Research Article

Turk J Agric For
34 (2010) 59-73

doi:10.3906/tar-0902-22

Impact of irrigation water quality, irrigation systems, irrigation rates and soil amendments on tomato production in sandy calcareous soil

Abdulrasoul M. AL-OMRAN[1], A. R. AL-HARBI[2], Mahmoud A. WAHB-ALLAH[2], Mahmoud NADEEM[1], Ali AL-ETER[1]

[1]Soil Science Department, College of Food and Agricultural Sciences, King Saud University, P.O. Box 2460, Riyadh 11451 - SAUDI ARABIA

[2]Plant production Department, College of Food and Agricultural Sciences, King Saud University P.O. Box 2460, Riyadh 11451 - SAUDI ARABIA

Received: 16.02.2009

Abstract: Low quality water for irrigation can impose a major environmental constraint to crop productivity. Effects of water quality, irrigation system, irrigation rates, and type of amendment on the yield and quality of tomato plants were investigated during the 2 growing seasons of 2005/2006 and 2006/2007. Two water quality treatments (fresh water with electrical conductivity (EC) of 0.86 dS m^{-1}, and saline water with EC of 3.6 dS m^{-1}), 2 drip irrigation systems (surface and subsurface), 3 irrigation rates (2, 4, and 6 L h^{-1}) and 3 amendment types (clay deposit, and organic matter and without amendment) were applied. The results revealed that the water quality significantly affected both the yield and water use efficiency (WUE). The decreases in yields due to using low quality water were 39.2% and 17.6% for the first and second season, respectively. At a high irrigation rate (6 L h^{-1}), tomato yields were higher and decreased significantly at a low irrigation rate (2 L h^{-1}) in both seasons. When fresh water was used, the amendment type affected both the yield and WUE in both seasons. Clay deposit increased the yield by 11.7% and 15% in the control treatments in the first and second season, respectively. Low quality of irrigation water significantly increased fruit pH, and significantly decreased the other 3 traits (average fruit weight, total soluble solid, and fruit thickness). The influence of salinity was more obvious on average fruit weight than the other 2 traits. Application of clay deposits on sandy soils modifies the distribution of soil water content in the root zone area where water could be retained by clay deposits applied in the subsurface layer. Using saline water increased the salt accumulation in the surface to about 15 dS m^{-1} compared with 5 dS m^{-1} for fresh water treatments. The clay deposit amendments for subsurface sandy soils using good irrigation water show quite valuable effects in storing irrigation water and then enhance the root growth and the yield.

Key words: *Lycopersicon esculentum* L., saline water, amendment, irrigation methods, irrigation rate, water use efficiency

* E-mail: rasoul@ksu.edu.sa

Introduction

Tomato (*Lycopersicon esculentum* Mill.), one of the world's most important and widespread crops, is classified as moderately salt tolerant (Maas 1986) and could act as a model crop for saline land recovery and use of poor-quality water as there is a wealth of knowledge of the physiology and genetics of this species, and the crop is already grown in large areas where saline conditions are a problem (Reina-Sanchez et al. 2005).

The continuous decrease in water resources in the world in general, and in arid regions such as Saudi Arabia in particular has forced farmers to use low quality water and to alter their irrigation practices. The agricultural sectors in the Gulf countries consume more than 85% of the total water (Al-Rashed and Sherif, 2000). Therefore, it is necessary to get the maximum yield in agriculture by using the available water in order to get the maximum profit from the unit area, and to achieve this we need to know and supply the right amount of water needed for the plants. Furthermore, it is essential to develop the most suitable irrigation schedule to get the optimum plant yield for different ecological regions (Ertek et al. 2002). To get the desired profit from irrigation, time, length, and quantity of irrigation should be usefully determined. Erroneous irrigation applications underestimating the irrigation time and quantity may cause yield decrease and salinity as well as alkalinity problems (Onest et al. 1995). Irrigation water quality can affect soil fertility and irrigation system performance as well as crop yields and soil physical condition. Therefore, knowledge of irrigation water quality is critical to the understanding of necessary management changes for long-term productivity (Bauder et al. 2004).

Most of the cultivated soils in Saudi Arabia are sandy soils characterized by low water holding capacities, high infiltration and evaporation rates, low fertility levels and deep percolation losses that induce low water use efficiency. The use of clay deposit materials and a drip irrigation system has helped to improve some of these constraints in crop production with better water management strategies (Al-Omran et al. 2002, 2004, 2005). The drip irrigation system provides an advantage using saline water with more frequent irrigation to keep a high soil matric and low salt concentration in the root zone. Malash et al. (2005) and Abdelgawad et al. (2005) reported that water use efficiency (WUE) was higher with drip irrigation over traditional methods on different tomato varieties. They also found higher sugar content of tomato fruit using saline irrigation water compared with soil irrigated with non-saline water. Wan et al. (2007) concluded on a 3-year field experiment using saline irrigation water ranging from 1.1 to 4.9 dS m^{-1} with a drip irrigation system and reported that water salinity had little effect on tomato yields, but had some effect on seasonal accumulative water use, water use efficiency (WUE), and irrigation water use efficiency (IWUE). They also concluded that soil salinity in 0-90 cm soil depth did not increase. The work on the use of subsurface drip irrigation on crop yields shows that crop yields under subsurface drip irrigation are equal or greater than those obtained by surface drip irrigation (Phene et al. 1987; Ayars et al. 1999; Al-Omran et al. 2005). In tomatoes, during the first stages of crop growth, subsurface drip irrigation can increase the efficiency of water use when compared with surface drip irrigation (Machado et al. 2003).

Soil water and salt distributions were reported in several studies using surface and subsurface drip irrigation. Shalhevet (1994) stated that it is still controversial whether the reduction in water uptake with increasing salinity is the cause or result of the reduction in growth, while Wan et al. (2007) concluded that water salinity of (1.1- 4.9 dS m^{-1}) had little effect on tomato yields. However, Al-Omran et al. (2008) reported that salt accumulation in the field was an important factor in reducing the yield. The purpose of this study was to investigate the influence of water quality, irrigation systems, and irrigation rates on tomato quality, yield, water use efficiency, and salt distribution in irrigated sandy soils amended with clay deposits or manure.

Materials and methods

Two successive field experiments were conducted at the College of Agricultural Research Station at Dirab (24°25´ N, 46°34´ E), 40 km southwest of Riyadh, Saudi Arabia, during the months of September-April (2005-2006 and 2006-2007).

Meteorological data are given in Table 1. The experiment included 36 treatments representing the combination of (A) 2 water quality treatments (fresh water with EC 0.86 dS m^{-1}, and saline water with EC 3.6 dSm^{-1}, (B) 2 drip irrigation systems (surface and subsurface), (C) 3 irrigation rates (2, 4, and 6 L h^{-1}), and (D) 2 amendment types (2.25% clay deposits and 1.25% organic manure added at 25 cm depth). An additional 12 control treatments (without amendment) were also included. The physical and chemical characteristics of clay deposits used were described previously by Al-Omran et al. (2005). The used main lines' tubing (16 mm in diameter with emitters built in at 50 cm spacing with 2, 4, and 6 L h^{-1} discharge rates) was placed at 25 cm depth in the subsurface system. Furthermore, gauges were installed for measuring the amount of water applied for each treatment as shown in Figure 1.

