

Management of Irrigation Water Salinity in Greenhouse Tomato Production under Calcareous Sandy Soil and Drip Irrigation

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ABSTARCT

A greenhouse experiment was conducted during the growing seasons (2008/2009 and 2009/2010) to investigate the effects of water quality and soil amendments, irrigation methods and rates on tomato (*Solanum lycopersicon* L. cv. Red Gold) yield and water use efficiency (WUE). Irrigation management treatments were fresh (0.86 dS m⁻¹) and saline waters (3.6 dS m⁻¹), surface and subsurface irrigation methods, 2, 4, and 6 L h⁻¹ irrigation rates applied at the same irrigation duration and interval, and clay deposit, organic matter, and control amendment treatments. The results showed that differences among treatments were highly significant ($P < 0.05$) for tomato yield and WUE. The interactions between water quality and the other three factors were highly significant ($P < 0.05$). Applying fresh water and clay deposit amendments in sandy soil under subsurface drip irrigation at 2 L h⁻¹ flow rate irrigation, water saving occurred due to improving soil water distribution in root zone. On the other hand, fresh application of saline water and clay deposit or organic matter amendments in sandy soil under subsurface drip irrigation method at 6 L h⁻¹ flow rate, reduced both high cost of water desalinization and deleterious effect of saline water. Therefore, this management practice is recommended for greenhouse tomato production.

Keywords: Amendment, Irrigation Methods, Irrigation Rate, Salinity, *Solanum lycopersicon* L., Water Use Efficiency.

INTRODUCTION

The scarcity of good quality water forces growers to use water with moderate or high salinity levels. The trend toward sustainable greenhouse production includes all agricultural practices that utilize available resources such as irrigation management of saline water. In addition to affecting crop yield and soil physical conditions, irrigation water quality can affect soil fertility and irrigation system performance. Therefore, knowledge of irrigation water quality is

critical in understanding the necessary management changes for long-term productivity (Bauder *et al.*, 2004). Most of the cultivated soils in Saudi Arabia are sandy, characterized by low water holding capacity, high infiltration rate, high evaporation, low fertility levels, and deep percolation losses that may induce low water use efficiency (Al-Omran *et al.*, 2004). Natural amendments could be used to improve the chemical and physical properties of these soils. The use of deposits may increase the productivity, especially in the areas where these materials are available

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naturally in abundance and they are inexpensive (Abou-Gabal *et al.*, 1990). Clay deposit materials and drip irrigation system have helped to alleviate some of these constraints in crop production with better water management strategies (Al-Omran *et al.*, 2008).

Tomato (*Solanum lycopersicon* L.) is one of the most widely grown vegetables in the world. Most commercial tomato cultivars are classified as moderately salt tolerant (Maas, 1986) and could act as a model crop for saline land recovery (Reina-Sanchez *et al.*, 2005). The daily water requirement for tomato in different growing systems varies from 0.89 to 2.31 L plant⁻¹ day⁻¹ (Tiwari, 2003). Drip irrigation applied with 75% of crop evapotranspiration (ET_c) was the optimum amount of irrigation for a humid tropical environment in order to maximize tomato yield (Harmanto *et al.*, 2005). Al-Omran *et al.* (2010) revealed in their field study on tomato that the water quality significantly affected both the yield and WUE. The use of low quality water resulted in 39.2% lower yields. Drip irrigation system will provide 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.*, 2008). Abdelgawad *et al.* (2005) reported that WUE was higher with drip irrigation over traditional methods in different tomato varieties.

The objective of this work was to investigate the effects of water quality and soil amendments, irrigation methods and rates on tomato yield and WUE under greenhouse conditions in sandy soils.

MATERIALS AND METHODS

Experimental Site

This study was conducted under greenhouse conditions at the Research and Agricultural Experimental Station of the College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia

during August to June of two growing seasons (2008/2009 and 2009/2010). Composite soil samples were taken from the surface and subsurface layers from the study area before starting the experiment, to be analyzed using the recommended methods as outlined in Klute (1986). The soil was non-saline (EC ranged from 1.8 to 2.75 dS m⁻¹) calcareous (CaCO₃ ranged from 24 to 32%), sandy in texture and had a pH ranging from 7.5 to 8.0. The fresh water had EC, pH and sodium adsorption ratio (SAR) of 0.86 dS m⁻¹, 6.05 and 4.33, respectively, while for the well water, these values were 3.6 dS m⁻¹, 7.45 and 7.7.

