Influence of Deficit Irrigation Using Saline Water on Yield of Tomato under Two Irrigation Systems

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ABSTRACT

Field experiment was conducted in calcareous soil at Maryout Experimental Station Farm, Desert Research Center, Egypt to investigate the influence of deficit irrigation water using highly saline water on yield and water productivity of tomato (*Lycopersicon esculentum, mill.*, cultivator 888) under drip and gated pipe irrigation systems. The tomato plants were subjected to 3 deficit irrigation depths (100, 75 and 50 % of ETc) throughout 3 growth stages (development, flowering and harvesting) using highly saline water of 9.15 dSm^{-1} plus control treatment. The tomato plants were irrigated by the full irrigation (100 % ETc) during the whole growth season using slightly saline water of 2.80 dSm^{-1}. The reduction percentage in tomato fruit yield ranged between 9.9 to 41.5 % and 9.1 to 30.9 % at treatment $T_2$100 – D (plants irrigated by the full irrigation: 100% of ETc) using highly saline water throughout the development stage then irrigated by the same water depth using slightly saline water (agricultural drainage water), throughout the other growth stages and treatment $T_9$50 – F (plants irrigated by deficit irrigation depth of 50% ETc using highly saline water, 9.15dSm^{-1}. The flowering growth stage of tomatoes was the highest stage influenced to deficit irrigation using highly saline water especially at deficit irrigation of 50 % ETc. The tomato fruit yield under drip irrigation system was significantly higher than that obtained under gated pipe irrigation system. The highest value of crop water productivity (CWP) was obtained at control treatment and the lowest value was obtained at treatment $T_9$50-F. The highest and lowest values were 9.5 and 5.56 kg/m^3 and 8.23 and 5.69 kg/m^3 under drip and gated pipe irrigation systems, respectively. A significant polynomial relationship between tomato fruit yield (Y), kg/m^2, and applied irrigation water (AW), m^3/m^2 was given with R^2 0.78. The predicted maximum yields were 18.54 and 11.63 kg/m^2 and the corresponding calculated the applied irrigation water were 2.57 and 2.59 m^3/m^2 under drip and gated pipe irrigation systems, respectively. The crop response factor (Ky) using highly saline water under drip and gated pipe irrigation systems were 1.090 and 0.743, respectively.

Keywords: deficit irrigation, saline water, crop water productivity, drip irrigation and gated pipe.

INTRODUCTION

The increasing demand for water resources in the world, especially in the arid and semi-arid regions has forced farmers to use low quality water for irrigation such as agricultural drainage water and marginal quality ground water. The use of these low qualities in irrigation is depending on total concentration, deficit irrigation, soil properties, climate, irrigation system, crop, plant growth stages and time use of the applied irrigation water during the growing season.

The influences of applied irrigation water on soil salinity distribution are depending on the quantity and quality of irrigation water and irrigation systems as well as time of the added irrigation water. Many investigators showed that the use of saline water in irrigation resulted in a marked increase in soil salinity, Kandiah, (1990), van Hoorn *et al.*, (1993), Pang *et al.*, (2004), Ma *et al.*, (2008) and Ben Ahmed *et al.*, 2012). On the other hand, El-Nagar (1995) stated that the soil salinity profile differs distinctly among several of irrigation systems due to the different methods of water application. Chartzoulakis and Michelakis (1990) agreed that salinity of soil saturation extracted under furrow, trickle, micro tube, porous clay tube and porous plastic tuber irrigation systems decreased with depth. Moreover, Singh-Saggu and Kaushal (1991) found that the plant root zone under trickle system remained almost salt free, while the high soil salinity values were recorded in it under the furrow system. While, Hanson and May (2004) concluded that soil salinity was the least near the drip line with values less than about 1 dS/m but salinity increased with horizontal distance from the drip line and with depth to values of about 7 dS/m. Furthermore, Assouline *et al.*, (2006) stated that the soil salinity affected by two main variables, namely, salt concentration in the soil solution and salt load in the root zone under daily irrigation. For a given water salinity, the salt concentration is dependent on the soil water content, while salt load is a function of the amount of water applied. Therefore, the salt regime in the root zone would be related to the water application rate or the irrigation frequency as these induce different spatial distribution of water content in the soil for similar total amount of applied water.

On the other hand, Chen and Feng, (2013) had mentioned that the mathematical relationships for soil salinity, irrigation amount and water salinity were established to evaluate the contribution of the irrigation amount and the salinity of saline water to soil salt accumulation under furrow irrigation system. They

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showed that soil salinities at the same amount of irrigation water but different water salinity increased with the water salinity. They noticed that when water salinity was 6.04 dS/m, the less water resulted in more salt accumulation in topsoil and less in deep layers. When water salinity was 2.89 dS/m, however, the less water resulted in less salt accumulation in topsoil and salinity remained basically stable in deep layers. Concerning the time of added irrigation water, Botia *et al.,* (2005) reported that, in general, the electrical conductivity of the soil extracts increased significantly with increasing time of exposure to saline water throughout the part or whole of growth season and decreased with soil depth.

The quantity and quality of applied irrigation water, the irrigation systems and irrigation management affect soil moisture distribution in the soil profile studied by several investigators. Chen and Feng, (2013) in their study on the dynamics of soil water-salt transportation and its spatial distribution characteristics under irrigation with saline water in a maize field experiment under furrow irrigation system revealed that the irrigation with water of high salinity could effectively increase soil water content, but the increment is limited comparing with the influence from irrigation amount. Under drip irrigation system, Selim, *et al.*, (2013) concluded that the daily irrigation regime kept the top soil layer moist with adequate amount of soil water as compared to the bi-weekly irrigation. On the other hand, Badr and Abou Hussein (2008) concluded that the soil water content under 1.4 ETc was much higher than under 1.0 ETc and 1.2 ETc for all soil depths. And the maximum soil water content for depth of 10 cm and for depth of 20 cm was comparable for all irrigation regimes while for depth of 30 cm, soil water content reached a maximum value under 1.4 ETc irrigation regime, probably because of greater input of irrigation water. Also, Dehghanisanij *et al.,* (2006) reported that volumetric soil water content as affected by irrigation regimes and crop growth stages were investigated at different radial distances from the emitter at a depth of 10 cm. Three irrigation regimes were applied: the first irrigation regime (ETc) was based on daily crop–water requirement while the two others were based on ETc + 20% and + 40% (1.2 ETc and 1.4 ETc, respectively). The results indicated that volumetric soil water content under 1.4 ETc was much higher than under ETc and 1.2 ETc for all radial distances.

