Value and Soil Properties*

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ABSTRACT. The effect of four saline irrigation regimes *viz.* 1.0, 15.6, 31.2 and 46.9 dSm^{-1} on vegetative growth, nutritive value, and soil properties was assessed in a randomized complete block field experiment under the arid environment of Western Saudi Arabia. Analysis of eight seasons (2 years) data revealed no significant differences among treatments on each of the nine morphological traits studied except for number of leaves and branch length in the winter of the first year and for number of branches per plant in the summer of the second year.

Salinity has no significant effects on mineral (N, P, K, Na, Ca, Mg, Cu, Fe, Mn, Zn) content of leaves, culms and soil and on soil properties such as pH, TSS, SAR, ESP, ECe and on concentrations of HCO_3^-, Cl^- and SO_4^{--} at variable depths. Effects of season on mineral contents of leaves and culms and on all morphological traits were significant. On the average, highest estimates for the morphological traits were recorded in the spring and winter; whereas those of mineral contents in leaves and culms varied with the season.

Introduction

Worldwide seed production from commercial plantations of jojoba is projected to amount to 9800 metric tons in the year 2000, namely from U.S.A, Latin America, Mexico and Israel (Brown *et al.,* 1996). At present, jojoba clones yielding up to 4 tons of seeds/ha are now under commercial plantation in Israel (Forti and Elharar, 1990).

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Jojoba is known to be salt-tolerant, but little is known about the extent of its tolerance under field conditions in arid areas. The main information on salinity effects on jojoba comes from the short term experiments with young seedlings or cuttings. Tal *et al.* (1979) showed that salt concentrations of up to 200 mM ($\simeq$ 20 Sm^{-1}) did not inhibit vegetative growth. Similarly, Yermanos *et al.* (1967) did not observe adverse effects on vegetative growth at a salinity of 108 mM ($\simeq$ 11dSm^{-1}), however, a serious reduction in the number of flower buds and potential yield was noticed at this level of salinity. Reductions in stem diameter and number of flowers coupled with an increase in branch length and number of branches were recorded at 14 dSm^{-1} salinity level (Francois, 1986). Similarly, Benzioni *et al.* (1992) recorded no reductions in stem elongation, number of nodes per branch and biological yield at salinity levels of up to 137 mM ($\simeq$ 14 dSm^{-1}).

Benzioni *et al.* (1992), Mills and Benzioni (1992) and Benzioni *et al.* (1996) assessed the performance of four jojoba clones, respectively, in potted experiments, in tissue culture as nodal segments and under field conditions. Their data indicated a differential response to salinity among the clones. Exposures to high salinity levels of 12 dSm^{-1} in pot experiments resulted in the reduction of number of viable flowers; whereas in the tissue culture experiments salinity of up to 20 dSm^{-1} did not reduce growth in one of the four clones. Performance of nodal segments to salinity was positively correlated to that of potted plants. Data of the field trial revealed no adverse effects of 6.4 dSm^{-1} salinity on plant growth (volume) and on the rate of CO_2 fixation. Clones that were less tolerant to salinity in tissue culture and in pots also showed to be the most sensitive in the field. Other physiological studies revealed that photosynthetic activity of jojoba populations from Arizona and from San Diego (coastal plants) was reduced to 50% only at – 36 bars and – 20 bars soil water potential, respectively (Al-Ani *et al.*, 1972).

As water is the main limiting factor in the Arabian Desert, future plantations of jojoba in the Kingdom of Saudi Arabia may only be grown under sewage effluents and/or brackish (saline) water. It is foreseeable that as fresh water resources become limited, agricultural irrigation systems will steadily increase in salinity. Consequently, utilization of salt tolerant plants in sand stabilization, landscape and greenification projects and in establishing open range lands and national recreation centres will save adequate amounts of fresh water for cultivation of traditional crops. Therefore, the present work is undertaken to assess the effect of continued saline irrigation on vegetative growth, biomass production and nutritive value of jojoba. Effects of salinity on soil properties were also studied.

