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EFFECT OF WATER QUALITY AND DEFICIT IRRIGATION ON TOMATO GROWTH, YIELD AND WATER USE EFFICIENCY AT DIFFERENT DEVELOPMENTAL STAGES

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ABSTRACT

A major problem affect agriculture worldwide is a lack of adequate water resources. Deficit irrigation is an optimization strategy that allows to some extent of water stress during a certain cropping stage or 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 deficit irrigation on growth, yield and water use efficiency of tomato (*Solanum lycopersicon* L.) cv. Red Gold at different growth stages. Two different water qualities; saline and non-saline water with electrical conductivities (EC) 3.6 and 0.9 dS m^{-1} , respectively and nine irrigation deficit treatments; three fixed irrigation regimes through the whole crop cycle at 100, 75 and 50% of the maximum crop evapotranspiration (ETc), irrigation deficit at 75% of ETc during vegetative, reproductive or fruiting stage and irrigation deficit at 50% of ETc during the aforementioned three growth stages; were used. The experimental layout was split-plot system in a randomized complete block design. The results showed that, irrigation with saline water reflected negative significant effects on tomato fruits yield and water use efficiency (WUE). The reductions in tomato fruits yield were 22% and 24% in the first and second

season, respectively. The negative effect of deficit irrigation (DI) was more obvious when coupled with salt stress. Fruiting and vegetative growth stages were the most tolerant to deficit irrigation 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 through the fruiting or vegetative growth stage did not significantly reduce the growth and fruits yield but, enhanced WUE , increased vitamin C and total soluble solids (T.S.S) content and saved 10 % of water irrigation.Therefore, this treatment could be recommended for tomato production under greenhouse conditions. To save approximately 21% of irrigation water, a deficit irrigation rate of 50% ETc could be used during the fruiting stage with non-saline water, but the total yield was reduced by 8.6%.

Keywords: *Solanum lycopersicon* L., water quality, water saving, salt stress, fruit quality, crop response factor.

INTRODUCTION

The sustainable use of water in agriculture has become a major concern. The adoption of strategies for saving irrigation water and maintaining acceptable yields may contribute to the preservation of this ever more restricted resource (Topcu *et al*., 2007). In areas of water shortage and long summer droughts, maximizing water productivity may be more beneficial to the farmer than maximizing crop yield. A recent innovative approach to save agricultural water is conventional deficit irrigation (DI). It is a water-saving strategy 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 expectation is that any yield reduction will be insignificant compared with the benefits that are gained from the conservation of water.

The goal of deficit irrigation is to increase crop water use efficiency (WUE) by reducing the amount of water that is applied or by reducing the number of irrigation events (Kirda, 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). Optimal irrigation schedules are often based on water productivity (Oweis and Zhang, 1998). DI strategies have the potential to optimize horticultural water productivity. Nevertheless, the effects of deficit irrigation on yield or harvest quality are crop specific (Costa *et al.*, 2007). Information on how different crops cope with mild water deficits forms the basis for a successful application of deficit irrigation.

Irrigation water quality can affect soil fertility and irrigation system performance as well as crop yield and soil physical conditions (Al-omran *et al*., 2010) . Therefore, knowledge of irrigation water quality is critical in understanding the management changes that are necessary for long-term productivity. Plant responses to salt stress depend on several interacting variables including the cultural environment, plant developmental stage and salinity level during the growth period (Munns, 2002). Most horticultural production areas are located in hot and dry climates because of their favourable weather conditions (high light, high temperature). However, the soil water deficit is rather frequent in these areas. Water-saving irrigation strategies such as DI may allow for the 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 most demanding in terms of water use (Peet, 2005). The application of DI strategies to this crop may significantly led to save irrigation water (Costa *et al*., 2007). Furthermore, studies have shown that water deficit occurs during certain stages of the growing season improves fruit quality, although water limitations may determine fruit yield losses (Patane and Cosentino, 2010). According to

Patane *et al.* (2011), the adoption of DI strategies in which a 50% reduction in ETc was applied for the whole or partial growing season to save water helped to minimize fruit losses and maintain high fruit quality. Pulupol *et al*. (1996) observed a significant reduction in dry mass yield for a glasshouse tomato cultivar using deficit irrigation, while Zegbe-Domínguez *et al*. (2006) did not find a reduction in tomato fruits yield of field-grown processing cultivar. Although, the effects of DI on tomato fruits yield may be different, many investigators such as Kirda *et al.*(2004) and Topcu *et al*.(2006) have demonstrated that 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} (Mass,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}) 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. A better understanding of the relationships among water quality, soil water deficit, fruit yield and quality traits could be better for growers to control irrigation water management.

In arid regions such as Riyadh (Saudi Arabia), water scarcity is an increasing concern and water costs are rising. These challenges have forced farmers to use low-quality water, and thus deficit irrigation 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 deficit irrigation program at different stages of plant growth on tomato fruits yield, fruits quality and water use efficiency.

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MATERIALS AND METHODS

1.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^{o} 39^{-}N, 46^{o} 44^{-} E). Before starting the experiment for each season, a composite soil sample was taken from surface and subsurface layers from the study area for analysis. Some physical and chemical characteristics of the experimental soil site are presented in Table 1.

Table 1. Some physical and chemical characteristics of the upper soil layer (0-50cm) of the experimental soil site in 2009/2010 and 2010/011 seasons.

