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EFFECTS OF SALINITY ON EGGPLANT (*SOLANUM MELONGENA* L.) GROWTH AND EVAPOTRANSPIRATION†

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ABSTRACT

The effects of irrigation water salinity on eggplant growth, yield, water consumption and mineral matter accumulation in leaves and fruits were investigated with a greenhouse experiment. For this purpose, five saline irrigation waters with electrical conductivities of 1.5, 2.5, 3.5, 5.0, 7.0 dS m^{-1} and tap water as a control treatment were utilized. Throughout the experiment, the amounts of irrigation water to be applied were determined based on the weight changes of each pot. After irrigation the amount of drainage water volume was measured in drain pans placed underneath each pot. We calculated the plant water consumption from the water budget information. Threshold soil salinity and slope values of the yield response to soil salinity level were determined as <1.5 dS m^{-1} and 4.4 respectively for fruit yield and 6.7 dS m^{-1} and 3.7 for the vegetative dry weight. The fruit yield results revealed that eggplant was moderately sensitive to salinity. Plant water consumption and water use efficiency decreased with increasing salinity. The crop yield coefficient (K_y) was 2.3. Salinity caused a decrease in K content, and increased Cl content of leaves. Although mineral concentration of the leaves did respond to increased mineral concentration of irrigation water, mineral concentration of fruits did not. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: greenhouse; water use efficiency; yield; salt tolerance

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RÉSUMÉ

Les effets de la salinité de l'eau d'irrigation sur la croissance de l'aubergine, le rendement, la consommation d'eau et l'accumulation de matières minérales dans les feuilles et les fruits ont été étudiés dans une expérience sous serre. À cette fin, cinq niveaux de salinité ont été utilisés avec une conductivité électrique de 1,5, 2,5, 3,5, 5,0, 7,0 dS m^{-1} et l'eau du robinet comme traitement de contrôle. Tout au long de l'expérience, la quantité d'eau d'irrigation à appliquer a été déterminée en fonction de la modification du poids de chaque pot. Après chaque irrigation le volume de drainage a été mesuré dans des récipients placés sous chaque pot. Nous avons calculé la consommation d'eau de la plante à partir du bilan hydrique. Le seuil de la salinité du sol et la pente de la courbe de réponse du rendement au niveau de salinité ont été déterminés comme étant $<1{,}5$ dS m^{-1} et 4,4 respectivement pour le rendement en fruit et 6,7 dS m^{-1} et 3,7 pour le poids de matière sèche. Le résultat sur le rendement en fruits montre que l'aubergine est modérément sensible à la salinité. La consommation d'eau des plantes et l'efficacité de l'utilisation de l'eau ont

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diminué avec l'augmentation de la salinité. Le coefficient de rendement des cultures (K_y) était de 2,3. La salinité a causé une diminution du contenu des feuilles en K et une augmentation en Cl. Bien que la concentration en minéraux des feuilles ait répondu à l'augmentation de concentration en minéraux de l'eau d'irrigation, ce n'a pas été le cas pour la concentration en minéraux des fruits. Copyright © 2008 John Wiley & Sons, Ltd.

MOTS CLÉS: serre; efficacité de l'utilisation de l'eau; rendement; tolérance au sel

INTRODUCTION

Soil salinity is one of the major constraints in the development of irrigated agriculture in arid and semi-arid regions in the world. Every year about 40 000 ha of land becomes unavailable for agricultural production because of salinization throughout the world. In addition, reports prepared by specialized agencies of the United Nations indicate that about 50% of the irrigated area of the world is either salinized or is potentially affected by salinity. Salinity problems can be severe in arid and semi-arid regions since precipitation is not sufficient and water supplies are also scarce as compared to water needs for crop production (Lamsal *et al*., 1999).

Global constraints on freshwater supplies and the need to dispose of agricultural, municipal and industrial waste waters have intensified interest in water reuse options. In many instances, the value of the water is decreased solely because of its higher salt concentration. Although quantitative information on crop salt tolerance exists for over 130 crop species, there are many vegetables which lack definitive data. Accurate scheduling of irrigation is essential for maximizing crop production while conserving water and ensuring irrigation systems are environmentally and economically sustainable. Correct scheduling requires a good knowledge of crop tolerance to salinity, crop water demand and soil water characteristics and must account for the type of irrigation method used (Theiveyanathan *et al*., 2004).

The prediction of crop yield in relation to water requirement or evapotranspiration is important for irrigation project planning and evaluation. Considerable research has been given to the development of simple models for predicting crop yield from evapotranspiration during the growing season (Doorenbos and Kassam, 1986; Howel and Musick, 1985; Ouda *et al*. 2006). Different conditions for evapotranspiration were obtained by applying different soil moisture regimes (Letey and Dinar, 1986), but rarely by using saline water (Katerji *et al*., 1998).