Materials and Methods

The present work was conducted at the Experimental Farm of King Abdulaziz University at Hada Al-Sham located 120 km northeast of Jeddah. The soil at the experimental site is sandy clay (72% sand, 18% clay and 10% silt) with a pH of 8.2 and an ECe of 0.96 dSm^{-1}. The meteorological data characterizing the experimental site is shown in Table 1. A seed lot of jojoba introduced from Arizona, U.S.A. was sown in 1989. Seeds harvested from this stock were used in establishing the saline irrigation test plots evaluated in this trial. The test plot was planted on 28/2/1993 in an area of 0.2 ha (28 rows × 4 m × 25 m) under a drip irrigation system. The test plot was divided into three blocks each of which, apart from marginal rows, consisted of eight experimental rows, two of which were (2 rows × 4 × 25 m) randomly allocated for each of the four (S_0, S_1, S_2 and S_3) saline irrigation treatments. These treatments were obtained by dissolving specified weights of NaCl and $CaCl_2$ (1:1 molar ratio) in 1000 L of irrigation water (S_0) for each irrigation as shown in Table 2. Four elevated fiber glass tanks, of 1000 L capacity each, supplied with a dripper system were used for irrigation. On the same date, all plots allocated for the saline irrigation treatments (S_1 to S_3) were irrigated with the S_1 saline level, in order to avoid a sudden physiological shock. A week later, all plots allocated for the S_2 and S_3 treatments received an S_2 irrigation water. Afterwards, all plots were irrigated according to their assigned salinity levels at a monthly interval until the 21st of December 1995. The gradual introduction of high saline treatments (S_2 and S_3) were intended to reduce sudden salinity shocks.

TABLE 1. Absolute seasonal maxima and minima of temperature and relative humidity recorded at the experimental site in the periods 21/12/93 and 21/12/1995.

Season	1993 / 94		1994 / 95	
	Temp. (ºC)	R.H. (%)	Temp. (ºC)	R.H. (%)
Winter (W)	6 - 40	22 - 98	10 -42	17 - 100
Spring (Sp)	14 - 49	24 - 93	18 - 49	19 - 95
Summer (S)	19 - 48	21 - 100	21 - 48	22 - 95
Fall (F)	14 -42	22 - 99	20 - 46	21 - 95

TABLE 2. Concentration of NaCl + CaCl2 solution (1:1 Molar ratio for different salinity levels).

Treatment	Weight of mixed salts (g / L)		Total ppm	EC dSm^{-1}**
	NaCl	Cal_2		
S_0	–	–	640	1.0
S_1	3.5	6.5	10,000	15.6
S_2	7.0	13.0	20,000	31.2
S_3	10.5	19.5	30,000	46.9

*S_0 irrigation water (well) available at the experimental site.
**EC in dSm^{-1} = ppm / 640.

Starting 21/3/1994, *i.e.* after 390 days from planting, and for eight consecutive seasons (*i.e.* until 21/12/1995) ten plants were randomly tagged from each plot and were used for determining plant height, number of basal branches per plant, basal branch length and number and total area of leaves per branch. In addition, culm, leaf and total dry weights per basal branch and specific leaf area (total leaf area/total leaf weight) were also determined. Mineral contents in the leaves and culms in four samples (seasons) of the first year and in a soil sample taken at three soil depths (0-50, 50-100, and 100-150 cm) on the last sampling date (21/12/94) of the first year were also determined. Other soil parameters [Electric Conductivity (e = soil extract) ECe, Exchangeable Sodium percent (ESP), Sodium Adsorption Ratio (SAR) and Total Soluble Salts (TSS)] were also determined from the soil samples.

Results

Jojoba plants generally maintained an overall positive growth in each of the two years of the study under each of saline irrigation treatments (Figs. 1A to 3C). Throughout the entire growth period saline irrigations (S_1, S_2, and S_3) adversely ($P \leq 0.01$) affected the number of branches per plant during the summer of 1995 (Fig. 2A). In contrast, significantly ($P \leq 0.05$) longer branches (Fig. 2B) bearing a relatively high number of leaves (Fig. 3A) were maintained under saline irrigation (S_1) than under the control (S_0) treatment during the winter of 1994. No visual damage to the leaves could be detected at any stage of the plant growth.

Significant differences among irrigation regimes in nitrogen contents (%) of leaves and culms were non-significant, whereas those among seasons were significant (Tables 3 and 4). The main cations that were accumulated in the leaves (Table 3) and in the culms (Table 4) were Na^+, K^+, $Ca2^+$, $P3^+$, $Fe3^+$, $Mn2^+$ and $Zn2^+$. Although, accumulation of these cations tended to increase with the salinity level, differences among the four saline irrigations, averaged over seasons, were all non-significant. Accumulation of Na^+ and K^+ in both leaves and culms were highest at the first and second sampling dates and were significantly reduced afterwards (Tables 3 and 4). Calcium, $Mg2^+$ and $Cu2^+$ in the leaves and $Cu2^+$ in the culms, on the other hand, increased with plant age.