Experimental Treatments and Design

The irrigation management treatments were fresh (0.86 dS m⁻¹) and saline (3.6 dS m⁻¹) waters, surface and subsurface drip irrigation methods, three irrigation rates (2, 4, and 6 L h⁻¹ applied to represent deficit, adequate, surplus irrigation conditions) and three soil amendments (semectite clay deposit, organic matter, and without amendment). The experimental layout was split-split plot design with three replicates. Water quality treatments were allocated to the main plots, irrigation methods treatments were arranged in the sub-plots, while irrigation rates and amendment type treatments were allocated to the sub-sub plots. Drip irrigation network was designed for this study. The 60 m long×12 m wide experimental area was divided into four equal plots with a buffer strip of 2 m left in the middle.

The amendments were applied in each row as a subsurface thin layer at a depth of 25 cm and at rates of 1 and 2% of the soil. The physical and chemical characteristics of clay deposits are described in Al-Omran *et al.* (2005). To irrigate the crop, main lines tubing (16 mm in diameter with emitters built at 50 cm spacing with 2, 4, and 6 L h⁻¹ discharge rates) were placed at the depth of 25 cm in the subsurface system. Furthermore, flow meters and pressure

gauges were installed for measuring the amount of water applied for each treatment. The quantity of irrigation water supplied for adequate irrigation treatments (4 L h^{-1} irrigation rate) was scheduled based on reference evapotranspiration (ET_o) calculated by Penman Monteith equation (Allen *et al.*, 1998) using data from the meteorological station near the study area. ET_o was matched with crop coefficient values of tomato for plant growing stages and justified for greenhouse conditions only for 4 L h^{-1} treatments. As irrigation scheduled for 4 L h^{-1} treatments was determined, 2 and 6 L h^{-1} treatments were rated as a fraction from adequate irrigation treatment in which all treatments had the same irrigation duration and interval. All treatments in the experiments received irrigation water, provided through the irrigation network, but different irrigation rates were applied by using different emitter rates.

Tomato (*Solanum lycopersicon* L. cv.Red Gold) seeds were sown in nursery in early August 2008 and 2009 for first and second seasons, respectively. Thirty day old seedlings were transplanted into the soil in the controlled polyethylene greenhouse. The average temperature and relative air humidity inside the greenhouse were $24 \pm 1.5^\circ\text{C}$ and $75 \pm 2\%$ during growth stages, respectively. Fertilization and other cultural practices were applied as commonly recommended in commercial greenhouse tomato production. At the beginning of each season, surface drip irrigation with fresh water was applied to all treatments for 10 days to establish the plants and to avoid any accumulation of salts affecting growth.

Salinity, Water Content and Root Measurements

The soil samples were collected representing the plant rhizosphere by augering the soil 15 cm far from each plant sides with depth of 30 cm. Soil samples were taken at a distance of 10 cm in all

directions. The EC of saturation extract (EC_e) was determined for each sample, and then the contour maps for water and salinity distributions in the root zone were drawn using Surfer Software (Golden Software 2002). In order to determine the root distribution; photos were taken using a digital camera from the soil profile at the root zone with the dimensions of 50 cm from the plant at the three directions left, right and depth. Then, photographs were transferred as a background for the dimensions of the Surfer Software program and took the X and Y dimensions of the root as described by FAO (1977). Then, the X and Y dimensions were drawn using Microsoft Excel program. Soil water content was determined by gravimetric method. The distribution of root system was measured for each treatment by digging a soil block of $50 \times 50 \times 70$ cm and excavating the soil around the plant. Then the plant was picked and the soil around the roots was removed.

Yield and WUE

At the end of each growing season, total fruit yield for each treatment was recorded to calculate the gross yield (Mg ha^{-1}). WUE (kg m^{-3}) was calculated by dividing gross fruit yield (kg ha^{-1}) by water applied ($\text{m}^3 \text{ha}^{-1}$).

