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Determination of Salt Tolerance of Stock (*Matthiola tricuspidata*) as a Potential Oil Crop

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Abstract: In this study the salt tolerance of stock (*Matthiola tricuspidata*) was investigated. For this purpose, a control and 4 different concentrations of NaCl + $CaCl_2$ were applied to plants grown under greenhouse conditions. Na, Cl and electrical conductivity (EC) analyses were conducted in soil, plant and leached samples. Yield, plant growth parameters and plant dry matter were also determined. All plants survived until the end of the experiments. Treatments affected the ion content and EC of leached and soil samples significantly. Increasing salinity conditions increased translocation of Na and Cl in plants. Flower numbers, seedpod numbers, and dry matter content of shoot and leaf were affected significantly. The second treatment, 2.0 dS m^{-1}, gave the highest seedpod number. However, treatments increased the plant dry matter up to 6.0 dS m^{-1} in the shoot and 8.0 dS m^{-1} in the leaf. The results suggest that irrigation of stock with saline water is feasible.

Key Words: salt tolerance, sodium, chloride, saline water, oil crop

Potansiyel Bir Yağ Bitkisi Olan *Matthiola tricuspidata*'nın Tuza Toleransının Belirlenmesi

Özet: Bu çalışmada, potansiyel bir yağ bitkisi olan *Matthiola tricuspidata*'nın tuzluluğa toleransı araştırıldı. Bu amaçla, kontrol ile birlikte dört farklı NaCl + $CaCl_2$ karışımı sera koşulları altında yetiştirilen bitkilere uygulandı. Toprak, bitki ve suda sodyum, klor, tuz analizleri yapıldı. Verim, bitki gelişme parametreleri ve bitki kuru maddesi belirlendi. Tüm bitkiler denemenin sonuna kadar hayatta kaldı. Artan tuzluluk toprak ve su örneklerinin sodyum, klor ve tuz değerlerini istatistiki olarak arttırdı. Sodyum ve klorun alımı ve bitkide taşınması açısından farklılıklar belirlendi. Çiçek sayısı, tohum kabı sayısı, ve gövde ile yaprakların kuru madde içeriğindeki değişimler istatistiki olarak önemli bulundu. En yüksek tohumkabı sayısı 2.0 dS m^{-1} de elde edildi. Bununla beraber, uygulamalar kuru madde miktarını gövdede 6.0 dS m^{-1} ve yaprakta 8.0 dS m^{-1} e kadar arttırdı. Elde edilen veriler ışığında *M. tricuspidata*'nın tuzlu sularla sulanmasının uygun olabileceği sonucuna varıldı.

Anahtar Sözcükler: tuza tolerans, sodyum, klor, tuzlu sular, yağ bitkisi

Introduction

Many areas that are of restricted use because of salt are located where there is abundant solar energy that can be used by plants to produce high yields. In these areas, 2 approaches may be taken. The first is to seek inexpensive and cost-efficient ways of desalting seawater to be used for irrigation purposes. The second is to determine probable crop plants that can grow and survive under highly saline conditions (Hale and Orcutt, 1987). The salt tolerance of a crop may be appraised according to 3 criteria: (1) The ability of the crop to survive on saline soils, (2) the yield of the crop on saline soils, and (3) the relative yield of the crop on a saline soil as compared to the yield of the crop on a nonsaline soil under similar growing conditions. Many previous observations on salt tolerance have been based mainly on the first criterion, the ability to survive; but this method of appraisal is of very limited practical significance in irrigation agriculture. Although it is recognized that the second criterion is perhaps of greater agronomic importance, the third criterion was used in compiling the salt-tolerance lists because it provides a better basis of comparison among diverse crops (Richards, 1954). Oilseed plants rich in essential polyunsaturated fatty acids

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may be a highly economical alternative for field crops that are irrigated with fresh water (Irving et al., 1988; Nerd, 1994). Stock (*Matthiola tricuspidata*) is a small annual crucifer, widespread on the sandy and shingle Mediterranean shores (Thanos et al., 1994) and a potential oilseed plant that might be used in industry. Success in growing this plant depends on the utilization of highly saline water. However, little is known about the salt tolerance of this plant. The aim of this study was to investigate the salt tolerance of *M. tricuspidata* as a new oil crop that can be used in the food industry.

