INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
14–287/2015/17–2–241–250
http://www.fspublishers.org

Full Length Article

Salinity and Deficit Irrigation Influence Tomato Growth, Yield and Water Use Efficiency at Different Developmental Stages

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Abstract

Deficit irrigation (DI) is an optimization strategy that allows water stress to some extent during certain cropping stages or for the whole season without a significant reduction in yield. A greenhouse experiment was conducted during the growing seasons of 2009/2010 and 2010/2011 to study the effect of water quality and DI on growth, yield and water use efficiency (WUE) of tomato at different growth stages. Two different water qualities (saline and non-saline water with electrical conductivities (EC) 3.6 and 0.9 dSm^{-1}, respectively) nine DI treatments and three irrigation treatments (100, 75 and 50% of Etc) were investigated in the experiment. Furthermore, DI at 75% and 50% of ETc during vegetative, reproductive, and fruiting stage were adopted. The result indicated that in general the irrigation with saline water decreased tomato fruits yield and WUE. Moreover, the negative effect of DI was more obvious when coupled with salt stress. Irrigation with saline water resulted in 22% and 24% reduction in yield during first and second season, respectively. Fruiting and vegetative growth stages were the most tolerant to DI; whereas, the reproductive stage was the most sensitive one. The crop response factor (Ky) values ranged between 0.24 and 0.75. Irrigation with non-saline water at 75% ETc at fruiting or vegetative growth stage did not significantly decrease the growth and fruit yield but enhanced WUE, increased vitamin C and total soluble solids (TSS) content and saved 10% of irrigation water. Therefore, this treatment can be recommended as an irrigation management strategy for tomato production under greenhouse conditions. By using this strategy, approximately 21% of irrigation water can be conserved without reduction in yield.

Keywords: Crop response factor; Fruit quality; Salt stress; *Solanum lycopersicon* L.; Water saving

Introduction

A recent innovative approach to save agricultural water is deficit irrigation (DI). It is a water-saving approach under which crops are exposed to a certain level of water stress either during a particular developmental stage or throughout the whole growing season (Pereira *et al*., 2002). The DI process irrigates the root zone with less water than that required for evapotranspiration and makes use of suitable irrigation schedules, which are usually derived from field trials (Oweis and Hachum, 2001). Crop tolerance to DI during the growing season changes with the phenological stage (Istanbulluoglu, 2009). DI strategies have the potential to optimize horticultural water productivity. Information on how different crops cope with mild water deficits forms the basis for a successful application of DI.

Irrigation water quality can affect soil fertility and efficiency of the irrigation system as well as crop productivity and soil physical situation (Al-Omran *et al*., 2010). Most horticultural production areas are situated in warm and arid climates because of their good weather conditions. However, the soil water deficit is rather frequent in these areas. DI may allow optimization of water productivity in these places by stabilizing yields and improving product quality (Costa *et al*., 2007).

Tomato (*Solanum lycopersicon* L.) is one of the most important vegetable crops and is one of the mainly demanding in terms of water use (Peet, 2005). According to Patane *et al.* (2011), the adoption of DI strategies in which a 50% reduction in ETc was applied for the entire or partial growing season to save water helped to minimize fruit losses and maintain high fruit quality. Furthermore, Kirda *et al.* (2004) and Topcu *et al*. (2006) confirmed that the DI saves substantial amounts of irrigation water and increases WUE. Tomato is classified as moderately tolerant crop to salinity at all plant developmental stages (Lim and Ogata, 2005). For maximum yield, the electrical conductivity (EC) of soil extracted from the root zone and in the irrigation water should not exceed 2.5 dS m^{-1} (Maas, 1986). Higher salinity levels (12 dS m^{-1}) caused a significant reduction in total fruits yield (49.7%) in comparison with the control (1.2 dS m^{-1}), while a moderate level (2.4 dS m^{-1})

To cite this paper: Al-Harbi, A.R., A.M. Al-Omran, M.M. Alenazi[1] and M.A. Wahb-Allah, 2015. Salinity and deficit irrigation influence tomato growth, yield and water use efficiency at different developmental stages. *Int. J. Agric. Biol*., 17: 241–250

had no significant effect in this concern (Alsadon *et al*., 2009). According to Olympios *et al*. (2003), increasing EC of irrigation water from 1.5 to 3.2 dS m^{-1} did not affect the vegetative growth, but the yield was 45% less.

In arid regions such as Riyadh (Saudi Arabia), water shortage is an increasing apprehension and water costs are rising. These challenges have forced farmers to use low-quality water, and thus DI strategies are quite important in these environments. Therefore, two identical greenhouse experiments, during the seasons of 2009/2010 and 2010/2011, were conducted to assess the main and interaction effects of water quality and DI program at different stages of plant growth on tomato fruit yield, and tomato quaity and WUE.

Materials and Methods

Experimental Site and Plant Materials

Two greenhouse experiments were conducted in 2009/2010 and 2010/2011 seasons at the Agricultural Research and Experimental Station, Faculty of Food and Agricultural Sciences, King Saud University, 35 km southwest of Riyadh, Saudi Arabia (24°39ˉN, 46°44ˉE). The soil was non-saline (EC ranged from 2.2 to 2.4 dS m^{-1}) calcareous ($CaCO_3$ ranged from 26 to 28%), sandy in texture and had a pH ranging from 7.9 to 8.4.