Statistical Analysis

Data were statistically analyzed using SAS software (version 8.1; SAS Institute, Cary, NC) software. Differences among means were tested using a revised LSD test at the 5% level.

RESULTS

Yield and WUE

Results of analysis of variance for tomato yield and WUE as affected by water quality, types of amendments, methods and rates of



irrigation showed that differences due to the four studied factors were highly significant for both tomato yield and *WUE*. The interactions between water quality and the other three factors were also highly significant, whereas the interactions between amendments type and irrigation methods or rates were not significant. The interactions between irrigation methods and irrigation rates and the other types of interactions were also not significant. These results reflect the positive effect of water quality, types of amendments, methods and rates of irrigation on tomato yield and *WUE*. It was noticed that the tested parameters for the first and second seasons were quite similar because plantations in the two seasons were carried out under the same conditions.

Saline water reduced tomato yield by 25 and 21%, compared with the fresh water treatment, for the first and second season, respectively. A similar trend was found with *WUE*; it decreased from 50.97 to 21.73 (58%) and from 50.10 to 22.58 (55%) kg m^{-3} for the first and second season, respectively (Table 1). Results indicated that amendment type significantly affected yield and *WUE* in both growing seasons. Clay deposit showed higher average yield and *WUE* followed by

organic matter and control, respectively. Clay deposit increased yield by 62% and *WUE* by 83% when compared with the control as the average of the two growing seasons. However, organic matter increased yield by 31% and *WUE* by 27%. The yield increased applying subsurface irrigation by 50.2% compared with surface drip irrigation, while; *WUE* was increased by 56.7 % applying subsurface compared to surface drip irrigation in both growing seasons. With respect to irrigation rates, results indicated that increasing irrigation rate from 2 L h^{-1} (deficit irrigation) to 4 L h^{-1} (adequate irrigation) significantly increased total yield in both growing seasons (by 16.5%). However, no significant difference between 4 L h^{-1} and 6 L h^{-1} (adequate and surplus irrigations) was observed. In contrast, *WUE* decreased as irrigation rate increased. It decreased from about 56 to 32 (43%) and to 21 (63%) kg m^{-3} as irrigation rates increased from 2 to 4 and to 6 L h^{-1} , respectively as the average of the two growing seasons (Table 1).

The results are further elaborated in order to evaluate the effect of irrigation quality, methods, and rates and soil amendment on yield and *WUE* as shown in Table 2. The

Table 1. Effect of water quality, type of amendment, method and rate of irrigation on tomato yield and water *WUE* under greenhouse condition.

Treatment	Yield (Mg ha^{-1})		<i>WUE</i> (kg m^{-3})	
	First season	Second season	First season	Second season
Water Quality				
Fresh Water	135.2 a *	132.9 a	50.97 a	50.10 a
Saline Water	101.4 b	105.4 b	21.73 b	22.58 b
Amendment Type				
Control	89.5 c	91.2 c	26.46 c	26.80 c
Clay deposits	146.9 a	145.8 a	48.25 a	48.88 a
Organic matter	118.4 b	119.5 b	34.34 b	33.20 b
Irrigation methods				
Subsurface drip	142.0 a	143.0 a	44.36 a	44.67 a
Surface drip	94.6 b	95.0 b	28.34 b	28.46 b
Irrigation rates				
2 L h^{-1}	106.7 b	105.6 b	56.37 a	55.79 a
4 L h^{-1}	122.6 a	124.7 a	31.73 b	32.27 b
6 L h^{-1}	125.4 a	126.1 a	20.96 c	21.07 c

* Treatment means with the same letter are not significant using LSD Test at 5% level.

Table 2. Effects of water quality and type of amendment, method and rate of irrigation on tomato yield (Mg ha^{-1}) and WUE (kg m^{-3}) under greenhouse condition.