In the soil, accumulation of cations (Table 5) and anions (Table 6) generally tended to decrease with soil depth. These reductions were, however, significant for P^{+3}, Cu^{+2}, Mn^{+2}, as most of the ions accumulated in the 0-50 cm top soil layer. Accumulation of these ions, with the exception of P^{3+} did not appear to be affected by salinity level or soil depth (Table 5).

Soil parameters, *i.e.* ECe, ESP, SAR, pH and TSS tended to be highest at the top soil layer and at the highest salinity level (S_3), but differences among the saline treatments or soil depths were generally non-significant (Table 6).

Discussion

Reduction in plant growth at increasing salinity could arise from the adverse effects of Na^+ and Cl^- on metabolism or from adverse water relations (Berstein, 1975; Greenway and Menns, 1980). Either of these factors may exert adverse effects on mature or growing tissues. Limitations of growth could, however, depend on the species, the variety and the environment. Many physiological mechanisms have been suggested for

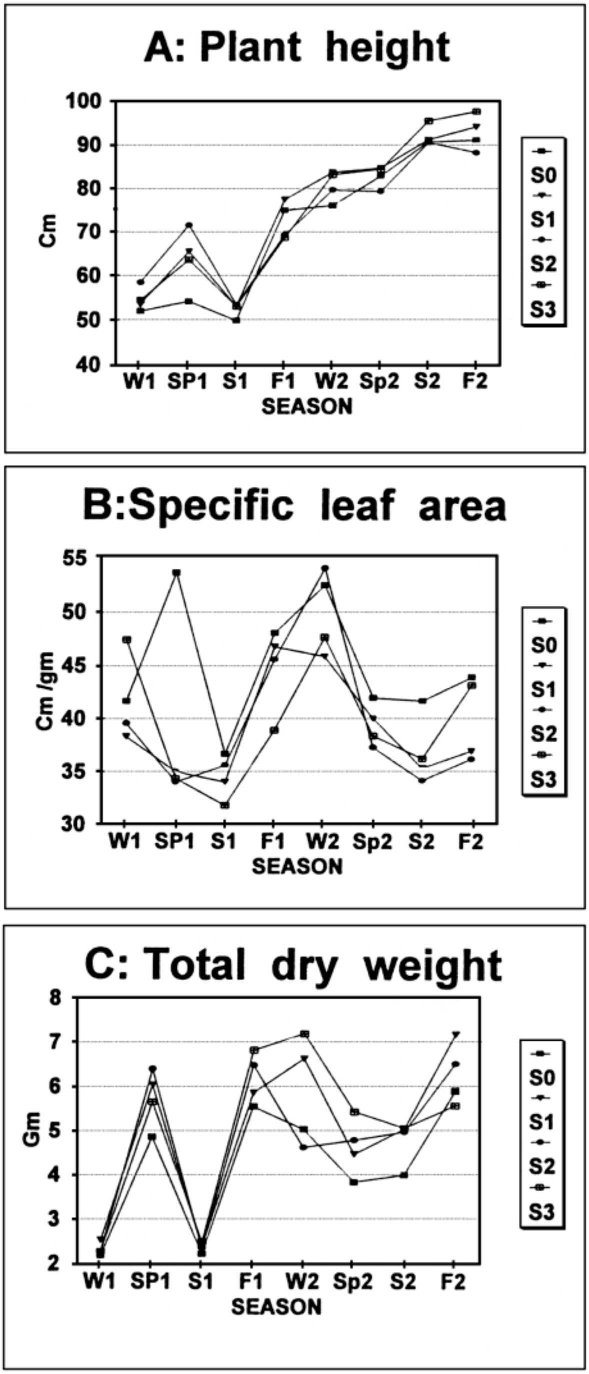

FIG. 1. Effect of saline irrigation on plant height (A), specific leaf area (B) and total dry weight (C) in eight growing seasons.