Salts in the soil water solution can reduce evapotranspiration by making soil water less "available" for plant root extraction. Salts have an affinity for water and hence additional force is required for the crop to extract water from a saline soil. The presence of salts in the soil water solution reduces the potential energy of the soil water solution (Allen *et al*., 1998). For example Yurtseven *et al*. (2005) irrigated tomato plants with four different irrigation water salinity levels (0.25, 2.5, 5.0 and 10 dS m^{-1}) and concluded that increased salinity levels in irrigation water caused decreases in water consumption of the crop. Compared with the control treatment, the decreases in water consumption were 21, 35 and 56% for the 2.5, 5.0 and 10 dS m^{-1} salinity levels respectively. In this instance it is possible to decrease the amount of water to be applied in saline soils or irrigations using saline water. Failure to account for the decrease in evapotranspiration will cause an excess of drainage water and other environmental problems.

Eggplant (*Solanum melongena* L.) is a traditional vegetable crop in many tropical, subtropical and Mediterranean countries. Conflicting literature exists on eggplant tolerance to soil salinity. For example, eggplant is classified as a moderately sensitive vegetable crop (Maas, 1984), whereas Bresler *et al*. (1982) classified it as salt-sensitive vegetable. We propose that this difference in its tolerance could be related to the varieties or cultivars used and to the different environmental conditions in those studies. In order to provide proper management, it is necessary to know the growth, yield and water consumption of the crop. The purpose of the present research was to obtain data on eggplant grown under 0.75, 1.5, 2.5, 3.5, 5.0 and 7.0 dS m^{-1} salinity levels and determine the salinity effect on yield, plant growth, water consumption and mineral matter accumulation on fruit and leaves.

MATERIAL AND METHODS

To evaluate the effects of different salinity levels in irrigation water on growth, yield, and water consumption of eggplant, an experiment was carried out in a glasshouse at Gaziosmanpaşa University. The geographic coordinates of the experimental area are 40° 20′ 07″ N and 36° 28′ 26″ E. The glasshouse was a Venlo-type greenhouse ventilated naturally with side and ridge openings. Its length, width and floor area were 13.3 m, 10.0 m and 133 m^2.

We utilized the Kemer cultivar of eggplant. This is the most common eggplant cultivar and is widely consumed as a fresh vegetable in Turkey. The Kemer cultivar is commonly grown in either fields or greenhouses. The fruit of this cultivar is about 14–18 cm in length, dark purple in colour and has small seeds. Plant height of the cultivar is about 70–80 cm. Yield per hectare is between 30 and 40 t (Vural *et al*., 2000).

The experiment was set up as a completely randomized design with five replications per treatment. In addition to the control treatment (tap water, T_0) with an electrical conductivity of 0.75 dS m^{-1}, five irrigation waters with different electrical conductivities (EC_i) were used ($T_1 = 1.5$, $T_2 = 2.5$, $T_3 = 3.5$, $T_4 = 5.0$ and $T_5 = 7.0$ dS m^{-1}). During the preparation of saline waters, sodium adsorption ratio (SAR) values of each treatment were maintained less than 5.0 in order to avoid the adverse effect of increasing SAR on soil structure and water gas movement. The salts were prepared by adding approximately equal amounts of Na, Ca and Mg, to the base concentrations in the control. To do this, calculated amounts of $CaCl_2$, $MgSO_4$ and NaCl were mixed to prepare irrigation water with given salinity for each treatment. Composition of the irrigation water is shown in Table I.

The soil was collected from a nearby field and sieved through a 4 mm screen to remove large particles and dry soil aggregates. A 45 kg sample of air-dried soil was placed in each of the pots with 35.6 dm^3 in volume. Some physical and chemical properties of the experimental soil are presented in Table II. Before transplanting, 19.3 g of potassium sulphate (K_2SO_4), 14.0 g triple superphosphate (TSP), and 12.5 g diammonium phosphate (DAP) were applied to each pot.

Eggplant seeds were sown on 12 April, germinated and raised under glasshouse conditions. When they had three real leaves, uniform (in appearance) eggplant seedlings were transferred to plastic pots (one plant per pot) on 4 June. Until the plants were established, they were irrigated with tap water (also used as control treatment). After establishment of plants (11 days after transplanting), saline water treatments were started. The pots were installed in double rows on the ground. The plant spaces in the rows and the space between two rows were 75 cm and the space between two double rows was 140 cm.

To determine the field capacity of each pot at the beginning of the experiment, pots were initially saturated with tap water and the pots were covered in order to prevent evaporation. The water content of the pots after the drainage stopped was assumed to be field capacity (W_{FC}). Each pot was weighed before each irrigation event. The amount of irrigation water to be applied was determined by weighing the pots just before irrigation. The amount of applied irrigation water (I) was calculated by the following equation:

$$I = \frac{\frac{W_{FC} - W}{\rho_w}}{1 - LF} \tag{1}$$

where LF is leaching fraction, which was set to a target of 0.15 as suggested by Ayers and Westcot (1985) for efficient irrigation, W_{FC} is the pot weight at field capacity, W is the pot weight just before irrigation and ρ_w is water bulk density (1 kg dm^3 or 1 kg l^{-1}). A drain pan was placed underneath each pot to collect leachate. Collected drainage water volume was measured after irrigation. Throughout the experiment, the plants were irrigated at 3–4 day intervals.