Treatment	Yield (Mg 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	99.0 d*	80.0 e	98.4 e	83.9 f	34.7 c	18.18 e	34.53 c	19.07 e
Clay deposits	175.1 a	118.8 c	168.8 a	122.9 c	72.8 a	23.71 d	70.18 a	27.69 d
Organic matter	131.6 b	105.2 d	131.4 b	107.5 d	45.4 b	23.30 d	45.32 b	21.06 e
Irrigation methods								
Subsurface drip	175.9 a	108.1 b	171.9 a	114.0 b	66.4 a	22.3 c	64.89 a	23.5 c
Surface drip	94.5 c	94.6 c	93.8 c	95.5 c	35.5 b	21.1 c	35.29 b	21.3 c
Irrigation rates								
2L h^{-1}	133.9 b	79.55 e	130.8 b	80.5 e	82.5 a	30.2 c	80.5 a	30.6 c
4L h^{-1}	142.8 a	102.5 d	143.5 a	105.9 d	43.9 b	19.5 d	44.2 b	20.1 d
6L h^{-1}	128.9 b	122.0 c	124.3 c	127.9 c	26.4 c	15.5 e	25.5 c	16.2 d

*Treatment means with the same letter are not significant using LSD Test at the $P \leq 0.05$ level.

results showed that clay deposit amendment combined with fresh water had the highest values for both yield and WUE followed by organic matter combined with fresh water for both growing seasons. When fresh irrigation water was used, clay deposit increased the yield by 75% (from 98.7 to 172 Mg ha^{-1}) and WUE by 107% (from 34.6 to 71.5 kg m^{-3}) when compared with the control as the average of the two growing seasons. However, when irrigation with saline water was used, clay deposit increased yield only by 48% (from 82 to 121 Mg ha^{-1}) and WUE by only 39% (from 18.6 to 25.7 kg m^{-3}). On the other hand, organic matter amendment increased yield by 34% (from 98.7 to 131.5 Mg ha^{-1}) and by 30% (from 82 to 106 Mg ha^{-1}) under irrigation with fresh and saline waters, respectively, as the average of the two growing seasons. Subsurface drip irrigation combined with fresh water had the higher values for both average yield and WUE for both growing seasons. The positive effect for subsurface methods on yield and WUE was more obvious with fresh water, while there was approximately no effect with saline water. Yield increased due to subsurface irrigation with fresh water by about 85% compared with the surface drip irrigation, while the increase due to subsurface irrigation with saline water was only 17%. Also, irrigation methods did not significantly affect WUE under saline water. The results clarified that with fresh water with increasing irrigation rate from 2 to 4 L h^{-1} total yield significantly increased by 7 and 10% for the first and second season, respectively. While no significant difference between 4 and 6 L h^{-1} was observed, saline water with increasing irrigation rate from 2 to 4 L h^{-1} significantly increased total yield by 29 and 32% for the first and second seasons, respectively. Increasing the irrigation rate from 4 to 6 L h^{-1} significantly increased total yield by 20 and 21% for the first and second season, respectively. The obtained results were in harmony with the trends obtained by Amer (2010) working on corn.



Soil Water Content, Salinity, and Root Distributions

Soil water content was highly obtained and distributed in amended soil when compared with the control in both surplus and deficit irrigations. Applying clay deposit, soil water content was well organized and increased (16 and 10% for 2 and 6 L h⁻¹, respectively) at a depth of 15-20 cm compared with organic or control treatments. Results showed that soil water content in distribution pattern decreased at the depth of 25 cm (site of dripper), increased gradually with decrease in depth until 15 cm, and gradually decreased up to the surface (with the lowest water content). The irrigation application of 6 L h⁻¹ increased soil water content in the soil profile and was highly achieved in the clay deposit treatment relative to other treatments as shown in Figure 1.

Soluble salt distribution (EC_e) in the root zone showed an inverse trend when compared with soil water content distribution (i.e. high salt accumulation on the surface and decreasing gradually with depth) for all treatments as shown in Figure 2. Soil without amendment showed a higher salt accumulation on the surface; however, soil amended with clay deposit showed a lower salt accumulation. The results showed that salt concentration was increased at 2 L h⁻¹ rate, consequently the salt concentrations increased in the rizosphere and dripper area. Soil salinity increased as time of growth and saline irrigation increased. Consequently, saline water increased salts in the soil surface layers to about 10 dS m⁻¹ compared to 8 dS m⁻¹ for fresh water treatments. The root density was decreased at surface layer down to a depth of 5 cm and increased gradually with increased in depth down to 25 cm. Clay deposit treatment had the highest root density compared with the organic matter or control treatments. Fresh water treatment enhanced root growth and distribution especially in the subsurface

treated layer, which had the highest soil water contents.

