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EFFECT OF WATER SALINITY AND POTASSIUM FERTILIZER LEVELS ON TOMATO PRODUCTIVITY AND WATER CONSUMPTION IN SIWA OASIS

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ABSTRACT

Effects of four irrigation water salinities; EC_{iw} (1.25, 2.5, 5 and 10 dS/m) and four potassium fertilizer levels; K^+ (0, 40, 80 and 120 kg K_2O/fed) on yield and some quality parameters and water consumptive use; WCU of tomato grown under Siwa Oasis conditions were investigated. The split-plots design was carried out during the two successive growing seasons of 2003/04 and 2004/05. Yield, some quality parameters, water consumptive use and soil salinity data were inspected and subjected to proper statistical analysis and Maas and Hoffman threshold model. Water use efficiencies were also quantified. Results indicated that, the maximum total and marketable yield of 17.5 and 14.76 Mg/fed, respectively was associated with the control treatment (EC_{iw}= 1.25 dS/m). Increasing the EC_{iw}, resulted in reducing the fruit number per plant, smaller fruit size and weight and consequently decreasing the total and marketable yield, increasing the fruits affected with blossom end rot (BER), higher total soluble solid content and decreasing the pH of the fruit juice were recorded. Increasing the EC_{iw} led to decreasing both of water consumptive use and water use efficiencies. While, under moderate EC_{iw} and high level of K^+ enhanced the plant growth parameters, total and marketable yield and water consumptive use and reduced the fruits affected with BER. However, the effect of the EC_{iw} on the tested parameters was more pronounced than the effect of the K^+. The decrease of the total and marketable yield was performed to linear slope of 11.14 and 14.69 % per dS/m after the recorded threshold (EC_t) value of 2.97 and 3.31 dS/m, respectively. The decrease of tomato fruit yield with salinity was mostly owing to a linear decrease of the fruit weight of 9.8% per dS/m. Reduction of the fruit number with salinity of 5.5% per dS/m made small contribution to reduced yield.

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A logarithmic regression model was developed to express water consumptive use, WCU in mm as a relation with EC_{iw} and K^+. Results indicated an opposite relationship between tomato quality and quantity. Tomato plants in the control treatment averaged a higher WCU and WUE of 637mm and 6.54 kg/m^3, respectively were compared with other treatments. Irrigation with saline water increased the soil salinity throughout the growing season and after harvesting .Overall increases were 0.613 dS/m of soil salinity for each dS/m of EC_{iw} during the growing season and 0.783 dS/m of final soil salinity for each dS/m of EC_{iw}. Results confirmed that, EC_{iw} up to 2.5 dS/m did not have major detrimental effects on marketable tomato yield. K^+ of 80 Kg/fed could mitigate the negative effects of salinity and enhance tomato productivity and decrease the percentage of fruits affected by BER in the Siwa environment.

***Keywords**: saline irrigated water, tomato, potassium fertilizer, yield, tomato quality, water efficiencies, soil salinity and Siwa Oasis.*

INTRODUCTION

The increasing demand for domestic, industrial, environmental and recreational water will force agriculturists to manage irrigation water carefully, contributing to environmental preservation. In parallel, brackish and saline water resources not used nowadays could be employed for irrigation if greater knowledge of salt tolerance and proper technology are developed. In applying saline water for irrigation, an integrated approach, which should account for soil, crop and water management at the same time should be adopted (Peterson, 1971). Tomato is moderately tolerant to salinity and could act as a model crop for saline water use because it is already cultivated in a few warm and rather dry areas where irrigation is essential for high yield. Natural soil hydrological processes in these regions frequently produce saline soils (Cuartero and Munoz, 1999). Crop management practices that enhance drought and salinity resistance, plant water use efficiency, plant growth and productivity would be beneficial under these circumstances. Several saline/brackish water irrigation researches were carried out on open culture tomatoes. The results evidently revealed that if suitable management practices were adapted, it is feasible to irrigate tomato using relatively high saline water under arid conditions. The tomato threshold; the electrical conductivity of saturated extract (EC_e) above which yield starts to decline; is 2.5 dS/m and the reduction in the total fruit yield with increasing the salinity is 9.9% per dS/m above threshold (Mass and Hoffman, 1977). Other threshold and rates of decrease have been attributed to different varieties and growth conditions (Dalton et al., 2001; Romero-Aranada et al., 2002; Agong et al., 2003 and Maggio et al., 2004). Cuartero and Munoz (1999) reported that salinity reduced tomato seed germination and lengthens the time needed for germination to such an extent that the establishment of a competitive crop by direct seeding would be difficult in soils where EC_e was equal to or above 8 dS/m. Romero-Aranda et al. (2002) mentioned that tomato seeds needs some 50% additional days to germinate at 8 dS/m than in a medium without salt. Not all the seeds that fail to germinate in a highly saline medium, lose their viability. If the salt concentration is lowered, due to rainfall or irrigation with non-saline water, more than 50% of these seeds would still be capable of germination. They added that, priming seeds primed with 1 M NaCl for 36 hours seems advisable to establish a crop by direct sowing in saline soils, and seedling conditioning, either by exposure to moderately saline water exposure or by withholding watering until seedling wilt for 20-24 hours, can be recommended for crops that are to be established by transplanting. Snapp and Shennan (1992) mentioned that, salinity not only slows tomato root growth, but also increases the dead roots in those genotypes very sensitive to salt. Soria and Cuartero (1997) reported that, the root growth in tomato appears to be less affected by salt than shoot growth and so the root/shoot dry weight ratio is higher in plants grown under salt stress than in control plants, at all stages of development. They added that tomato plants grown with saline water have a significantly lower water uptake than those grown with fresh water. Cuartero and Munoz (1999) and Dorias et al. (2001) mentioned that 10% reduction in fruit weight is caused by irrigation with water has electrical conductivity; EC_{iw} of 5-6 dS/m, 30% reduction with 8 dS/m and about 40% at higher EC_{iw}. They added that tomato varieties which are to be grown under saline conditions must have notably bigger fruits in non-saline conditions in order to compensate for the weight loss that salty water will cause. Adams and Ho (1995) stated that several characteristics such as total soluble solids (TSS), sugars, acidity and pH are important quality parameters for both fresh and processing tomatoes, other characteristics such as taste and shelf life are more important only for the fresh market. TSS content is the most important quality criterion for tomato paste processing. TSS increases with salinity and hence the use of moderately saline irrigation water (3-6 dS/m) is recommended to improve fruit quality. However, special care must be taken when using saline water because salinity produces blossom end rot (BER) which makes fruits unacceptable for both the fresh market and the processing industry. Maggio and Barbieri (2004) reported that salinity reduced total plant water uptake and seemed to be a very important variable affecting total plant water uptake. They added that salinity of the irrigation water should be taken in account when calculating tomato water requirements. They worked on well fertilized plants and irrigated with non-saline water found that the lower limit of EC_e at which yield starts to decline is higher than proposed by Maas and Hoffman and ranges from 1.6 – 3.1 dS/m. This suggests an interaction between fertilization and tolerance to salt stress (Favaro-Blanco et al., 2003). Potassium; K^+ is the most prominent inorganic plant solute and as such makes a major contribution to lower the osmotic potential in the stele of roots that is a prerequisite for turgor pressure driven solute transport in xylem and water balance of plant. Adequate potassium fertilization of crop plants may facilitate osmotic adjustment, which maintains turgor pressure at lower leaf water potentials and can improve the ability of plants to tolerate drought and salinity stress (Lindhauer, 1985). Eakes et al. (1991) stated that adequate levels of potassium; K^+ nutrition enhanced drought and salinity resistance, water use efficiency, plant growth and productivity under drought and salinity conditions. Marschner (1995) mentioned that adequate potassium levels are essential for plants survival in saline habitats. Little information is available about the possibility of reducing the negative effects of irrigation water salinity by potassium applications and the influence of potassium fertilization levels and water quality on tomato growth and productivity. Therefore, the objectives of this study were to assess the effect of different salinity levels of irrigation water and potassium fertilization levels on the tomato yield and quality, water consumptive use and water use efficiencies. This information will enable the determination of EC threshold values according to Maas and Hoffman threshold model (1977) that optimize tomato fruit yield, quality and consequently growers' incomes in this region.

