Effect of Irrigation Scheduling Using Drainage Water on Moisture and Salinity of Root Zone and Leaf Water Potential of Tomato

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ABSTRACT

Using low quality water in agriculture comprises many restrictions and challenges. A field experiment was carried out during 2007 summer season on a calcareous sandy clay loam soil to study the effect of drainage water stress on soil moisture and salinity distributions and leaf water potential under tow irrigation systems (drip (DR) and gated–pipe (GP)). Three drainage water stress treatments (T1=100%, T2=75% and T3=50% of ET_c) were applied during different growth stages of Tomato (*Lycopersicon esculentum, mill.*, cultivator 888). Results showed different soil moisture distributions under both irrigation systems down to 60 cm depth with higher soil moisture profiles under GP. The lowest residual soil moisture was obtained when T2 and T3 were applied during the harvesting stage. Salt concentration of the soil profiles increased with water application rate. Soil salinity profiles were obviously dependent on the applied water stress treatments and irrigation system, where applying T2 and T3 during the harvesting stages resulted in the highest soil salinity profiles under GP. Conversion points of soil salinity profiles at 40 cm depth under DR represented the effective wetted sphere of the emitters under the study condition. Higher soil salinity profiles were obtained under DR. Flowering stage was the most sensitive to water stress treatments. Leaf water potential increased under T2 and T3.

Key words: Irrigation scheduling, Drainage water, Soil moisture, Salinity distribution, Leaf water potential.

INTRODUCTION

As a result of the shortage in good quality irrigation water resources, unconventional sources such as drainage water, treated wastewater and brackish water are being increasingly used in agriculture. Their utilization provides new sources of water for more food production. In the arid and semi-arid regions, yield and quality traits of vegetable crops are adversely affected by drought and/or high salinity of the root zone (Goyal et al. 2003). Irrigation with saline water requires larger and more frequent applications than irrigation with good quality water (Boman and Stover, 2002). Results reported by El-Nagar,1995; Singh-Saggu and Kaushal 1991; Chartzoulakis and Michelakis, 1990 indicate that soil salinity profiles differ distinctly under various irrigation systems where the plant root zone under furrow irrigation salts tend to accumulate in the seedbeds because leaching occurs primarily below furrows while drip irrigation provides a greater advantage in using saline water because the system maintains high matric potential and low salt accumulation in the wetting zone as reported by Ragab et al. 1984; Hanson and May, 2011. In this aspect Hanson, et al., 2009; Chartzoulakis and Drosos, 1995; Dehghanisanij et al., 2006; Assouline et al., 2006 indicated that factors affecting soil salinity of root zone under drip irrigation include the salinity of irrigation water, irrigation scheduling, soil hydraulic characteristics, placement of drip lines relative to plant rows and crop growth stages. Salinity and drought stresses due to either lack of adequate water resources or using low quality irrigation water adversely affect tomato fruit yield through influencing leaf water potential and stomatal conductance and thus inhibiting photosynthetic metabolism (Pasternak and De Malach, 1995; Katerji et al., 1998; Baker and Rosenqvist, 2004; Maggio et al., 2004; Lobna et al., 2009). The extent of these effects depend on the type of irrigation system, managerial practices, environmental conditions and growth stages of the plant (Fisher and Nel, 1990; Olympios et al., 2003; Malash et al., 2005; Mathieu et al., 2007).

The objective of this study was to investigate the effects of irrigation scheduling using drainage water under two irrigation systems (drip and gated pipe) on soil moisture and salinity profiles and leaf-water potential of tomato plants (*Lycopersicon esculentum, mill.*, cultivar 888) grown in a sandy clay loam calcareous soil.

MATERIALS AND METHODS

1. Experimental site and soil:

Field experiment was carried out at Maryout Experimental Station Farm, Desert Research Center (N 30° 55', E 29° 51' and 50 m ASL) during the summer season of the year 2007. A representative soil profile was sampled at 0-25, 25-50, 50-75 and

75-100 cm depths. Soil bulk density, particle-size distribution and saturated hydraulic conductivity were determined according to Klute (1986). Soil textural class was found to be sandy clay loam for all profile layers (Table 1). Chemical analyses of the experiment soil (Table 1) were determined according to Richards (1954), Jackson (1967) and Page (1986). The soil was classified as Typic Torrifluvents. The drainage water used in this study had an EC = 2.81 dS m^{-1}, pH = 7.31 and SAR = 12.15