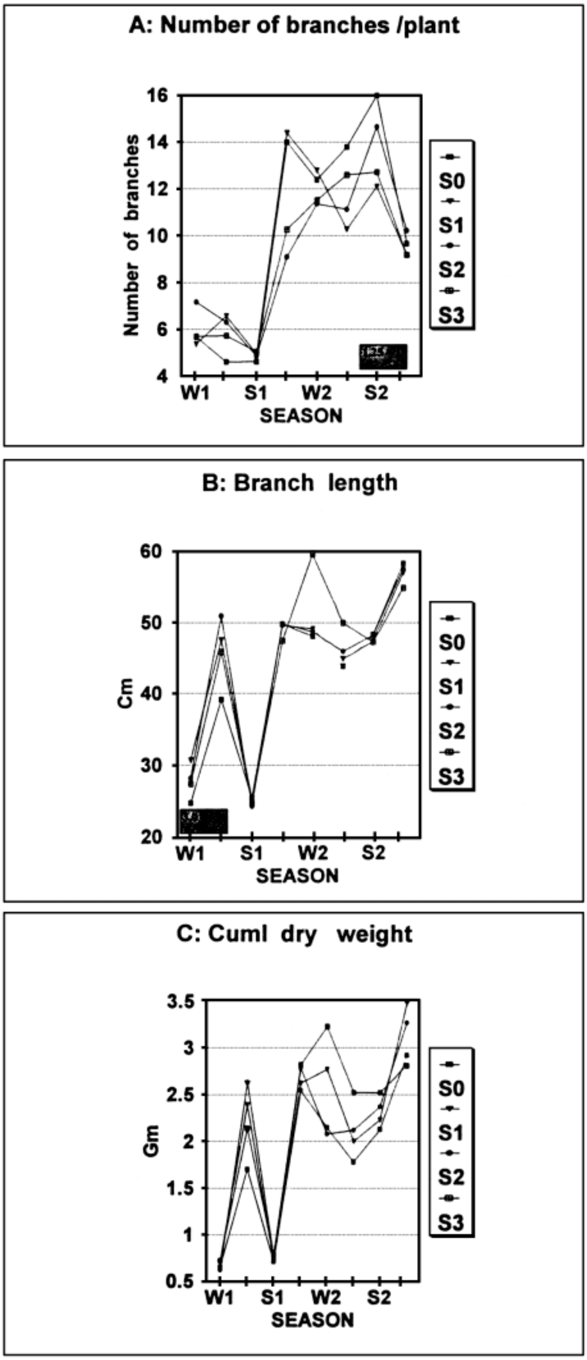

FIG. 2. Effect of saline irrigation on number of branches per plant (A), branch length (B) and culm dry weight (C) in eight growing seasons (shaded figures refer to LSD AT P ≤ 0.05).