Materials and Methods

Plant Material

Seedlings of *M. tricuspidata* were planted at the beginning of January 2001 in 10 l buckets filled with a 1:1 tuff to vermiculite mixture. The experiment was carried out throughout the entire life of the plants and finished at the end of June 2001. The buckets were placed in a greenhouse at the Experimental Station in Bet Dagan, Israel.

Salt Treatments

The experimental treatments consisted of 4 salinity levels of irrigation water (2.0, 4.0, 6.0 and 8.0 dS m^{-1}). National carrier water (with a salinity of 1 dS m^{-1}) served as the nonsaline control. The salinity levels were obtained by the addition of appropriate amounts of NaCl and $CaCl_2$ to national carrier water at a ratio of 8:2. Salt treatment was started at the flowering stage. The experiment was set up according to a completely randomized block design with 15 replicates and 2 plants per bucket. Plants were irrigated with an amount of water accounting for a leaching factor of 20-25% and fertilized with 0.2% liquid fertilizer 'Shefer 5-2-8' (N-P_2O_5-K_2O) enriched with micronutrients. Average water applied per pot was about 2100 ml during the experiment.

Chemical and Physiological Analyses

Electrical conductivity (EC) and leached volume were measured throughout the entire irrigation period. In order to determine the distribution of EC in the growing media profile, the growing media in the buckets were divided into 3 layers: 0-8, 9-16 and 17-24 cm. Samples taken from each layer were extracted with distilled water (1 g of growing media and 5 ml of H_2O), and EC determined. Na and Cl contents in the growing media, plant and water samples were measured by using flame photometry (Jenway PFP7), and a chloridemeter (Jenway PCLM 3) (Kacar, 1972, 1996).

Plant growth was determined by measuring plant height at 1-week intervals after planting. Another approach to determine plant growth was to measure the accumulation of weight in plant organs. After sampling each plant was separated into organs, weighed and dried at 65 °C for 72 h and weighed again. In addition, flower and seed pod numbers were counted at weekly intervals during the growing period. Minimum and maximum temperatures in the greenhouse were measured daily. The data are presented in Figure 1.

Statistical Analyses

The obtained data were presented with the least significant difference ($LSD_{0.05}$) between treatments, derived from an analysis of variance. In addition, correlation and regression analyses were carried out to investigate relationships between treatments and some leached-plant parameters (Littel and Hills, 1978).

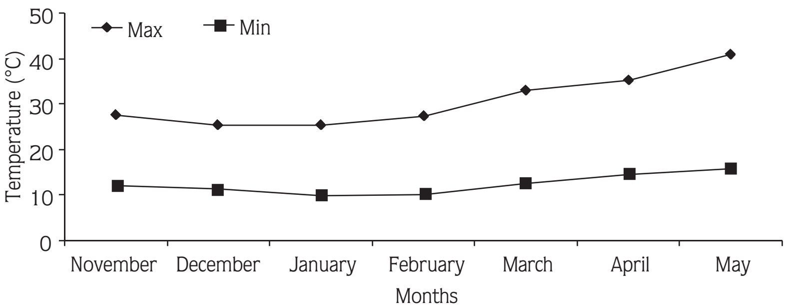

Figure 1. Monthly average temperatures of the greenhouse.

Results and Discussion

As shown in Figure 2, leached volume was positively correlated (r = 0.957, significant at 1%) with increasing salt applications. During the experiment growth media were washed with tap water when EC values were higher than planned. Although the leaching factor was high, some fluctuations in EC were observed. Average water applied per pot was about 2100 ml during the experiment. The regression equation and correlation coefficients are presented in Table 1.

Infiltration rate (IR) and hydraulic conductivity (HC) decreasing with diminishing growing media salinity and with increasing exchangeable Na is the probable reason for the increasing leached volume under increasing salinity conditions. IR is more strongly affected by low salinity and exchangeable Na levels than HC because of the mechanical impact and stirring action of applied water and freedom for soil particle movement at the soil surface. Owing to the presence of excess salts and the absence of significant amounts of exchangeable Na, saline soils were generally flocculated, and as a consequence, permeability was equal to or higher than that of similar nonsaline soils. A saline-alkali soil has been described as similar to a saline soil as long as excess salts are present (Shainberg and Levy, 1992, 1996; Oster et al., 1996; Oster and Shainberg, 2001).