2. Experiment layout:

Two irrigation systems, drip and gated pipe were operated in this station. The total experimental area was 500 m^2. This area was divided into two main plots, one for each irrigation system. Each irrigation system consisted of 21 experimental subplots, 9.0 m long with 1.0 m furrow spacing. Each drip lateral line contained nine GR-type emitters at 50 cm spacing with 4 ℓ hr^{-1} water discharge. PVC 4" and 3" pipes were used in the gated pipe irrigation system. Orifices were made to suit furrow spacing of 1.0 m. Each plot was equipped with a control valve and water gauge to measure the amount of applied irrigation water. Irrigation intervals were two and four days for drip and gated pipe irrigation system, respectively. Three water stress treatments of 100% (T1), 75% (T2), and 50% (T3) of crop evapotranspiration (ET_c) were applied to tomato plants during development (D), flowering (F) and harvesting (H) stages according to the scheme in Table (2).

3. Calculation of ET_c:

Metrological parameters of the study area were collected from the weathering station of Maryout Research Station, for the year 2007 (Table 3). Crop water requirements were calculated using CROPWAT 4WIN computer software package which based on the Penman-Monteith equation. Crop factor values (k_c) used were 0.60, 1.15 and 0.80 for the development, flowering and harvesting growth stages respectively (Allen, et al., 1998). Accordingly, depth of irrigation water and the time of water stress treatments T1, T2 and T3 were applied during development (D, 35 days), flowering (F, 45 days) and harvesting (H, 30 days) growth stages (Table 4).

4. Tomato Planting:

Tomato seeds (*Lycopersicon esculentum, mill.*, cultivar 888) were germinated in seedling plates filled with mixture of peatmos and vermiculite on 1st April. After 30 days, the seedlings were transported to the experimental field plots and planted at 50 cm spacing and 1.0 m line spacing. Different treatments were applied one week after the transplanting date. Harvesting was started on 24th August. All agronomic practices such as weed and pest control, fertilization, etc., were followed as recommended for tomato production (Adminestration Centre of Agricutural Extention, 1998).

5. Measurements:

Volumetric soil moisture content of the soil was determined using the neutron scattering technique (Hydro Probe CPN, 503 DR 50 mCi) after the last irrigation of each plant growth stage at four depths (0-25, 25-50, 50-75 and 75-100 cm) according to Kutilek and Nielsen (1994). Under drip irrigation access tubes were installed in root zone of plants. Disturbed soil samples were also collected at the same depths to determine soil salinity. These samples were air dried and sieved through a 2- mm sieve for laboratory measurement of the electrical conductivity of soil paste extracts (EC, dS m^{-1}).

Table 1. Some selected soil initial properties and drain water analysis at the experimental site.

Soil depth, cm	EC_e, dS m^{-1}	pH	$CaCO_3$, %	SAR	Particle- size distribution, % Sand	Silt	Clay	Bulk density, g cm^{-3}	Ks, cm h^{-1}
0-25	2.13	8.2	29.50	4.14	59	13	28	1.37	2.97
25-50	2.39	8.3	28.50	3.48	56	16	28	1.39	2.76
50-75	2.55	8.3	32.80	2.76	56	13	31	1.44	3.22
75-100	3.24	8.1	33.10	3.24	51	16	33	13	28

Table 2. Layout scheme of water stress imposition.

Irrigation System	Growth Stages	Water Stress Treatments T1		T2			T3	
Drip	D		x*			x		
	F			x			x	
	H				x			x
Gated Pipe	D		x			x		
	F			x			x	
	H				x			x

x*: represents the application of the water stress treatments during a given growth stage,
Blank cells indicate the application of 100% ET_c

Table 3. Metrological data collected from Maryout Research Station, Desert Research Center for the year 2007.

Month	Maximum Temperature*, °C	Minimum Temperature*, °C	Humidity*, %	Wind speed*, Km d^{-1}	Sunshine Hours*
January	17.5	7.5	70.0	343.0	6.6
February	17.5	7.5	70.0	343.0	7.6
March	22.5	12.5	60.0	354.2	8.3
April	25.0	12.5	60.0	334.4	9.2
May	27.0	15.0	60.0	311.0	10.4
June	30.0	20.0	60.0	311.0	11.9
July	30.0	22.5	60.0	338.7	12.0
August	37.0	25.0	60.0	337.0	11.3
September	33.0	24.0	60.0	334.4	10.7
October	28.5	20.0	60.0	337.8	9.2
November	25.0	19.0	62.0	338.7	7.4
December	21.0	14.0	70.0	342.1	6.5

* Average values

Table 4. Calculated water requirements for different water stress levels, % ET_c, under used irrigation systems.