DISCUSSION

Yield and WUE

Results indicated that using saline water with EC of 3.6 dS m⁻¹ reduced tomato yield by 21- 25%, relative to that of fresh water. This result is in general agreement with the finding of Olympios *et al.* (2003) and Amer (2010). The cause of reduction of yield under salinity is a matter of controversy. It has been related either to salt-induced disturbance of water balance or to a loss of leaf turgor, which can reduce leaf expansion and consequently photosynthetic leaf area (Shannon and Grieve, 1999). Although the threshold value for tomato irrigation EC_w is 2.7 dS m⁻¹ (Cuartero and Fernandez-Munoz, 1999), the leaching of salts at the beginning of each season and the use of fresh water (EC= 0.86 dS m⁻¹) for 10 days before starting using the saline water (EC= 3.6 dS m⁻¹) was effective to have a marketable yield of 101.4 and 105.4 Mg ha⁻¹ compared with 135.2 and 132.9 Mg ha⁻¹ for the first and second season, respectively, when using fresh water through the growing season. Results also indicated that the amendment type affected both yield and WUE in both growing seasons. The increase in yield could be due to improving the sandy soil characteristics, in particular the low available water content and nutrient status (Al-Omran *et al.*, 2004, 2005). Tomato yield was increased under subsurface drip irrigation compared with surface drip irrigation system. These results are in agreement with results reported by Al-Omran *et al.* (2010) on tomato under open field conditions. The advantages of subsurface drip irrigation might be due to the creation of more suitable conditions in the root zone. It is attributed to the less water evaporated from soil surface.