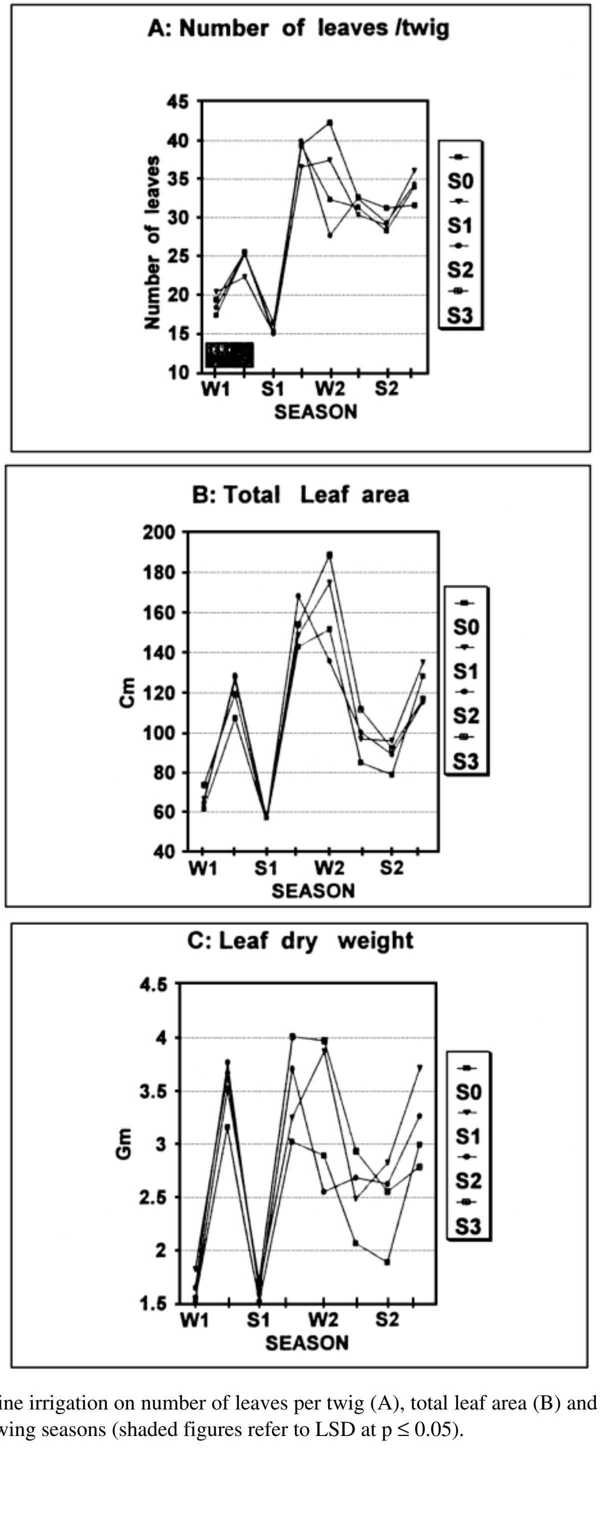

FIG. 3. Effect of saline irrigation on number of leaves per twig (A), total leaf area (B) and leaf dry weight (C) in eight growing seasons (shaded figures refer to LSD at $p \leq 0.05$).

salt tolerance (Flowers, 1972; Shannon, 1979; Marschner *et al.* 1981). Among these morphological adaptation and osmotic regulations through active ion transport were the most common. At high levels of NaCl water supply to the shoots, especially in the summer of an arid environment, becomes inadequate and thus growth is retarded. Thus the reduction in number of branches observed at the S_1, S_2 and S_3 levels in the summer of 1995 in contrast to the control (S_0) could be attributed to one or more of these factors.

TABLE 3. Effect of season and saline irrigation on mineral content of jojoba leaves

Season	N	P	K	Na	Ca	Mg	Cu	Fe	Mn	Zn
	%	(mg kg^{-1})								
Salinity Level										
S_0	2.16	753	5399	1360	265	22.1	4.85	521	120	22.8
S_1	2.20	613	5510	1489	342	111	5.83	482	144	12.0
S_2	2.16	778	5614	2428	328	130	5.40	545	142	14.8
S_3	2.05	843	5217	2245	331	113	6.58	575	148	23.0
Mean	2.15	734	5435	1880	317	94.3	5.66	531	138	18.1
S.E.±	0.85	73.2	195.1	274.9	31.3	28.4	0.49	39.8	7.8	5.9
Winter 1994	2.21	718	10250	2575	2.01	1.18	3.95	506	130	17.8
Spring 1994	2.26	618	10250	4275	2.22	1.18	4.15	586	122	21.0
Summer 1994	2.03	752	742	452	701	202	7.50	545	183	9.8
Fall 1994	2.08	848	499	219	563	173	7.05	487	119	24.0
Mean	2.15	734	5435	1880	317	94.3	5.66	531	138	18.1
S.E.±	0.25**	73.2	195.1**	274.9**	31.3**	28.4**	0.49**	38.9	7.8**	5.9

** indicates significant differences among seasons at $P \leq 0.0$.

TABLE 4. Effect of saline irrigation and season on mineral content of jojoba culms

Season	N	P	K	Na	Ca	Mg	Cu	Fe	Mn	Zn
	%	(mg kg^{-1})								
Salinity level										
S_0	1.40	633	3713	281	46.8	78.6	3.9	298	17.8	26.5
S_1	1.46	608	4266	554	85.8	19.4	5.0	331	24.8	16.8
S_2	1.36	563	3889	428	81.4	15.4	3.9	300	16.8	11.8
S_3	1.44	640	3820	618	77.9	18.6	4.5	341	19.0	10.8
Mean	1.42	616	3922	470	73.0	33.0	4.3	317.2	19.6	16.4
S.E. ±	0.006	88.6	256.8	96.6	18.7	24.1	0.43	36.2	3.8	3.9
Winter 1994	1.46	678	7000	250	0.59	0.17	3.4	212	10.8	13.3

TABLE 4. Contd.