Water stress treatment	Plant groups*	ET_c, mm/growth stage			Total applied irrigation, mm/ season	
		Growth stage			Irrigation system	
		D	f	h	Drip	Gated pipe
T1	D	**217.54**	320.87	174.45	891.08	1096.57
	F	217.54	**320.87**	174.45	891.08	1096.57
	H	217.54	320.87	**174.45**	891.08	1096.57
T2	D	**163.15**	320.87	174.45	823.09	1012.92
	F	217.54	**240.65**	174.45	790.80	973.17
	H	217.54	320.87	**130.84**	836.56	1029.47
T3	D	**108.77**	320.87	174.45	755.11	929.28
	F	217.54	**160.44**	174.45	690.53	849.78
	H	217.54	320.87	**87.23**	782.04	962.37

* Stage of stress imposition

Leaf water potential (LWP) was measured using a portable pressure chamber apparatus (Soil Moisture Equipment Corp., Santa Barbara, CA, USA) at predawn using the fourth leaf in the plant.

6. Statistical Analysis:

Statistical analysis of the obtained leaf potential data was carried out to calculate the least significant difference ($LSD_{.05}$) according to Steel and Torrie (1980).

RESULTS AND DISCUSSION

1. Impact of Water Stress Treatments on Soil Moisture Profiles:

The soil moisture profiles under surface drip and gated pipe irrigation systems are depicted in Figs 1A through 1D. Although soil moisture profiles were generally higher under gated pipe system, as expected (Figs. 1C and 1D), there were no differences between the values of moisture content for T2 and T3 treatments under both irrigation systems. There were differences between soil moisture profiles (about 5%) in the top 40 cm soil layers under drip and gated pipe irrigation systems. Due to the application of water stress treatment during the harvesting stage, the lowest soil moisture profiles were observed under both irrigation systems. These trends are in agreement with those obtained by Badr and Abou Hussein (2008), Dehghanisanij et al. (2006) and Li et al. (2005)

2. Impact of Water Stress on Soil Salinity Profiles:

Soil salinity profiles at the end of growth season under water stress treatments during the development growth stage for drip and gated pipe irrigation systems are presented in Figure (2). Generally, the results show that soil salinity profiles had greater values compared with the initial soil salinity profiles. This increase in soil salinity load might be due to the salt accumulation which the result of applying low water quality (EC = 2.81 dS m^{-1}). In addition, soil salinity values were found to increase with depth for each salinity profile. This trend can be attributed to the downward movement of soluble salts through leaching processes occurred during irrigation intervals under both irrigation systems (Figs. 2A and B). These results are in agreement with those obtained by Hanson et al. (2009).