Table I. Irrigation water composition

EC (dS m^{-1})	Na (me l^{-1})	K (me l^{-1})	Ca (me l^{-1})	Mg (me l^{-1})	Total cation (me l^{-1})	Cl (me l^{-1})	SO_4 (me l^{-1})	Alk (me l^{-1})	Total anion	pH	Osmotic pressure (M Pa)	SAR
0.76	1.2	0.08	4.3	3.0	8.5	0.8	6.01	0.84	7.7	6.69	0.03	0.6
1.5	6.6	0.08	6.1	5.0	17.8	8.1	8.01	0.84	17.0	6.68	0.06	2.8
2.5	11.1	0.08	9.0	8.2	28.4	15.5	11.2	0.84	27.5	6.67	0.10	3.8
3.5	15.7	0.08	12.8	12.4	41.0	23.9	15.4	0.84	40.2	6.68	0.14	4.4
5	21.6	0.08	19.4	19.7	60.7	36.4	22.7	0.84	59.9	6.65	0.20	4.9
7	25.9	0.08	26.4	27.6	80.1	48.2	30.3	0.84	79.4	6.64	0.25	5.0

Table II. Some physical and chemical properties of the experimental soil

Particle size distribution	
• Sand (%)	53.0
• Silt (%)	28.8
• Clay (%)	18.2
Soil water contents (dry weight basis)	
• Saturation (%)	45.0
• Field capacity (%)	22.4
• Wilting point (%)	4.2
Bulk density (g cm^{-3})	1.56
Electrical conductivity (paste) (dS m^{-1})	0.63
pH$_e$ (paste)	7.3

Evapotranspiration volume (ET) between two consecutive irrigations was calculated by using the water balance equation as follows:

$$\mathrm{ET} = \frac{(W_n - W_{n+1})}{\rho_\mathrm{w}} + (I - R) \tag{2}$$

where W_n and W_{n+1} are the pot weights before the nth and $n+1$th irrigation (kg), ρ_w is water bulk density (1 kg dm^3 or 1 kg l^{-1}), I and R are amounts of applied and drainage water (litres). In addition, the daily evapotranspiration (mm) was calculated by dividing the determined ET volume for the irrigation interval by soil surface area and the number of days between the irrigations.

We measured plant height and stem diameter in each treatment before terminating the experiment. The harvested fruits were weighed as fresh and then oven-dried at 70°C to a constant dry weight. The dried samples taken from each pot were ground in a mill having a 0.5-mm sieve to determine the mineral content of the fruits. At the end of the experiment (on 2 October), the plants were cut at 1 cm above the soil surface. Vegetative fresh and dry weights (oven-dried at 70°C to a constant weight) were obtained for each replication. Immediately after the plants were cut, soil samples were taken from each pot. The plant roots were next removed from each pot by washing the soil inside the pot. Length, fresh and dry weight of roots were measured.

Soil samples taken from each pot were air dried and crushed to pass through a 2-mm screen. Saturated soil pastes were prepared, kept in the laboratory for 24 h, then saturation extracts were taken and electrical conductivities of saturated soil extracts (EC$_e$) were measured. The salt tolerance model suggested by Maas and Hoffman (1977) was evaluated by the computer program developed by van Genuchten (1983) for fruit yield and vegetative dry weight. Then the threshold soil salinity value and slope value beyond the threshold value were calculated for each of these growth parameters. The salt tolerance model suggested by Maas and Hoffman (1977) is

$$\frac{Y_\mathrm{a}}{Y_\mathrm{m}} = 1 - (\mathrm{EC_e} - \mathrm{EC_{e\ threshold}}) \times \frac{b}{100} \tag{3}$$

where Y_m is the maximum yield from control treatment (g), Y_a is the actual yield from a salinity treatment, $\mathrm{EC_{e\ threshold}}$ is threshold soil salinity (dS m^{-1}) beyond which yield decreases, EC$_e$ in this equation is either the soil salinity of the extract or $\mathrm{EC_{e\ threshold}}$, whichever is greater (dS m^{-1}) and b is the slope value which is the percentage yield loss per unit increase in electrical conductivity of the saturated soil extract beyond the threshold value.