The experimental layout was a split-split plot in randomized complete block design with 3 replications. Water quality treatments were allocated to the main plots, irrigation system treatments were arranged in the sub-plots, and irrigation rates and amendment type treatments (9 treatments) were allocated to the sub-sub plots. A drip irrigation network was designed for this study, and the 60-m-long × 12-m-wide field plot was divided into 4 equal plots (7 × 4 m^2) with a buffer strip of 2 m left in the middle (Figure 1).

Tomato seeds (Tanshet Crystal cv.) were sown in a nursery on 1 September 2005. One-month-old seedlings were transplanted in the field for the first season. For the second season the seeds were sown in a greenhouse on 4 September 2006 and transplanted on 5 October 2006. Nitrogen as urea (46%, N), potassium as potassium sulfate (48%, K_2O), and micro nutrients were weekly applied with the irrigation water at recommended doses, which were 300 kg urea and 150 kg potassium sulfate. Surface drip irrigation was applied to all treatments for 1 week to establish the plants and to avoid any accumulation of salt affecting growth early. The irrigation treatments were applied for all the treatments by providing the irrigation water through the irrigation network, but different irrigation rates were obtained by using different emitter rates. Data collected in the experiment were applied to water for each treatment, total ripe fruit yield, root distribution, soil salinity, and

Table 1. Metrological data of the experimental site.

Month Year	Average Air Temperature °C	Maximum Relative Humidity %	Total Rainfall mm	Solar Radiation 10^4 W^{-2}	Wind Speed m s^{-1}	ET0 mm day^{-1}
September 2005	31.69	38.33	0	38.24	5.30	6.31
October 2005	24.94	54.32	0	34.01	4.49	4.72
November 2005	21.79	69.88	4.57	27.55	3.71	2.98
December 2005	16.00	73.47	0	24.94	3.73	2.77
January 2006	14.65	68.85	0.5	24.40	4.69	2.72
February 2006	18.05	67.28	0.29	27.65	4.95	3.53
March 2006	21.04	53.97	0	35.26	5.11	4.73
April 2006	26.15	59.41	2.52	35.95	5.35	5.43
September 2006	30.77	37.64	0	37.89	4.95	6.20
October 2006	27.8	45.18	0	33.01	4.96	4.97
November 2006	20.1	69.93	7.88	24.10	4.31	3.07
December 2006	12.69	79.99	9.9	22.68	4.33	2.23
January 2007	11.84	76.37	15.99	24.41	4.33	2.41
February 2007	17.94	71.71	12.96	30.58	4.65	3.52
March 2007	22.11	52.88	0	35.99	5.17	4.84
April 2007	27.71	52.5	2.53	38.13	7.70	6.07

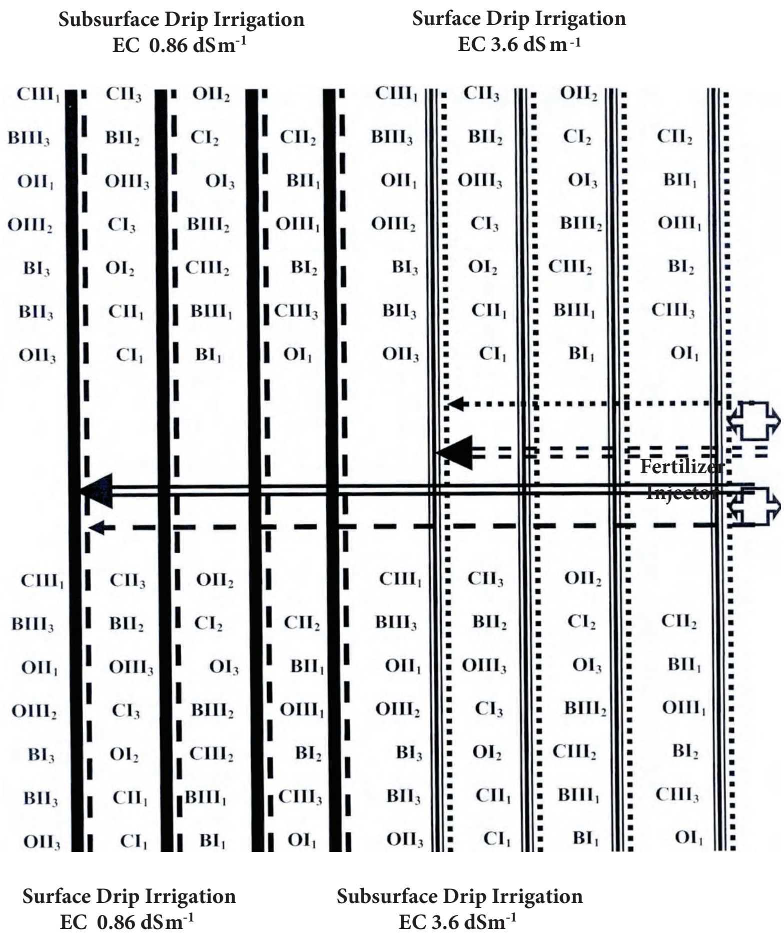

Figure 1. Field experiment layout for each block.
C = Control, B = Clay Deposits, O = Organic Matter, I = Irrigation Rates 2 L h^{-1}, II = Irrigation Rates 4 L h^{-1}, III = Irrigation Rates 6 L h^{-1}, number 1,2,3 = Replicates.

soil water content during seasons. Sampling locations for both soil water content and soil salinity were 0.25 m from the plant at the soil surface and 0.15 m depth intervals down to 0.60 m depth. The electric conductivity of saturation extract (ECe, dS m^{-1}) was determined for each sample then contour maps for water and salt distributions in the root zone area were introduced using Surfer Software (Golden Software, 2000). Root distribution was determined using a digital camera. Soil water content was determined by the gravimetric method.

Water-use efficiency (WUE) was calculated according to the following formula as reported in Kirda et al. (2004):

WUE (kg m^{-3}) = Gross fruit yield (kg ha^{-1}) / applied water (m^3 ha^{-1})

Before starting the experiment, a composite soil sample was taken from surface and subsurface layers from the study area for analysis. Some physical and chemical characteristics of soil samples and irrigation water are shown in Tables 2 and 3. Recommended methods as outlined in Kulte (1986) were used for analyzing the soil samples. A random representative sample of fruits, consisting of 5 tomatoes, was taken from each replication at middle harvesting time and the fruit thickness was measured. From the homogenized juice of the fruits, pH and TSS were recorded using a hand pH meter and refractometer.

Table 2. Some physical and chemical characteristics of experimental soil.