One important method to increase water use efficiency (WUE) or crop water productivity (CWP) is deficit irrigation (Kirda *et al.,* 2004; Cheng *et al.,* 2012 and Al-Harbi, *et al.,* 2008), in which crops are deliberately exposed to some degree of deficit irrigation through the whole growth stage or at certain stages of the growth (Kirda *et al.,* 2004). On the other hand, Al-Harbi *et al.,* (2015) reported that the irrigation with saline water decreased tomato fruits yield and WUE. Moreover, the negative effect of deficit irrigation was more obvious when coupled with salt stress. Irrigation with saline water resulted in 23% reduction in yield. On the contrary, Zegbe-Dominguez *et al.,* (2003) studied deficit irrigation on tomato planted in greenhouse and found that the dry mass yield did not decrease under deficit irrigation compared with full irrigation. Moreover, the deficit irrigation can save up to 50% of irrigation water and increase WUE by 200%, with satisfactory yield.

Studies on yield response factor (Ky) to water deficiency in different crops are well documented in literature (Doorenbos and Kassam, 1986, Kirda *et al.,* 2004, and Ayas & Domirtas, 2009). When crops have Ky values lower than one, they are considered as tolerant to water deficit. On the contrary, crops having Ky values greater than one are considered as not tolerate to deficit irrigation. Doorenbos and Kassam (1979) reported that Ky value for total growing period of tomato was 1.05. While, Al-Harbi, *et al.*, 2015 reported that Ky values for tomato grown in greenhouse at Saudi Arabia irrigated by saline and non-saline irrigation water ranged between 0.24 and 0.75. On the other hand, Doorenbos and Kassam (1986) recorded that Ky values for tomato fruit yield subjected to deficit irrigation water during vegetative, flowering, yield formation and ripening stages were 0.4, 1.1, 0.8 and 0.4, respectively. While, Al-Harbi, *et al.*, (2015) revealed that the fruiting and vegetative growth stages were the most tolerant to deficit irrigation; whereas, the reproductive stage was the most sensitive one. The objective of the present study was to evaluate the influence of deficit irrigation using highly saline water applied throughout different growth stages on water productivity of tomato under drip and gated pipe irrigation systems.

MATERIALS AND METHODS

Field experiment was carried out at Maryout Experimental Station Farm, Desert Research Center, Egypt during 2007 summer season. The station located at latitude 30° 55' 71″ N, longitude 29° 51' 67" E and 50 m above sea level. The soil is a calcareous sandy clay loam (59 % sand, 13 % silt and 28 % clay) with 29.50 % total carbonate and 1.37 Mg/m^3 bulk density, which were determined accordingly Kulte (1986). The electric conductivity of initial soil paste extract (ECe) was 2.13 dS m^{-1} and soil pH was 8.2 which were measured in soil paste using pH meter according to Page (1984). Soil salinity (ECe) and total soluble salts were determined in the soil saturation extract (Richards, 1954). The soil profile were classified as (0 – 50 cm) was the upper soil layer and the (50 - 100 cm) was the deep layer.

The layout of the experiment was a completely randomized design (CRD) with three replicates. Drip and gated pipe irrigation systems were used in this experiment. The tomato plants (*Lycopersicon esculentum, mill.*, cultivator 888) were used. The space between plants was 0.5 m with distance between rows of 1 m and the plot area was 15 m^2. The amount of applied water was measured using water meters installed on lines for each treatment. The used emitters were GR with discharge 4 Lh^{-1} and the gated-pipe irrigation system was orifice gates. Two irrigation water salinities were used in the experiment. The first one was agricultural drainage water of 2.81 dSm^{-1} and the second was well water of 9.15 dSm^{-1}.

Each irrigation system is consisted of 10 irrigation treatments combined between 3 deficit irrigation depths of 100, 75 and 50% of crop evapotranspiration (ETc), using highly saline water (well water) of 9.15 dSm^{-1} and 3 growth stages (development, flowering and harvesting) plus control treatment, where the tomato plants were irrigated by the full irrigation (100% ETc) during the whole growth season using agricultural drainage water of 2.80 dSm^{-1} as follows:

- $T_1$100 (control): the plants were irrigated by full irrigation (100% of ETc) using agricultural drainage water of 2.81dSm^{-1} throughout the whole growth season.
- $T_2$100 – D: the plants were irrigated by full irrigation (100% of ETc) using highly saline water (well water), 9.15dSm^{-1}, throughout the development stage then irrigated by the same irrigation water depth using agricultural drainage water, 2.80 dSm^{-1}, throughout the other growth stages.
- $T_3$100 – F: the plants were irrigated by full irrigation (100 % of ETc) by highly saline water, 9.15dSm^{-1}, during the flowering stage and irrigated by the same irrigation water depth using agricultural drainage water, 2.80dSm^{-1}, throughout the other growth stages.
- $T_4$100 – H: the plants were irrigated by full irrigation (100% of ETc) by highly saline water, 9.15 dSm^{-1}, throughout the harvesting stage and irrigated by the same irrigation water depth using agricultural drainage water, 2.80 dSm^{-1}, throughout the other growth stages.
- $T_5$75 – D: the plants were irrigated by deficit irrigation depth of 75 % of ETc) using highly saline water, 9.15 dSm^{-1}, throughout the development stage and irrigated by full irrigation (100% of ETc) using agricultural drainage water, 2.80 dSm^{-1}, throughout the other growth stages.
- $T_6$75 – F: the plants were irrigated by deficit irrigation depth of 75 % of ETc using highly saline water, 9.15 dSm^{-1}, throughout the flowering stage and irrigated by full irrigation (100% ETc) using agricultural drainage water, 2.80 dSm^{-1}, throughout the other growth stages.
- $T_7$75 – H: the plants were irrigated by the deficit irrigation depth of 75% of ETc using highly saline water, 9.15 dSm^{-1}, throughout the harvesting stage and irrigated by full irrigation (100% of ETc) using agricultural drainage water, 2.80 dSm^{-1}, throughout the other growth stages.
- $T_8$50 – D: the plants were irrigated by the deficit irrigation depth of 50% of ETc using highly saline water, 9.15 dSm^{-1}, throughout the development stage and irrigated by full irrigation (100% ETc) using drainage water, 2.80 dSm^{-1}, throughout the other growth stages.
- $T_9$50 – F: the plants were irrigated by deficit irrigation depth of 50% of % ETc using highly saline water, 9.15dSm^{-1}, throughout the flowering stage and irrigated by full irrigation (100% of ETc|) using agricultural drainage water, 2.80dSm^{-1}, throughout other growth stages.
- T_{10}50 – H: the plants were irrigated by the deficit irrigation depth of 50% of ETc using highly saline water, 9.15dSm^{-1}, throughout the harvesting stage and irrigated by full irrigation (100% of ETc) using agricultural drainage water, 2.80 dSm^{-1}, throughout the other growth stages.