MATERIALS AND METHODS

Field Experimental sites

A field experiment was carried out and repeated during the two successive growing seasons of 2003/04 and 2004/05 at El-Kaf region represented newly reclaimed sandy soil in Siwa Oasis (29° 5́ -29° 25́ N and longitude 25° 8́ – 26° 5́ E). Four irrigation treatments and four different potassium application levels were applied to asses the response of tomato to irrigation with saline water and to test the hypothesis that salt stress may be mitigated by potassium fertilization. Before transplanting, soil samples were collected to a depth of 90 cm at 30 cm intervals to determine some physical properties. Electrical conductivity; EC_e and pH were determined in 1:5 soil water suspensions and its extract. Soluble cations and anions were measured in the soil paste extracts that were prepared for each sample. Some soil characteristics were determined according to and Page (1982) at Nubaria Research Station and are summarized in Table 1 and 2.

Table 1. Some soil physical properties for the experimental site

Soil depth (cm)	Particle size distribution (%)			Soil texture class	BD (gcm^{-3})	θ_s m^3m^{-3}	PWP m^3m^{-3}	FC m^3m^{-3}	AW m^3m^{-3}	k_s mm h^{-1}
	Sand	Silt	Clay							
0-30	94.4	4.7	0.9	Sandy	1.55	0.335	0.058	0.111	0.05	71.7
30-60	94.1	4.8	1.1	Sandy	1.56	0.330	0.056	0.108	0.05	68.5
60-90	95.0	3.9	1.1	Sandy	1.56	0.327	0.054	0.106	0.05	66.9
Aver.	94.5	4.47	1.03	Sandy	1.56	0.331	0.056	0.108	0.05	69.0

BD: bulk density, θ_s: saturated moisture content, PWP: permanent welting point, FC:field capacity, AW: available water and k_s: saturated hydraulic conductivity.

Table 2. Some soil chemical properties for the experimental site

Soil depth	EC_e dS/m	pH	SAR	$CaCO_3$ %	Soluble cations (meq/l)				Soluble anions (meq/l)			
					Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-
0-30cm	3.19	8.33	10.39	7.65	3.01	5.96	22.0	0.89	-	5.35	9.1	17.80
30-60cm	2.75	8.28	8.81	6.88	2.13	5.85	17.6	0.90	-	3.95	7.9	15.25
60-90cm	2.33	8.20	8.07	6.11	2.11	4.70	14.9	0.85	-	3.69	6.5	12.73
Aver.	2.76	8.27	9.09	6.88	2.42	5.50	18.2	0.88	-	4.33	7.8	15.26

Soil salinity was monitored three times; before sown, during the growing season and after harvesting to a depth of 90 cm at 30 cm intervals.

Field experiment

Tomato variety of Floradade was sown in the nursery at July 10, 2003 and July 17, 2004, respectively. Floradade is a cultivar recommended for open field cultivation with saline water. During the seed bed preparation, Organic manure with rate of 30 m^3/fed was well mixed with super phosphate (15.5% P_2O_5) with rate of 31 kg P_2O_5/fed. Seedlings were transplanted to the experimental plots at August 25, 2003 and August 30, 2004, respectively at 0.3 m within rows and 0.8 m between rows. The experimental area was plowed, leveled and divided into 3 areas (to represent the replications) and each area was divided into 16 plots. Each plot area was about 20 m^2 (5 m × 4 m). It was contained five rows with spacing of 0.8 m and distance of 5 m. Each plot was bounded by 1 m dikes to avoid the interference effect. All plots received a uniform application of 120 kg/fed nitrogen fertilizer as ammonium nitrate (33.5% NH_4O_3) spitted three equal doses added at 30, 70 and 90 days after transplanting. The experimental site was irrigated using surface irrigation system, which is the common irrigation system used in Siwa Oasis. Prior to planting and 30 days after transplanting the whole experimental plots were irrigated with good quality water form Dakrory deep well of 1.25 dS/m to ensure tomato seedling surviving and good plant establishment.

The statistical split plot design with three replications was adopted. Where, two variables were considered in the analysis. The main plots represented by four salinity levels of irrigation water; EC_{iw}, namely I_1 = 1.25, I_2 = 2.5, I_3 = 5 and I_4 =10 dS/m. Those were prepared by mixing of highly saline drainage water and good quality well water at appropriate ratio to obtain the desired EC_{iw}. The chemical properties of the irrigation water treatments were represent in Table 3. The sub-plots were incorporated by four potassium application levels, namely K_0 = 0, K_{40} = 40, K_{80} = 80 and K_{120} =120 kg K_2O/fed. Those were spitted by four equal doses of potassium sulphate (K_2SO_4, 48% K_2O) during the seed bed preparation, 20, 40 and 70 days after transplanting. All treatments were fully randomized within each of three replicates. The treatment of I_1K_0; irrigation water salinity; EC_{iw} of 1.25 dS/m and potassium application of 0 kg K_2O/fed was represented the control treatment. All pesticides and herbicidal treatment were applied as recommended.

Table 3. Chemical properties of the irrigation water treatments.

Treat-ment	EC_{iw} dS/m	pH	SAR	Soluble cations (meq/l)				Soluble anions (meq/l)		
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
I_1	1.25	7.4	1.57	8.2	6.2	4.3	0.35	6.5	3.4	1.6
I_2	2.5	8.25	3.63	8.4	6.7	10.0	0.81	6.85	10.85	7.5
I_3	5.0	8.51	8.55	11.8	8.8	27.5	1.36	8.36	17.1	23.9
I_4	10.0	8.65	13.50	20.1	15.8	57.2	6.65	21.4	29.6	49.9

Surplus irrigation water was added to provide a leaching fraction; LR according to Ayers and Westcot (1985) as follows:

$$LR = \frac{EC_{iw}}{5\,EC_e - EC_{iw}} \text{ ---------------(1)}$$

where: LR: the leaching requirement to keep soil salinity within tolerable limits for crop production, EC_{iw}: the electrical conductivity of irrigation water (dS/m) and EC_e: the EC of the soil saturation extract for tomato crop appropriate to the tolerable degree of yield depression as defined by Maas and Hoffman (1977).

Water consumptive use; WCU

Soil samples were taken from different soil depths before and after each irrigation time to determine water consumptive use through the interval irrigation time, WCU_m in mm according to Israelsen and Hansen (1962) as:

$$WCU_m = \sum_{i=1}^{n} \frac{M_{ai} - M_{bi}}{100} \times \gamma_{si} \times z_i \text{ ---------------(3)}$$

where: m: the irrigation No., i: the soil layer No., n: the soil layer numbers, M_{ai} and M_{bi}: represent the soil moisture content (%) after irrigation by 24h and before the next irrigation immediately for layer i, γ_{si}: the specific bulk density of soil layer, and z_i: depth of the soil layer. The three layer (0-30, 30-60 and 60-90 cm) were taken to represent the effective root zone. Seasonal water consumptive use; WCU was calculated from the sum of WCU_m for all irrigation times.