Parameters	Soil depth, cm			
	0-15	15-30	30-50	50-70
Particle–size distribution, %				
Sand	93.0	89.0	89.0	89.0
Silt	1.0	6.0	4.0	6.0
Clay	6.0	5.0	7.0	5.0
Textural Class	sand	sand	sand	sand
Organic matter content, %	0.03	0.13	0.16	0.02
$CaCO_3$, %	32.0	27.0	24.0	30.0
Saturation water content, %(w/w)	27.2	28.3	29.3	29.8
Field capacity, %(w/w)	14.8	16.4	17.1	16.8
Permanent wilting point, %(w/w)	6.4	7.2	6.7	6.3
Plant available water, %(w/w)	8.4	9.2	10.4	10.5
pH	7.51	7.72	7.92	8.05
Electrical conductivity (EC_e dS m^{-1})	2.75	2.65	2.00	1.80
Soluble Cations, me L^{-1}				
Ca^{2+}	16.4	11.1	11.1	9.1
Mg^{2+}	6.0	6.7	5.6	5.0
Na^{+}	11.0	14.4	6.5	6.4
K^{+}	1.5	2.1	1.7	1.5
Soluble Anions, me L^{-1}				
$CO_3^{=}$	Tr.	Tr.	Tr.	Tr.
HCO_3^{-}	3.9	4.0	2.0	4.0
Cl^{-}	9.8	10.5	7.0	5.0
$SO_4^{=}$	12.8	13.9	10.9	8.7
SAR	3.29	4.83	2.18	2.41

At the end of growing seasons, tomato growth parameters such as plant weight, shoot system weight, root system weight, weight of tomato fruits per plant and the weight of 10 cm segments of root system were recorded and the gross yield was calculated. Total fruit yield for each replicate was recorded to calculate the gross yield (t ha^{-1}). The distribution of root system was calculated for each treatment by digging a soil block of 50 cm × 50 cm × 70 cm and excavating the soil around the plant; then the plant was picked and the adhesive soil was removed. The root system was weighed and the root density system was calculated for each plant according to Machado and Oliveria (2003).

Results

Yield and WUE

The data in Table 4 show that there were significant effects of the studied factors (10 different treatments; 2 water quality, 2 irrigation systems, 3 irrigation rates, and 3 amendment types) with the exception of amendment type during the 2 growing seasons. The results show that subsurface drip irrigation system, high irrigation rate, and fresh water improved tomato yield and WUE. The results are further elaborated in order to evaluate the effect of each treatment on the yield and WUE of the studied factors. There were significant decreases in the tomato

Table 3. Chemical analysis of the 2 sources of irrigation water.

Parameters	Well water	Fresh water
pH	7.45	6.05
Electric conductivity (dS m^{-1})	3.60	0.86
Sodium Adsorption Ratio (SAR)	4.33	7.7
Soluble Cations, me L^{-1}		
Ca^{2+}	12.11	1.30
Mg^{2+}	10.83	0.36
Na^{+}	16.69	7.00
K^{+}	0.50	0.17
Soluble Anions (mg L^{-1})		
CO_3^{-}	Tr.	Tr.
HCO_3^{-}	4.00	1.00
Cl^{-}	14.76	4.80
SO_4^{-}	2.80	5.40
NO_3^{-}	44.34	14.28

yield in the second season compared to that in the first season. However, the trend of the influence of the studied factors was similar in the 2 seasons.

The results indicate that the tomato yield was higher at a high irrigation rate (6 L h^{-1}), but decreased significantly at a low irrigation rate (2 L h^{-1}) in both seasons. The average yield of the first and second seasons increased to about 38.7% and 46% with the increasing irrigation rate from low to high, respectively. With a medium irrigation rate (4 L h^{-1}) the yield increased by 25% and 39% for the first and second seasons, respectively. In contrast, WUE decreased with the increasing irrigation rate. It decreased to about 115% and 105% for the first and second seasons, respectively, with the increasing irrigation rate from 6 L h^{-1} to 2 L h^{-1}. Moreover, it decreased to about 61% for the first season and about 42% for the second season with the medium irrigation rate. The results also showed that using saline water significantly reduced the tomato yield and WUE

Table 4. Effect of amendment, irrigation system, irrigation level and water quality on tomato yield and water use efficiency (WUE).

Treatment	Yield (t ha^{-1})		WUE (kg m^{-3})	
	First Season	Second Season	First Season	Second Season
Amendment Type				
Control	61.0	28.2	17.01	8.75
Clay Deposits	62.8	27.6	17.01	8.3
Organic Matter	58.3	27.1	17.0	9.4
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.
Irrigation System				
Surface Drip	55.8 b	23.9 b	15.6 b	7.9 b
Subsurface Drip	65.6 a	31.8 a	18.6 a	9.7 a
$LSD_{0.05}$	3.7	2.7	1.7	0.9
Irrigation Level				
2 L h^{-1}	50.1 c	21.7 b	24.6 a	12.1 a
4 L h^{-1}	62.5 b	30.2 a	15.3 b	8.5 b
6 L h^{-1}	69.5 A	31.7 A	11.4 c	5.9 c
$LSD_{0.05}$	4.6	3.3	0.8	1.2
Water Quality				
Fresh Water	75.0 a	30.6 a	21.3 a	9.7 a
Saline Water	45.6 b	25.2 b	12.8 b	7.9 b
$LSD_{0.05}$	7.8	2.8	1.7	1.0

Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD test at 0.05 level.

compared to fresh water. The decrease in the yield was 39.2% and 17.6% for the first and second seasons, respectively. A similar trend was found with WUE; it decreased to 40% and 18.5% for the first and second seasons, respectively.

The results are further elaborated in order to evaluate the effect of each parameter tested with fresh and saline water on the yield and WUE (16 treatments represent the combination of the 2 water quality and the other 8 treatments: 2 irrigation systems, 3 irrigation rates, and 3 amendment types). The data in Table 5 show that using fresh water the amendment type affected both the yield and WUE in both seasons. When sand was amended with clay deposit and irrigated with fresh water, fruit yields increased by 11.7% and 15% compared to the control treatment for the first and second seasons, respectively. Amended with organic matter and irrigated with saline water, sand has a higher yield in both seasons. A similar trend was found with WUE. Differences in the tomato yield and WUE due to the irrigation system, i.e. surface and subsurface drip irrigation, were significant in both seasons. Subsurface irrigation increased the yield by about 18.6% and 41% over the surface drip irrigation in the first and second seasons, respectively. Furthermore, subsurface irrigation increased WUE by 24.7% and 33.7% compared to surface drip irrigation for the first and second seasons, respectively. Subsurface irrigation system using both fresh and saline water increased the yield compared to surface irrigation. The increase of irrigation rate significantly increased the yield in the case of using fresh water, but made no significant difference in the yield between 4 and 6 L h^{-1} using saline water (Table 5).