Seeds of commercial greenhouse tomato (*Solanum lycopersicon* L.) cv. Red Gold were sown (obtained from Golden Valley Seed Company, USA) in seedling trays on August 14 and 16 in 2009 and 2010, respectively. The seeds were grown in fibre glass greenhouse under controlled conditions at temperatures of 25±1ºC/day and 20±1ºC/night. After four weeks of seed sowing, seedlings of uniform size having five true leaves were transplanted into rows of 8 m length and 1 m width. The distance between plants was 40 cm. The air temperature in the greenhouse was set at 25±2°C during the day and 29±2ºC throughout the night with 74±2% RH through the entire growing seasons. Fertilization and other cultural practices were applied as commonly recommended in commercial tomato production (Maynard and Hochmuth, 2007).

Irrigation Treatments

Each experiment included 18 treatment combinations of two sources of irrigation water quality and nine levels of DI. The two sources for irrigation water quality were; saline water with average electrical conductivity (EC) of 3.6 dS m^{-1} that was obtained from an existing local well and non-saline water with an EC of 0.9 dS m^{-1}that was gained from the same well and purified in a water desalination station. The non-saline water had pH 6.05 and sodium adsorption ratio (SAR) 4.33; while, for the saline water these values were 7.45 and 7.7, respectively. The nine DI treatments of maximum evapotranspiration (ETc) were used in the experiment (Table 1) The growing season of tomato was divided into three growth stages i.e. vegetative stage: started from the beginning of transplanting till the beginning of flowering; reproductive stage: started from the beginning of flowering till the formation of first full-sized green fruit; and fruiting stage: started from thedevelopment and ripening of fruits till the termination of the experiment.

Irrigation scheduling methods were based on pan evaporations, which are available and easy to use in the greenhouse (Harmanto *et al.,* 2004). Crop evapotranpiration ETc was calculated using the following equation:

$$ET_c = E_o \times K_p \times K_c \quad (1).$$

Where,

ET_c = maximum daily crop evapotranspirition in mm.

E_o = evaporation from a class A pan in mm.

K_p = pan coefficient with ranges between 0.7 and 0.9.

K_c = crop coefficient with ranges between 0.4 and 1.2 depending on growth stage.

The Kp and Kc were calculated according to the equations of Allen *et al*. (1998).

The gross water requirement (GWR) was calculated with the following equation (Cuenca, 1989):

$$GWR= ETc/ (1-LR) Effirr \quad (2)$$

Where,

GWR = gross water requirement (mm/day).

Effirr = irrigation efficiency.

LR = leaching requirement (%).

WUE was used to evaluate the comparative benefits of the different irrigation treatments. It was calculated as the ratio between total epigeous dry matter at harvest and total water used calculated by balance. Total yield water use efficiency (TYWUE) was also calculated from the fresh total fruits yield and total water use (Lovelli *et al*., 2007).

$$WUE = biomass\ yield\ /\ water\ applied \quad (3)$$

$$TYWUE = fresh\ yield\ /\ water\ applied \quad (4)$$

The relationship between the evapotranspiration deficit [1 – (ETa/ETc)] and yield depression [1 – (Ya/Ym)] is always linear (Doorenbos and Kassam, 1986). The slope of this linear relationship is always called yield response factor or crop response factor (Ky) (Kirda *et al*., 2004). The Ky is the yield response factor that is defined as the decrease in yield per unit decrease in ET (Singh *et al*., 2010). This relationship is expressed

Table 1: Deficit irrigation (DI) treatments for each source of water

DI treatments	Description
T1	Irrigation at100% of ETc during the different growth stages (100%)
T2	Irrigation at 75% of ETc during the vegetative growth stage, then irrigation at 100% of ETc for the remaining growth stages (75% S1)
T3	Irrigation at 75% of ETc at during the reproductive growth stage, then irrigation at 100% of ETc for the remaining growth stages (75% S2)
T4	Irrigation at 75% of ETc during the fruiting growth stage, then irrigation at 100% of ETc for the remaining growth stages (75% S3)
T5	Irrigation at 75% of ETc during the different growth stages (75%)
T6	Irrigation at 50% of ETc during the vegetative growth stage, then irrigation at 100% of ETc for the remaining growth stages (50% S1)
T7	Irrigation at 50% of ETc during the reproductive growth stage, then irrigation at 100% of ETc for the remaining growth stages (50% S2)
T8	Irrigation at 50 % of ETc during the fruiting growth stage, then irrigation at 100% of ETc for the remaining growth stages (50% S3)
T9	Irrigation at 50 % of ETc during the different growth stages (50%)

Table 2: Total biomass, total fruits yield, water use efficiency (WUE) and total yield water use efficiency (TYWUE) of tomato as affected by deficit irrigation (DI) treatments during 2009/2010 and 2010/2011 seasons

DI treatment	Total biomass (ton ha^{-1} DW)		Total fruits yield (ton ha^{-1} FW)		WUE (kg DW m^{-3})		TYWUE (kg FW m^{-3})	
	2009/2010	2010/2011	2009/2010	2010/2011	2009/2010	2010/2011	2009/2010	2010/2011
T1 (100%)	11.583 cd	11.795 cd	112.460 a	113.422 a	2.41 e	2.45 e	23.42 e	23.62 e
T2 (75% S1)	12.140 ab	11.951 bc	109.872 b	110.661 ab	2.75 cd	2.70 cd	24.88 cd	25.05 cd
T3 (75% S2)	11.289 d	11.422 d	106.508 c	107.255 c	2.61 cd	2.64 d	24.65 cd	24.82 d
T4 (75% S3)	12.582 a	12.427 ab	110.862 ab	110.470 ab	2.81 cd	2.78 d	24.83 cd	24.74 d
T5 (75%)	11.620 cd	11.754 d	95.641 f	96.350 f	3.23 b	3.27 b	26.62 b	26.82 b
T6 (50% S1)	12.338 ab	12.564 a	99.106 de	99.715 de	3.06 bc	3.11 bc	24.57 d	24.73 d
T7 (50% S2)	12.023 bc	12.207 abc	96.962 ef	97.270 ef	3.13 bc	3.17 c	25.25 bc	25.33 c
T8 (50% S3)	12.177 ab	12.217 abc	101.904 d	102.670 d	2.94 cd	2.95 d	24.68 cd	24.87 d
T9 (50%)	11.913 bc	12.089 abc	87.602 g	87.922 g	4.96 a	5.03 a	36.50 a	36.63 a