Applied irrigation water; AIW

For each irrigation time, the amount of the applied irrigation water; AIW_m was calculated according to the following equation

$$AIW_m = \frac{WCU_m}{E_a^*\left(1-LF\right)} \text{---------------} (2)$$

where: E_a^*: designed water application efficiency, which was 0.7.

Irrigation water for each plot was applied using 800 mm length and 70 mm in diameter P.V.C. spiles. The calibration of the spiles was carried out under the operation conditions using volume and time method**.** Seasonal applied irrigation water; AIW was calculated from the sum of AIW_m.

Tomato yield and quality parameters

Harvesting season was started at 104 and 110 days after transplanting for the first and second season, respectively. Total fruit yield; T Yield, marketable yield; M Yield (the non-marketable yield included yellow fruits and fruits having blossom end rot; BER), the number of fruit per plant; FN/plant and the average weight of the fruit per plant; FW were determined. To evaluate the physical quality aspects of the tomato fruits, fruit height; FH and fruit diameter; FD were measured, while to evaluate the chemical quality aspects the total soluble solid content; TSS and the pH values of the fruit juice were determined.

Irrigation water efficiencies

Irrigation water used efficiency; IWUE was calculated as a ratio between the total fresh yield; FY and seasonal applied irrigation water; AIW (Michael, 1978). While, water used efficiency; WUE was calculated as a ratio between the total fresh yield; FY and seasonal water consumptive use; WCU (Jensen, 1983).

Plant growth and productivity response to salinity

Plant growth and productivity response to salinity was evaluated according to the threshold–slop model as described by Maas and Hoffman (1977) as:

$$R.Y = 100 - S\ (EC_e - EC_t) \text{ ---------------}(4)$$

where: RY: relative yield (%), S: the percent yield decrease per unit salinity increase above the threshold, EC_t: threshold (maximum root zone salinity without yield reduction) and EC_e: average root zone soil salinity.

Statistical analysis:

The data obtained from the two growing seasons were subjected to proper statistical analysis using CoHort Software (2005). The treatment's means were compared using the least significant difference test (LSD) at 5% probability level. Water consumptive use was considered in the analysis.

RESULTS AND DISCUSSION

The effect of irrigation water salinity; EC_{iw} and potassium fertilizer levels; K^+ on some tomato growth and productivity parameters as was investigated as follows:

Number of fruit per plant; FN

Results of the average number of fruit per plant (FN) for the two growing season are given in Table (4). The obtained results show significant differences in the average FN values among the treatments. The maximum FN of 56 was recorded in I_1 treatment followed by I_2, I_3 and I_4 treatments, respectively. Increasing the EC_{iw} form 1.25 dS/m to 2.5, 5 and 10 dS/m led to decreasing the FN by about 8.9, 21.4 and 30.4%, respectively. It means that the reduction of the fruit number with salinity was approximately 5.5% per dS/m. However, increasing the K^+ from 0.0 to 40, 80 and 120 kg/fed resulted in increasing the FN by about 9.8, 22 and 29.3%, respectively. A significant interaction of EC_{iw} and K^+ on the FN was noted. I_1K_{120} treatment had the maximum FN of 63 followed by I_1K_{80}, I_2K_{120} and I_2K_{80}, respectively. I_4K_0 had the minimum FN of 36, about 23.4% less than the control treatment (I_1K_0). These results declared that the effect of EC_{iw} levels on the FN was more pronounced than the effect of the K^+ treatments.

Fruit size

Fruit diameter (FD) and height (FH) were investigated and the results were presented in Table (4). The results show highly significant effect of the treatments on the fruit diameter and height. Increasing the salinity level of irrigation water (EC_{iw}) strongly decreased these parameters. While, increasing the potassium fertilizer (K^+) slightly enhanced these parameters. The maximum FD and FH values of 55.8 and 52 mm, respectively were obtained with I_1 treatment. Increasing the EC_{iw} to 5 and 10 dS/m resulted in decreasing the FD and FH by about 16.59, 29.15% and 15.38, 27.88 %, respectively. In the other hand increasing the K^+ to 80 and 120 Kg/fed led to increase the FD and FH by about 9.3, 11.48% and 8.14, 11.05%, respectively. A significant interaction of EC_{iw} and K^+ on the FD and FH was noticed. I_1K_{120} treatment had the maximum FD and FH values of 59 and 55 mm, respectively. While I_4k_0 had the minimum FD and FH values of 37 and 36 mm, respectively. These results are in agreement with Satti and Lopez (1994) and disagree with those of Petersen and et al. (1998), who mentioned that K^+ did not have any effect on the fruit size for salt stressed tomato.

Fruit production per plant

Results of the average fruit weight per plant (FW) for the two growing seasons are given in Table (4). Data obtained pointed out a highly significant effect of the EC_{iw} and K^+ treatments on the FW. The high EC_{iw} inhibited the fruit production and appeared considerable decrease in the FW. I_1 treatment had the heights FW value of 1380.5 g/plant. Increasing the EC_{iw} form 1.25 to 2.5, 5 and 10 dS/m decreased the FW by about 11.4, 38.4 and 53.5 %, respectively. The data showed that a linear decrease of the fruit weight with 9.8% per dS/m. However, increasing the K^+ from 0.0 to 40, 80 and 120 kg/fed resulted in increasing the FW by about 9.2, 26.4 and 32 %, respectively. These results demonstrate highly effect of EC_{iw} on the FW than the K^+. A significant interaction among the treatments was noted. I_1k_{120} treatment had the maximum FW of 1586 g/plant followed by I_1K_{80} and I_2K_{120}, respectively. While I_4K_0 had the minimum FW value of 610 g/plant, about 46.8 % less than the control treatment.

Total yield; T.Yield and Marketable yield; M.Yield

Data of the average total tomato yield (T.Yield) for the two growing seasons are presented in Table (4). Results clearly show highly influence of EC_{iw} and K^+ treatments on tomato yields. Concerning the total tomato yield, I_1 treatments had the highest average tomato yield of 17.5 Mg/fed. Slightly decrease in the total yield of 6 % was noticed by I_2 treatments. However, increasing the EC_{iw} to 5 and 10 dS/m adversely affected the total yield by about 26.4 and 56.3%, respectively. In the other side, increasing the K^+ enhanced the average total yield. Increasing the K^+ to 40 and 80 kg/fed increased the average total yield by about 7.7 and 20.1%, respectively. However, no significant differences were found between the total tomato yield of K_{80} and K_{120} treatments. These results demonstrate the highly effect of the EC_{iw} on the tomato yields than the K^+. A significant interaction of EC_{iw} and K^+ on the average total yield was noticed. The maximum average total yield of 18.85 Mg/fed was obtained by I_1K_{80} treatment followed by I_1K_{120}, I_2K_{120} and I_2K_{80} treatments, respectively. While, I_4K_0 treatment had the minimum average total yield of

7.2 Mg/fed. Regarding the marketable yield, I_1 and I_2 treatments had the maximum marketable yield of 14.76 and 14.55 Mg/fed, respectively. Increasing the EC_{iw} to 5 and 10 dS/m resulted in decreasing the average marketable yield by about 30.7 and 68.2%, respectively. The percentage of the non-marketable yield was approximately about 15.7, 15, 20.6 and 38.7% by I_1, I_2, I_3 and I_4 treatments, respectively. Also, it seems from the results presented in Table (4) that the percentage of the marketable yield to the total yield was enhanced by increasing the K^+ except K_{120} treatments.