Fruit quality

The results presented in Table 6 illustrated that effects of amendment type, irrigation system, and irrigation level on average fruit weight, pH, total

Table 5. Effect of amendment, irrigation system, and irrigation level on tomato yield and water use efficiency (WUE) under the 2 water qualities.

Treatment	Yield (t ha^{-1})				WUE (kg m^{-3})			
	First Season		Second Season		First Season		Second Season	
	Fresh Water	Saline Water	Fresh Water	Saline Water	Fresh Water	Saline Water	Fresh Water	Saline Water
Amendment Type								
Control	75.3 b	46.2ab	29.7 b	26.6ab	20.8 b	13.1ab	9.0	8.5 ab
Clay Deposits	84.1 a	41.2 b	34.2 a	21.0 b	23.1 a	11.0 b	10.4	6.3 b
Organic Matter	67.0 c	49.1 a	27.9 c	27.9ab	20.2 b	14.2 a	9.7	9.0 ab
$LSD_{0.05}$	3.9	6.0	4.2	3.5	1.55	1.7	n.s.	1.2
irrigation system								
Surface Drip	69.2 b	42.0 b	25.4 b	22.4 b	19.0 b	12.2	8.3 b	7.5
Subsurface Drip	82.1 a	49.0 a	35.8 a	27.9 a	23.7 a	13.4	11.1 a	8.4
$LSD_{0.05}$	3.2	4.9	3.4	2.8	1.3	n.s.	1.5	n.s.
irrigation level								
2 L h^{-1}	63.7 c	35.8 b	24.7 c	18.7 b	31.4 a	17.7 a	13.8 a	10.4 a
4 L h^{-1}	74.0 b	51.0 a	30.8 b	29.7 a	18.3 b	12.5 b	8.6 b	8.3 b
6 L h^{-1}	89.3 a	49.7 a	36.3 a	27.1 a	14.6 c	8.1 c	6.7 c	5.1 c
$LSD_{0.05}$	3.9	6.0	4.2	3.5	1.55	1.7	1.79	1.2

Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD test at 0.05 level

Table 6. Effect of amendment, irrigation system, irrigation level, and water quality on average fruit weight, pH, TSS, and fruit thickness of tomato plants.

Treatment	Average fruit weight (g)		Fruit juice (%)		TSS (%)		Fruit thickness (mm)	
	First Season	Second Season	First Season	Second Season	First Season	Second Season	First Season	Second Season
Amendment Type								
Control	86.7	84.2	5.54 b	5.56b	6.45	6.80	0.74	0.80
Clay Deposits	82.5	83.6	5.62 ab	5.58b	6.06	6.18	0.71	0.78
Organic Matter	85.0	89.1	5.71 a	5.79a	6.11	6.61	0.71	0.77
$LSD_{0.05}$	n.s.	n.s.	0.13	0.16	n.s.	n.s.	n.s.	n.s.
Irrigation System								
Surface Drip	79.3 b	81.1 b	5.57	5.61	6.1	6.0	0.73	0.81
Subsurface Drip	90.2 a	91.6 a	5.68	5.82	6.2	6.4	0.71	0.75
$LSD_{0.05}$	10.4	8.3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Irrigation Level								
2 L h^{-1}	79.8	78.2	5.73	5.60	5.97	6.08	0.70	0.82
4 L h^{-1}	88.0	90.2	5.56	5.68	6.25	6.33	0.73	0.80
6 L h^{-1}	86.4	88.9	5.59	5.71	6.40	6.60	0.74	0.79
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Water Quality								
Fresh Water	123.1a	120.2a	5.55 b	5.60 b	7.3 a	7.1 a	0.83 a	0.90 a
Saline Water	46.4 b	54.6 b	5.70 a	5.80 a	5.0 b	5.2 b	0.62 b	0.69 b
$LSD_{0.05}$	10.4	8.3	0.13	0.16	0.3	0.4	0.04	0.06

Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD test at 0.05 level

soluble solid (TSS), and fruit thickness of tomato plants were not significant, except for pH trait, which was high with organic matter, and for average fruit weight, which was high with subsurface irrigation. On the other hand, irrigation with saline water significantly increased fruit pH, and significantly decreased the other 3 traits. The influence of salinity was more obvious on average fruit weight than on the other 2 traits and the reduction was more than 50% in both seasons.

Water content and salt distributions

The data of soil water content and salt distributions in the root zone area for the 2 seasons and at different times during the growth period for all the treatments are graphically illustrated on a surface contour base and the data of selected treatments are presented in Figures 2 and 3, respectively. Figure 2 shows that soil water content has specific distribution patterns in amended soil when compared with the control soil in both high and low irrigation rate. In soil treated with clay deposit, soil water contents at a depth of 15-20 cm, amended subsurface layer, were generally higher (16% and 12.5% for high and low irrigation rate, respectively) compared with organic or control treatments. In all the treatments, soil water contents were generally low in the surface and increased gradually with depth.

Soluble salt distribution (ECe, dS m^{-1}) in the root zone area showed an adverse trend when compared with soil water distribution, i.e high salt accumulation on the surface and decreased gradually with the depth for all treatments. Amended soil with clay deposit indicated a higher salt accumulation on the surface (Figure 3).

The data of salt distribution in the root zone at different times of growth for all treatments are graphically illustrated and data of selected treatments are given in Figure 4. The figures show that soil