Crop water requirement was calculated using CROPWAT 8 computer program using Penman-Monteith equation. The duration of tomato stages and the crop factor of these stages were 35, 45 and 30 days and 0.60, 1.15 and 0.80 for development, flowering and harvesting growth stages, respectively, according to Allen, *et al.*, (1998). The irrigation system efficiencies were 85 and 65 % for drip and gated pipe irrigation systems, respectively, and the leaching requirements were calculated accordingly, Doorenbos and Pruitt (1984).

The applied irrigation water (AW) was calculated as follows:

Applied water (mm) = (ETc (mm)/Ei) + LR ……. (1)

Where: ETc is crop evapotranspiration (mm/d), Ei is irrigation system efficiency as percentage and LR is leaching requirements as percentage.

Volumetric soil water content of the soil layers, (Θ_V %), was determined by the neutron scattering – using the hydro probe CPN, 503 DR 50 mCi after the last irrigation at depths of 0-25, 25-50, 50-75 and 75-100 cm at the end of studied growth stages according to Kutiluk and Nielsen (1994). Fruit tomato yield in kg/ m^2 was determined at harvest.

The crop water productivity (CWP) is defined as the ratio of crop yield (kg) to volume of applied water (m^3) accordingly Kijne *et al.*, (2002) and Kijne *et al.*, (2003) and Ahmed *et al.*, (2004) as follows:

CWP = Yield/ Applied water …………. ………..(2)

The crop water productivity (CWP) reflects the benefit of applied water in production of yield. The CWP becomes curvilinear as some of the excess applied water goes to drainage or loss. A useful way to express the water production function is on a relative basis, where actual yield (Ya) is divided by maximum yield (Ym) and actual evapotranspiration (ETa) is divided by maximum crop evapotranspiration (ETm). The relationship between evapotranspiration deficit (1 – (ETa/ETm)) and yield depression (1 – (Ya/Ym)) is considered linear (Doorenbos and Kassam, 1986), with a slope called the yield response factor of the crop or crop response factor (Ky), (Kirda *et al.*, 2004). This relationship was expressed by the following equation:

$$(1- (Y_a/Y_{max})) = Ky\ (1- (ET_a/ET_m)) \quad (3)$$

The quadratic polynomial function of Helweg (1991) was expressed as follows:

$$Y_a = b_0 + b_1W + b_2W^2 \quad (4)$$

Where, Y_a is crop production or yield (kg/m^2), W is applied irrigation water (m^3/m^2) and b_0, b_1 and b_2 are fitting coefficients. When yield approaches its maximum value, the slope of the water productivity function against water applied goes to zero; therefore, the maximum applied water (W_{max}) was calculated by differentiating the CWP (Eq. 3) and equalized by zero, then the maximum predicted yield (Y_m) can be calculated by substituting the W_{max} in the Eq. (3):

$$\partial Y / \partial W = +b_1 + 2b_2W = 0 \quad (5)$$

$$W_{max} = - b_1/2b_2 \quad (6)$$

$$Y_{max} = b_0+b_1W_{max} + b_2W^2_{max} \quad (7)$$

Analysis of variance by 2 Way Completely Randomized was used to test the degree of variability among the obtained data. Least significant difference (LSD) test was used for the comparison among treatments means (Steel and Torrie, 1980). CoHort computer program was used for the statistical analysis, Version 6.400.

RESULTS AND DISCUSSION

Irrigation schedule of tomato plants:

The applied irrigation water during different growth stages (irrigation scheduale of tomato plant) is presented in table (1).

Soil salinity under drip and gated pipe irrigation methods:

Soil layers salinity values, at the end of different growth stages of tomato as affected by deficit irrigation depths of 100, 75 and 50 % of ETc using highly saline water (well water) of 9.15 dSm^{-1} throughout development, flowering and harvesting growth stages under studied irrigation systems were increased as compared to soil layers salinity values of full irrigation (100% of ETc) using agricultural drainage water of 2.81 dSm^{-1} (control treatment) or as compared to soil layers salinity values of full irrigation (100% ETc) using highly saline water of 9.15dSm^{-1}during individual growth stages. The results in Table (2) reveal that soil salinity average values of active root zone, top layers,

Table 1.Irrigation schedule of tomato plants subjected to deficit irrigation by 9.15 dSm^{-1} under drip and gated pipe irrigation methods.

Treatment	ETc at growth stages (mm)			ETc (mm)	Applied water (AW) (m^3m^{-2})	
	Development	Flowering	Harvesting	D. &G.	Drip	Gated pipe
T1(Control)*	125.46	350.66	180.65	656.8	0.8680	1.1328
$T_2$100 – D	125.46*	350.66	180.65	656.8	0.8680	1.1328
$T_3$100 – F	125.46	350.66*	180.65	656.8	0.8680	1.1328
$T_4$100 – H	125.46	350.66	180.65*	656.8	0.8680	1.1328
$T_5$75 – D	94.10*	350.66	180.65	625.4	0.8265	1.0787
$T_6$75 – F	125.46	263.00*	180.65	569.1	0.7521	0.9816
$T_7$75– H	125.46	350.66	135.49*	611.6	0.8083	1.0549
$T_8$50 – D	62.73*	350.66	180.65	594.0	0.7851	1.0246
$T_9$50 – F	125.46	175.33*	180.65	481.4	0.6363	0.8304
T_{10}50 – H	125.46	350.66	90.33*	566.5	0.7486	0.9770

* The tomato plants subjected to deficit irrigation water using highly saline water (9.15dSm^{-1}) throughout development, flowering and harvesting growth stages. (D. & G. are drip and gated pipe irrigation.)

Control treatment (Agric. drainage water of EC= 2.81 dSm^{-1}) was used.