Table 4. Statistical analysis of some growth and productivity parameters of tomato as affected by different irrigation water salinity and potassium fertilizer levels.

Treatments	Growth and productivity tomato parameters					
	FN/plant	FD mm	FH mm	FW/plant g	T.Yield Mg/fed	M.Yield Mg/fed
I_1	56a	55.8a	52.0a	1380.5a	17.50a	14.76a
I_2	51b	53.0b	48.3b	1223.8b	16.45b	14.55a
I_3	44c	46.5c	44.0c	851.3c	12.89c	10.23b
I_4	39d	39.5d	37.5d	642.5d	7.65d	4.69c
Significance L	***	***	***	***	***	**
K_0	41d	45.75d	43d	876.5d	12.02c	9.24c
K_{40}	45c	48c	44.5c	957.5c	13.15b	10.7b
K_{80}	50b	50b	46.5b	1107.5b	14.66a	12.16a
K_{120}	53a	51a	47.75a	1156.5a	14.72a	12.13a
Significance L	***	***	***	***	***	**
I_1K_0	47	52	50	1146	15.65	12.65
I_1K_{40}	53	55	50	1280	16.75	14.30
I_1K_{80}	60	57	53	1510	18.85	16.20
I_1K_{120}	63	59	55	1586	18.73	15.90
I_2K_0	43	50	46	980	14.00	11.35
I_2K_{40}	47	52	46	1065	15.60	14.25
I_2K_{80}	55	55	50	1385	18.00	16.35
I_2K_{120}	57	55	51	1465	18.20	16.25
I_3K_0	38	44	40	770	11.22	9.10
I_3K_{40}	42	46	44	850	12.35	9.90
I_3K_{80}	46	47	45	885	13.90	10.80
I_3K_{120}	50	49	47	900	14.10	11.10
I_4K_0	36	37	36	610	7.20	3.85
I_4K_{40}	38	39	38	635	7.65	4.35
I_4K_{80}	40	41	38	650	7.90	5.30
I_4K_{120}	43	41	38	675	7.85	5.25
Significance L	***	***	***	***	***	***

Means within each column followed by the same letter/s are insignificant at 0.05 level of probability, *: significance at the 0.05 probability level, **: significance at the 0.01 probability level, and ***: significance at the 0.001 probability level.

The increase in tomato yield in treatments of I_1 and I_2 treatments compared to the other treatments can be explained by the significant increase in fruit weight and numbers. In the other side, the reduction in tomato yield by I_3 and I_4 corresponds with a reduction in fruit weight and numbers as shown in Table (4). These results confirmed that, appropriate EC_{iw} and K^+ enhanced the growth and productivity of tomato plant and were consistent with those reported by Caruso and Postigliono (1993), who reported that marketable yield was high where low to moderate saline water was used.

Fruits with blossom end rot; BER

The presented results in Table (5) revealed that the Fruits with blossom end rot; BER was significantly affected by EC_{iw} and K^+ treatments. I_1 and K_{120} treatments had the smallest percentage of the fruits with BER of 7.13 and 12.01 %, respectively. Increasing the EC_{iw} from 1.25 to 2.5, 5 and 10 dS/m resulted in considerable increase the percentage of fruits with BER by about 29.6, 96.4 and 184 %, respectively. However, increasing the K^+ from 0.0 to 40, 80, and 120 Kg/fed led to decrease the BER values by about 3.3, 9.1 and 10.5%, respectively. These results show highly effect of the EC_{iw} on BER than the K^+. A significant interaction of EC_{iw} and K^+ on the BER was observed. I_4K_0 treatment has the heights percentage of fruits with BER of 20.4%, while I_1K_{120} treatment exhibited the lowest percentage of fruits with BER of 6.45%.

Total soluble solids; TSS

Data of the TSS of tomato fruit juice as affected by EC_{iw} and K^+ treatments were shown in Table (5). The obtained results show highly significant effect of the EC_{iw} treatments on the TSS. Increasing EC_{iw} strongly increased the TSS. However, the results clearly showed that the TSS was not significantly affected by K^+ treatments. The minimum TSS value of 5.12 % was obtained by I_1 treatments. Increasing the EC_{iw} to 5 and 10 dS/m increased the TSS values by about 48.4 and 98.2%, respectively. These results confirmed that the TSS was strictly related to the EC_{iw}. The interaction effect of the EC_{iw} and K^+ treatments on the TSS was not noticed. Also, these results indicated an opposite trend between tomato quality and quantity as shown in Fig. (1). Increasing tomato yield decreases TSS content. The highest TSS value of 10.2% resulted from I_4 treatments, which produced the least tomato yield. This may be related to the available soil moisture. Under high available soil moisture the root may absorb more water resulted in an increase in the fruit weight and a reduction in the TSS due to the dilution by water.

Table 5: Statistical analysis the effect of different EC_{iw} and different K^+ on tomato fruit quality; BER, TSS and pH juice, and WCU.

Treatments	tomato fruit quality			WCU mm
	BER %	TSS %	pH juice	
I_1	7.13d	5.12d	4.68a	637a
I_2	9.24c	5.98c	4.49ab	610b
I_3	14.00b	7.60b	4.20b	529 c
I_4	20.25a	10.15a	3.76c	458d
Significance L	***	***	**	***
K_0	13.42a	7.11b	4.48a	534 c
K_{40}	12.98b	7.21ab	4.24ab	554b
K_{80}	12.20c	7.26a	4.23ab	568ab
K_{120}	12.01d	7.27a	4.19b	579a
Significance L	***	n.s.	n.s.	*
I_1K_0	7.90	5.00	4.55	610
I_1K_{40}	7.50	5.15	4.53	633
I_1K_{80}	6.66	5.17	4.52	645
I_1K_{120}	6.45	5.17	4.50	660
I_2K_0	10.84	5.85	4.55	575
I_2K_{40}	10.10	5.95	4.53	610
I_2K_{80}	8.20	6.04	4.48	625
I_2K_{120}	7.80	6.08	4.40	630
I_3K_0	14.50	7.55	4.33	510
I_3K_{40}	14.00	7.55	4.25	521
I_3K_{80}	13.80	7.63	4.20	535
I_3K_{120}	13.70	7.65	4.20	551
I_4K_0	20.40	10.10	3.90	440
I_4K_{40}	20.35	10.12	3.78	452
I_4K_{80}	20.15	10.18	3.70	466
I_4K_{120}	20.10	10.20	3.64	474
Significance L	***	n.s.	n.s.	n.s.

Values are means of three replicates for each treatment over two years. Means within each column followed by the same letter/s are insignificant at 0.05 level of probability. n.s.: not significance at the 0.05 probability level, *: significance at the 0.05 probability level, **: significance at the 0.01 probability level, ***: significance at the 0.001 probability level.

pH of fruit juice:

Results of the pH of the tomato juice are given in Table (5). Results show significantly effect of EC_{iw} treatments on the pH values. I_1 treatment had the maximum pH value of 4.68. Increasing the EC_{iw} from 1.25 to 10 dS/m resulted in decreasing the pH value by about 19.5%. However the pH of the tomato juice was not significantly affected by K^+ treatments. Also, the interaction effect of EC_{iw} and K^+ treatments on the pH was not noted.