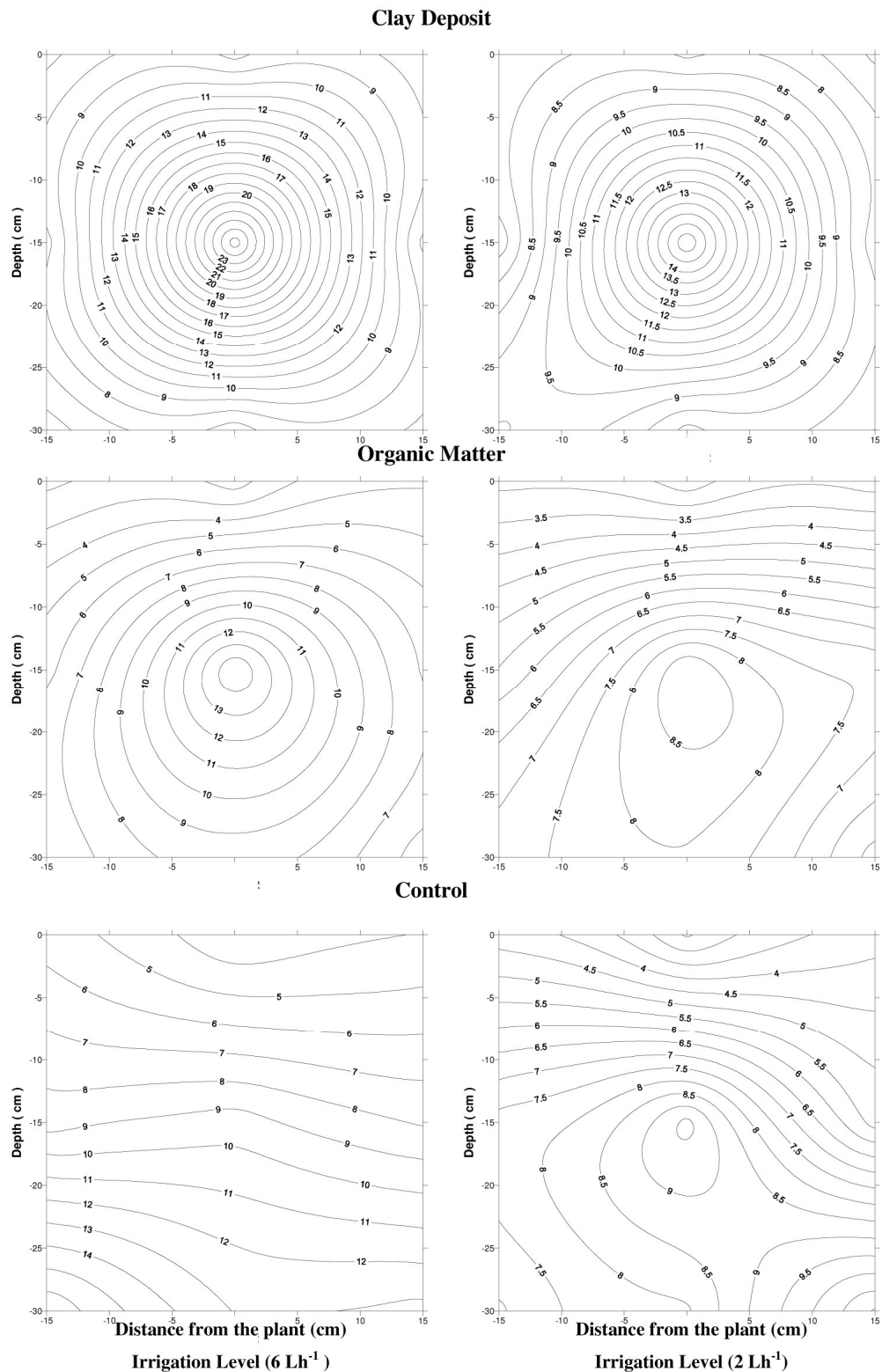


Figure 1. Water content distribution in root zone (15 cm left and right of the plant at the depth of 30 cm) for different types of amendment (25 cm depth) at high and low application irrigation rates for subsurface drip irrigation (the main line tubings were placed at 25 cm depth).