Parameters	2009/2010	2010/2011
Sand (%)	88	88
Silt (%)	4	4
Clay (%)	8	8
Organic matter content (%)	0.14	0.12
$CaCO_3$ (%)	27	28
Saturation water content (%w/w)	29.0	30
Field capacity (%w/w)	17.2	17.5
Permanent wilting point (%w/w)	5.5	5.6
Plant available water (%w/w)	10.5	10.7
pH	7.9	8.4
Electrical conductivity (dS m^{-1})	2.2	2.37
Ca^{2+} (me L^{-1})	11.5	9.5
Mg^{2+} (me L^{-1})	5.8	5.21
Na^{+} (me L^{-1})	6.8	8.22
K^{+} (me L^{-1})	1.9	1.98
CO_3^{-2} (me L^{-1})	Tr.	Tr.
HCO_3^{-} (me L^{-1})	3.0	3.1
Cl^{-} (me L^{-1})	8.0	8.5
SO_4^{-2} (me L^{-1})	11.2	7.5

Seeds of commercial greenhouse tomato (*Solanum lycopersicon* L.) cv. Red Gold were sown in seedling trays on August 14 and 16 in 2009 and 2010,respectively. The seeds were grown in fibreglass

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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 8m length and 1m 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 a relative humidity of 74 ± 2% through the entire growing seasons. Fertilization and other cultural practices were applied as commonly recommended in commercial tomato production (Maynard and Hochmuth, 2007).

2. Irrigation treatments

Each experiment included 18 treatments represent all combinations of two sources of irrigation water quality and nine treatments of deficit irrigation. 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 chemical properties of the two water sources used in irrigation are listed in Table 2. The nine deficit irrigation treatments of maximum evapotranspirition (ETc) are listed in Table 3. The growing season of tomato was divided into three growth stages; 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 the development and ripening of fruits till the termination of the experiment.

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Table 2. Chemical analysis of the two sources of irrigation water in 2009/2010 and 2010/011 seasons.

Parameters	Saline water		Non-saline water	
	2009/2010	**2010/2011**	**2009/2010**	**2010/2011**
pH	7.50	7.45	6.40	6.05
EC (dS m^{-1})	3.40	3.75	0.90	0.86
Ca^{++} (me L^{-1})	12.50	17.31	2.50	2.30
Mg^{++} (me L^{-1})	10.50	11.95	1.20	1.36
Na^{+} (me L^{-1})	16.50	18.96	7.10	7.00
K^{+} (me L^{-1})	0.60	0.51	0.20	0.17
CO_3^{--} (me L^{-1})	Tr.	Tr.	Tr.	Tr.
HCO_3^{-} (me L^{-1})	4.30	4.00	1.10	1.00
Cl^{-} (me L^{-1})	14.50	16.40	5.10	4.80
SO_4^{--} (me L^{-1})	5.90	8.4	2.90	4.40
No_3^{-} (ppm)	12.40	14.3	7.20	8.28
B (ppm)	2.11	2.27	1.51	1.73
SAR	5.80	5.60	7.50	7.70

Table 3. Deficit irrigation treatments for each source of water

Treatment	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 remainder growth stages. (75% S1).
T3	irrigation at 75% of ETc at during the reproductive growth stage, then irrigation at 100% of ETc for the remainder growth stages (75% S2).
T4	irrigation at 75% of ETc during the fruiting growth stage, then irrigation at 100% of ETc for the remainder 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 remainder growth stages (50% S1).
T7	irrigation at 50% of ETc during the reproductive growth stage, then irrigation at 100% of ETc for the remainder growth stages. (50% S2).
T8	irrigation at 50 % of ETc during the fruiting growth stage, then irrigation at 100% of ETc for the remainder growth stages. (50% S3)
T9	irrigation at 50 % of ETc during the different growth stages. (50%)

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

$ET_c = E_o K_p K_c$ (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

GWR= ETc/ (1-LR) Effirr (Cuenca, 1989) (2)

Where:

GWR= gross water requirement (mm/day).

Effirr = irrigation efficiency.

LR = Leaching requirement (%)

Water use efficiency (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 measured 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 = Total biomass yield/Total water applied (3)

TYWUE = Total fresh yield/ Total water applied (4)

The relationship between the evapotranspiration deficit (1 – (ETa/ETc)) and yield depression (1 – (Ya/Ym)) is always linear (Doorenbos and Kassam, 1986) with a slope called the yield response factor for the crop 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 by the following equation:

$(1- Ya/Ym) = Ky\ (1- ETa/ETm)$ (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.

3. Experimental design

The experimental layout was a split-plot system in a randomised complete block design with three replications. Water sources and deficit irrigation 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.

4. 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 samples of fruits (approximately 2 kg from the first and second trusses) were taken from each experimental unit at the peak of harvesting (the fourth picking) for laboratory analyses. The homogenised

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fruits juice was subjected to the following determinations; total soluble solids (T.S.S, °Brix) using a portable refractometer , vitamin C content using the pigment of 2,6-dichlorophenol-indophenol while, acidity (pH) was measured with a glass electrode pH meter (A.O.A.C., 1990)

2.5. 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 among the means were evaluated for significance using a Revised Least Significant Difference (L.S.D.) test at 0.05 level, as described by Snedecor and Cochran (1989).