We collected undamaged leaves at harvest to determine mineral content. These leaf samples were washed with tap water and then distilled water in turn, then dried in an oven and ground. For the measurements of mineral content, plant samples were ashed in a muffle furnace at 500°C for 6 h, dissolved in 5 ml of 2 M HNO_3, and finally diluted to 25 ml with distilled water. Extracts were filtered and stored in plastic vials until analysed. Sodium and K were measured by flamephotometer (Jenway PFP7; ELE Instrument Co. Ltd. Mention of trade names and company names in this manuscript does not imply any endorsement or preferential treatment by the USDA), and water extractable Cl was determined by potentiometric titration with $AgNO_3$ as described by Lambert and DuBois (1971).

The experimental data were analyzed using the SPSS statistical analysis software package (SPSS, 2002). The General Linear Model (GLM) procedure was used to perform analysis of variance. Unless otherwise noted, all statistical tests were performed at the 0.01 level of significance. Duncan's multiple range test was used to separate means.

RESULTS AND DISCUSSION

Effects of irrigation water salinity on soil salinity

Effects of irrigation water salinity on measured soil extract salinity values are given in Table III. The mean EC_e values increased with increasing salinity levels of applied irrigation water up to T_2 treatment and then remained relatively constant around $EC = 10\,dS\,m^{-1}$ for T_2, T_3 and T_4 treatments. The maximum EC_e value ($13.2\,dS\,m^{-1}$) was observed for the highest EC_i treatment (T_5), however it was not significantly different from those of the T_2, T_3, and T_4 treatments at 0.05 probability levels.

There was no significant difference among leaching fractions of treatments which indicate that we maintained a constant leaching fraction with variable water consumption. Measured leaching fractions ranged from 0.13 to 0.14 (0.13 for T_2, T_3 and T_5, and 0.14 for T_0, T_1 and T_4 treatments). The ratios of EC_e/EC_i were 2.4, 2.6, 4.2, 2.9, 2.0 and 1.9 for T_0, T_1, T_2, T_3, T_4 and T_5 treatments, respectively, which are higher than the expected value (1.7 times EC_i for a leaching fraction of 0.14, and assuming $EC_e = 0.5 \times EC_{sw}$) according to Ayers and Westcot (1985). The reasons for higher soil salinity values than expected may be due to bypass flow through the soil–pot interface (edge flow) that decreases the effectiveness of leaching. However, assuming that the bypass was similar for the various treatments then constant leaching fractions and variable EC_i values should have resulted in constant EC_e/EC_i values.

We consider the water budget data, based on measured values of irrigation and drainage water collected over the entire growing season, to be more reliable than the EC_e data. This seems reasonable since the samples for EC_e were collected at the end of the experiment and with only one composted sample per container. Subsequent analysis of data related to soil EC will utilize the calculation of average soil EC from the relationship

$$EC_{sw} = (EC_{iw} + EC_d)/2 \tag{4}$$

and

$$EC_e = EC_{sw} \times \theta_{sw}/\theta_e \tag{5}$$

where EC_{sw} is the soil water electrical conductivity at field capacity, EC_{iw} and EC_d are the electrical conductivities of the irrigation and drainage water, θ_{sw} and θ_e are the volumetric water contents at field capacity and saturation point, respectively (Table II). Each treatment was irrigated considering the plant water needs. For higher salinity irrigation water treatments (T_4 and T_5), plant growth was reduced even in the early stages of the experiment and they utilized less water than the other treatments.

Table III. Electrical conductivity of soil extracts, irrigation, drainage and soil water

EC_i ($dS\,m^{-1}$)	EC_e ($dS\,m^{-1}$)	EC_{sw}, ($dS\,m^{-1}$)	EC_d ($dS\,m^{-1}$)	Correction factor[a]	EC_e calculated
0.75	1.8	3.1	5.4	7.1	1.5
1.5	4.0	6.1	10.7	7.1	3.0
2.5	10.0	10.9	19.2	7.7	5.4
3.5	10.1	15.3	27.0	7.7	7.6
5.0	10.0	20.4	35.7	7.1	10.2
7.0	13.2	30.4	53.8	7.7	15.1

[a] Correction factor = 1/leaching fraction.

Table IV. Effect of irrigation water salinity on the experimental soils, water use and yield parameters

Analysis	Treatments ($dS\ m^{-1}$)						Mean	P > F
	T_0 (0.75)	T_1 (1.5)	T_2 (2.5)	T_3 (3.5)	T_4 (5.0)	T_5 (7.0)		
EC_e ($dS\ m^{-1}$)	$1.8^{\#,b,£}$	4.0^{b}	10.0^{a}	10.1^{a}	10.0^{a}	13.2^{a}	8.3	*
LF	0.14	0.14	0.13	0.13	0.14	0.13	0.14	NS
ET (lt)	118^{a}	113^{a}	104^{b}	$98^{b,c}$	95^{c}	83^{d}	102	*
Yield ($g\ pot^{-1}$)	566^{a}	$491^{a,b}$	$388^{b,c}$	$361^{b,c}$	$302^{c,d}$	211^{d}	375	*
Number of Fruit	3.6	3.0	3.2	3.2	3.2	2.4	3.1	NS
Fruit dry matter ratio (%)	8.0^{b}	$9.2^{a,b}$	8.2^{b}	8.8^{b}	10.1^{a}	10.0^{a}	8.9	*

[#] Each value is the mean of five replications.