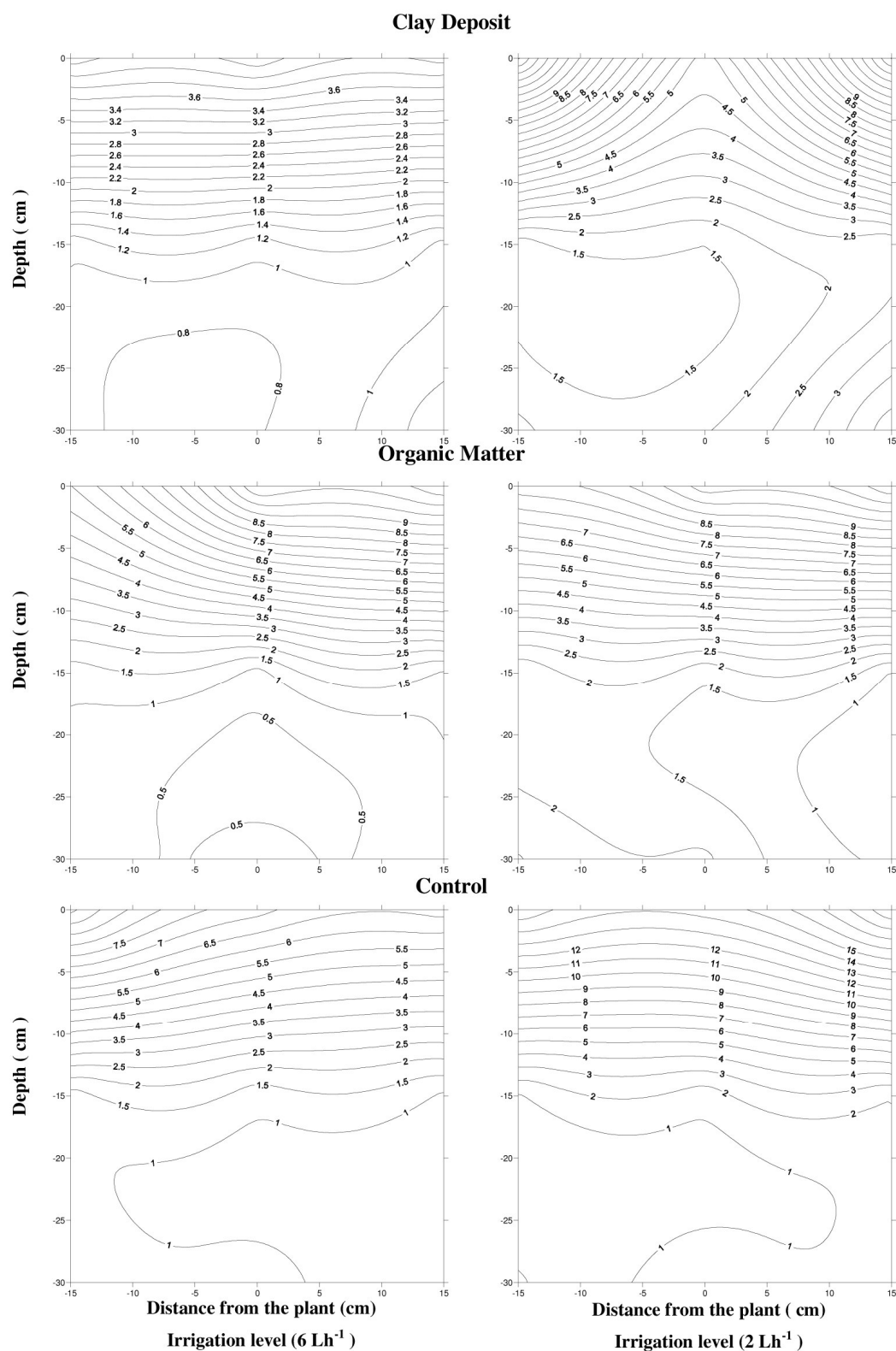


Figure 2. Salt distribution in root zone (15 cm left and right of the plant at the depth of 30 cm) for different types of amendments (25 cm depth) at high and low application irrigation rates for subsurface drip irrigation (the main line tubings were placed at 25 cm depth).

Moreover, it allows maintaining optimum soil moisture content in the root zone, which improved the efficiency of water and fertilizer use. The reduction in yield at low irrigation rate could be due to both the non-availability of water and the more accumulation of salts in the root zone. Moreover, the yield reduction was additionally increased because of using saline irrigation water without proper leaching. These results are in agreement with those of Kirda *et al.* (2004) and Harmanto *et al.* (2005). They reported that the application of irrigation at a lower amount of the water requirement resulted in lower yield; however, over-irrigation did not increase the tomato yield above the maximum yield. There was a considerable decrease in *WUE* as irrigation rate increased. This decrease was attributed to the increase of applied water. Similar results were reported by Harmanto *et al.* (2005) and Howell (2006).

The results of different types of interactions indicated that organic matter amendment was less affected by saline water than the clay deposit amendment. The positive effect for subsurface methods on yield and *WUE* was more obviously with fresh water, while this effect almost did not occur with saline water. The yield was highly affected by saline water under subsurface drip irrigation method than surface method. No significant difference was observed on tomato yield irrigated with fresh or saline water under surface drip irrigation. It clarifies that subsurface drip irrigation creates more suitable conditions in the root zone area for plant growth and production. This result is in agreement with the results reported by Lamm and Trooien (2003) and Al-Omran *et al.* (2010). There were two different ways for the effect of irrigation rates dependent on the irrigation water quality. First with fresh water, using low rate (2 L h^{-1}) which achieved only 7–10% yield reduction and 50% water saving. Second with saline water, increasing irrigation rate from 4 to 6 L h^{-1} significantly increased total yield by 20% and extra water used by 50%. Therefore, 2 L h^{-1} with fresh water was recommend under a given irrigation method. For a given irrigation method and used saline water, 6 L h^{-1} irrigation rate was

recommended. Using fresh water, stress on plants occurred only by water deficit. But using saline water, plant stress occurred by both water deficit and salt concentration. Reduction of plant water uptake with salinity could be related to a reduction in morphological and/or physiological parameters like leaf number and dry weight.