RESULTS AND DISCUSSION

1. Total biomass and total fruits yield

The impact of water quality and deficit irrigation treatments on total dry biomass and total tomato fruit yield, in 2009/2010 and 2010/2011 seasons, are presented in Table 4. Irrigation with saline water significantly reduced total dry biomass and total fruits yield compared to irrigation with non saline water , in both seasons. The reduction in total biomass and total fruits yield were approximately 31% and 21%, respectively. 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%. Cuartero and Fernandez-Munnza (1999) suggested that, even under normal growing conditions, the EC of root solution is close to the threshold value for yield reduction. Similarly, 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}.

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Table 4. total biomass and total fruits yield of tomato as affected by water quality and deficit irrigation, in 2009/2010 and 2010/011 seasons.

Water quality	Deficit irrigation treatment	Total biomass (ton ha^{-1} DW)		Total fruits yield (ton ha^{-1} FW)	
		2009/2010	2010/2011	2009/2010	2010/2011
Non-saline water		14.274 a	14.353 a	114.347 a	115.04
Saline water		9.839 b	9.926 b	90.301 b	90.68 b
	T1 (100%)	11.583 cd	11.795 cd	112.460 a	113.422 a
	T2 (75% S1)	12.140 ab	11.951 bc	109.872 b	110.661 ab
	T3 (75% S2)	11.289 d	11.422 d	106.508 c	107.255 c
	T4 (75% S3)	12.582 a	12.427 ab	110.862 ab	110.470 ab
	T5 (75%)	11.620 cd	11.754 d	95.641 f	96.350 f
	T6 (50% S1)	12.338 ab	12.564 a	99.106 de	99.715 de
	T7 (50% S2)	12.023 bc	12.207 abc	96.962 ef	97.270 ef
	T8 (50% S3)	12.177 ab	12.217 abc	101.904 d	102.670 d
	T9 (50%)	11.913 bc	12.089 abc	87.602 g	87.922 g

* Values followed by the same letter(s), within a comparable group of means, do not significantly differ using revised L.S.D test at 0.05 probability level.

The total dry biomass accumulation was significantly increased using deficit irrigation treatments T_2, T_4, T_6 and T_8, in 2009/2010 and only T_4 and T_6, in 2010/2011 (Table 4). However, no significant differences were observed among the remainder of 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. These results illustrated that deficit irrigation treatments(T_2 and T_6) during the vegetative growth stage or (T_4 and T_8) during the fruiting growth stage significantly increased the total dry biomass; however, deficit irrigation treatments (T_3 and T_7) during the reproductive growth stage 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.

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Under all DI treatments, the total fruits 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 (Table 4). 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 fruits 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. Deficit irrigation 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, Deficit irrigation during all growth stages at T5 and T9 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 deficit irrigation were fruiting and vegetative growth stages and the most sensitive one was reproductive stage. These findings are in line with the results of Srinivasa *et al.* (2000) who showed that the reproductive tomato growth stage is more sensitive phenological stage to water deficit than vegetative growth stage. According to Savic *et al*. (2011) they reported that, the phenological stages of tomato may react differently to deficit irrigation and scheduling irrigation should take into account the stages in which the crop is particularly sensitive to water deficits.

The interaction effects of water quality and deficit irrigation significantly affected both the total dry biomass and total fruits yield, in the two growing seasons (Table 5). The obtained results illustrated that when the two types of stresses; saline and deficit irrigation were coupled together, a serious reduction occurred on total dry biomass and total fruits yield. The highest value of total dry biomass was recorded when deficit irrigation 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 when irrigation at 100% of Etc (T_1), 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. While, the lowest magnitude of total fruits yield was recorded when the irrigation through all growth stages was achieved with non saline water at 50% of Etc (T_9) , in both seasons.

Table 5. Total biomass and total fruits yield of tomato as affected by the interaction of water quality and deficit irrigation, in 2009/2010 and 2010/011 seasons.

Water quality	Deficit irrigation treatment	Total biomass (ton ha^{-1} DW)		Total fruits yield (ton ha^{-1} FW)	
		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
	T2 (75% S1)	14.137 bcd	13.862 d	121.872 b	122.673 ab
	T3 (75% S2)	13.256 e	13.237 e	118.366 c	119.260 c
	T4 (75% S3)	14.878 a	15.081 a	122.966 ab	123.620 ab
	T5 (75%)	13.956 d	13.941 d	108.189 f	108.920 ef
	T6 (50% S1)	14.483 abc	14.789 ab	110.563 e	111.200 e
	T7 (50% S2)	14.655 ab	14.745 abc	108.560 ef	108.420 f
	T8 (50% S3)	14.464 bc	14.735 abc	113.893 d	115.120 d
	T9 (50%)	14.316 bcd	14.431 bc	100.116 g	100.220 g
Saline water	T1 (100%)	9.129 j	9.486 i	100.323 g	100.925 g
	T2 (75% S1)	10.276 fg	10.160 fg	97.872 h	98.650 gh
	T3 (75% S2)	9.465 ij	9.715 hi	94.650 i	95.250 i
	T4 (75% S3)	10.468 f	10.023 g	98.758 gh	97.320 hi
	T5 (75%)	9.472 ij	9.718 ghi	83.092 m	83.780 l
	T6 (50% S1)	10.343 fg	10.499 f	87.650 k	88.230 jk
	T7 (50% S2)	9.646 hi	9.903 gh	85.364 l	86.120 k
	T8 (50% S3)	10.070 gh	9.924 gh	89.914 j	90.220 j
	T9 (50%)	9.686 hi	9.906 gh	75.088 n	75.625 m

* Values followed by the same letter(s), within a comparable group of means, do not significantly differ using revised L.S.D test at 0.05 probability level.