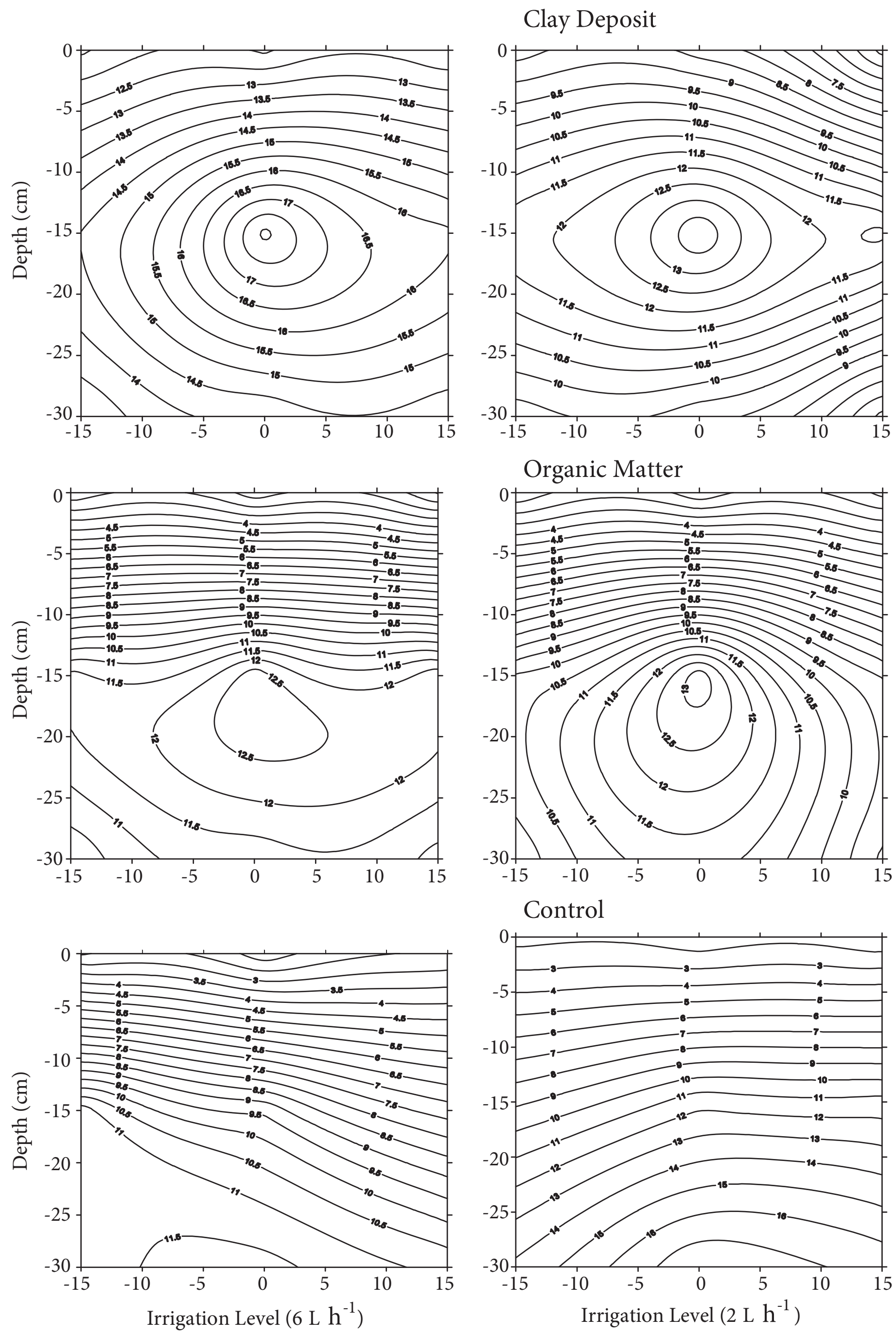

Figure 2. Water content distribution in root zone area for different types of amendments at high and low application irrigation rates for subsurface drip irrigation.

salinity increases with time and with the saline irrigation treatment. Soil salinity was high on the surface and decreased gradually with depth to the lowest values at 45 cm depth. As expected, using saline water increased the salt accumulation in the surface to about 15 dS m^{-1} compared to 5 dS m^{-1} for fresh water treatments.

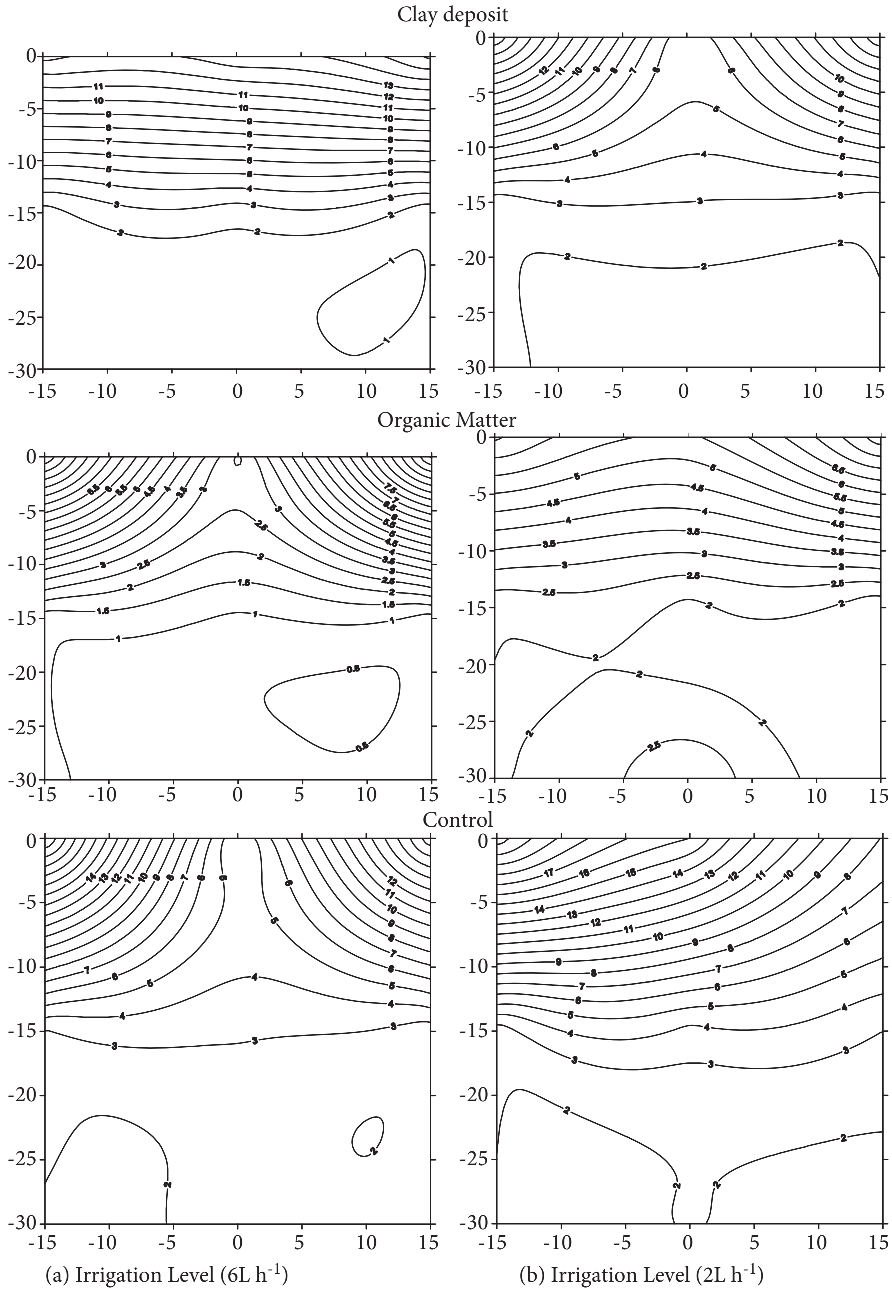

Figure 3. Salt distribution in the root zone area at different types of amendments at a high application rate (a) and a low application rate (b).

Root distribution

The data of root distributions in the root zone area for the 2 seasons and at different times during the growth for all the treatments are graphically illustrated on a surface contour base and the data of selected treatments are given in Figure 5. The data showed that clay deposit treatment had the highest root density compared with the organic matter or control treatments. Moreover, fresh water treatment seems to enhance root growth and distribution especially in the subsurface treated layer, which has higher soil water content.