Table 2.Average values of soil salinity of soil layers at the end of different growth stages of tomato plants subjected to deficit irrigation (well water of 9.15dSm^{-1}) under drip and gated pipe irrigation systems

Treatment	Soil depth, cm	Soil salinity at the end of growth stages, ECe (dSm^{-1})					
		Development		Flowering		Harvesting	
		Drip	Gated pipe	Drip	Gated pipe	Drip	Gated pipe
T1 (Control)	0.0-50	3.19	2.69	3.28	3.17	3.41	3.24
	50-100	4.20	4.44	4.41	4.52	4.62	4.57
$T_2$100 – D	0.0-50	3.90	3.78	3.95	3.58	4.17	3.67
	50-100	5.11	5.16	5.11	5.15	5.16	5.23
$T_3$100 – F	0.0-50	3.60	3.23	4.27	3.83	3.99	3.58
	50-100	4.55	4.89	5.32	5.46	5.15	5.33
$T_4$100 – H	0.0-50	3.64	3.15	3.95	3.49	4.40	3.77
	75-100	4.47	4.99	4.89	5.07	5.34	5.56
$T_5$75– D	0.0-50	4.00	3.73	3.91	3.72	3.97	3.45
	50-100	5.17	5.39	5.00	5.31	5.14	5.29
$T_6$75– F	0.0-50	3.64	3.22	4.35	4.09	3.94	3.50
	50-100	4.58	4.98	5.35	5.55	5.22	5.28
$T_7$75– H	0.0-50	3.53	3.22	3.79	3.77	4.28	4.08
	50-100	4.45	4.94	5.07	5.22	5.54	5.67
$T_8$50– D	0.0-50	4.22	3.57	4.34	3.35	3.90	3.29
	50-100	5.32	5.47	4.92	5.37	5.21	5.39
$T_9$50– F	0.0-50	3.46	3.27	4.46	4.32	3.76	3.31
	50-100	4.69	5.01	5.41	5.56	5.29	5.36
T_{10}50– H	0.0-50	3.59	3.28	3.66	3.77	4.24	4.19
	50-100	4.62	5.03	4.92	5.29	5.60	5.92

(0 – 50 cm) at the end of different growth stages under drip irrigation system were higher than that obtained under gated pipe irrigation system. This behavior could be attributed to drip irrigation system enhanced salt accumulation in active root zone. The soil salinity average values of the deep layers (50 – 100 cm) at the end of different growth stages under drip irrigation system were lower than that obtained under gated pipe irrigation system. These results are in agreement with those obtained by Hanson and May (2004).

Under studied irrigation systems, the obtained results showed that the soil salinity average values at the end of the different growth stages for top and deep soil layers at full irrigation (100% ETc) increased by increasing of the irrigation water salinity (Table 2). On the other hand, the results elucidated that the soil salinity average values at the end of different tomato growth stages for top and deep soil layers were increased by decreasing the irrigation amounts (deficit irrigation depths of 100, 75 and 50 % ETc) using the same irrigation water salinity (9.15dSm^{-1}). These results indicated that the increase of irrigation water salinity was effectively more on salt accumulation in soil of active root zone and deep layers than that obtained under the decrease of irrigation water amounts with the same irrigation water salinity. Consequently, the influences of the same irrigation water salinity with different irrigation water amounts on soil salinity values are closely related to the irrigation water salinity. This conclusion is confirmed with those reported by Chen and Feng (2013), Assouline *et al.,* (2006) and Selim *et al.,* (2013)

Under drip irrigation system, the soil salinity average values of active root zone at the end of harvesting growth stage of tomatoes subjected to deficit irrigation of 100, 75 and 50 % ETc using highly saline water (9.15dSm^{-1}) were the lowest values (Table 2). Consequently, this stage is the lowest stage as affected by deficit irrigation depths of 75 and 50% ETc using highly saline water of 9.15dSm^{-1} than that obtained for other growth stages, the soil salinity average values of active root zone at the end of flowering growth stage were high. (Table 2). Consequently, this stage is the highest growth stage that can be affected by deficit irrigation using highly saline water than that other growth stages especially at deficit irrigation of 50% ETc under drip irrigation system. At the same deficit irrigation depth, the soil salinity average values in deep soil layers at the end of harvesting growth stage were the lowest (Table 2). Consequently, this stage is the least affected by deficit irrigation depths using highly saline water than other growth stages, while, the deep layers salinity average values at the end development growth stage, subjected to deficit irrigation depths of 100, 75 and 50 % ETc by highly saline water, 9.15dSm^{-}

1, had the opposite trend obtained that in active root zone, whereas; the salinity average values were highest (Table 2). Thus, this stage is the highest growth stage which is affected by deficit irrigation depths using highly saline water than the other growth stages especially at deficit irrigation of 50 % ETc, under drip irrigation system.

Under gated pipe irrigation system, the soil salinity average values of active root zone at harvesting growth stage of tomatoes subjected to deficit irrigation depths of 100, 75 and 50 % ETc using highly saline water, 9.15dSm^{-1}, were the lowest values (Table 2). Consequently, this stage is the lowest as affected to deficit irrigation water amounts using highly saline water than that other growth stages. While, the soil salinity average values of active root zone at development growth stages of tomatoes in general were the highest values (Table 2). Thus, this stage is the more stage as affected to deficit irrigation water amounts using highly saline water than that other growth stages under gated pipe irrigation system in environmental conditions. The soil salinity average values in deep layers at the end of development growth stage of tomatoes subjected to deficit irrigation depths of 100, 75 and 50% ETc using highly saline water, 9.15dSm^{-1}, were the lowest values (Table 2). Consequently, this stage is the lowest stage as affected to deficit irrigation water amounts using highly saline water than that other growth stages. While, the soil salinity average values in deep layers at the end of flowering growth stage of tomatoes were highest values (Table 2). Consequently, this stage is the highest stage as affected to deficit irrigation water amounts using highly saline water than that other growth stages especially at deficit irrigation of 50 % ETc, under gated pipe irrigation system in environmental conditions.

Soil moisture content under drip and gated pipe irrigation systems.