The effects of water quality and deficit irrigation through variant growth stages on reduction of fruits yield and saving of irrigation water, in 2009/2010 and 2010/2011, are summarised in Figure 1. As an average of the two seasons, irrigation with non saline water during vegetative or fruiting stage at 75% of Etc i.e T_2 and T_4 resulted in a reduction of total fruits yield by 2.6 and 1.6 %, but saved 10.9 and 9.8% of irrigation water, consecutively. However, irrigation with non saline water during flowering stage at 75% of Etc (T_3) reduced total fruits yield by 5.2 %, but conserved 12.7% of irrigation water. Moreover, irrigation with non saline water during fruit set stage at 50% of Etc (T_8) reduced total fruits yield by 8.6%, but saved 15 % of irrigation water. Irrigation with saline water throughout all growth stages at 50% of Etc (T_9) attained the lowest total fruits yield (20%) compared to the control treatment (T_1) , however, T_9 treatment saved 50%. of water irrigation.

However, when the crop was only exposed to salt stress (saline water combined with T1 treatment), the yield reduction (19.6%) was approximately equal with the results of a higher degree of water stress using good quality water (T_9), but without any savings in irrigation water. Furthermore, the yield reduction was doubled (40%) when saline water was combined with T_9. These results indicated that salt stress had a more adverse impact on tomato total yield than water stress at the different developmental stages.

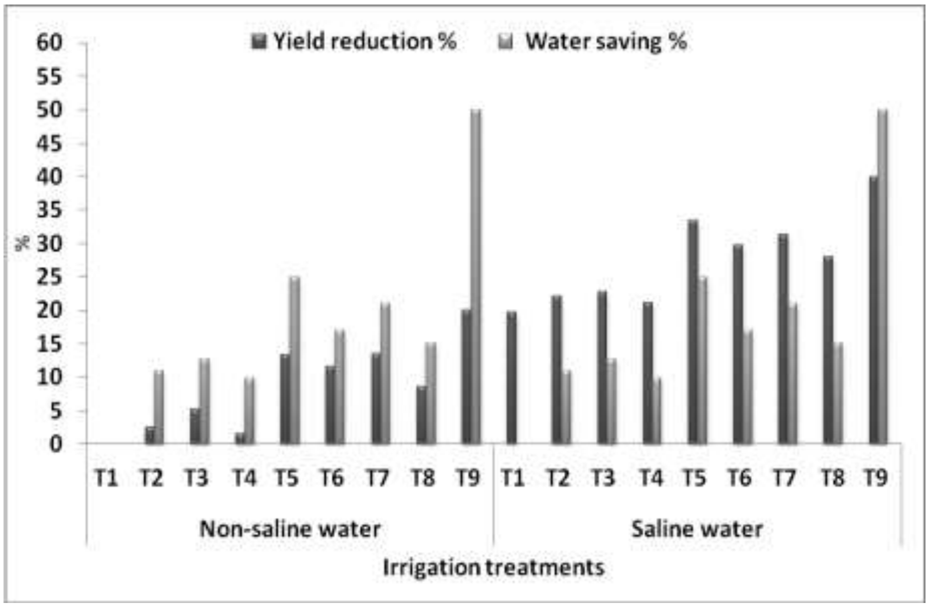

Figure 1.Yield reduction and irrigation water saving percentages of tomato as affected by water quality and deficit irrigation, as an average of the two seasons (2009/2010 and 2010/011).

2. Fruit quality characteristics

Significant variations in tomato fruit quality traits were obvious due to quality of irrigation water. Irrigation with non saline water gave significantly higher magnitudes of fruit weight and vitamin C content than Irrigation with non saline water, in 2009/2010 and 2010/2011 (Table 6). The reverse was true for TSS and pH traits (Table 7). 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 %, orderly. These results indicated that, the depletion in total fruits 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 Favatil *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 a biotic stress. As average of the two seasons, irrigation with saline water gave significantly higher values of total soluble solids (T.S.S.) and acidity(PH) than irrigation with non saline water by 11.1% and 6.9 %, orderly. The positive effect of irrigation with saline water on T.S.S. content of fruits probably arised as a result of reduction in water intake by the fruits (Sakamoto *et al*., 1999; Tantawy, 2009 and Al-Yahyai ,2010). Moreover, Munns (2002) reported that, under saline conditions an active accumulation of solutes, which were mainly ions and organic molecules, occurred. The enhancing effect of irrigation with saline water on acidity is in harmony with those of Sanders *et al*. (1989) who reported a positive relationship between salinity rate in irrigation water and acidity in tomato fruits.

Table 6. Fruit weight and vitamin C content of tomato as affected by water quality and deficit irrigation, in 2009/2010 and 2010/011 seasons.