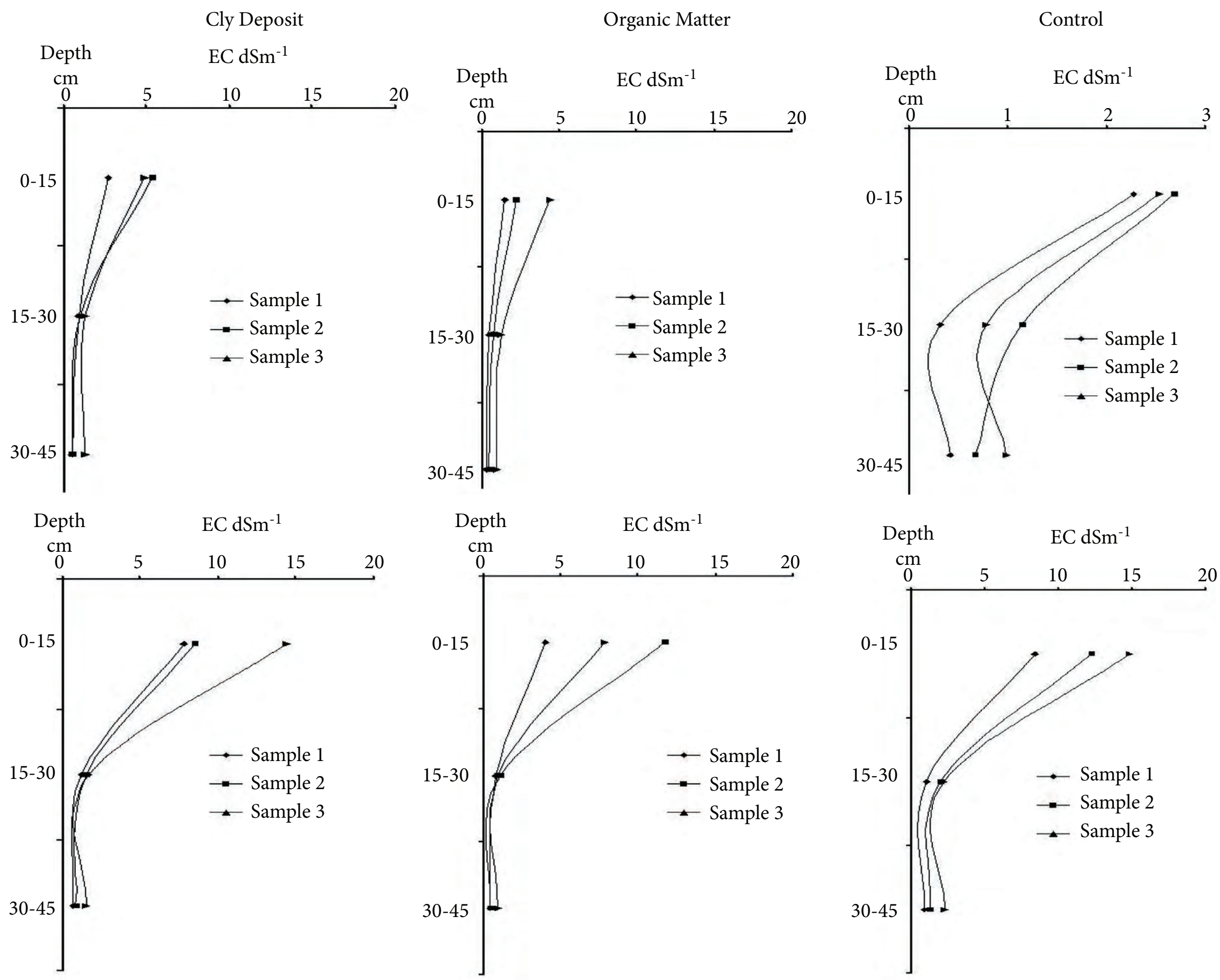

Figure 4. Salt distribution as a function of soil depth at different times of growth with saline water (a) and fresh water (b) at high application rates.

Discussion

Yield and WUE

The drastic reduction in yield and WUE in the second season was a result of a very cold condition during the winter season in the second season as the temperature reached zero on several nights in December and January 2006 (Table 1), in addition to the effect of salt accumulation in the field.

The reduction in the yield and the increase in WUE at the low irrigation rate could be due to both the unavailability of water and the possible accumulation of salts in the root zone areas as a result of using saline irrigation water without proper leaching in the open field experiment. The water quality significantly affects the yield and WUE. The huge decrease in both the yield and WUE in both seasons was the result of using high saline irrigation water without proper leaching.

Clay deposit increased the yield and WUE for the 2 seasons. The increase in the yield could be due to the improvement of sandy soil characteristics, particularly the available water content and nutrient status as reported in other studies (Al-Omran et al. 2004, 2005; Sheta et al. 2006). Differences in the tomato yield and WUE due to the irrigation system were significant in the first and second seasons. The