Water Content, Salinity, and Root Distributions

Soil water content after redistribution (24 hours after irrigation) was generally lower at the soil surface, increasing gradually with depth down to 15 cm, and then decreasing at the depth of 25 cm. This trend could be due to evaporating water from the soil surface. It is clear that water seems to be stored in the amended layer with little seepage below the 30 cm depth. Application of clay deposits to sandy soil modified the distribution of soil water content in the root zone where water was retained by clay deposits which were applied in the subsurface layer. Salt accumulation was reversibly related to soil water content distribution. Therefore, irrigation with 6 L h^{-1} increased soil water content in clay deposit amended layer and alleviated the harmful effect of salt accumulation by increasing the distance of salt removal far from the plant site. Subsurface application of clay deposits had a clear influence on the distribution of roots growth. Therefore, clay deposit amendments to subsurface sandy soil and using adequate irrigation water showed quite valuable effects in storing irrigation water and ultimately enhance root growth and yield. Similar results were obtained by Malash *et al.* (2008) and Al-Omran *et al.* (2010) under field conditions.

CONCLUSIONS

The irrigation management treatments were fresh and saline waters, surface and subsurface drip irrigation methods, three irrigation rates applied to represent deficit,



adequate, surplus irrigation conditions, and three soil amendments. Results showed that applying fresh water under a given irrigation method highly increased tomato yield and water saving, relative to that of using saline water. Results indicated that applying amendments improved yield and WUE due to retaining clay deposits in root zone, and in turn, increasing the capacity of available water in sandy soils. Adequate irrigation quantity under subsurface drip irrigation, relative to that of surface drip, enhanced tomato yield and improved its quality in both growing seasons.

Based on the results from this study it can be concluded that applying fresh irrigation water, clay deposit amendments in sandy soils, and subsurface drip irrigation at 2 L h^{-1} irrigation rate reduced the quantity of irrigation water and modified the distribution of soil water content in the root zone. On the other hand, applying saline irrigation water, clay deposit or organic matter amendments in sandy soils, and subsurface drip irrigation method at 6 L h^{-1} irrigation rate was recommended for greenhouse tomato production to reduce the high cost of water desalinization and reducing the deleterious effect of saline water.

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مدیریت شوری آب آبیاری در تولید گوجه فرنگی گلخانه ای تحت شرایط خاک شنی آهکی و آبیاری قطره‌ای

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چکیده

به منظور بررسی اثرات کیفیت آب، اصلاح خاک، روش آبیاری و نرخ آن بر عملکرد و کارایی مصرف آب (WUE) گوجه فرنگی (*Solanum lycopersicon* L. cv. Red Gold) یک آزمایش گلخانه ای در فصول رویشی ۲۰۰۸/۲۰۰۹ و ۲۰۰۹/۲۰۱۰ انجام شد. تیمارهای مدیریت آبیاری عبارت بودند از: آب‌های شیرین ($0/86 \text{ dS m}^{-1}$) و شور ($3/6 \text{ dS m}^{-1}$)، روشهای آبیاری سطحی و زیر سطحی در نرخ‌های ۲، ۴ و 6 L h^{-1} که در دوره‌های زمانی یکسان اعمال شدند و تیمارهای اصلاح خاک رسوبات رس، مواد آلی و شاهد. نتایج نشان دادند که تفاوت میان تیمارها از نظر بازده WUE کاملاً معنی‌دار بود ($P < 0.05$). با استفاده از آب شیرین و اصلاح خاک شنی با رسوبات رس تحت آبیاری قطره ای زیرسطحی با نرخ 2 L h^{-1} ، بر اثر بهبود توزیع آب در ناحیه ریشه در مصرف آب صرفه جویی شد. از طرف دیگر کاربرد آب شور و اصلاح خاک شنی با رسوبات رس یا مواد آلی تحت



آبیاری قطره‌ای زیرسطحی با نرخ $L h^{-1}$ هم هزینه‌های شیرین کردن آب و هم اثرات تخریبی آب شور را کاهش داد. بنابراین این روش مدیریتی برای تولید گوجه فرنگی گلخانه ای توصیه می‌شود.