Water quality	Deficit irrigation treatment	Average fruit weight (g)		vitamin C content (mg/100g FW)	
		2009/2010	2010/2011	2009/2010	2010/2011
Non-saline water		111.7 a	113.1 a	32.4 a	32.3 a
Saline water		76.2 b	78.1 b	29.2 b	27.3 b
	T1 (100%)	109.3 a	110.6 a	28.1 d	28.1 e
	T2 (75% S1)	106.3 bc	107.3 b	29.0 d	28.9 e
	T3 (75% S2)	104.7 c	104.7 b	29.5 cd	28.9 e
	T4 (75% S3)	107.6 ab	108.1 ab	29.3 d	29.1 cde
	T5 (75%)	91.8 d	97.2 c	32.8 ab	30.9 b
	T6 (50% S1)	82.1 e	84.8 e	30.6 c	30.2 bc
	T7 (50% S2)	79.1 f	79.1 f	32.1 b	30.1 bcd
	T8 (50% S3)	91.9 d	94.2 d	31.8 b	29.8 bcd
	T9 (50%)	72.9 g	74.1 g	33.8 a	32.4 a

* Values followed by the same letter(s), within a comparable group of means, do not significantly differ using revised L.S.D test at 0.05 probability level.

Table 7. Total soluble solids and acidity(pH) of tomato fruits as affected by water quality and deficit irrigation, in 2009/2010 and 2010/011seasons.

Water quality	Deficit irrigation treatment	T.S.S (%)		pH	
		2009/2010	2010/2011	2009/2010	2010/2011
Non-saline water		5.41 b	5.88 b	4.17 b	4.46 b
Saline water		6.05 a	6.49 a	4.58 b	4.64 a
	T1 (100%)	4.92 e	5.27 e	4.10 c	4.16 c
	T2 (75% S1)	5.19 d	5.91 cd	4.14 c	4.18 c
	T3 (75% S2)	5.24 d	5.56 de	4.24 c	4.32 c
	T4 (75% S3)	5.09 de	5.52 de	4.15 c	4.23 c
	T5 (75%)	6.33 b	6.58 b	4.58 ab	4.79 ab
	T6 (50% S1)	5.89 c	6.28 c	4.45 b	4.68 ab
	T7 (50% S2)	5.91 c	6.38 b	4.54 b	4.78 ab
	T8 (50% S3)	6.09 bc	6.42 b	4.44 b	4.68 b
	T9 (50%)	6.96 a	7.25 a	4.75 a	4.90 a

* Values followed by the same letter(s), within a comparable group of means, do not significantly differ using revised L.S.D test at 0.05 probability level.

Average fruit weight significantly decreased at all DI treatments compared to the check treatment (T_1), over the course of the two seasons, except T_4 treatment where the difference was not significant (Table 6). 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 illustrate that deficit irrigation from 100 to 75% ETc during vegetative stage (T_2) or fruiting stage (T_4) did not affect fruit weight, whereas the deficit irrigation during reproductive stage (T_3) or during the whole season (T_5) significantly reduced fruit weight. While, deficit irrigation from 100 to 50% Etc (T_6, T_7, T_8 and T_9), irrespective of the growth stage, significantly reduced fruit weight.

Deficit irrigation treatments, on the contrary, reflected significant positive effects on vitamin C, T.S.S. and pH contents (Tables 6 and 7). 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.

The enhancing effect of deficit irrigation on vitamin C content can be explained on the basis that, tomato plants irrigated at 100% Etc produced large canopy which probably results in suitable fruits cover and shading relative to those exposed to moderate or severe water stress during their growth (Patanè, 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 deficit irrigation on T.S.S. content can be discussed on the basis that, reduction of fruit size under deficit irrigation was mainly attributed to the reduction of water rather than the reduction of assimilates imported into the fruit (Ho,1987). This observation might explain why the plants subjected to deficit irrigation produce higher content of T.S.S. in fruits.

Comparisons among the mean values of the interaction between water quality and deficit irrigation treatments showed significant differences in the studied fruits quality traits, throughout the two experimental seasons (Tables 8 and 9).Regarding average fruit weight, the highest magnitudes were recorded when irrigation with non saline water combined with deficit irrigation 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) , consecutively , in both seasons (Table 8). Meanwhile, the lowest value of average fruit weight was obtained when irrigation with saline water combined with deficit irrigation 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 deficit irrigation 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), orderly ,in both seasons (Table 9). 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.

As for total soluble solids and acidity(pH), the highest content of both were attained when irrigation with saline water combined with deficit irrigation at 50% Etc during all growth stages (T_9) followed by

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deficit irrigation 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 (T1), in both years with one exception (Table 9) .

Table 8. Average fruit weight and vitamin C content of tomato fruits as affected by the interaction of water quality and deficit irrigation, in 2009/2010 and 2010/2011 seasons.