The effects of salinity on leached and growing media are given in Tables 2 and 3, respectively. As expected, Na and Cl contents, and EC of leached and growing media samples rose significantly with the increase in treatments. However, the salinity of the control pots was higher than expected. The probable reason for this medium-high salinity was the relatively high Cl levels in the water from the national carrier, mainly because of the dry winter with very low precipitation and the liquid fertilizer that was used in the experiment. On the other hand, the EC of the growing media was significantly lower than that of the leached.

Distribution of ions showed a similar trend among the growing media layers (Table 4). Pots were surface irrigated throughout the experiment. Probably, in spite of the high leaching ratio, Na and Cl were carried and accumulated in upper layers by capillary action because of evaporation taking place under the high greenhouse

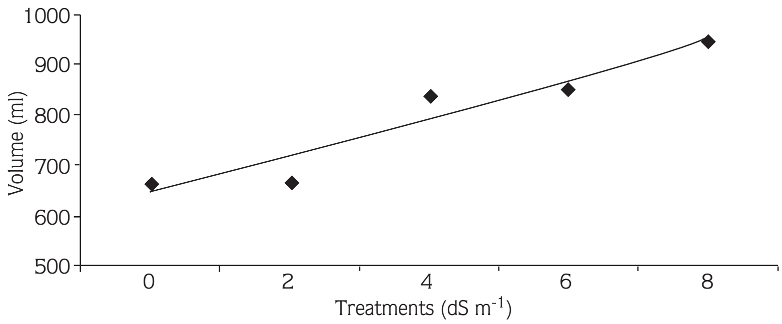

Figure 2. Effect of salinity on average leached volumes.

Table1. Regression equations, determination and correlation coefficients of relations between salinity (dependent variable) and leached volume, plant height, flower number and seedpod number (independent variable) (n = 5).

Independent variable	Regression equation	Determination coefficient (R^2)	Correlation coefficient (r)
Salinity-leached volume	$Y = 584.0 + 61.0 X+2.5 X^2$	91.5	0.957**
Salinity-plant height	$Y = 191.3 + 10.1 X-1.53 X^2$	66.5	0.816 ns
Salinity-flower number	$Y = 18.7 + 0.9 X -0.156 X^2$	70.2	0.946**
Salinity-seedpod number	$Y = 437.6 + 43.2 X -6.25 X^2$	81.1	0.901*

** : Significant at the 1% level, * : Significant at the 5% level, ns : non-significant

Table 2. Effect of salinity on sodium, chloride and electrical conductivity of leach.

Analysis	Treatments (dS m^{-1})				
	Control	2	4	6	8
Na (mg l^{-1})	193.6e*	306.6d	641.6c	1023.2b	1388.9a
Cl (mg l^{-1})	304.7e	578.8d	1396.9c	2346.9b	3249.7a
EC (dS m^{-1})	2.3e	3.1d	5.6c	8.1b	10.2a

* Mean separation between treatments by LSD test, 5% level.

Table 3. Effect of salinity on sodium, chloride and electrical conductivity of growing media.

Analysis	Treatments (dS m^{-1})				
	Control	2	4	6	8
Na (mg kg^{-1})	204.0d*	252.5d	600.6c	988.2b	1501.2a
Cl (mg kg^{-1})	126.7d	212.9d	641.1c	1170.5b	1980.2a
EC (dS m^{-1})	1.5d	1.7d	3.1c	4.7b	7.2a

* Mean separation between treatments by LSD test, 5% level.

Table 4. Effect of soil depth on sodium chloride and electrical conductivity of growing media.

Analysis	Soil depths		
	0-8 cm	9-16 cm	17-24 cm
Na (mg kg^{-1})	771.4a*	657.2b	699.3ab
Cl (mg kg^{-1})	938.4a	751.5b	788.8b
EC (dS m^{-1})	4.1a	3.4b	3.5b

* Mean separation between treatments by LSD test, 5% level.

temperatures (Figure 1). Other probable reasons were relatively higher ion absorption in the second and third layers by the roots and a higher leaching ratio in the third layer.