[£] Within rows, means followed by the same letter are not significantly different according to Duncan's multiple range test at 0.05 significance level.

[*,**] significant at the 0.01 and 0.05 probability levels, respectively.

NS: non-significant.

Effects of irrigation water salinity on yield

Eggplant fruit yields were affected significantly by irrigation water salinity treatments at the 0.01 probability level (Table IV). Increasing salinity of the applied irrigation water caused decreases in fruit yields. The highest fruit yield (566 g pot^{-1}) was obtained from the control treatment, which was significantly different from all but the T_1 treatment. The lowest yield (211 g pot^{-1}) was observed from the T_5 treatment as expected. Compared to the control treatment, percent yield reduction was 13, 31, 36, 47 and 63 for T_1, T_2, T_3, T_4 and T_5 treatments, respectively.

In a hydroponic study Chartzoulakis and Loupassaki (1996) used six solutions with 1.2 dS m^{-1} (0 mmol added NaCl), 1.9 dS m^{-1} (10 mmol NaCl), 3.4 dS m^{-1} (25 mmol NaCl), 5.7 dS m^{-1} (50 mmol NaCl), 9.4 dS m^{-1} (100 mmol NaCl) and 12.2 dS m^{-1} (150 mmol NaCl) electrical conductivities on eggplant growth. They determined yield decreases of 23, 41, 69 and 88% for EC = 3.4, 5.7, 9.4 and 12.2 dS m^{-1} treatments, respectively. They evaluated these data according to the classification proposed by Maas and Hoffman (1977), however they considered only the EC_i without consideration of EC_e or $EC_{sw,}$ thus salt tolerance cannot be precisely determined. Based on the classification, the eggplant hybrid ''Delica'' is moderately sensitive to salinity with a low threshold EC value (1.9 dS m^{-1}).

The salt tolerance model for fruit yield of eggplant is presented in Figure 1 by using the calculated EC_e values obtained from each treatment. The linear model revealed that there was reduction in eggplant fruit yield even for the control (EC_e 1.5 dS m^{-1}). The yield decrease (slope) was 4.4% per unit increase in EC_e. Based on these results, the Kemer cultivar of eggplant is considered moderately sensitive to salinity.

Fruit numbers were not significantly affected by irrigation water salinity treatments at 0.05 probability level (Table IV). Considering these results, it is apparent that soil salinity in this range has an important determinative effect on fruit yield of eggplant but not on fruit number. In other words, decreased yield of eggplant was not a result

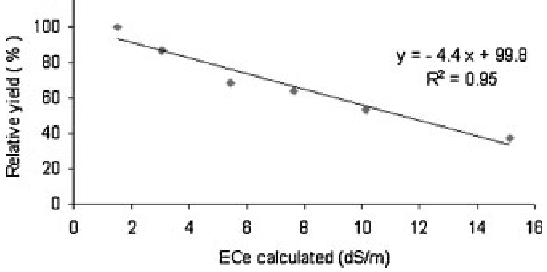

Figure 1. Salt tolerance model for relative fruit yield of eggplant

Table V. Effect of irrigation water salinity on plant properties

Analysis	Treatments (dS m^{-1})						Mean	P > F
	T_0 (0.75)	T_1 (1.5)	T_2 (2.5)	T_3 (3.5)	T_4 (5.0)	T_5 (7.0)		
Plant height (cm)	61^{b}	71^{a}	62^{b}	59^{b}	55^{b}	48^{c}	59	*
Stem dia. (mm)	11.6	11.6	11.5	10.7	10.6	10.4	11.1	NS
Root length (cm)	54.4	72.0	64.0	60.0	51.2	54.4	58.9	NS
Vegetative. dry weight (g/plant)	$27.1^{a,b}$	34.2^{a}	25.7^{b}	24.5^{b}	22.4^{b}	20.5^{b}	25.4	**
Root dry weight (g/plant)	16.1	18.6	15.0	14.6	16.5	14.4	15.8	NS

**significant at 0.05 probability level.
NS: non-significant.

of decreased fruit number in plant but decreased mean fruit weight. This result is in agreement with Shalhevet *et al.* (1983) who concluded that increasing salinity caused a decrease in individual fruit weight of eggplant. They obtained a 50% yield decrement at EC_e of 8.5 dS m^{-1}. Also, Savvas and Lenz (2000) stated that the detrimental effects of moderate salinity on the yield of hydroponically grown eggplants are due only to a decreased mean fruit weight. This yield response of eggplant was observed at EC values up to 8.1 dS m^{-1}.

Fruit dry matter ratio increased with increasing salinity (Table IV). The T_4 and T_5 treatments have the higher dry matter ratios than the T_0, T_2 and T_4 treatments, statically. The control treatment has the lowest dry matter ratio (8.0%), but the T_4 treatment has the highest (10.1%).