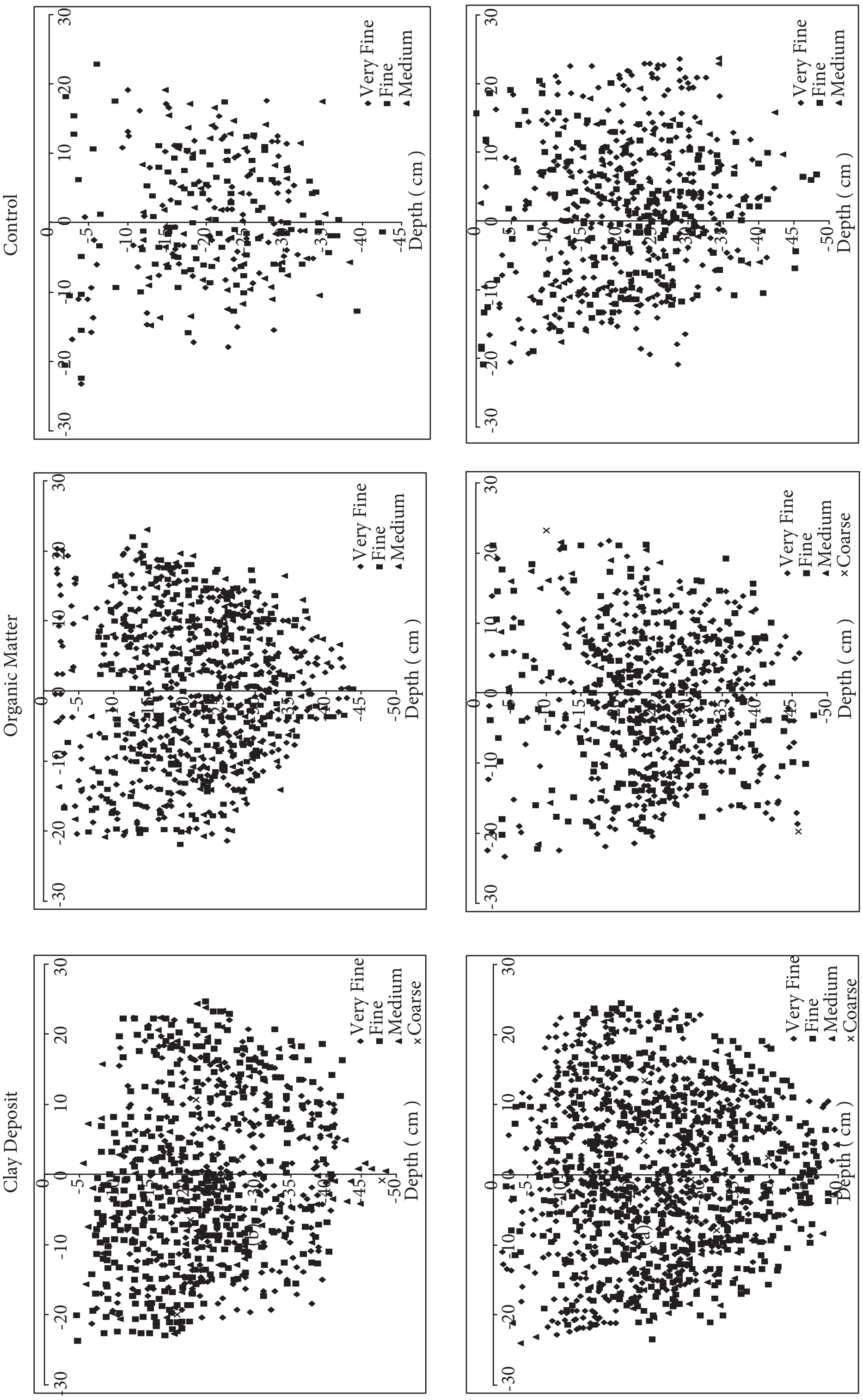

Figure 5. Root distribution as a function of soil depth at a high application rate (a) and a low application rate (b).

advantages of subsurface drip irrigation might be due to the creation of more suitable conditions in the root zone area by the subsurface drip irrigation compared to surface drip irrigation. These results are in agreement with the results reported by (Lamm and Trooien 2003; Al-Omran et al. 2005). Lower yield with the clay deposit treatment using saline water may be due to the accumulation of salts in the root zone. Such decrease in the yield using saline irrigation could be due to the characteristics of the treated soil with clay deposit, particularly higher water content and thus higher salt accumulation without proper leaching. The reduction in the yield supports the suggestion of Cuartero and Fernandez-Munoz (1999) that even under normal growing conditions the EC of the root solution is close to the threshold for yield reduction. The effect of salinity in the yield becomes more obvious as the salinity levels increased; about 50% yield reduction occurs under saline regime of 8 dS m^{-1} (Subbarao and Johansen 1994).

Fruit quality

The influence of salinity was more obvious on the average fruit weight than on the other 2 traits and the reduction was more than 50% in both seasons. Van-Ieppren (1996) reported a significant reduction in the average fruit weight even when low levels of salinity were applied for the whole experimental period. These results are in general agreement with the finding reported by Olympios (2003). The effect of salinity in the yield becomes more marked as the harvest period progresses, due initially to a restriction in fruit size during the first 4 weeks of the harvest, but later to a decrease in fruit number (Adams and Ho 1989; Cuartero and Fernandez-Munnza 1999). Sanders et al. (1989) reported that fruit pH decreased as irrigation rates increased. In contrast, Machado et al. (2003) reported that fruit pH was not affected by the irrigation rate. Irrigation with saline water significantly decreased TSS traits. Stress-specific responses determine fruit quality to a larger extent, which could even result in a more variable response due to different sensitivity levels and defense strategies of cultivars. Keutgen and Pawelizik (2007) reported that 2 cultivars of strawberry varied significantly in their response to salt stress. In fruit of cv. Korona (less salt sensitive) TSS did not change under NaCl salinity while, in cv. Elsanta (salt sensitive) a considerable decrease of more than 40% was detected. The present results are in contrast to those published by Machado et al. (2003) and Yurtseven et al. (2005), who reported a significant increase in TSS in response to salt treatments. The differences between the present results and those reported by Machado et al. (2003) and Yurtseven et al. (2005) are due to the differences in cultivars' response to salinity level.

Water content distribution

Soil water contents were generally low in the surface and increased gradually with depth. This trend could be due to water evaporation from the surface and hence decreased soil water content in the surface layer. Similarly, Malash et al. (2008) reported that soil moisture was at a minimum in the root zone (20-40 cm layer), but showed a gradual increase at 40-60 and 60-90 cm and was stable at 90-120 cm depth. They also reported that soil water content decreased gradually as the distance from the irrigation water source increased. The highest irrigation rate showed relatively high soil water content along with the soil profile and it was more pronounced in the clay deposit treatment. It is clear that water seems to be stored in an amended layer with little seepage below 30 cm depth. It might be concluded that application of clay deposits in sandy soils modifies the distribution of soil water content in the root zone area where water could be retained by clay deposits applied in the subsurface layer.

Salt and root distributions

Salt accumulation was lower in the amended layer with clay deposits compared to the control treatment. It appears that salt accumulation is reversibly related to soil water content distribution. Therefore, irrigation, increasing soil water content in the clay deposit amended layer counters the harmful effect of salt accumulation.

The distribution of root growth was clearly related to the subsurface application of clay deposits. Therefore, the clay deposit amendments for subsurface sandy soils using good irrigation water show quite valuable effects in storing irrigation water and then enhance the root growth and the yield. The result indicated that fresh water treatment enhances root growth and distribution, especially in the subsurface treated layer, which has higher soil water content. Similar results have been reported previously (Bar-Yosef et al. 1980; Oliveira et al. 1996; Machado et al. 2003). They reported that root growth occurs preferentially in the 0-40 cm soil layer and the increase in the quantity of water applied led to greater root development in the top 30 cm of the soil. However, Sanders et al. (1989) observed contrasting results in a trial in which 0.35, 0.70 and 1.05 of ET were applied, the root density being the highest in the first 30 cm of soil where the lowest water regime was applied.

Conclusion

The study showed that subsurface drip irrigation increased the yield and WUE of the tomato crop and resulted in the saving of applied irrigation water by creating a good moisture distribution in the root zone depth. At a high irrigation rate (6 L h^{-1}), tomato yields were higher and decreased significantly at a low irrigation rate (2 L h^{-1}). It can also be concluded that using saline water salinity (3.6 dS m^{-1}) for irrigation reduced the average tomato yield by 20%-40% compared with good water quality (0.86 dS m^{-1}). Addition of clay deposits to sandy soils improves soil water content in the root zone area where water could be retained by clay deposits applied in the subsurface layer. Using saline water increased the salt accumulation in the surface to about 15 dS m^{-1} compared to 5 dSm^{-1} for fresh water treatment. The clay deposit amendments for subsurface sandy soils using good irrigation water show quite valuable effects in storing irrigation water and then enhance the root growth and the yield.