*Values followed by the same letter(s), within a particular column of means, do not significantly different using revised LSD test at 0.05 probability level

Table 3: Average fruit weight, vitamin C content, total soluble solids (TSS) and pH of tomato fruits as affected by deficit irrigation (DI) treatments during 2009/2010 and 2010/2011 seasons

DI treatment	Average fruit weight (g)		Vitamin C content (mg 100 g^{-1} FW)		TSS (%)		pH	
	2009/2010	2010/2011	2009/2010	2010/2011	2009/2010	2010/2011	2009/2010	2010/2011
T1 (100%)	109.3 a	110.6 a	28.1 d	28.1 e	4.92 e	5.27 e	4.10 c	4.16 c
T2 (75% S1)	106.3 bc	107.3 b	29.0 d	28.9 e	5.19 d	5.91 cd	4.14 c	4.18 c
T3 (75% S2)	104.7 c	104.7 b	29.5 cd	28.9 e	5.24 d	5.56 de	4.24 c	4.32 c
T4 (75% S3)	107.6 ab	108.1 ab	29.3 d	29.1 cde	5.09 de	5.52 de	4.15 c	4.23 c
T5 (75%)	91.8 d	97.2 c	32.8 ab	30.9 b	6.33 b	6.58 b	4.58 ab	4.79 ab
T6 (50% S1)	82.1 e	84.8 e	30.6 c	30.2 bc	5.89 c	6.28 c	4.45 b	4.68 ab
T7 (50% S2)	79.1 f	79.1 f	32.1 b	30.1 bcd	5.91 c	6.38 b	4.54 b	4.78 ab
T8 (50% S3)	91.9 d	94.2 d	31.8 b	29.8 bcd	6.09 bc	6.42 b	4.44 b	4.68 b
T9 (50%)	72.9 g	74.1 g	33.8 a	32.4 a	6.96 a	7.25 a	4.75 a	4.90 a

*Values followed by the same letter(s), within a particular column of means, do not significantly different using revised LSD test at 0.05 probability level

by the following equation:

$$[1- (Ya/Ym)] = Ky [1- (ETa/ETm)] \quad (5)$$

Where, Ym (kg ha^{-1}) and Ya (kg ha^{-1}) are the maximum (from a fully irrigated treatment) and actual yields, respectively. The ETm (m^3 ha^{-1}) and ETa (m^3 ha^{-1}) are the maximum (from a fully irrigated treatment) and actual evapotranspiration, respectively, while Ky is the yield response factor.

Experimental Design

The experimental layout was a split-plot system in a randomised complete block design with three replications. Water sources and DI treatments were randomly allocated to the main and sub-plots, respectively. The sub-plot area was 8 m^2 including 20 plants. A total of 1080 plants were used in each experiment. A drip irrigation network was designed for this study. The experimental area was divided into three equal parts represent three replicates, with a buffer strip of 3 m. Each replicate was divided into two equal main plots with a buffer strip of 2 m. Each main plot, represents a source of water, contained nine rows (sub plot area) that were connected through a valve. Each row in the main plots represents a level of deficit irrigation treatment.

Data Recorded

At harvest, three representative plant samples were randomly chosen from each sub-plot and separated into stems, leaves and fruits. The plant parts were dried at 70^{o}C in a forced-air oven until the weight became constant and the total dry biomass ha^{-1} was calculated.

Afterwards, the total tomato fruits weight through the entire harvesting period for each experimental unit was recorded and converted into total tomato fruits yield ha^{-1}. Average fruit weight was calculated by dividing the total weight of all harvested fruits from each sub-plot across the whole season by their number.

A random fruits sample (approximately 2 kg from the first and second trusses) was taken from each experimental unit at the peak of harvest (the fourth harvest) for laboratory analyses. The homogenised fruits juice was subjected to the following determinations: total soluble solids (TSS, °Brix) using a portable refractometer; vitamin C content using the pigment of 2,6-dichlorophenol-indophenol; while, pH was measured with a glass electrode pH meter (AOAC, 1990).

Statistical Analysis

Data on the dry biomass, total fruits yield and quality traits were statistically analysed using Statistical Analysis System (SAS) version 8.1 (SAS Institute, 2008). An analysis of variance was conducted separately within each year. Differences between the means were evaluated for significance using a Revised Least Significant Difference (LSD) test at 0.05 levels as described by Snedecor and Cochran (1989).

Results

Water Quality Treatments

Irrigation with saline water significantly reduced total dry biomass (Fig. 1a), total fruits yield (Fig. 1b), WUE calculated on the basis of total dry biomass (Fig. 1c) and TYWUE calculated on the basis of total fruits yield (Fig. 1d), in comparison to irrigation with non-saline water, in both experimental seasons. Irrigation with non-saline water gave significantly higher magnitudes of fruit weight and vitamin C content than irrigation with saline water (Fig. 1e and 1f). The reverse was true for TSS and pH traits (Fig. 1g and 1h).