Effects of irrigation water salinity on vegetative growth

According to the results of many studies, plants may differ in their salinity response to fruit yield, vegetative growth and root development. The vegetative dry weight of the eggplant decreased with increasing soil salinity except for the T_1 treatment (Table V). But it is not unusual to observe an increase in yield with an initial increase in salinity. For example, Andriolo *et al.* (2005) observed a positive effect of low EC on shoot fresh mass of lettuce, which increased 28.5% from 0.8 to 1.9 dS m^{-1}, and then decreased 16.5% from 1.9 to 4.7 dS m^{-1}. The positive effect of low salinity on shoots of several plants has been reported by many other authors (Brown and Berstein, 1953, Feinerman *et al.*, 1982, Hoffman *et al.*, 1983). The cause is not known but could be related to mineral nutrition. The experimental data for the vegetative dry weights were used to develop a salt tolerance model (Figure 2). Root development was not used for this purpose since there was no significant difference among root dry weights of treatments (Table V). The threshold and slope salt tolerance values were 6.7 dS m^{-1} and 3.7%, respectively, for the vegetative dry weight of eggplant. The threshold and slope value for vegetative growth were higher than those for fruit yield. These results show that fruit yield and vegetative growth of eggplant have different responses to salinity, with fruit yield being more sensitive.

There is a statistically significant difference among treatments for plant heights at the 0.05 probability level. As presented in Table V, the highest plant height (71 cm) was measured for the T_1 treatment and the lowest for the T_5

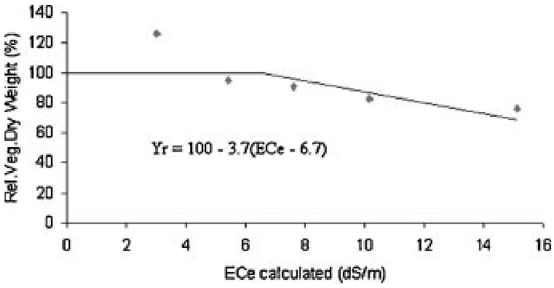

Figure 2. Salt tolerance model for vegetative dry weight of eggplant

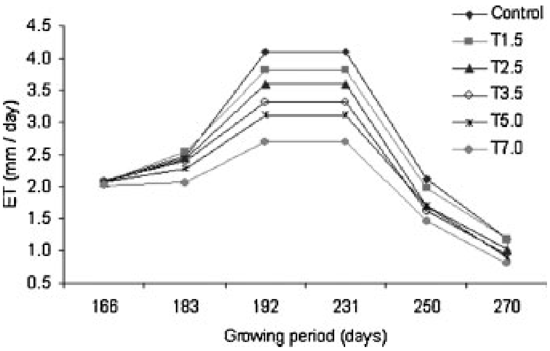

Figure 3. Effects of irrigation water salinity on daily evapotranspiration

treatment (48 cm); these were significantly different from each other and from the height of the other treatments. However, increased EC_e or EC_i did not have a significant effect on plant stem diameter, root length and root dry weight at the 0.05 probability level (Table V).

Effects of irrigation water salinity on plant water consumption

Evapotranspiration values were calculated by using Equation (2) and total ET values for each treatment. As shown in Table IV, the ET values ranged from 118 l pot^{-1} for the control treatment to 83 l pot^{-1} for the highest irrigation water salinity treatment. The ET of the control treatment did not significantly differ from that of the T_1 treatment. The ET results were consistent with the soil salinities, irrigation water and calculated salinities (Table III). The ET values decreased by 11, 17, 19 and 29% for T_2, T_3, T_4, and T_5 treatments, respectively.

Changes in ET values among treatments throughout the experiment are presented in Figure 3. Since the same soil material was used for the experiment, soil salinity levels were initially the same for all replications and treatments (0.63 dS m^{-1}). Following the saline irrigation water application 11 days after transplanting, plants were subjected to continuously increasing soil salinity. After a few irrigations, differences in water consumptions of treatments became evident and gradually increased. Figure 3 shows that, at the beginning of the experiment, daily ET values for all treatments were about 2.1 mm. Daily ET values reached their maximum value during 26–65 days after the experiment was initiated (between calendar days 192 and 231). During this period daily ET values were 4.1, 3.8, 3.6, 3.3, 3.1 and 2.7 mm for T_0, T_1, T_2, T_3, T_4 and T_5 treatments, respectively. Similarly, daily ET values were 1.2, 1.2, 1.0, 0.9, 0.9 and 0.8 mm for the treatments between the last irrigation and harvest. Daily ET values of plants were relatively high. In mid-season when the highest ET was realized, there is a 1.4 mm day^{-1} difference between the ET values of the control and the T_5 treatment. The daily water consumption of plants in the T_5 treatment in mid-season was 34% lower than that of the control treatment.