Acknowledgements

The authors are thankful to King Abdul Aziz City for Science and Technology (KACST) for funding part of this research through project # AR-24-47.

The authors also wish to express their deep thanks and gratitude to "Shaikh Mohammad Alamoudi Chair for Water Research" http://awc.ksu.edu.sa at King Saud University, http://www.ksu.edu.sa, who kindly participated in sponsoring this work.

References

Abdelgawad G, Arslan A, Gaihbe A and Kadouri F (2005) The effect of saline irrigation water management and salt tolerant tomato varieties on sustainable production of tomato in Syria (1999-2002). Agric Water Manage 73: 39-53.

Adams P and Ho LC (1989) Effects of constant and fluctuating salinity on the yield quality and calcium status of tomatoes. J Hort Sci 64: 725-732.

Al-Omran AM, El-Damry S, Nadeem M and Al-Eter A (2008) Impact of irrigation regime and emitter depth on tomato growth and yield. King Saud J Agric Science (accepted).

Al-Omran AM, Choudahry MI, Shalaby AA and Mursi MM (2002) Impact of nature clay deposits on water movement in calcareous sandy soil. Arid Land Res Manage 16: 185-193.

Al-Omran AM, Falatah AM, Sheta AS and Al-Harbi AR (2004) Clay deposits for water management of sandy soils. Arid Land Res. Manage 18: 171-183.

Al-Omran AM, Sheta AS, Falatah AM and Al-Harbi AR (2005) Effect of drip irrigation on squash (*Cucurbita pepo*) yield and water-use efficiency in sandy calcareous soils amended with clay deposits. Agric Water Manage 73: 43-55.

Al-Rashed MF and Sherif MM (2000) Water resources in the GCC countries: overview. Water Resources Manage 14: 59-75.

Ayars JE, Phene CJ, Hutmacher RB, Davis KR, Schoneman RA, Vail SS and Mead RM (1999) Subsurface drip irrigation of row crops: a review of 15 years of research at the Water Management Research Laboratory. Agric Water Manage 42: 1-27.

Bar-Yosef B, Stammers C and Sagiv B (1980) Growth of trickle-irrigated tomato as related to rooting volume and uptake of N and water. Agron J 72: 815-822.

Bauder TA, Cardon GE, Waskam RM and Davis JG (2004) Irrigation water quality. Calorado State University. Cooperative Extension Agriculture 506.

Cuartero J and Fernandez-Munoz R (1999) Tomato and salinity. Scientia Horticulturae 78: 83-125.

Ertek A, Sensoy S, Ildis M and Kabay T (2002) Estimation of the most suitable irrigation frequencies and quantities in eggplant grown in greenhouse condition by using pan evaporation coefficient. KS Univ Life Sci Eng J 5: 57-67 (in Turkish).

Golden Software. 2000. Contouring and 3D surface mapping for scientists and engineers version 7. Golden Software, Inc. www.goldensoftware.com

Keutgen A and Pawelizik E (2007) Modifications of taste-relevant compounds in strawberry fruit under NaCl salinity. Food Chemistry 105: 1487-1494.

Kirda C, Cetin M, Dasgan Y, Topcu S, Kaman H, Ekici B, Derici MR and Ozguven AI (2004) Yield response of greenhouse-grown tomato to partial root drying and conventional deficit irrigation. Agric Water Manage 69: 191-201.

Kulte A (1986) Methods of soil analysis. Part 1. Physical and mineralogical methods. 2nd ed. Agronomy No. 9 American Society of Agronomy, Madison, WI.

Lamm FR and Trooien TP (2003) Subsurface drip irrigation for corn productivity: a review of 10 years of research in Kansas. Irrig Sci 22: 195-200.

Machado RMA, Rosario M, Oliveira G and Portas CAM (2003) Tomato root distribution, yield and fruit quality under subsurface drip irrigation. Plant and Soil 255: 333-341.

Machado RMA and Oliveira G (2003) Comparison of tomato root distributions by minirhizotron and destructive sampling. Plant and Soil 255: 375-385.

Maas EV (1986) Salt tolerance of plants. Applied Agriculture Research 1: 12-26.

Malash NM, Flowers TJ and Ragab R (2005) Effect of irrigation system and water management practices using saline and non-saline water on tomato production. Agric Water Manage 78: 25-38.

Malash NM, Flowers TJ and Ragab R (2008) Effect of irrigation methods, management and salinity of irrigation water on tomato yield, soil moisture and salinity distribution. Irrig Sci 26: 313-323.

Oliveira MRG, Calado AM and Portas CAM (1996) Tomato root distribution under drip irrigation. J Am Soc Hort Sci 121: 644-648.

Olympios CM, Karapanos IC, Lionoudakis K and Apidianakis I (2003) The growth, yield and quality of greenhouse tomato in relation to salinity applied at different stages of plant growth. Acta Hort 609.

Onest A, Demir K, Cakmak B and Kendirili B (1995) Drip Irrigation Scheduling in Head Lettuce Grown in Greenhouse Condition (In Turkish). 5. Ulusal Kulturteknik Kongresi Bildirileri, Kemer-Antalya, p.208

Phene CJ, Davis KR, Hutmacher RB and McCormick RL (1987) Advantages of subsurface drip irrigation for processing tomatoes. Acta Hort 200: 101-113.

Reina-Sanchez A, Romero-Aranda R and Cuartero J (2005) Plant water uptake and water use efficiency of greenhouse tomato cultivars irrigated with saline water. Agric Water Manage 78: 54-66.

Sanders DC, Howell TA, Hile MMS, Hodges L, Meek D and Phene CJ (1989) Yield and quality of processing tomatoes in response to irrigation rate and schedule. J Am Soc Hort Sci 114: 904-908.

Shalhevet J (1994) Using water of marginal quality for crop production: major issues. Agric Water Manage 25: 233-269.

Sheta AS, Al-Omran AM, Falatah AM and Al-Harbi AR (2006) Effect of clay deposit, physiochemical and intermittent evaporation characteristics of Torripsamment. Arid Land Research and Manage 20: 295-307.

Subbarao GV and Johansen C (1994) Strategies and scope for improving salinity tolerance in crop plants. In: Pessarakli, M. (Ed.), Handbook of Plant Crop Stress. Marcel Dekker Inc., New York, pp 559-579.

Van-Ieperen W (1996) Effects of different day and night salinity levels on vegetative growth, yield and quality of tomato. J Hort Sci 71: 99-111.

Wan S, Kang Y, Wang D, Liu SH and Feng L (2007) Effect of drip irrigation with saline water on tomato (*Lycopersicon esculentum*) yield and water use in semi-humid area. Agric Water Manage 90: 63-74.

Yurtseven E, Kesmez GD and Unlukara A (2005) The effects of water salinity and potassium levels on yield, fruit quality and water consumption of native center anatolian tomato species (Lycopersicon esculentum). Agric Water Manage 78: 128-135.