Volumetric soil water content (Θ_v %) in soil layers at the end of different growth stages as affected by deficit irrigation using highly saline water of 9.15 dSm^{-1} were increased comparing to soil water content values, of full irrigation (100 % ETc) using slightly saline water of 2.81 dSm^{-1} (control treatment) and decreased comparing to soil water content values of full irrigation (100 % ETc) with highly saline water of 9.15 dSm^{-1} during the individual growth stages, respectively (Table 3). The increase in soil water content might be attributed to the increased soil salinity resulted due to using highly saline water of 9.15dSm^{-1} while the decrease in soil water content might be attributed to the deficit irrigation water amounts throughout the development, flowering and harvesting growth stages.

The obtained results revealed that the soil water contents of the active root zone (upper layer, 0 – 50 cm) and deep layers (50 – 100 cm) at the end of the different growth stages of tomato plants as affected by deficit irrigation depths using highly saline water of (9.15 dSm^{-1}) were lower than that obtained under gated pipe irrigation system (Table 3). This is associated with the decrease amounts of applied irrigation water under drip irrigation system than under gated pipe irrigation system (Table 1). Furthermore, the obtained results elucidated that the soil water content values decreased, although, the increasing soil salinity at the end of the different growth stages as affected by the same deficit irrigation treatments (Table 2). This decrease is attributed to the decrease of the applied irrigation water amounts. These results indicated that the amount of applied irrigation water is effectively major factor on soil water content values; while, that of irrigation water salinity is a minor factor. Consequently, the influences of the same irrigation water salinity with different irrigation water amounts on soil water content values are closely related to the amount of applied irrigation water. Also, the influences of the same applied irrigation water amount with different irrigation water salinities on soil water content values are closely related to the irrigation water salinity value. These results are similar obtained by Selim *et al*., (2013).

Under drip irrigation system, the average values of soil water content for active root zone at harvesting growth stage of tomatoes subjected to deficit irrigation depths of 75 and 50 % ETc using highly saline water, 9.15dSm^{-1}, were the lowest values although, the soil active root zone salinities at the end of this stage are relatively high, (Table 3). The lowest values might be attributed to the applied irrigation water amount of tomato plants during this stage is low than that other stages. Also, this stage is the highest growth stage of tomato plants as affected by deficit irrigation water amounts using highly saline water than that other growth stages, especially at deficit irrigation depth of 50% ETc, under drip irrigation system in environmental conditions. On the other hand, The soil water content values in deep layers at growth stages of tomatoes subjected to deficit irrigation depths of 75 and 50 % ETc using highly saline water, 9.15dSm^{-1}, were corresponded with that obtained in active root zoon,(Table 3).

Under gated pipe irrigation system, the soil moisture content (average values) in active root zone at harvesting growth stage of tomatoes subjected to deficit irrigation depths of 75 and 50 % ETc using highly saline water, 9.15dSm^{-1}, were the lowest values, although the soil active root zone salinities at the end of this stage are relatively high, (Table 2).

Table 3. The average values of volumetric soil moisture content of soil layers (Θ_v%) at the end of different growth stages of tomato subjected to deficit irrigation depths using highly saline water of 9.15dSm^{-1} under drip and gated pipe irrigation system

Treatment	Soil depth, cm	Θ_v % of soil layers at the end of growth stages					
		Development		Flowering		Harvesting	
		Drip	Gated pipe	Drip	Gated pipe	Drip	Gated pipe
T1 (Control)	0.0-50	17.93	19.86	17.96	19.51	17.21	18.35
	50-100	23.62	25.88	24.12	24.04	23.29	24.47
$T_2$100 – D	0.0-50	20.92	21.77	18.45	19.92	18.29	18.64
	50-100	25.69	26.20	24.37	24.14	24.24	24.57
$T_3$100 – F	0.0-50	18.31	20.16	20.12	19.73	18.06	18.60
	50-100	23.95	25.96	24.46	24.50	23.71	24.84
$T_4$100 – H	0.0-50	18.44	20.29	18.74	19.54	18.63	18.85
	75-100	24.38	25.98	24.35	24.20	24.52	25.64
$T_5$75– D	0.0-50	16.91	18.76	18.47	18.37	17.46	17.65
	50-100	22.85	24.15	23.24	23.57	23.05	23.72
$T_6$75– F	0.0-50	18.53	19.68	16.91	18.04	16.83	18.62
	50-100	23.70	25.97	23.28	22.40	23.27	24.50
$T_7$75– H	0.0-50	18.34	20.08	18.52	19.05	15.81	15.50
	50-100	24.12	25.89	22.61	24.54	22.38	22.53
$T_8$50– D	0.0-50	14.47	16.24	18.07	17.85	17.46	17.86
	50-100	22.17	22.92	22.53	23.66	22.83	24.06
$T_9$50– F	0.0-50	17.64	19.65	15.90	15.90	17.25	17.86
	50-100	23.32	25.91	22.90	21.56	23.07	23.55
T_{10}50– H	0.0-50	18.43	19.29	18.63	19.35	13.53	14.49
	50-100	23.28	25.90	23.46	24.14	21.35	21.45

The lowest values might be attributed to the applied irrigation water amounts during this stage is low. Consequently, this stage is the highest stage as affected by deficit irrigation depths using highly saline water than that other growth stages, especially at deficit irrigation depth of 50% ETc, under gated pipe irrigation system in environmental conditions. While, the average values of soil water content for soil deep layers at the end of growth stages for tomatoes subjected to deficit irrigation depths of 75 and 50% ETc using highly saline water, 9.15dSm^{-1}, are confirmed with that obtained in active root zoon, (Table 2).

Fruit yield and water consumptive use

Tomato fruit yield (kgm^{-2}) as influenced by deficit irrigation depths of 100%, 75% and 50% of ETc using highly saline water of 9.15 dSm^{-1} subjected throughout development, flowering and harvesting growth stages under studied irrigation systems significantly reduced compared to tomato fruit yield in control treatment, (Table 4). This reduction in fruit yield may be mainly attributed to the harmful salinity effects using highly saline irrigation water and deficit irrigation water amounts. In this respect, many investigators found that increasing salinity of irrigation water and /or deficit of irrigation water depth were decreased the yield of tomatoes, Kirda *et al.,* (2004) and Cheng *et al.,* (2012).), Al-Harbi *et al*., (2008) and Al-Harbi *et al*., (2015). The reduction percentage values in tomato fruit yield ranged between 9.9 to 41.5 % and 9.1 to 30.9 % at treatment $T_2$100 – D and treatment $T_9$50 – F under drip and gated pipe irrigation systems, respectively. The tomato fruit yield for subjected plants during flowering stage is low. This low in fruit yield may be due to the decrease of the applied irrigation water amounts, Table (1) and high soil salinity values at the end of this stage especially at deficit irrigation depth of 50% ETc, under irrigation systems in environmental conditions, (Table 2).