Na and Cl analyses showed that the treatments increased the quantity and translocation ratios of these elements in plant organs from root to leaf (Table 5). The effect of treatments on the Na content of different plant organs was statistically significant (5%). The results suggested that translocation of Na from root to shoot was limited by the plants up to 6 dS m^{-1}. After that the ratio of this limitation decreased and a greater quantity of Na was translocated to the leaf by the plants. In higher plants that are able to tolerate salinity several mechanisms have been recognized. Roughly speaking, one can distinguish between salt excluders and salt includers. Salt excluders possess mechanisms that ensure that salt reaches the shoot only in very small amounts. This might be due to a very efficient selectivity toward K during absorbtion, as in many grasses. Another possibility is that Na is absorbed in significant amounts but is reabsorbed from the xylem sap in proximal parts of the root, or in the shoot, and is then either stored or retranslocated to the soil. In contrast, salt includers absorb salt and store it at high levels in the stem and leaves. Here, sequestration of salt from the cytosol is the problem. Many salt includers are succulent, probably because of the accumulation of salt in large vacuoles of the mesophyll cells. Other salt-including species have special areas on the leaf surface that excrete salt at a high concentration. It is evident that, whatever the strategy by which a plant is able to adapt to salinity, transport phonomena play a significant role (Staples and Toenniessen, 1984).

However, no Na typed limitation in translocations of Cl was determined among the plant organs. Translocation of Cl from root to shoot was increased gradually by the plants up to 8 dS m^{-1} (Table 5). Mengel and Kirkby

Table 5. Effect of salinity on sodium and chloride contents of different plant organs.

Analysis	Plant Organs	Treatments (dS m^{-1})				
		Control	2	4	6	8
Na (mg kg^{-1})	Root	4.8b*	4.9b	6.7ab	7.6a	8.5a
	Shoot	3.3b	3.4b	5.9a	5.7a	6.6a
	Leaf	14b	16b	20ab	22ab	26a
	Seedpod	4.9b	5.1b	5.9ab	6.5ab	7.7a
Cl (mg kg^{-1})	Root	4.3c	5.6c	8.1b	9.6b	11.5a
	Shoot	9.2b	9.6b	13.7a	13.4a	14.3a
	Leaf	37.9b	40.8b	57.1ab	56.8ab	61.9a
	Seedpod	8.8b	9.4b	12.7a	12.3ab	12.2ab

* Mean separation between treatments by LSD test, 5% level.

(1982) stated that most plant species take up Cl very rapidly and in considerable amounts. The uptake rate depends primarily on the concentration in the nutrient or soil solution. There is considerable evidence that uptake is metabolically controlled. Cl uptake is sensitive both to variations in temperature and to metabolic inhibitors. Uptake also occurs against an electrochemical gradient. In the movement of Cl into plant tissues plasmalemma is fairly permeable. When Cl concentration in the outer medium is high, tonoplast rather than the plasmalemma becomes a limiting barrier to Cl movement. Cl can thus be accumulated in the cytoplasm under conditions of high uptake. In its transportation through the cortex to the central cylinder there is evidence that a symplastic pathway constitutes the main route.

Both the Na and Cl contents of the seedpod were determined at lower levels than the leaf in all the treatments. According to Hale and Orcutt (1987), in the halophytes more than 90% of the Na is in the shoot, with the highest concentration in the leaves. Translocation out of leaves is non-existent. When Na is applied to leaves, it remains there and is not translocated to other parts of the plant. Given the nature of the selection processes in absorption across membranes in root cells and leaf cells, the entrance of Na is limited. As a result of the site of absorption, there is sometimes a high concentration of salt in the roots and sometimes in the stems of plants, but a low concentration in the leaves. Plants in general may be divided into salt excluders and nonexcluders because of differences in the selectivity of the membranes that vary among plant species.

Another important approach to assess the effects of salinity on plant growth is to measure accumulation of weight in plant organs. In general, treatments increased the dry matter of plants. However, this effect was not significant in all plant organs. The effect of salinity on dry matter (%) is given in Table 6. According to Staples and Toenniessen (1984), there is no correlation between the extent of Cl retranslocation and growth depression caused by salinity in several species. With regard to Na,

Table 6. Effect of salinity on dry matter (%) of different plant organs.