Deficit Irrigation Treatments

The total dry biomass accumulation was significantly increased using DI treatments T_2, T_4, T_6 and T_8, in 2009/2010 and only T_4 and T_6, in 2010/2011 (Table 2). However, no significant differences were observed for remaining DI treatments. The lowest biomass value was observed using T_3, in both seasons, while the highest value was observed with T_4 followed by T_6, in the first season and T_6 followed by T_4, in the second season. Under all DI treatments, the total tomato fruit yield was significantly decreased, except when T_4 treatment was utilized in the 1st season and both T_2 and T_4 treatments were used in the 2nd season. Significant differences in WUE and TYWUE due to DI treatments were detected in both seasons (Table 2). Comparisons among mean values of the different DI treatments showed that DI at 50% ETc through the various growth stages (T_9) recorded the highest mean values of WUE and TYWUE followed by DI at 75% ETc through all growth stages (T_5), which saved the largest amounts of irrigation water, in both experimental years. DI at 100% ETc through the different growth stages recorded the lowest magnitudes of WUE and TYWUE, in both growing seasons.

Average fruit weight significantly decreased in all DI treatments compared to control (T_1), over the course of the two seasons, except T_4 treatment where the difference was not significant (Table 3). The highest value of fruit weight was observed with T_1 followed by T_4 treatment, while the lowest one was observed with T_7 followed by T_9 treatment, in both seasons. Moreover, T_4 and T_2 treatments did not significantly differ from each other. These results illustrated that DI from 100 to 75% ETc during vegetative stage (T_2) or fruiting stage (T_4) did not affect fruit weight; whereas, the DI during reproductive stage (T_3) or during the whole season (T_5) significantly reduced fruit weight. However, DI from 100 to 50% ETc (T_6, T_7, T_8 and T_9), irrespective of the growth stage, significantly reduced fruit weight. DI, on the contrary, reflected significant positive effects on vitamin C, TSS and pH contents (Table 3). The highest mean values of vitamin C, TSS and pH contents were attained by T_9 followed by T_5 treatment, during the two growing seasons.

Interaction Effects

The interaction effects of water quality and DI significantly affected total dry biomass, total fruits yield, WUE and TYWUE in the two growing seasons (Table 4). The highest value of total dry biomass was recorded with DI at 75% of ETc (T_4), through fruiting stage, combined with non-saline water, during the two growing seasons. The lowest value of total biomass gained was obtained when irrigation at 100% of ETc (T_1) was applied through all growth stages, combined with saline water, during both seasons. The highest value of total fruits yield was obtained when the irrigation was performed at 100% of ETc (T_1) at all growth stages combined with non-saline water, in both seasons. The lowest magnitude of total fruits yield in both seasons was recorded when the irrigation through all growth stages was applied with non-saline water at 50% of ETc (T_9).

Comparisons among the mean values of the interaction between water quality and DI treatments showed significant differences in the studied fruit quality traits, throughout the two experimental seasons (Table 5). Regarding average fruit weight, the highest