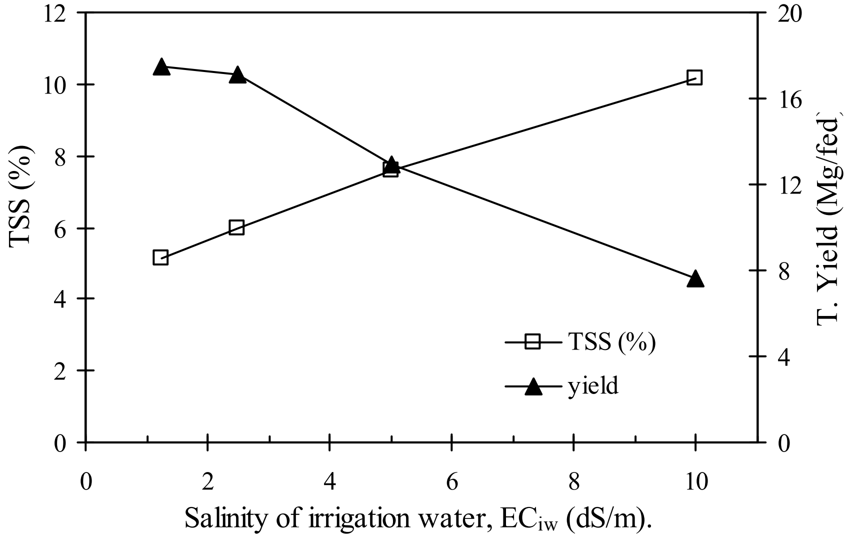

Fig. (1): Relationship between tomato fruit quantity and quality as affected by EC_{iw}.

Water consumptive use, WCU

Water consumptive use values based on the soil water depletion between two irrigation events and the corresponding average values of the total amount of applied irrigation water (AIW) were presented in Table (6). Also, the relationship between WCU and EC_{iw} was illustrated in Fig. (2). Potassium fertilizer levels, K^+ have slightly effect on WCU, however WCU showed a strongly relation to salinity level. WCU decreased logarithmically as the EC_{iw} increased. I_1 treatments had the greatest WCU value of 637 mm followed by I_2 treatments, while I_4 treatments had the lowest WCU value of 458 mm, which was less than the I_1 treatments by about 28.10%. However, WCU of I_2 and I_3 were less by about 4.24 and 16.95% compared to I_1 treatments. A logarithmic regression model was developed to express water consumptive use, WCU in mm as a relation with irrigation water salinity; EC_{iw} in dS/m and potassium fertilizer levels; K^+ in kg K_2O/fed as the following:

$$WCU = 644 + 0.35\ K^{+} - 88\ \ln(EC_{iw})$$

With a correlation coefficient; $R^2 = 0.9$

Based on the above mentioned results, salinity of irrigation water should be taken into account when calculating tomato water requirements.

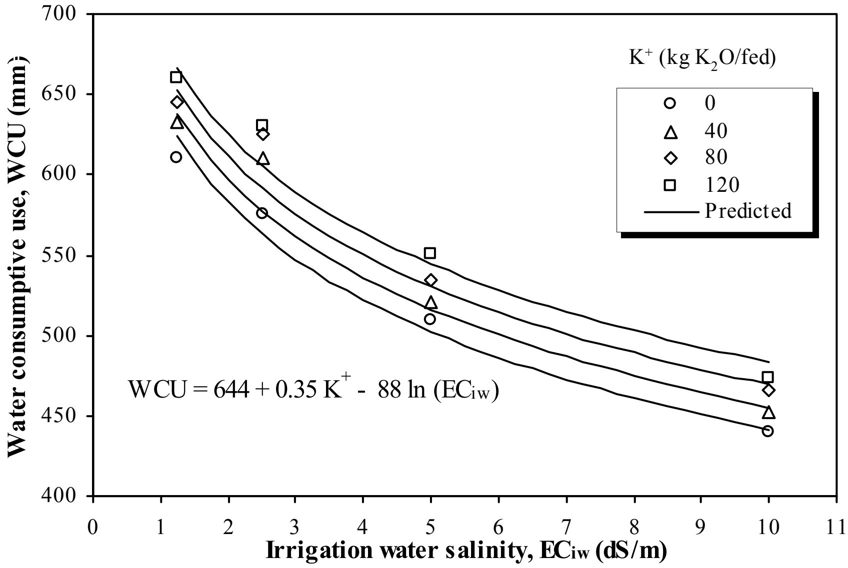

Fig. (2): Relationship between water consumptive use, WCU as affected by irrigation salinity; EC_{iw} and potassium fertilizer; K^{+}.

Water use efficiency; WUE and irrigation water use efficiency; IWUE

Results of WUE as affected by EC_{iw} were illustrated in Fig. (3) and Table (6). Tomato WUE decreased linearly as the EC_{iw} increased. I_1 treatments had the maximum WUE value of 6.54 Kg/m^3 while I_4 treatments had the lowest WUE value of 3.98 Kg/m^3. The same trend was observed with IWUE. I_1 treatments had the greatest IWUE of 4.05 kg/m^3 followed by I_2 and I_3 , respectively. However, I_4 treatments had the lowest IWUE value of 1.83 kg/m^3. The relationship between water use efficiency; WUE and irrigation water use efficiency; IWUE as affected by irrigation salinity; EC_{iw} have been studied. The best correlation is shown in Fig. (3) as

$$WUE = -0.302\ EC_{iw} + 7.1 \qquad \text{with } R^2 = 0.9778$$

$$IWUE = -0.256\ EC_{iw} + 4.39 \qquad \text{with } R^2 = 0.9996$$

Similar results have been reported by Al-Karaki (2000). While, Romero-Aranda et al. (2002) mentioned that, the WUE and IWUE increased as the EC_{iw} increased. This discrepancy could be attributed to the range of salinity tested, the environmental conditions under which plants have been growing and the cultivar used.

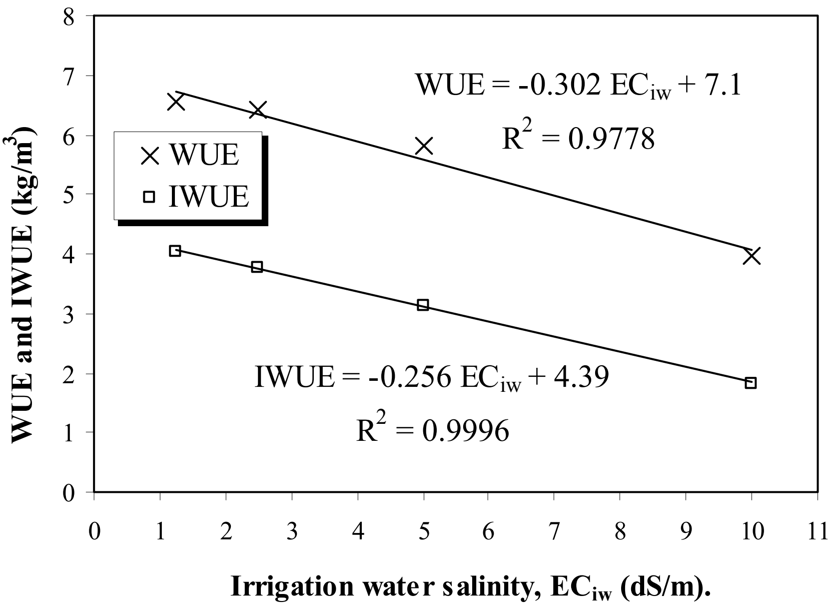

Fig. (3): Relationship between Water use efficiency; WUE and irrigation water use efficiency; IWUE as affected by irrigation salinity; EC_{iw}.