Water quality	Deficit irrigation treatment	Average fruit weight (g)		vitamin C content (mg/100g FW)	
		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
	T2 (75% S1)	125.5 ab	124.6 b	30.2 efg	31.4 ef
	T3 (75% S2)	124.1 b	123.3 b	30.8 d-g	31.9 cde
	T4 (75% S3)	127.2 ab	126.1 ab	31.1 cde	32.2 b-e
	T5 (75%)	108.4 d	116.1 c	34.4 a	33.2 ab
	T6 (50% S1)	98.5 e	99.5 d	31.8 cd	32.8 bcd
	T7 (50% S2)	94.1 ef	95.1 de	34.2 a	33.1 bc
	T8 (50% S3)	113.3 c	115.2 c	33.9 ab	31.6 def
	T9 (50%)	86.4 gh	88.2 fg	35.2 a	34.4 a
Saline water	T1 (100%)	90.5 fg	91.2 ef	26.4 i	25.8 i
	T2 (75% S1)	87.2 fgh	90.1 efg	27.8 hi	26.4 hi
	T3 (75% S2)	85.4 h	86.2 g	28.2 hi	25.9 i
	T4 (75% S3)	88.1 fgh	90.2 efg	27.6 l	26.1 i
	T5 (75%)	75.2 i	78.3 h	31.2 cde	28.7 g
	T6 (50% S1)	65.8 jk	70.2 i	29.4 gh	27.6 gh
	T7 (50% S2)	64.2 k	63.1 j	29.9 efg	27.0 hi
	T8 (50% S3)	70.6 j	73.2 hi	29.8 fg	28.1 g
	T9 (50%)	59.4 l	60.1 j	32.4 bc	30.4 f

* Values followed by the same letter(s), within a comparable group of means, do not significantly differ using revised L.S.D test at 0.05 probability level.

Table 9. Total soluble solids and acidity(pH) of tomato fruits as affected by the interaction of water quality and deficit irrigation, in 2009/2010 and 2010/2011 seasons.

Water quality	Deficit irrigation treatment	TSS (%)		pH (%)	
		2009/2010	2010/2011	2009/2010	2010/2011
Non-saline water	T1 (100%)	4.72 i	4.93 g	3.96 k	4.04 i
	T2 (75% S1)	4.96 hi	5.91 cde	3.98 jk	4.06 i
	T3 (75% S2)	5.02 hi	5.26 fg	4.12 ij	4.20 hi
	T4 (75% S3)	4.86 i	5.12 g	4.02 jk	4.14 hi
	T5 (75%)	5.95 d	6.18 c	4.30 fgh	4.66 cde
	T6 (50% S1)	5.36 fg	5.64 def	4.16 hij	4.56 ef
	T7 (50% S2)	5.50 ef	5.92 cde	4.27 f-i	4.72 cde
	T8 (50% S3)	5.78 de	6.04 cd	4.21 f-i	4.63 def
	T9 (50%)	6.61 bc	6.98 b	4.56 de	4.75 b-e
Saline water	T1 (100%)	5.12 gh	5.62 ef	4.25 f-i	4.28 gh
	T2 (75% S1)	5.42 fg	5.92 cde	4.30 fgh	4.30 gh
	T3 (75% S2)	5.46 ef	5.86 cde	4.36 ef	4.45 fg
	T4 (75% S3)	5.32 fgh	5.93 cde	4.28 fgh	4.32 gh
	T5 (75%)	6.72 b	6.98 b	4.86 ab	4.92 ab
	T6 (50% S1)	6.42 bc	6.92 b	4.75 bcd	4.81 bcd
	T7 (50% S2)	6.31 c	6.85 b	4.81 abc	4.85 bc
	T8 (50% S3)	6.40 bc	6.81 b	4.68 cd	4.73 cde
	T9 (50%)	7.31 a	7.53 a	4.95 a	5.06 a

* Values followed by the same letter(s), a comparable group of means, do not significantly differ using revised L.S.D test at 0.05 probability level.

3. Water use efficiency

Irrigation with saline water, significantly, reduced WUE and TYWUE; calculated on the basis of total dry biomass and total fresh fruits yield respectively, in comparison with irrigation with non saline water, in both experimental seasons (Table 10). The adverse effect of irrigation with saline water on total dry biomass and total fresh fruits yield (Table 5) confirm the reduction in WUE and TYWUE. Similar conclusions on tomato crop were documented by Al-Harbi *et al.*(2009) and Al-Omran *et al.*(2012).

Significant differences in WUE and TYWUE due to deficit irrigation rate were detected, in both seasons (Table 10). Comparisons among mean values of the different deficit irrigation treatments showed that deficit irrigation at 50%Etc through the various growth stages (T_9) recorded the highest mean values of WUE and TYWUE followed by deficit irrigation at 75%Etc through all growth stages (T5) which saved the largest amounts of irrigation water, in both experimental years. Meanwhile, deficit irrigation at 100% Etc through the different growth stages recorded the lowest magnitudes of WUE and TYWUE, in 2009/ 2010 and 2010/2011. The obtained results are in agreement with previous findings of tomato plants grown under a wide range of deficit irrigation treatments (Ozbahce and Tari, 2010; Patane *et. al*., 2010 and Wahb-Allah *et. al*. ,2011).

Table 10. Water use efficiency (WUE) and total yield water use efficiency (TYWUE) of tomato as affected by water quality and deficit irrigation in 2009/2010 and 2010/011 seasons.