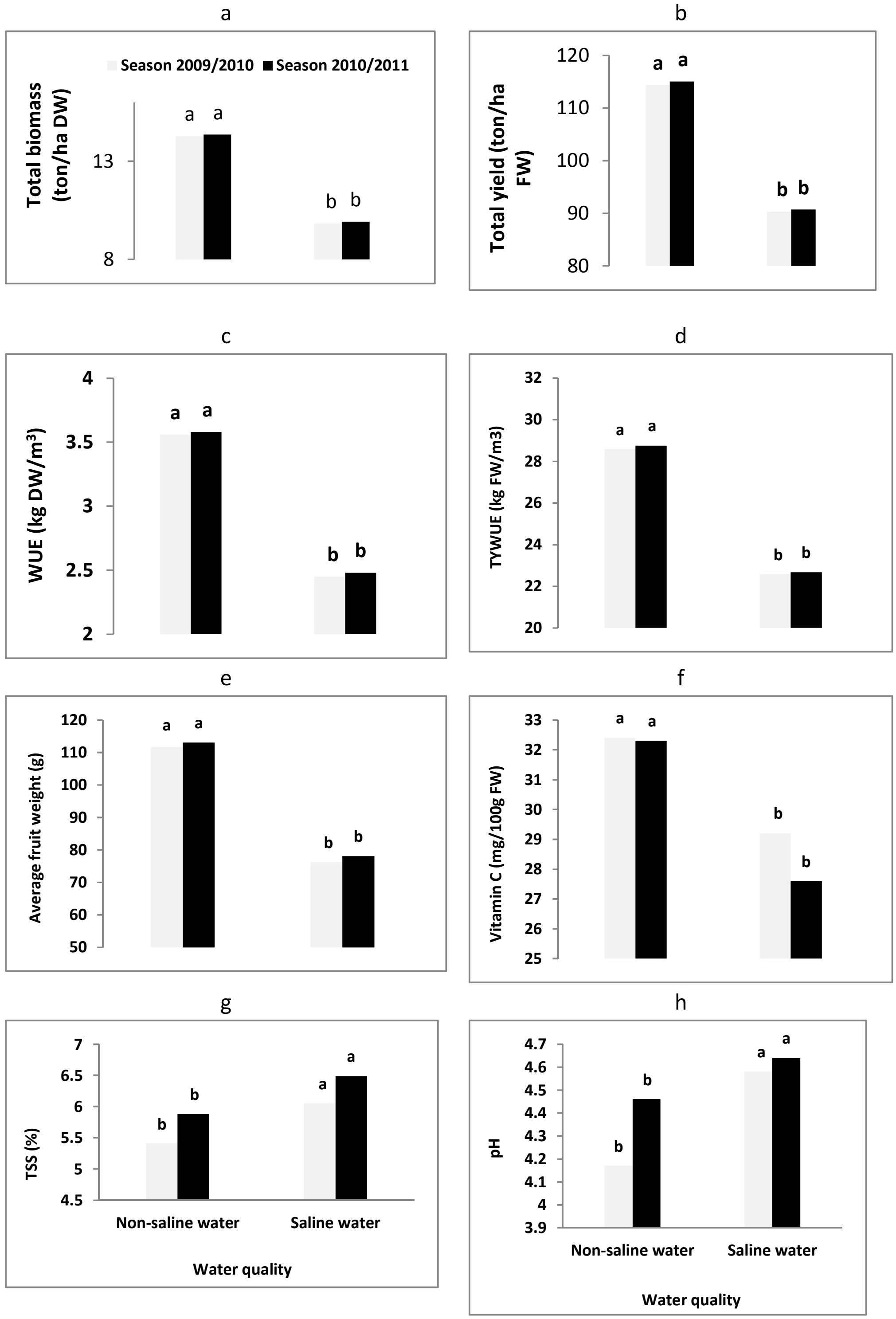

Fig. 1: Effect of water quality on (a) total biomass, (b) total fruits yield, (c) water use efficiency, (d) total yield water use efficiency, (e) average fruit weight, (f) vitamin C content, (g) total soluble solids and (h) pH of tomato in 2009/2010 and 2010/2011 seasons

magnitudes were recorded when irrigation with non-saline water combined with DI at 100% Etc followed by irrigation at 75% ETc during fruiting stage (T_4), 75% ETc during vegetative stage (T_2) and 75% ETc during flowering stage (T_3). Meanwhile, the lowest value of average fruit weight was obtained when irrigation with

Table 4: Total biomass, total fruits yield, water use efficiency (WUE) and total yield water use efficiency (TYWUE) of tomato as affected by the interaction of water quality and deficit irrigation (DI), during 2009/2010 and 2010/011 seasons

Water quality	DI treatments	Total biomass (ton ha^{-1} DW)		Total fruits yield (ton ha^{-1} FW)		WUE (kg DW m^{-3})		TYWUE (kg FW m^{-3})	
		2009/2010	2010/2011	2009/2010	2010/2011	2009/2010	2010/2011	2009/2010	2010/2011
Non-saline water	T1 (100%)	14.328 bcd	14.354 c	124.597 a	125.920 a	2.98 fgh	2.99 fg	25.95 de	26.23 de
	T2 (75% S1)	14.137 bcd	13.862 d	121.872 b	122.673 ab	3.20 ef	3.13 ef	27.59 cd	27.77 cd
	T3 (75% S2)	13.256 e	13.237 e	118.366 c	119.260 c	3.06 fg	3.06 fg	27.39 cd	27.60 cd
	T4 (75% S3)	14.878 a	15.081 a	122.966 ab	123.620 ab	3.33 def	3.37 def	27.54 cd	27.69 cd
	T5 (75%)	13.956 d	13.941 d	108.189 f	108.920 ef	3.88 bc	3.88 bc	30.11 bc	30.32 bc
	T6 (50% S1)	14.483 abc	14.789 ab	110.563 e	111.200 e	3.59 b-e	3.66 bcd	27.42 cd	27.57 cd
	T7 (50% S2)	14.655 ab	14.745 abc	108.560 ef	108.420 f	3.81 bcd	3.83 bcd	28.27 bcd	28.23 bcd
	T8 (50% S3)	14.464 bc	14.735 abc	113.893 d	115.120 d	3.50 c-f	3.56 cde	27.59 cd	27.88 bcd
	T9 (50%)	14.316 bcd	14.431 bc	100.116 g	100.220 g	5.96 a	6.01 a	41.71 a	41.75 a
Saline water	T1 (100%)	9.129 j	9.486 i	100.323 g	100.925 g	1.90 j	1.97 i	20.90 f	21.03 f
	T2 (75% S1)	10.276 fg	10.160 fg	97.872 h	98.650 gh	2.32 ij	2.30 hi	22.16 ef	22.33 f
	T3 (75% S2)	9.465 ij	9.715 hi	94.650 i	95.250 i	2.19 ij	2.24 hi	21.91 f	22.04 f
	T4 (75% S3)	10.468 f	10.023 g	98.758 gh	97.320 hi	2.34 ij	2.24 hi	22.12 ef	21.80 f
	T5 (75%)	9.472 ij	9.718 ghi	83.092 m	83.780 l	2.63 ghi	2.70 gh	23.13 ef	23.32 ef
	T6 (50% S1)	10.343 fg	10.499 f	87.650 k	88.230 jk	2.56 ghi	2.60 gh	21.73 f	21.88 f
	T7 (50% S2)	9.646 hi	9.903 gh	85.364 l	86.120 k	2.51 hi	2.57 gh	22.23 ef	22.42 ef
	T8 (50% S3)	10.070 gh	9.924 gh	89.914 j	90.220 j	2.43 i	2.40 i	21.78 f	21.85 f
	T9 (50%)	9.686 hi	9.906 gh	75.088 n	75.625 m	4.03 b	4.12 ab	31.28 b	31.51 b