There was a very high negative relation ($R^2 = -0.98$) between soil salinity and total water consumption of the plants, as illustrated in Figure 4. Plant water consumption decreased by 2.1% for per unit increase in soil salinity. Excess salinity within the root zone has a deleterious effect on plant growth which was manifested as nearly equivalent reductions in the transpiration and growth rates (Rhoades *et al.*, 1992).

Decreases in plant water consumption due to salinity should be taken into account when irrigating in order to prevent excess water applications and excess leaching.

Stewart and Hagan (1973) proposed a model to predict crop yield from evapotranspiration during the plant growing season. The relation between relative evapotranspiration and relative yield decreases for water stress with yield response factor (K_y) has been used to evaluate plant tolerance to water stress (Doorenbos and Kassam, 1986). If $K_y \leq 1$, the plant is tolerant and if $K_y \geq 1$, the plant is sensitive to water stress. Some scientists have also used this method for salinity (Stewart *et al.*, 1977; Shalhevet, 1994; Katerji *et al.*, 1998). The model was used to predict eggplant yield under saline conditions:

$$\frac{Y_m - Y_a}{Y_m} = K_y \frac{ET_m - ET_a}{ET_m} \tag{6}$$

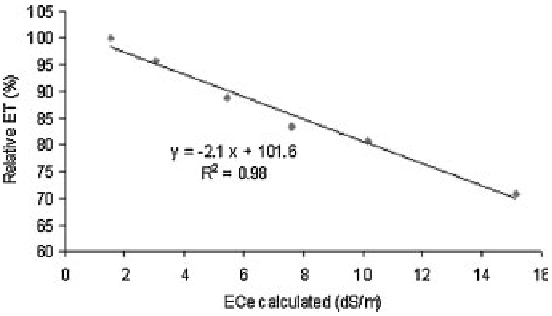

Figure 4. Relationship between soil salinity and relative evapotranspiration

where Y_m and ET_m are maximum crop yield and evapotranspiration for non-saline or control treatment, K_y is crop yield coefficient, Y_a and ET_a are actual crop yield and evapotranspiration respectively for saline treatments. In our irrigation salinity experiment, the relationship between relative fruit yield and relative evapotranspiration of eggplant is shown in Figure 5. From this figure, a strong linear relationship ($R^2 = 0.97$) is observed with a slope of 2.3. This high K_y value indicates that eggplant is highly sensitive to water stress caused by salinity.

Water use efficiency (WUE) is an important indicator for plant water use. Results of an ANOVA test showed significant differences among treatments for WUE. Increased salinity in irrigation water resulted in decreases in WUE (Figure 6). The lowest WUE was obtained for the highest salinity level treatment (T_5) which was significantly different from those of the T_0 and T_1 treatments. Further increases in irrigation water salinity above 5.0 dS m^{-1} led to significant reductions of water use efficiency of the plants. Fresh fruit weights per litre water use were 4.8 and 2.5 g l^{-1} for T_0 and T_5 treatments, respectively. With increased soil salinity, fruit yields and plant water consumption decreased.

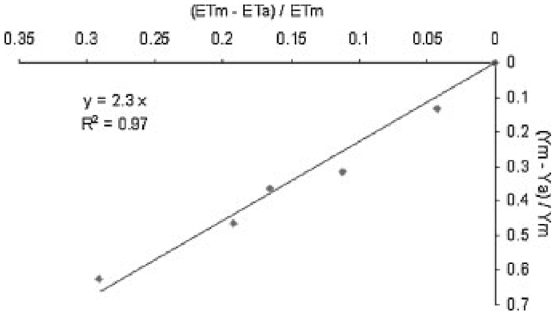

Figure 5. Relationship between relative yield and relative evapotranspiration

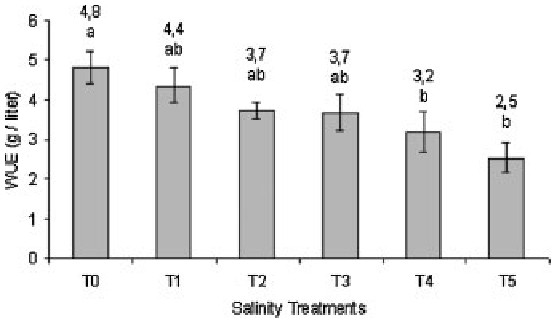

Figure 6. Effects of irrigation water salinity on water use efficiency of eggplant