Water quality	Deficit irrigation treatment	WUE (kg DW m^{-3}) 2009/2010	WUE (kg DW m^{-3}) 2010/2011	TYWUE (kg FW m^{-3}) 2009/2010	TYWUE (kg FW m^{-3}) 2010/2011
Non-saline water		3.56 a	3.58 a	28.58 a	28.75 a
Saline water		2.45 b	2.48 b	22.57 b	22.67 b
	T1 (100%)	2.41 e	2.45 e	23.42 e	23.62 e
	T2 (75% S1)	2.75 cd	2.70 cd	24.88 cd	25.05 cd
	T3 (75% S2)	2.61 cd	2.64 d	24.65 cd	24.82 d
	T4 (75% S3)	2.81 cd	2.78 d	24.83 cd	24.74 d
	T5 (75%)	3.23 b	3.27 b	26.62 b	26.82 b
	T6 (50% S1)	3.06 bc	3.11 bc	24.57 d	24.73 d
	T7 (50% S2)	3.13 bc	3.17 c	25.25 bc	25.33 c
	T8 (50% S3)	2.94 cd	2.95 d	24.68 cd	24.87 d
	T9 (50%)	4.96 a	5.03 a	36.50 a	36.63 a

* Values followed by the same letter(s), within a comparable group of means, do not significantly differ using revised L.S.D test at 0.05 probability level.

The interaction effects of water quality and deficit irrigation treatments significantly affected both WUE and TYWUE, over the two seasons (Table 11). Irrigation with non saline water together with deficit irrigation at 50% Etc, during all growth stages (T_9) , reflected best values of WUE and TYWUE, while irrigation with saline water at 100%Etc during all growth stages (T_1), in 2009/2010 and 2010/2011 (Table 12). These results indicate that 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 (evapotranspiration) through the following strategies; reducing water loss by unproductive evaporation, increasing the proportion of marketable yield to the total biomass produced (harvest index) 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).

Table 11. water use efficiency (WUE) and total yield water use efficiency (TYWUE) of tomato as affected by the interaction of water quality and deficit irrigation, in 2009/2010 and 2010/2011 seasons

Water quality treatment	Deficit irrigation treatment	WUE (kg DW m^{-3})		TYWUE (kg FW m^{-3})	
		2009/2010	2010/2011	2009/2010	2010/2011
Non-saline water	T1 (100%)	2.98 fgh	2.99 fg	25.95 de	26.23 de
	T2 (75% S1)	3.20 ef	3.13 ef	27.59 cd	27.77 cd
	T3 (75% S2)	3.06 fg	3.06 fg	27.39 cd	27.60 cd
	T4 (75% S3)	3.33 def	3.37 def	27.54 cd	27.69 cd
	T5 (75%)	3.88 bc	3.88 bc	30.11 bc	30.32 bc
	T6 (50% S1)	3.59 b-e	3.66 bcd	27.42 cd	27.57 cd
	T7 (50% S2)	3.81 bcd	3.83 bcd	28.27 bcd	28.23 bcd
	T8 (50% S3)	3.50 c-f	3.56 cde	27.59 cd	27.88 bcd
	T9 (50%)	5.96 a	6.01 a	41.71 a	41.75 a
Saline water	T1 (100%)	1.90 j	1.97 i	20.90 f	21.03 f
	T2 (75% S1)	2.32 ij	2.30 hi	22.16 ef	22.33 f
	T3 (75% S2)	2.19 ij	2.24 hi	21.91 f	22.04 f
	T4 (75% S3)	2.34 ij	2.24 hi	22.12 ef	21.80 f
	T5 (75%)	2.63 ghi	2.70 gh	23.13 ef	23.32 ef
	T6 (50% S1)	2.56 ghi	2.60 gh	21.73 f	21.88 f
	T7 (50% S2)	2.51 hi	2.57 gh	22.23 ef	22.42 ef
	T8 (50% S3)	2.43 i	2.40 i	21.78 f	21.85 f
	T9 (50%)	4.03 b	4.12 ab	31.28 b	31.51 b

* Values followed by the same letter(s), within a comparable group of means, do not significantly differ using revised L.S.D test at 0.05 probability level.

4. Crop yield response factor

The crop yield response factor (Ky) was determined for the different deficit irrigation 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 to not be tolerant to deficit irrigation, as noted by Ayas and Domirtas (2009). The yield response factor 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 (Figure 2), indicating that the reduction in crop productivity is proportionally less than the relative ET deficit in both cases. 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 *et al*. (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.