The obtained results showed that tomato fruit yield (kgm^{-2}) significantly reduced by the decreasing of deficit irrigation depths of 75 and 50 % ETc using highly saline water of 9.15dSm^{-1} subjected throughout development, flowering and harvesting growth stages relative to fruit yield values at full irrigation using the highly saline irrigation water subjected during different growth stages under studied irrigation systems, especially at deficit irrigation depth of 50% ETc. The reduction percentage values in tomato fruit yield for the plants subjected to deficit irrigation amounts using highly saline water applied during development stage relative to tomato fruit yield value subjected to full

Table 4. Fruit yield, Crop water productivity and irrigation requirement of tomato plants subjected to deficit irrigation during different growth stages under drip and gated pipe irrigation systems

Treatments	Yield (kg m^{-2})		CWP (kg m^{-3})		Total irrigation requirements		
	Drip	Gated pipe	Drip	Gated pipe	ETc, mm	AW, m^{-3}m^{-2}	
						Drip	Gated pipe
T1 (Control)	9.50	8.23	10.94	7.27	656.8	0.8680	1.1328
$T_2$100 – D	8.56	7.48	9.86	6.60	656.8	0.8680	1.1328
$T_3$100 – F	7.46	6.91	8.59	6.10	656.8	0.8680	1.1328
$T_4$100 – H	8.40	7.54	9.68	6.66	656.8	0.8680	1.1328
$T_5$75 – D	7.98	7.20	9.65	6.67	625.4	0.8265	1.0787
$T_6$75 – F	6.76	6.58	8.99	6.70	569.1	0.7521	0.9816
$T_7$75 – H	7.96	7.16	9.85	6.79	611.6	0.8083	1.0549
$T_8$50 – D	7.36	7.04	9.37	6.87	594.0	0.7851	1.0246
$T_9$50 – F	5.56	5.69	8.74	6.85	481.4	0.6363	0.8304
T_{10}50 – H	7.30	6.56	9.75	6.71	566.5	0.7486	0.9770
Average	7.68	7.04	9.54	6.72	-	-	-
LSD 0.05 Irrigation system	0.241		0.277		-	-	-
LSD 0.05 Treatment	0.538		0.620		-	-	-

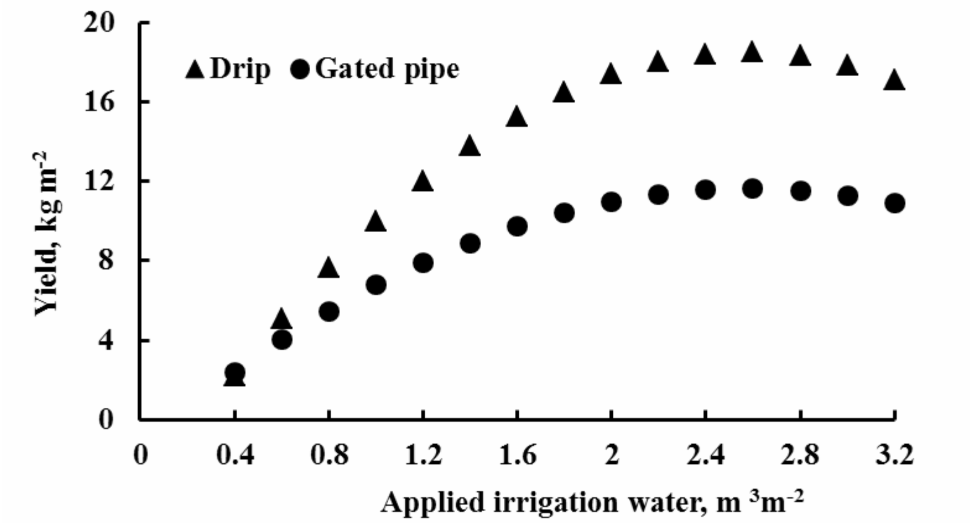

Fig. 1. The relationship between tomato fruit yield and applied irrigation water at deficit irrigation using saline water

irrigation water using highly saline water applied during different growth

stages ranged between 6.8 to 14.0 % and 3.7 to 5.9 % at treatment $T_5$75 – D and treatment $T_8$50 – D under drip and gated pipe irrigation systems, respectively.

Although the drip irrigation system enhanced salt accumulation in the active root zoon more than gated pipe irrigation system, the tomato fruit yield values under drip irrigation system were significantly higher than that under gated pipe irrigation system. Thus, the uptake of soil water for tomato plants in active root zone under drip irrigation system is easier and without stress than that under gated pipe irrigation system, thus, the effect of salt stress on tomato plants under drip irrigation system is less than that under gated pipe irrigation system.

A polynomial relationship between tomato fruit yield (Y), and applied irrigation water (AW), for the studied irrigation systems were estimated. A significant relations were obtained with the coefficient values of multiple determination (R^2) are equal 0.778 and 0.783 (n = 9), under drip and gated pipe irrigation systems, respectively, (Fig. 1), and expressed by the following regression equations:

(a) drip irrigation system

$$Y = -3.4906\ AW^2 + 17.9055\ AW - 4.4262$$

(b) under gated pipe irrigation system

$$Y = -1.9274\ AW^2 + 9.9796\ AW - 1.2849$$

According to the mathematical analysis of aforementioned regression equations, the predicted maximum yields were 18.54 and 11.63 kgm^{-2} and the corresponding calculated applied irrigation water amounts were 2.565 and 2.589 m^3m^{-2} under drip and gated pipe irrigation systems, respectively. These results are similar to those reported by Al-Harbi *et al.*, (2008).