*Values followed by the same letter(s), within a particular column of means, do not significantly different using revised LSD test at 0.05 probability level

Table 5: Average fruit weight, vitamin C content, total soluble solids and pH of tomato fruits as affected by the interaction of water quality and (DI) during 2009/2010 and 2010/2011seasons

Water quality	DI Treatment	Average fruit weight (g)		vitamin C content (mg 100 g^{-1} FW)		TSS (%)		pH	
		2009/2010	2010/2011	2009/2010	2010/2011	2009/2010	2010/2011	2009/2010	2010/2011
Non-saline water	T1 (100%)	128.2 a	130.1 a	29.9 efg	30.5 f	4.72 i	4.93 g	3.96 k	4.04 i
	T2 (75% S1)	125.5 ab	124.6 b	30.2 efg	31.4 ef	4.96 hi	5.91 cde	3.98 jk	4.06 i
	T3 (75% S2)	124.1 b	123.3 b	30.8 d-g	31.9 cde	5.02 hi	5.26 fg	4.12 ij	4.20 hi
	T4 (75% S3)	127.2 ab	126.1 ab	31.1 cde	32.2 b-e	4.86 i	5.12 g	4.02 jk	4.14 hi
	T5 (75%)	108.4 d	116.1 c	34.4 a	33.2 ab	5.95 d	6.18 c	4.30 fgh	4.66 cde
	T6 (50% S1)	98.5 e	99.5 d	31.8 cd	32.8 bcd	5.36 fg	5.64 def	4.16 hij	4.56 ef
	T7 (50% S2)	94.1 ef	95.1 de	34.2 a	33.1 bc	5.50 ef	5.92 cde	4.27 f-i	4.72 cde
	T8 (50% S3)	113.3 c	115.2 c	33.9 ab	31.6 def	5.78 de	6.04 cd	4.21 f-i	4.63 def
	T9 (50%)	86.4 gh	88.2 fg	35.2 a	34.4 a	6.61 bc	6.98 b	4.56 de	4.75 b-e
Saline water	T1 (100%)	90.5 fg	91.2 ef	26.4 i	25.8 i	5.12 gh	5.62 ef	4.25 f-i	4.28 gh
	T2 (75% S1)	87.2 fgh	90.1 efg	27.8 hi	26.4 hi	5.42 fg	5.92 cde	4.30 fgh	4.30 gh
	T3 (75% S2)	85.4 h	86.2 g	28.2 hi	25.9 i	5.46 ef	5.86 cde	4.36 ef	4.45 fg
	T4 (75% S3)	88.1 fgh	90.2 efg	27.6 l	26.1 i	5.32 fgh	5.93 cde	4.28 fgh	4.32 gh
	T5 (75%)	75.2 i	78.3 h	31.2 cde	28.7 g	6.72 b	6.98 b	4.86 ab	4.92 ab
	T6 (50% S1)	65.8 jk	70.2 i	29.4 gh	27.6 gh	6.42 bc	6.92 b	4.75 bcd	4.81 bcd
	T7 (50% S2)	64.2 k	63.1 j	29.9 efg	27.0 hi	6.31 c	6.85 b	4.81 abc	4.85 bc
	T8 (50% S3)	70.6 j	73.2 hi	29.8 fg	28.1 g	6.40 bc	6.81 b	4.68 cd	4.73 cde
	T9 (50%)	59.4 l	60.1 j	32.4 bc	30.4 f	7.31 a	7.53 a	4.95 a	5.06 a

*Values followed by the same letter(s), within a particular column of means, do not significantly different using revised LSD test at 0.05 probability level

saline water combined with DI at 50% ETc during all growth stages (T_9), in both years. Concerning the fruit vitamin C content, the highest magnitudes were recorded when irrigation with non-saline water combined with DI at 50% Etc during all growth stages (T_9) followed by irrigation at 75% ETc during all growth stages (T_5), 50% ETc during flowering stage (T_7) and 50% Etc during vegetative stage (T_6), in both seasons. Meanwhile, the lowest value of vitamin C content was obtained when irrigation with saline water combined with irrigation at 100% Etc during whole growth stages (T_1), in both years. Regarding TSS and pH, the highest content of both parameters were attained when irrigation with saline water combined with DI at 50% ETc during all growth stages (T_9) followed by DI at 75% ETc during whole growth stages (T_5); whereas, the lowest ones were occurred when irrigation with non-saline water coupled with irrigation at 100% ETc during whole growth stages (T_1), in both years.

Yield Response Factor

The yield response factor (Ky) was calculated in this experiment for both non-saline and saline water by considering the pooled data from the two seasons. The average crop response factor for different treatments throughout the tomato growth stages was 0.49 and 0.56 for non-saline and saline water, respectively (Fig.