Table .6: The effect of different EC_{iw} on WCU, AIW, WUE and IWUE.

Treatments	WCU (mm)	AIW (mm)	WUE (kg/m^3)	IWUE (kg/m^3)
I_1	637	1029	6.54	4.05
I_2	610	1036	6.42	3.78
I_3	529	983	5.80	3.12
I_4	458	997	3.98	1.83

Soil salinity; EC_e

Fig. (4) represents the relationship between salinity level of irrigation water (EC_{iw}) and soil salinity (EC_e). Irrigation with saline water resulted in increased the soil salinity throughout the growing season and after harvesting. Overall increases were 0.613 dS/m of soil salinity for each dS/m of EC_{iw} during the growing season and 0.783 dS/m of final soil salinity for each dS/m of EC_{iw}. The mean EC_e values throughout the growing season and after harvesting with the soil depth as affected by different salinity levels of irrigation water were presented in Fig. (4).

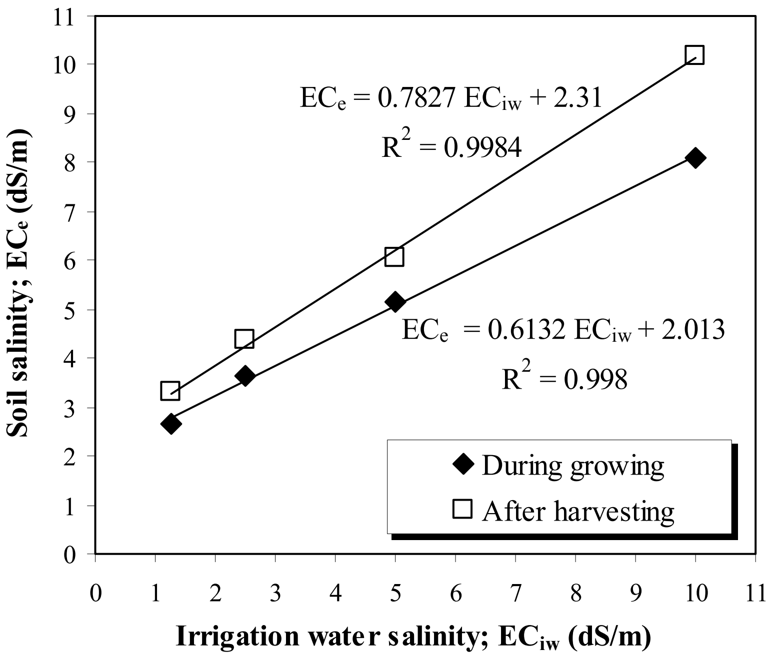

Fig.(4): Soil salinity; EC_e as affected by irrigation water salinity; EC_{iw}.

The relationship between Soil salinity; EC_e as affected by irrigation water salinity; EC_{iw} has been studied. The best correlation is shown in Fig. (4) as

During growing season:

$$EC_e = 0.6132\ EC_{iw} + 2.013 \qquad \text{with } R^2 = 0.998$$

After harvesting:

$$ECe = 0.7827\ EC_{iw} + 2.31 \qquad \text{with } R^2 = 0.9984$$

Salt accumulation and distribution

Fig. (5) shows the soil salinity; EC_e distribution with the soil depth as affected by different EC_{iw} before sowing, during growing season and after harvesting. The EC_e values before sowing was indicated by dotted line in. During the growing season, the EC_e for I_1 treatment was improved, while EC_e values for I_2 treatment were increased as compared with their values before sowing. The mean EC_e values during the growing season ranged from 3.15 to 2.1 dS/m and from 4.10 to 3.20 dS/m for I_1 and I_2 treatments,

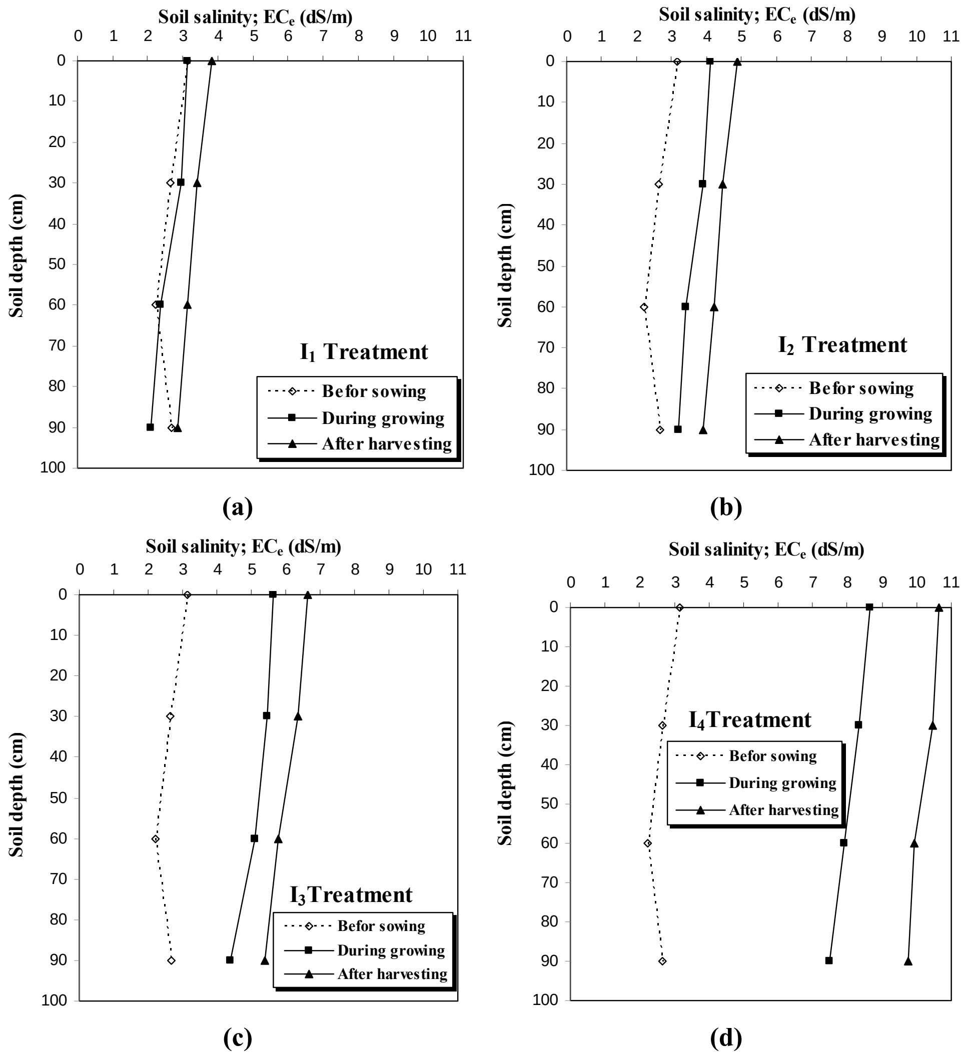

Fig. (5). Soil salinity; EC_e profile as affected by different irrigation water salinity; EC_{iw}.

respectively. Increasing the EC_{iw} to 5 and 10 dS/m adversely affected the EC_e that severely increased and showed different distribution throughout the soil profile according to the salinity level of irrigation water. The highest EC_e mean value of 8.1 and 10.2 dS/m was measured with I_4 treatment during the growing season and after harvesting, respectively.