The crop water productivity (CWP):

The crop water productivity (CWP) expresses the productivity of the amount of irrigation water related to the yield. CWP values, kgm^{-3}, generally significant decreased as affected by the deficit irrigation depths of 100, 75 and 50% ETc using highly saline water of 9.15 dSm^{-1} subjected throughout development, flowering and harvesting growth stages compared to CWP value at full irrigation (100% of ET_c) using slightly saline water of 2.81 dSm^{-1} (control treatment) under studied irrigation systems, (Table 4). On the other hand, CWP values generally increased by the decreasing of applied irrigation water amount using highly saline water of 9.15dSm^{-1} throughout development, flowering and harvesting growth stages relative to CWP values at full irrigation using the highly saline water subjected during individual growth stages under studied irrigation systems with some exceptions. These results are confirmed with Kirda *et al.*, (2004) and Cheng *et al.*, (2012). These exceptions were at deficit irrigation depths of 75 and 50% ETc subjected throughout development stage under drip irrigation system; whereas, the CWP values were decreased. The decrease percentage in CWP values were 2.1 and 4.9% for tomato plants subjected to deficit irrigation depths of 75 and 50% ETc subjected during development stage using highly saline water of 9.15 dSm^{-1} compared to CWP value at full irrigation (100% ETc) using highly saline water of 9.15dSm^{-1} subjected during development stage, respectively. Under drip and gated pipe irrigation systems, the tomato water productivity highest value was obtained at full irrigation (100% ETc) using slightly saline water of 2.81 dSm^{-1} (control treatment) and the lowest value was obtained at treatment $T_9$50-F, (Table 4). The highest and lowest values were 9.5 & 5.56 kg/m^3 and 8.23 & 5.69 kg/m^3 under drip and gated pipe irrigation systems, respectively.

Crop yield response factor (Ky)

Crop yield response factor usually indicates a linear relationship between the relative yield reduction and relative crop evapotranspiration deficit accordingly Doorenbos and Kassam (1986) and Kidra *et al.*, (2004). The significantly relationships between the relative tomato fruit yield reduction and relative evapotranspiration deficit using highly saline water, 9.15dSm^{-1}, subjected throughout growth stages under drip and gated pipe irrigation systems in environmental condition are illustrated in Fig.(2). The crop response factor values for total growing period of tomato fruit yield affected by deficit irrigation depths of 100, 75 and 50% ETc using highly saline water subjected throughout development, flowering and harvesting growth stages under drip and gated pipe irrigation systems were 1.090 and 0.743 with relationship coefficients (R^2) are equal > 0.91 (n = 6), respectively, (Fig. 2). These results indicate that the tomato plants subjected to deficit irrigation using highly saline water under drip and gated pipe irrigation systems at arid environmental conditions can be considered sensitive and tolerant to water deficit, respectively. Ky values indicated that the tomato plants were the most tolerant to deficit irrigation in harvesting and development stages while, at flowering stage was the less tolerant one under both drip and gated pipe irrigation systems.

These results are similar to those obtained by Al-Harbi *et al.*, (2015). Also, the obtained results of Ky values for tomato plants subjected to deficit irrigation depths of 100, 75 and 50 % ETc using highly saline water throughout the flowering stage results are corresponding with the obtained results of the fruit yield values for tomato plants subjected to the same deficit irrigation treatments throughout the flowering stage under studied irrigation systems; whereas, the tomato fruit yield at this stage was less than that obtained others stages.

These results are similar to those obtained by Al-Harbi *et al.*, (2015). Also, the obtained results of Ky values for tomato plants subjected to deficit irrigation depths of 100, 75 and 50 % ETc using highly saline water throughout the flowering stage results are corresponding with the obtained results of the fruit yield values for tomato plants subjected to the same deficit irrigation treatments throughout the flowering stage under studied irrigation systems; whereas, the tomato fruit yield at this stage was less than that obtained others stages.

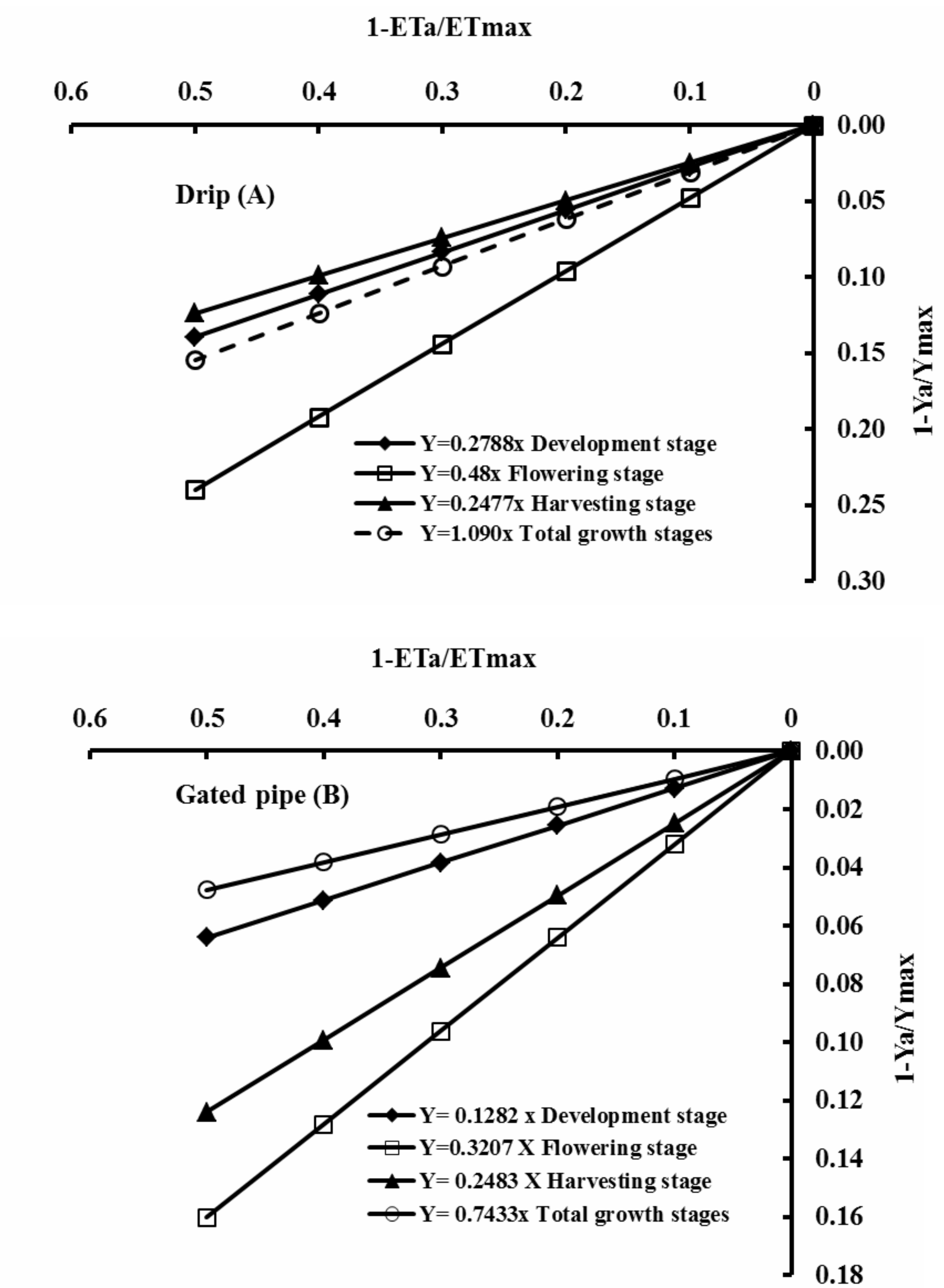

Fig.2. The relationships between the relative tomato fruit yield reduction and relative evapotranspiration under drip (A) and gated pipe (B) irrigation systems