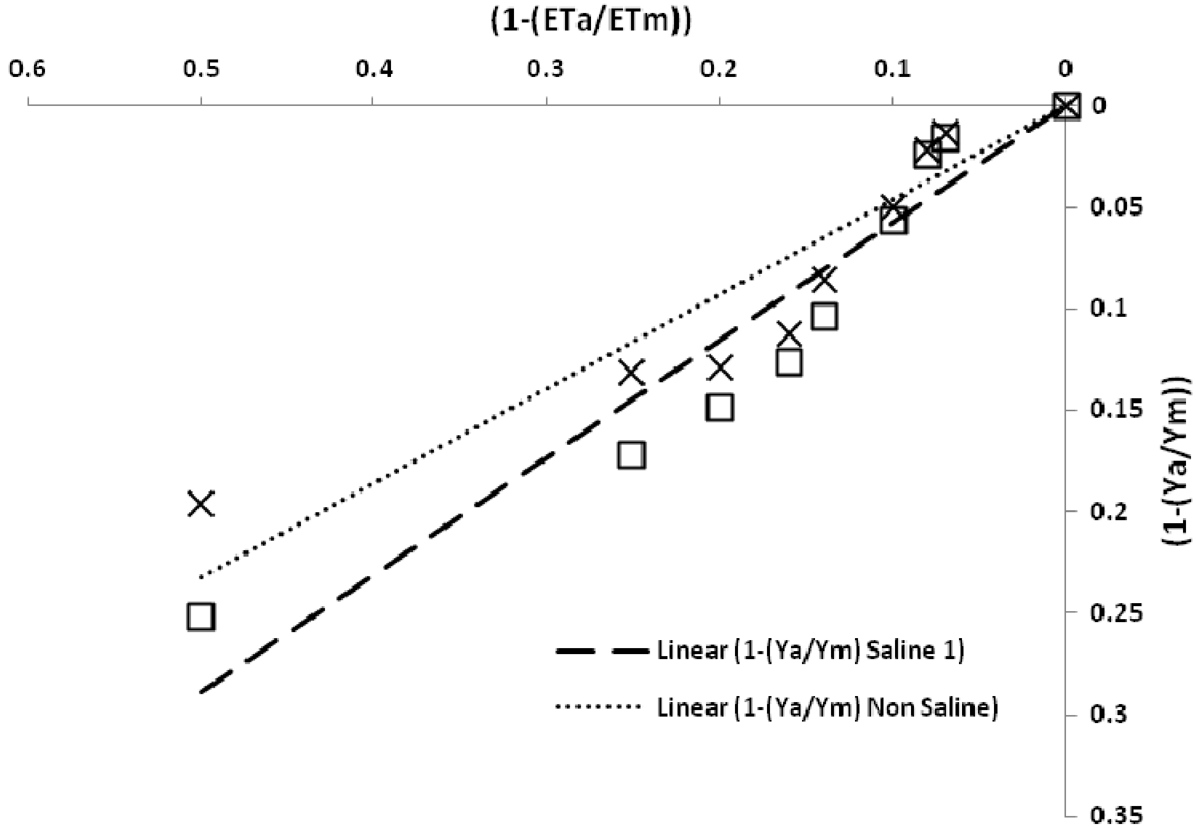

Fig. 2: Change in the relative yield as function of relative evapotranspiration measured in tomato (pooled of the two seasons)

2), indicating that the reduction in crop productivity is proportionally less than the relative ET deficit in both cases.

Discussion

Irrigation with saline water reduced total biomass and total fruit yield by approximately 31% and 21%, respectively. This is due to high salts concentration results in high osmotic potential of the soil solution; consequently, the plant has to use more energy to absorb water. Moreover, under extreme salinity conditions, plants cannot absorb water even when the surrounding soil is saturated. Similar results were reported by Al-harbi *et al.* (2009). They mentioned that, irrigation with saline water having EC 4.7 dS m^{-1} significantly reduced the total fruits yield by 24.3%. Maggio *et al.* (2007) reported that there was an approximately 6% reduction in plant dry mass per one dS m^{-1} increase until approximately 9 dS m^{-1}, whereas, only 1.4% decrease in yield per dS m^{-1} after 9 dS m^{-1}. Al-Harbi *et al.* (2009) and Al-Omran *et al.* (2012) concluded that the adverse effect of irrigation with saline water on total dry biomass and total fresh tomato fruit yield were the reduction in WUE and TYWUE.

As average of the two seasons, irrigation with non-saline water gave heavier fruit weight and more content of vitamin C than irrigation with saline water by 31.4% and 12.7%, respectively. These results indicated that, the depletion in total tomto fruit yield might be ascribed to a more significant decrease in average fruit weight than fruit number. Van-Ieperen (1996) reported a significant reduction in average fruit weight, but number of fruits did not affect even when low salinity levels were applied for the whole experimental period. Results of Favati *et al.* (2009) clarified that the larger the tomato fruit, the lower was the vitamin C content. This association is mainly due to the secondary osmotic stress induced by this abiotic stress. Irrigation with saline water gave significantly higher values of TSS and pH than irrigation with non-saline water by 11.1% and 6.9%, respectively. The positive effects of irrigation with saline water on TSS content of fruits probably arise as a result of reduction in water intake by the fruits (Al-Yahyai, 2010). Moreover, Munns (2002) reported that, under saline conditions an active accumulation of solutes (mainly ions and organic molecules) occurred. The enhancing effect of irrigation with saline water on pH is in harmony with those of Sanders *et al.* (1989) who reported a positive relationship between salinity rate in irrigation water and pH of tomato fruits.