Application of Maas and Hoffman model on yield

Data of the total and marketable fruit yield in response to increasing salinity were analyzed using the Maas and Hoffman conceptual model. Relative total and marketable yield decreased linearly with increasing the soil salinity above the threshold value (EC_t) as shown in Fig. (6 and 7). The relationships between relative total and marketable tomato yield; R.T.Yield and R.M.Yield, respectively and the soil salinity; EC_e have been studied according to Maas and Hoffman model. The best correlation is shown in Fig. (6 and 7) as:

$$R.T.Yield = 100 - 11.14\ (EC_e - 2.97) \quad \text{for } EC_e > 2.97, \text{ with } R^2 = 0.9942$$

$$R.M.Yield = 100 - 14.693\ (EC_e - 3.31) \quad \text{for } EC_e > 3.31, \text{ with } R^2 = 0.9869$$

Where, the average yield at the irrigation water salinity of 1.25 dS/m was used as control value. Therefore, the average salinity threshold; EC_t values for total and marketable fruit yield were 2.97 and 3.31 dS/m, respectively.

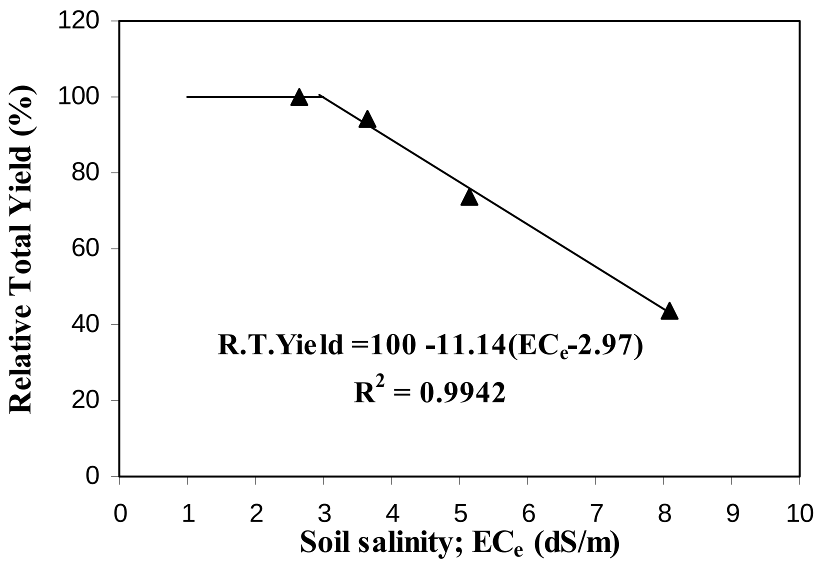

Fig. (6) Relationship between relative total tomato yield and soil salinity as expressed by Maas and Hoffman model.

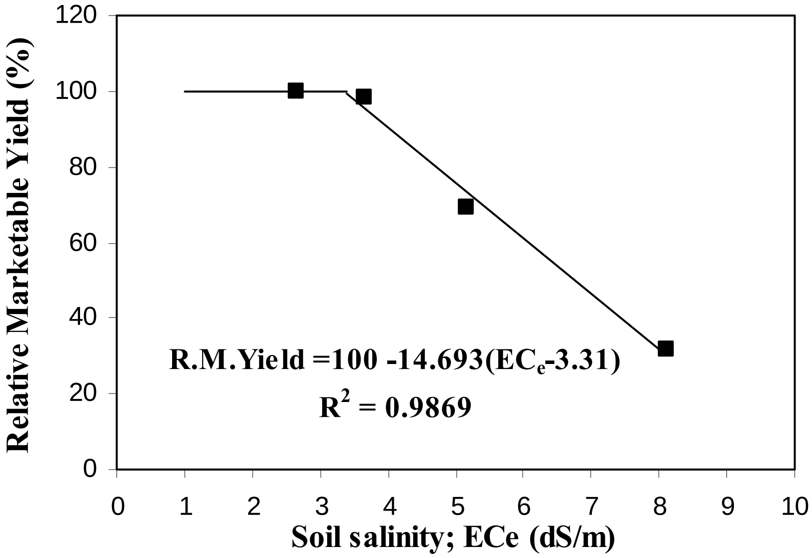

Fig. (7) Relationship between relative marketable tomato yield and soil salinity as expressed by Maas and Hoffman model.

The decreases of total and marketable yield with salinity were followed the linear slope of 11.14 and 14.693 % per dS/m after EC_t values, respectively. These results are higher than those reported by Maas and Hoffman (1977), and are in accordance with those reported by Cuartero and Munoz (1999).

CONCLUSIONS

Based upon results, the following can be concluded:

1. Total yield decreased by extent of 6, 26.4 and 56.3% with increasing salinity from 1.25 to 2.5, 5 and 10 dS/m.
2. Increasing the K^+ to 40 and 80 kg/fed increased the average total yield by about 7.7 and 20.1%, respectively. However, no significant differences were found between total yield of K_{80} and K_{120} treatments.
3. Increasing the salinity improved various aspects of fruit quality. However, salinity decreased fruit size, which is a major determinant of marketing. Also, increasing the potassium application levels affected significantly the fruit quality parameters.
4. Increasing the salinity increased the percentage of fruit affected with blossom end rot. However, increasing the potassium application levels slightly decreased this percentage.

5. A logarithmic regression model was developed to express water consumptive use, WCU in mm as affected by irrigation water salinity; EC_{iw} in dS/m and potassium fertilizer levels; K^+ in kg K_2O/fed as:

$$WCU = 644 + 0.35\ K^+ - 88\ \ln (EC_{iw})$$

6. The relationship between water use efficiency; WUE and irrigation water use efficiency; IWUE as affected by irrigation salinity; EC_{iw} have been expressed as

$$WUE = - 0.302\ EC_{iw} + 7.1$$

$$IWUE = -0.256\ EC_{iw} + 4.39$$

7. The relationship between Soil salinity; EC_e as affected by irrigation water salinity; EC_{iw} has been expressed as

   During growing season: $EC_e = 0.6132\ EC_{iw} + 2.013$

   After harvesting: $ECe = 0.7827\ EC_{iw} + 2.31$

8. The relationship between relative total and marketable tomato yield; R.T.Yield and R.M.Yield, respectively and the soil salinity; EC_e has been studied according to Maas and Hoffman model as:

$$R.T.Yield = 100 - 11.14\ (EC_e - 2.97)$$

$$R.M.Yield = 100 - 14.693\ (EC_e - 3.31)$$

9. The threshold; EC_t values for total and marketable fruit yield were 2.97 and 3.31 dS/m, respectively.
10. The decreases of total and marketable yield with EC_e were followed the linear slope of 11.14 and 14.69 % per dS/m after EC_t, respectively.

Specific conclusion could be made as follows:

Under Siwa oasis conditions, it is advisable to maintain root zone EC at or bellow the suggested EC_t of 3 dS/m. this conclusion has important practical implications for the management of soil amendments, irrigation and drainage system in Siwa, where irrigation water obtained from wells, tend to have different levels of salinity.