Season	N	P	K	Na	Ca	Mg	Cu	Fe	Mn	Zn
	%	(mg kg^{-1})								
Spring 1994	1.47	643	7750	1400	1.04	0.32	2.8	406	27.8	26.0
Summer 1994	1.48	558	494	131	144.8	51.5	5.0	344	19.8	13.3
Fall 1994	1.25	685	444	99	146.0	80.0	6.2	308	20.0	13.3
Mean	1.42	616	3922	470	73.0	33.0	4.3	317.2	19.6	16.4
S.E. ±	0.006**	88.6	256.8**	96.6**	18.7	24.1	0.4**	36.2*	3.8	3.9

* and ** indicate significant differences among seasons at P ≤ 0.05 and P ≤ 0.05, respectively.

TABLE 5. Effect of saline irrigation on mineral content at different soil depths

Depth (cm)	P	K	Cu	Fe	Mn	Zn	Ca	Mg	K	Na
	mg/kg						meg/L			
Salinity level										
S_0	2.07	314.0	0.70	3.33	2.53	0.29	28.00	6.57	1.36	88.0
S_1	3.60	504.0	0.61	4.30	1.60	0.38	38.67	8.67	2.40	87.0
S_2	2.63	340.7	0.70	5.30	2.23	0.25	34.0	7.73	1.20	93.3
S_3	2.53	330.7	0.68	4.10	1.43	0.38	34.00	8.50	1.23	106.7
Mean	2.96	372.3	0.67	4.26	1.95	0.33	33.67	7.87	1.55	93.8
S.E. ±	0.16*	48.6	0.07	0.83	0.42	0.09	7.32	2.37	0.36	11.5
0 - 50	3.60	351.0	1.01	4.00	2.89	0.44	36.25	11.68	10.28	98.3
50 - 100	3.08	389.5	0.48	4.75	1.55	0.20	30.25	6.98	1.47	99.5
100 - 150	2.2	376.5	0.53	4.03	1.33	0.34	34.50	4.95	1.90	83.5
Mean	2.96	372.3	0.67	4.26	1.95	0.33	33.67	7.87	1.55	93.8
S.E. ±	0.14*	42.1	0.06*	0.72	0.37*	0.08	6.34	2.05	0.31	9.9

*indicates significant differences among depths or salinity levels at P ≤ 0.05

TABLE 6. Effect of saline irrigation on soil properties at different depths

Depth (cm)	pH	TSS %	SAR	ESP	ECe	HCO_3	CL	SO_4
					dSm^{-1}	meg/L		
Salinity level								
S_0	7.13	0.24	21.13	22.8	3.78	1.07	16.7	23.00
S_1	7.47	0.51	17.83	19.9	8.01	0.79	56.7	27.00
S_2	7.43	0.51	17.67	22.8	7.95	0.98	63.7	27.67

TABLE 6. Contd.

Depth (cm)	pH	TSS %	SAR	ESP	ECe	HCO_3	CL	SO_4
	dSm^{-1}				meg/L			
S_3	7.47	0.66	24.73	26.03	10.21	1.11	99.7	10.00
Mean	7.38	0.48	20.34	22.89	7.49	0.99	59.2	21.92
S.E. ±	0.16	0.17	3.55	2.36	2.62	0.13	22.1	7.71
0 - 50	7.38	0.66	20.15	22.10	10.25	1.78	98.5	22.75
50 - 100	7.30	0.42	23.40	24.78	6.50	0.81	47.8	22.00
100 - 150	7.45	0.37	17.48	21.80	5.71	0.98	31.3	21.00
Mean	7.38	0.48	20.34	22.89	7.49	0.99	59.2	21.92
S.E. ±	0.14	0.15	3.08	2.04	2.27	0.11	19.1	6.68

*indicates significant differences among depths or salinity levels at $P \leq 0.05$

Stimulation of plant growth at relatively low salinity levels has been reported in jojoba (Tal *et al.,* 1979), salt bushes (Ashby and Bendle, 1957) and in barley (Al-Rahmani *et al.,* 1997) and was attributed to activation of protein synthesis (Hall and Flowers, 1973), absorption of N and P which are necessary for protein synthesis (Al-Anni, 1975). In this study, N and P contents of the leaves and culms (Tables 3 and 4) at the S_1 level were statistically similar to those recorded at the S_2, S_3 and S_0 (the control). Thus, the attainment of significantly longer branches (Fig. 2B) with a higher number of leaves (Fig. 3A) in comparison to the control treatment could only partially be attributed to these metabolic trends. Tal *et al.* (1979), similarly, indicated that the length of jojoba branches at – 8.3 bars of NaCl ($\simeq$ 22 dSm^{-1}) was greater than in the control. Thus, apparently, apart from the reduction in branch length observed in the summer of 1994, the jojoba plant had tolerated the high levels of salinity imposed by continued irrigation.