CONCLUSIONS

The management of water under water scarcity in arid environmental conditions includes multiple policies. which should aim to reduce the non-beneficial water uses, particularly those related to crop water requirement and to the non-reusable fraction of the diverted water. Reduced water demand can be achieved by adopting improved farm, irrigation systems and deficit irrigation amounts as well as using saline irrigation water.. The results of fruit yield, CWP and Ky indicated that tomato plants subjected to deficit irrigation using highly saline irrigation water throughout harvesting stage and development stage under drip and gated pipe irrigation systems was the most tolerant to deficit irrigation depths using highly saline irrigation water; while, the flowering stage was the less tolerant one. Soil salinity and soil water content values at the end of different growth stages of tomato as affected by deficit irrigation depths using highly saline water of 9.15dSm^{-1} were subjected throughout growth stages obviously increased comparing to soil salinity values of control treatment under studied irrigation systems. The influences of the same irrigation water salinity with different irrigation water amounts on soil salinity values are closely related to the irrigation water salinity. The influences of the same irrigation water salinity with different irrigation water amounts on soil water content values are closely related to the irrigation water amounts.

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الملخص العربي

تأثير نقص مياه الري بإستخدام مياه مالحه علي محصول الطماطم تحت نظامي ري مختلفين

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أجريت تجربة في أرض جيرية بمزرعة محطة بحوث مريوط – مركز بحوث الصحراء – مصر لدراسة تأثير نقص مياه الري بإستخدام مياه مرتفعة الملوحة علي المحصول وإنتاجية وحدة مياه الري من الطماطم (صنف ٨٨٨) تحت نظامي الري بالتنقيط والسطحي ذات الفتحات البوابية. عُرضت نباتات الطماطم إلي ثلاثة مستويات من نقص مياه الري (١٠٠، ٧٥ و ٥٠% من بخرنتح المحصول) وذلك خلال ثلاثة مراحل من مراحل نمو المحصول (النمو الخضري – التزهير والنضج) بإستخدام مياه مرتفعة الملوحة (٩,١٥ ديسيمنز/ متر) بالإضافة إلي المعاملة الكنترول (نباتات تم ريها بمياه ذات ملوحة ٢,٨١ ديسيمنز/ متر وبنسبة ١٠٠% من بخر نتح المحصول وذلك طوال موسم النمو). تراوحت نسبة نقص المحصول بين ٩,٩ إلى ٤١,٥ % و ٩,١ إلي ٣٠,٩% لمعاملة T2 – 100 D (مجموعة النباتات التي تم ريها بنسبة ١٠٠% من بخرنتح المحصول بإستخدام مياه بئر مرتفعة الملوحة (٩,١٥ ديسيمنز/ متر) خلال مرحلة النمو الخضري ثم تم الري بإستخدام مياه منخفضة الملوحة (٢,٨٠ ديسيمنز/ متر) في باقي مراحل النمو والمعاملة $T_9$50–F (مجموعة النباتات التي تم ريها بنسبة ٥٠% من بخرنتح المحصول بإستخدام مياه بئر مرتفعة الملوحة (٩,١٥ ديسيمنز/ متر) خلال مرحلة التزهير ثم تم الري بنسبة ١٠٠% من البخرنتح بإستخدام مياه منخفضة الملوحة (٢,٨٠ ديسيمنز/ متر) في باقي مراحل النمو تحت نظامي الري بالتنقيط والسطحي ذات الفتحات البوابية علي الترتيب. كانت مرحلة التزهير أكثر المراحل حساسية لنقص مياه الري بإستخدام مياه مرتفعة الملوحة خاصة عند مستوي ٥٠% من البخرنتح المحسوب. كانت قيمة محصول الطماطم تحت نظام الري بالتنقيط أعلي معنوياً من المتحصل عليها تحت نظام الري السطحي ذات الفتحات البوابية. كانت أعلي قيمة لإنتاجية وحدة المياه في المعاملة الكنترول وأقل قيمة عند معاملة $T_9$50-F. كانت القيم الأعلي والأقل ٩,٥ و ٥,٥٦ كجم / م^3 و ٨,٢٣ و ٥,٦٩ كجم / م^3 تحت نظام الري بالتنقيط ونظام الري السطحي ذات الفتحات البوابية على التوالي. كان أعلي محصول متوقع ١٨,٥٤ و ١١,٦٣ كجم/م^2 وكانت كمية المياه المضافة ٢,٥٧ و ٢,٥٩ م^3/م^2 لنظامي الري بالتنقيط ونظام الري السطحي ذات الفتحات البوابية علي التوالي. وجدت علاقة معنوية بين محصول الطماطم (Y) (كجم/م^2) وكمية مياه الري المضافة (AW) (م^3/م^2) وكانت قيمة (R^2= 0.78) كانت قيم معامل المحصول (Ky) عند استخدام مياه الري مرتفعة الملوحة ١,٠٩٠ و ٠,٧٤٣ لنظامي الري بالتنقيط و السطحي ذات الفتحات البوابية علي الترتيب. كانت قيم معامل المحصول للنباتات التي تعرضت لنقص مياه الري ١٠٠، ٧٥ و ٥٠% من بخرنتح المحصول بإستخدام مياه الري مرتفعة الملوحة ٠,٢٧٩، ٠,٤٨٠ و ٠,٢٤٨ تحت نظام الري بالتنقيط و ٠,١٢٨ ، ٠,٣٢١ و ٠,٢٤٨ تحت نظام الري السطحي ذات الفتحات البوابية علي التوالي.