In general, moderate salt concentration in irrigation water up to 2.5 dS/m can be used for tomato production in the specific environment considered, without major detrimental effect on tomato yield. At higher salts concentration in irrigation water, yield may be seriously reduced and considered economically unacceptable. Also, appropriate potassium application levels of 80 kg/fed could mitigate the negative effects of salinity and enhance tomato growth and productivity and consequently the income.

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الملخص العربى

تأثير ملوحة مياه الري و مستويات التسميد البوتاسي علي الإنتاجية و الاستهلاك المائي لمحصول الطماطم فى واحة سيوه

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يهدف هذا البحث إلى دراسة و تقدير تأثير مستويات مختلفة من ملوحة مياه الري و التسميد البوتاسي علي الإنتاجية و الاستهلاك المائي لمحصول الطماطم تحت ظروف واحة سيوه. لتحقيق هذا الهدف أجريت تجربتين حقليتين خلال موسمي النمو 2004/2003 و 2005/2004 في منطقة الكاف. تم تصميم التجربة إحصائيا باستخدام تصميم القطع المنشقة في ثلاث مكررات و اشتملت علي متغيرين:

1- أربع مستويات مختلفة لملوحة مياه الري (I): (EC_{iw}= 1.25، 2.5 ، 5 ، 10 dSm^{-1})

2- أربع مستويات مختلفة للتسميد البوتاسي (K^+): (0.0 ، 40، 80 ، 120 كيلوجرام/فدان).

تم تحليل النتائج الخاصة بالمحصول و جودته و معدل الاستهلاك المائي إحصائيا كما تم تقدير كفاءة استخدام المياه ودرجة و توزيع الملوحة في قطاع التربة . استخدمت البيانات المتحصل عليها لتقدير درجة ملوحة المحلول المائي للتربة والذي يبدأ المحصول بعده في التناقص (Threshold; EC_t) وذلك وفقا للنموذج الرياضي (Maas and Hoffman, 1977). و كانت أهم النتائج المتحصل عليها كالتالي:

1- تأثرت إنتاجية و خصائص الجودة لمحصول الطماطم معنوياً نتيجة المعاملات وكان تأثير معاملات درجة ملوحة مياه الري أكثر معنوية عن معاملات مستويات التسميد البوتاسي.

2- سجلت متوسطات المعاملة I_1 (1.25 dSm^{-1}) أعلي قيه للمحصول الكلي و المحصول التجاري وقدرها 17.5 و 14.76 ميجاجرام/فدان، علي الترتيب.

3- أدت زيادة درجه ملوحة مياه الري الي انخفاض عدد الثمار للنبات والي صغر حجم الثمار و زيادة نسبة الثمار المصابة بالعفن مما أدي إلى نقص فى المحصول الكلي بنسبة 6، 26.4، 56.3% مع أستخدام مياه ري ملوحتها 2.5 ، 5 ، 10 dSm^{-1} علي الترتيب.

4- أدت زيادة درجه ملوحة مياه الري الي تحسين بعض خصائص الجودة للثمار، حيث أدت إلي زيادة نسبة المواد الصلبة الكلية وخفض نسبة الحموضة.

5-أدت زيادة التسميد البوتاسي إلي تحسين خواص النمو و الإنتاج لمحصول الطماطم و الي نقص نسبة الثمار المصابة بالعفن و بالتالي الي زيادة المحصول و ذلك عند مياه ري ذات درجة ملوحة معتدله إلا أن هذا لم يحد بالدرجة الكافية من التأثير السلبي للملوحة مياه الري.

1-باحث - معهد بحوث الهندسة الزراعية- مركز البحوث الزراعية.

2- مدرس الهندسة الزراعية – كلية الزراعة – الشاطبي - جامعة الاسكندرية

3- رئيس بحوث متفرغ- الأدارة المركزية لمحطات البحوث و التجارب الزراعية- مركز البحوث الزراعية.

6- أدت زيادة درجه ملوحة مياه الري الي خفض الاستهلاك المائي و الي خفض كفاءة استخدام الماء حيث سجلت متوسط المعاملة I_1 ($1.25\ dSm^{-1}$) أعلي معدل للاستهلاك المائي و قدره 637 مم و كذلك أعلي قيمة لكفاءة استخدام المياه وقدرها 6.54كجم/م^3.

7- وقد أستنبطت معادلة للتنبؤ بالأستهلاك المائي WCU لمحصول الطماطم كدالة فى كل من مستوى ملوحة مياه الري EC_{iw} (dSm^{-1}) ، ومستوى التسميد البوتاسي K^+ ($kg\ K_2O/fed$) كدليل استرشادي في واحة سيوه كمايلى

$$WCU = 644 + 0.35\ K^+ - 88\ \ln(EC_{iw})$$

8- كما تم أستنباط معادلتين للتنبؤ بكفاءة أستخدام المياه WCU (كجم/م^3) لمحصول الطماطم كدالة فى متوسط مستوى ملوحة مياه الري EC_{iw} (dSm^{-1}) كدليل استرشادي في واحة سيوه كمايلى

$$WUE = -\ 0.302\ EC_{iw} + 7.1$$

9- أدت زيادة درجه ملوحة مياه الري الي زيادة الملوحة خلال قطاع التربة بزيادة مقدارها 0.613 dS/m خلال موسم الزراعة لكل وحدة ملوحة زيادة في مياه الري. و بزيادة نهائية مقدارها 0.783 dS/m لكل وحدة ملوحة زيادة في مياه الري كما أستنبطت معادلتين للتنبؤ بملوحة التربة فى خلال الموسم وبعد الأنتهاء من الحصاد كدالة فى متوسط مستوى ملوحة مياه الري المستخدمة EC_{iw} (dSm^{-1}) في واحة سيوه كمايلى

خلال الموسم $$EC_e = 0.6132\ EC_{iw} + 2.013$$

بعد الأنتهاء من الحصاد $$EC_e = 0.7827\ EC_{iw} + 2.31$$

10- وبتطبيق النموذج الرياضي لـ Maas and Hoffman لتنبؤ بكلا من المحصول الكلي T.Yield والمحصول التجاري M.Yield كنسبة مئوية من متوسط محصول معاملة 1.25 dSm^{-1} كدالة فى متوسط مستوى ملوحة مياه الري EC_{iw} كدليل استرشادي في واحة سيوه كمايلى

$$R.T.Yield = 100 - 11.14\ (EC_e - 2.97)$$

$$R.M.Yield = 100 - 14.693\ (EC_e - 3.31)$$

وهذا يعنى أن معدل النقص فى المحصول الكلي والمحصول التجاري يكون بمقدار 11.14 ، 14.693% علي الترتيب لكل وحدة زيادة فى الملوحة عن قيمة threshold وهى 2.96 ، 3.31 dS/m للمحصول الكلي والمحصول التجاري علي الترتيب.

هذا و قد خلص البحث إلى إن استخدام مياه ري في واحة سيوه حتى dS/m2.5 في إنتاج الطماطم لا يترتب علية أضرارا جسيمة بالمحصول شريطة المحافظة علي threshold عند او أقل من 3 dS/m . كما ان زيادة التسميد البوتاسي حتى 80 كجم/فدان يمكن ان يحد من التأثير السلبي لزيادة ملوحة مياة الري كما يحفز من نمو و إنتاجية المحصول و يقلل من نسبة الثمار المصابة بالعفن.