Table VI. Effect of irrigation water salinity on plant mineral uptake

Analysis	Treatments (dS m^{-1})						Mean	$P > F$
	T_0 (0.75)	T_1 (1.5)	T_2 (2.5)	T_3 (3.5)	T_4 (5.0)	T_5 (7.0)		
%Cl of leaf dry matter	1.15^{b}	1.18^{b}	1.31^{b}	1.25^{b}	1.27^{b}	1.75^{a}	1.33	*
%Ca of leaf dry matter	1.56^{b}	1.63^{b}	1.64^{b}	1.50^{b}	1.50^{b}	2.40^{a}	1.71	*
%K of leaf dry matter	2.75^{a}	$2.59^{a,b}$	$2.30^{b,c}$	$2.39^{a,b}$	$2.54^{a,b}$	2.01^{c}	2.42	*
%Mg of leaf dry matter	$0.74^{b,c}$	0.72^{c}	$0.97^{a,b,c}$	$1.0^{a,b,c}$	$1.03^{a,b}$	1.10^{a}	0.94	**
%Na of leaf dry matter	0.04	0.05	0.06	0.07	0.17	0.24	0.11	NS
%Ca of fruit dry matter	0.55	0.58	0.50	0.60	0.47	0.50	0.54	NS
%K of fruit dry matter	3.83	3.49	4.05	4.12	3.57	3.66	3.82	NS
%Mg of fruit dry matter	0.33	0.27	0.24	0.18	0.20	0.30	0.25	NS
%Na of fruit dry matter	0.05	0.08	0.09	0.11	0.07	0.13	0.08	NS

[#] Each value is the mean of five replications.

[*,**] significant at the 0.01 and 0.05 probability levels, respectively.

NS: non-significant.

Effects of irrigation water salinity on mineral matter contents of fruits and leaves

Increasing salinity resulted in increased ion content in the leaves for all ions except K which decreased with salinity. These results are consistent with the increasing concentration of all ions (except K which was constant) in the irrigation water with increasing salinity. The differences were not significant among treatments for Na, but the salinity level of applied irrigation water significantly affected Cl, Ca, and K contents of leaves at the 0.01 probability level and Mg content at the 0.05 probability level (Table VI). Accumulation of Cl causes toxic effects on plant leaves. Salt injury symptoms such as chlorosis, burning of leaf margins and necrosis were not observed in plants throughout the experiment. Compared to other treatments, only the T_5 treatment altered the Cl content of leaves (Table VI).

Akıncı *et al*. (2004) reported that increasing NaCl in the solution led to a decrease in the K/Na ratio and increased Na in several eggplant varieties. Their investigation showed that as NaCl concentration increased, Na^{+} content increased in leaves indicating that the eggplant (which has a glycophytic reaction) could not control uptake of Na^{+}. In our experiment K content was slightly decreased with increasing salinity level in irrigation water (Table VI). There was a weak relationship ($R^2 = 0.18$) between soil salinity and K content of leaves. The highest (2.75%) K content in leaves was observed in control treatment whereas the lowest (2.01%) was in T_5 treatment (Table VI).

The highest Mg content (1.10%) in leaves was observed for T_5 treatment which was not significantly different from those of the T_2, T_3 and T_4 treatments, whereas the lowest (0.74%) was for the control treatment which was not significantly different from that of T_1 treatment (Table VI). Similar to Cl and K content in leaves, there was a weak positive relationship ($R^2 = 0.29$) between soil salinity and Mg content of leaves. Savvas and Lenz (2000) investigated effects of NaCl or nutrient-induced salinity on growth, yield, and composition of eggplants grown in rockwool and they found that all salinity treatments reduced the concentration of Mg in the leaves to the same degree, thus indicating that this salt effect is not ion-specific. In this study, the reason for increased Mg content in leaves may be as a result of Mg addition as part of added salts with irrigation practices. Increasing Mg content with increasing salinity is a typical characteristic of natural waters.

There were no significant differences in the ion content of the fruit with increasing salinity, suggesting that there is a restriction to salt translocation to the fruit.

CONCLUSIONS

In this study we investigated relations between irrigation water salinity, fruit yield, plant growth parameters, and water consumption of eggplant. The salt tolerance model parameters for the vegetative dry weights were different from that of the fruit yield. Threshold values of 1.5 and 6.7 dS m $^{-1}$ were determined for fruit yield and vegetative dry weight, respectively. Threshold EC_e values indicated that fruit yield was more sensitive to salinity than vegetative growth in eggplant. The slope value of 4.4% was obtained for the fruit yield whereas it was 3.7% for the vegetative dry weight. Considering the results for fruit yield, eggplant is moderately sensitive to salinity.

Increased soil salinity resulted in a decrease in water consumption of the plant and thus a decreased growth rate. A high value of the K_y coefficient (2.3) which shows the relationship between relative decrease in plant water consumption and relative decrease in yield, also indicates that eggplant is sensitive to water stress caused by salinity. Irrigation water salinity increased soil salinity and increased soil salinity caused a decrease in ET. The ET value for the T_5 treatment was about 29% less than that of the control treatment. Therefore it is suggested that salinity effects should be taken into account in water consumption calculations to prevent over-applications of saline waters and yield loss. The water use efficiency decreased with increasing salinity, indicating that for eggplant under saline conditions, more water is used per unit of production as compared to non-saline conditions.

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