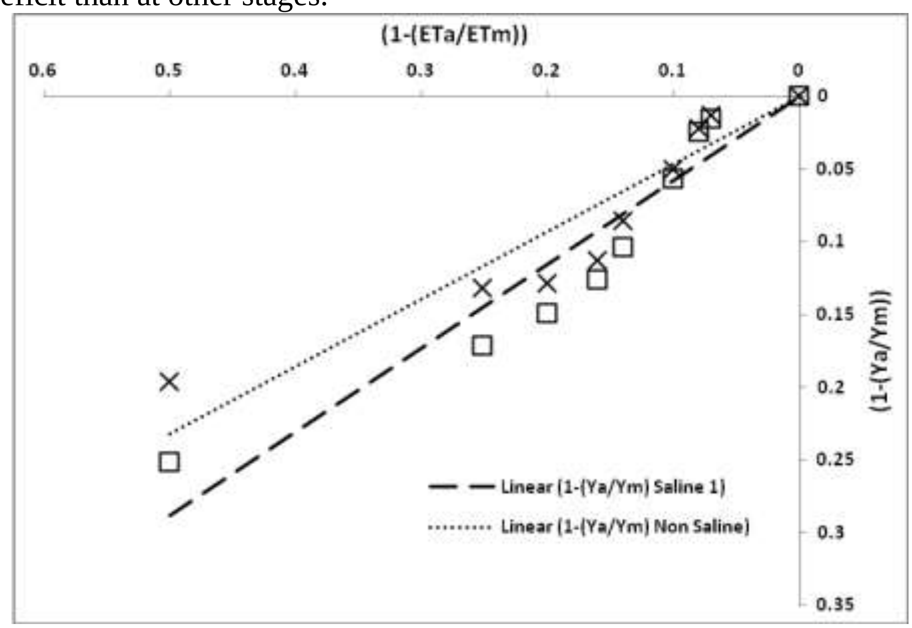

Fig. 2 Relative yield decrease as function of relative evapotranspiration decrease measured in tomato (pooled of the two seasons).

CONCLUSION

Tomatoes grown under greenhouse conditions could be considered to be a water stress-tolerant crop. 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 deficit irrigation and the reproductive stage could be considered the most sensitive one. To save approximately 21% of the irrigation water, a deficit irrigation 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.

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الملخص العربي

تأثير جودة مياه الري ونقص الري خلال مراحل النمو المختلفة للطماطم على النمو والإنتاجية وكفاءة استخدام المياه

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المشكلة الرئيسية المؤثرة على الزراعة في جميع أنحاء العالم عدم وجود موارد كافية من المياه لاستخدامها في الأغراض الزراعية، واستخدام الري الناقص - الذي يسمح بقدر من الإجهاد المائي خلال بعض أو كل مراحل نمو النبات دون حدوث انخفاض مؤثر في كمية المحصول - احد وسائل التوفير في كميه مياه الري المستخدمة. تهدف الدراسة الحالية إلى اختبار تأثير كل من جودة مياه الري و برنامج الري الناقص خلال مراحل النمو المختلفة على النمو والإنتاجية وكفاءة استخدام مياه الري لنبات الطماطم لذلك أجريت تجربتان متماثلتان داخل البيوت المحمية خلال موسمي النمو 2010/2009 و 2011/2010م . استخدم في الدراسة نوعان من مياه الري يختلفان في جودتهما (ماء بئر عادي ذو معامل توصيل كهربائي مقداره 3.6 ديسيسيمنز/متر وماء نفس البئر العادي بعد تنقيته بمحطة تحليه المياه ليصبح ذو معامل توصيل كهربائي مقداره 0.9 ديسيسيمنز/متر) بالإضافة إلى تسع معاملات للري الناقص تشمل ثلاثة معاملات للري بمعدل 100% ، 75% ، 50 % من قيمة البخر نتح طوال حياه النبات ، ثلاث معاملات للري بمعدل 75 ٪ من قيمة البخر نتح خلال مرحلة النمو الخضري أو مرحلة النمو التكاثري أو مرحلة الإثمار ثم الري بمعدل 100% من قيمة البخر نتح خلال بقية مراحل النمو ،

ثلاث معاملات للري بمعدل 50 ٪ من قيمة البخر نتح خلال مرحلة النمو الخضري أو مرحلة النمو التكاثري أو مرحلة الإثمار ثم الري بمعدل 100% من قيمة البخر نتح خلال بقية مراحل النمو . استخدم في تنفيذ الدراسة نظام القطع المنشقة لمرة واحدة في تصميم عشوائي كامل بثلاثة مكررات.

أوضحت النتائج تأثيرات معنوية لجودة مياه الري على كل من المحصول وكفاءة استخدام المياه حيث أدى الري بالماء المالح إلى انخفاض المحصول الكلى للثمار بنسبة 22٪ ، 24٪ أثناء الموسم الأول والثاني على التوالي. التأثير السلبي لمعاملات الري الناقص على الإنتاجية كان أكثر وضوحا عند استخدام الماء المالح مقارنة بالماء الغير مالح ، ولقد كانت مرحله النمو الخضري والنمو الثمري أكثر تحملا للري الناقص مقارنه بمرحلة النمو التكاثري والتي يمكن اعتبارها الأكثر حساسية لنقص مياه الري. تراوحت قيمة معامل استجابة المحصول بين 0.24- 0.75 لمعاملات الري الناقص مما يدل على تحمل نبات الطماطم لنقص مياه الري . أيضا أشارت النتائج أن معاملة الري بالماء الغير مالح بمعدل 75 ٪ من قيمة البخر نتح خلال مرحلة النمو الخضري أو مرحلة النمو الثمرى لم تؤثر معنويا على النمو والإنتاجية حيث انخفض المحصول الكلى للثمار بنسبة اقل من 2.6٪ ، بالإضافة إلى أنها أدت إلى تحسين كل من كفاءة استخدام المياه و محتوى الثمار من فيتامين ج و المواد الصلبة الذائبة الكلية ، علاوة على توفير 10٪ من كمية المياه المستخدمة في الري وبالتالي يمكن التوصية باستخدام هذه المعاملة عند إنتاج الطماطم بالبيوت المحمية . على الرغم أن معاملة الري بالماء الغير مالح بمعدل 50 ٪ من قيمة البخر نتح خلال مرحلة النمو الثمرى أدت إلى توفير 21٪ من كميه المياه المستخدمة في الري إلا أن الانخفاض في محصول الثمار بلغ تقريبا 8.6 %.