Adams *et al.* (1977), Adams *et al.* (1978) and Tal *et al.* (1979) indicated that jojoba grown under high saline conditions is capable of osmatic adjustments without growth inhibition through accumulation of ions such as Na^+ and Cl^-. The uptake and accumulation of ions in response to salinity is shown by Yermanos *et al.* (1967), Tal *et al.* (1979) and Benzioni *et al.* (1996). In these studies, Na^+, Cl^-, Ca^{2+} and Mg^{2+} increased and K^+ decreased with an increase in salinity.

The accumulation of ions in the leaves which was several times higher than that in culms was also reported by Yermanos (1967). The high levels of Na^+ accumulated in the leaves of jojoba was accounted for as a possible mechanism for osmotic adjustments as indicated by Benzioni *et al.* (1996) for jojoba and by Al-Rhamani *et al.* (1997) for barley. Reductions in K^+ concentration with increasing salinity was reported to have adverse effects on growth as it is needed for metabolic processes (Epstein, 1972). In this study high levels of K^+ accumulated in the jojoba leaves, at all salinity levels (Table 3), indicating no selective uptake of K^+ by jojoba under saline or non-saline conditions.

Thus, apparently through osmotic balance and balanced uptake of K^+, jojoba plants normally survived the high salinity levels imposed in this study. Under such environmental conditions, jojoba – as reported by Benzioni *et al.* (1996) – maintained positive net photosynthesis and consequently no apparent reductions, except for number of branches in the summer. This behaviour was observed in all morphological traits evaluated in this study. Furthermore, the soil at the experimental site, 72% sand, might have contributed to the normal performance of jojoba under high saline conditions as reported by Ayers et al. (1952) for barley. Thus apparently, jojoba plants do accumulate sodium, potassium, and other ions in their leaves and stems and use this strategy, typical for many halophytes, to cope with high salinity specially in sandy soils. This obviously will, encourage the introduction of jojoba as a browse or landscape shrub in sand stabilization and greenification projects at present. Its introduction for seed production under high continued saline irrigation in the Arabian Desert warrants further investigation

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الهوهـوبا : الشجيـرة الواعـدة بالصحـراء العربيـة : ٣- أثـر الري بالميـاه المالحـة على النمو الخضري ، القيمة الغذائية وخواص التربة*

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كلية الأرصاد والبيئة وزراعة المناطق الجافـة ، جامعة الملك عبد العزيز

جـــــدة - المملكة العربية السعودية

المستـخلص . نفـذت التـجربـة الحاليـة بالمنطقـة الغـربيـة من المملكة باستعمال تصميم المرابيع العشوائية الكاملة حيث درست أربع معاملات ري ملحية تمثلت في الري بالمعدلات : ٠,١ ، ٦٢,١٥ ، ٢,٣١ ، ٩,٤٦ dS/ م . أوضحت النتائج التي سجلت خلال ثمانية مواسم متتالية (عامان) عدم وجود فروقات معنوية بين المعاملات الأربع في كل الصفات التسع التي درست عدا صفتي عدد الأوراق وطول الفرع خلال الشتاء من العام الأول وعدد الأفرع خلال الصيف من العام الثاني كذلك لم تؤثر الملوحة على محتوى الأوراق والسوق والتربة من عناصر : Mn, Fe, Cu, Mg, Ca, Na, K, P, N و Zn وعلى خواص التربة مثل TSS, pH, SAR, ESP, Ece وتركيزات HCO_3^- و Cl^- و SO_4^{--} . أما أثر الموسم على كل الصفات المورفولوجية وعلى محتوى الأوراق والسوق من العناصر المختلفة فقد كان معنويًا حيث سجلت أعلى القياسات للصفات النباتية خلال فصلي الربيع والشتاء بينما اعتمدت معدلات محتويات الأوراق والسوق من العناصر المختلفة على الرسم .

* أجري هذا البحث بدعم من مدينة الملك عبد العزيز للعلوم والتقنية بالمنحة رقم أت-١٣-٢٣ .