Plant organ	Treatments (dS m^{-1})				
	Control	2	4	6	8
Seed	15.5	14.7	17.5	18.3	20.3
Root	19.4	19.2	19.5	20.1	21.5
Leaf	10.5abc	10.2b	10.3bc	11.2ab	11.5a
Shoot	20.4b*	20.3b	20.4b	23.2a	22.4ab

* Mean separation between treatments by LSD test, 5% level.

however, there were significant correlations between the decrease in dry matter production and Na retranslocation from leaves, and, in particular, the efflux of Na from the roots.

Salinity increased plant height until treatment with 4 dS m^{-1}, when it suddenly decreased. However, this effect was not significant. The regression equation and correlation coefficients are presented in Table 1.

Plants produced many flowers in all treatments; therefore, counting was stopped after 10 weeks from planting with the onset of fruits. Then, only the seed pods were counted until the end of the experiment. The flower numbers of plants were significantly affected by the treatments. The effect of salinity on average flower numbers is given in Figure 3. All the plants in the experiment produced fewer or no flowers after the sixth week of counting, except for the second treatment, 2 dS m^{-1}. The plants in the second treatment continued to produce flowers for another 3 weeks after that. The regression equation and correlation coefficients are presented in Table 1.

In terms of the effect of treatments on seedpod numbers, a similar result was obtained to that of the flower numbers. Treatments affected seedpod numbers significantly (Figure 4). Throughout the experiment, treatments showed a similarity until the sixth week of counting. At the end of the experiment, the highest seedpod numbers were obtained in plants subjected to the 2 dS m^{-1} treatment. The regression equation and correlation coefficients are presented in Table 1.

Conclusions

The results suggested that irrigation of *M. tricuspidata* with saline water is feasible. Therefore, *M. tricuspidata* might be grown in arid and semiarid regions by using non-conventional water resources such as saline water and treated sewage effluent, which is also quite saline. Since *M. tricuspidata* can be used as a food supplement in the food industry, these findings might be of important value in practical applications.

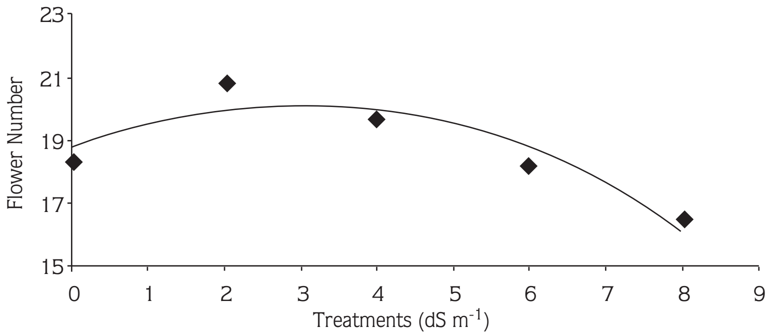

Figure 3. Effect of salinity on average flower numbers.

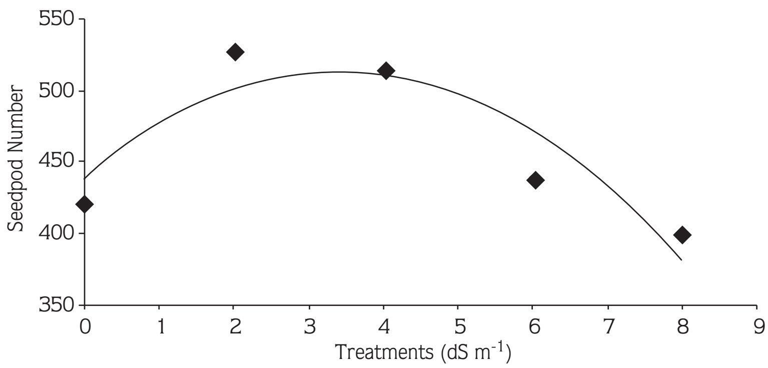

Figure 4. Effect of salinity on total seedpod numbers.

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