The results of effect of DI treatments illustrated that DI during the vegetative growth stage (T_2 and T_6) or during the fruiting growth stage (T_4 and T_8) significantly increased the total dry biomass; however, DI during the reproductive growth stage (T_3 and T_7) or during the whole season (T_5 and T_9) did not induce significant changes in the final dry biomass, in both seasons. Generally, a similar DI effect was reported by Patane *et al*. (2011). They mentioned that the DI at a 50% Et_c did not induce any losses in tomato total dry biomass when starting from the initial stages or from flowering and onwards. When the amount of irrigation water was reduced from 100 to 75% ET_c during the vegetative (T_2) or fruiting (T_4) stage, there was insignificant reduction in total tomto fruit yield. As compared to the control treatment (T_1), the reduction in yield was only 1.6 ton ha^{-1} (1.4%) and 2.9 ton ha^{-1} (2.6%) when the treatment T_4 was conducted in the first and second seasons, and 2.6 ton ha^{-1} (2.3%) and 2.7 ton ha^{-1} (2.4%) when T_2 was achieved in the first and second seasons, respectively. DI during the reproductive stage at T_3 and T_7 significantly reduced the total fruits yield by approximately 5.4% and 14% in comparison with the control (T_1), as an average of the two experimental seasons, respectively. However, DI during all growth stages at T_5 and T_9 was negatively pronounced and significantly produced lower total fruits yield than the control T_1 nearly by 15% and 22%, as an average of the two experimental seasons, respectively. These results indicated that the most tolerant growth phases to DI were fruiting and vegetative growth stages and the most sensitive one was reproductive stage. These findings are in line with the results of Srinivasa Rao *et al*. (2000) who showed that the reproductive tomato growth stage is more sensitive phenological stage to water deficit than vegetative growth stage. Furthermore, Savic *et al*. (2011) reported that the phenological stages of tomato may react differently to DI and scheduling irrigation should take into account the stages in which the crop is particularly sensitive to water deficits.

The enhancing effect of DI on vitamin C content can be explained on the basis that tomato plants irrigated at 100% Ec produced large canopy, which probably results in suitable fruit cover and shading relative to those exposed to moderate or severe water stress during their growth (Patanè *et al*., 2011). Previous studies revealed that vitamin C content decreased in tomato fruits that were shaded during ripening (Gautier *et al*., 2008). The stimulating effect of DI on TSS content can be ascribed to the reduction of fruit size under DI was mainly attributed to the reduction of water rather than the reduction of assimilates imported into the fruit (Ho *et al.,* 1987). This observation might explain why the plants subjected to DI produce higher content of TSS in fruits.

The interaction effects of water quality and DI illustrated that when the two types of stresses; saline and DI were coupled together, a serious reduction occurred on total dry biomass and total fruits yield. The productivity of water irrigation for both dry biomass (WUE) and fresh total fruits yield (TYWUE) were positively affected by DI, while being negatively affected by water salinity. Consequently, it is possible to improve the WUE and save water through a DI strategy for tomato production; however, to attain sufficient fruits yield, good-quality water should be applied to the crop throughout the whole growing season, even if at a low rate (50% ETc). Increasing water productivity in response to DI can be explained on the basis that DI can increase the ratio of yield over crop water consumption through the following strategies; reducing water loss by unproductive evaporation, increasing the proportion of marketable yield to the total biomass produced and applying adequate fertiliser and avoiding bad agronomic conditions during crop growth such as water logging in the root zone, pests and diseases, and other challenges (Steduto and Albrizio, 2005; Geerts and Raes, 2009).

A water deficit at the vegetative or fruiting growth stages at a rate of 75% of ETc, while using non-saline water insignificantly reduce the yield and enhanced WUE. The fruiting and vegetative growth stages could be considered to be the most tolerant to DI and the reproductive stage could be considered the most sensitive one. To save approximately 21% of the irrigation water, a DI rate of 50% ETc could be used during the fruiting stage with non-saline water, but the total fruit yield was reduced by 8.6%. It is possible to improve the WUE and save water through a DI strategy for tomato production; however, to attain sufficient fruit yield and minimize fruit losses, good-quality water should be applied to the crop throughout the whole growing season, even if at a low rate, 50% of ETc.

The crop yield response factor (Ky) was determined for the different DI treatments. The Ky usually indicates a linear relationship of the relative reduction in water that was consumed with a relative reduction in yield (Lovelli *et al*., 2007). When crops have Ky values that are lower than one, they are considered to be tolerant of water deficiency. On the contrary, crops with Ky values greater than one are considered not to be tolerant for DI, as noted by Ayas and Demirtas (2009). The average crop response factor was 0.49 and 0.56 for non-saline and saline water, respectively. This finding indicates that tomatoes grown in greenhouse conditions could be considered to be a water stress-tolerant crop. However, plants were more tolerant to water stress using non-saline water than saline water. These results were similar to those reported by Patane and Cosentino (2010). Furthermore, when the Ky values were calculated for each growth stage, a lower value was obtained for the fruiting stage, while the highest value was obtained for the reproductive stage. This observation indicates that the fruiting stage was less affected by soil water deficit than at other stages.

Conclusion

Tomato grown under greenhouse conditions, the fruiting and vegetative growth stages could be considered to be the most tolerant to DI, while, reproductive stage could be considered the most sensitive one. A water deficit at the vegetative or fruiting growth stages at a rate of 75% of ETc, with non-saline irrigation water insignificantly decreased the growth and fruits yield; however, enhanced the WUE, increased vitamin C and TSS content. Therefore, the rate of 75% of ETc treatment could be recommended for tomato production under greenhouse conditions in order to save water. On the other hand, a deficit irrigation rate of 50% ETc during the fruiting stage with non-saline water saved approximately 21% of the total amount of water used in the irrigation; however, it reduced the total yield by 8.6%.

Acknowledgements

This project was supported by NSTIP strategic technologies program number (12-AGR2508-02) in the Kingdom of Saudi Arabia.

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(Received 10 April 2014; Accepted 18 August 2014)