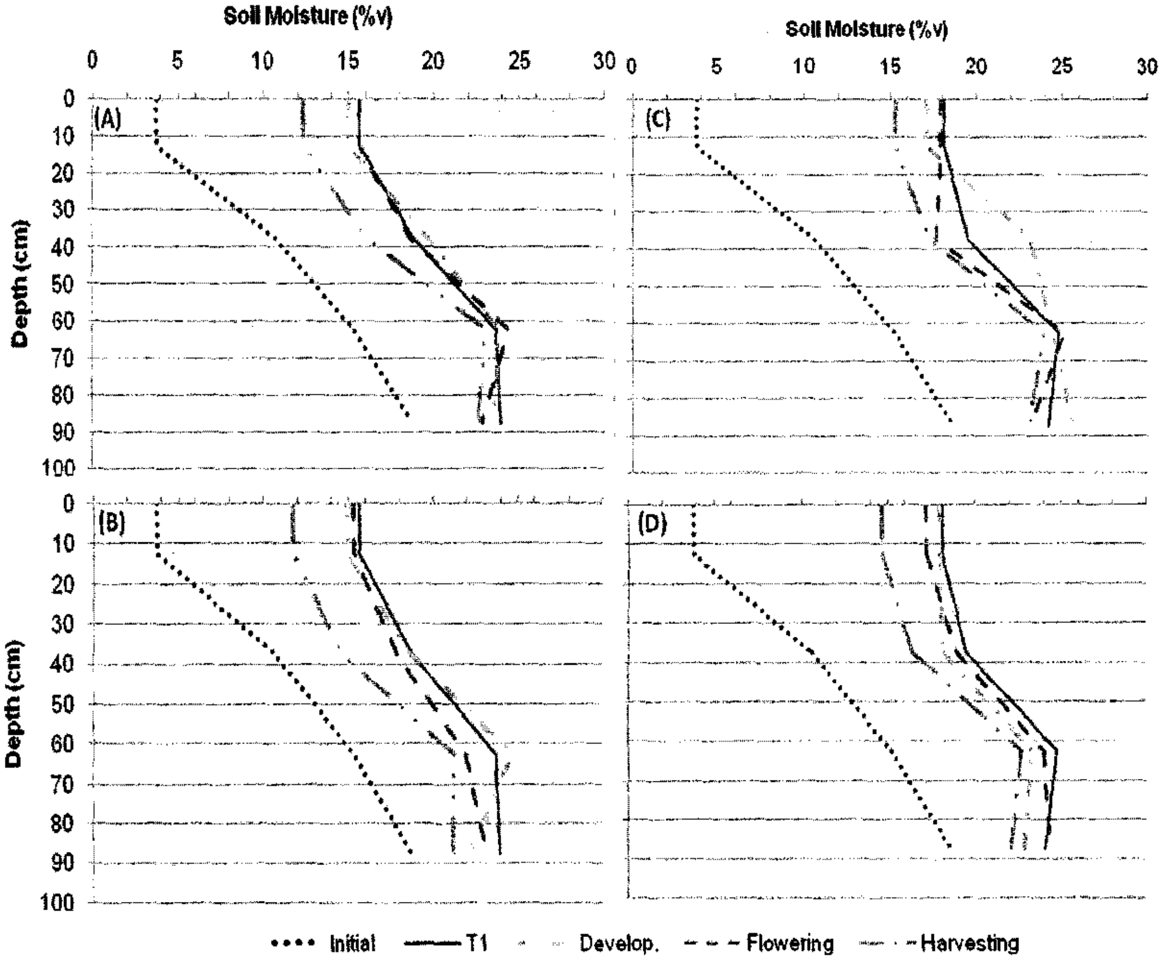

Fig. 1. Volumetric soil moisture profiles as affected by T2 and T3 treatments applied during the different growth stages under drip irrigation (A & B) and gated pipe (C & D).

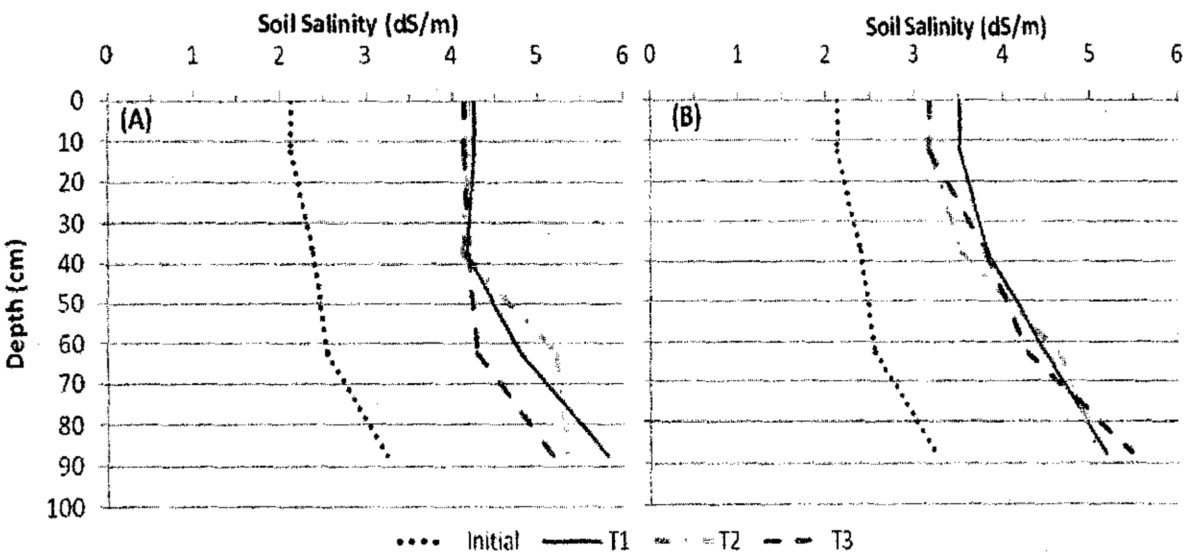

Fig. 2. Soil salinity profiles as affected by irrigation treatments applied during the development stage under Drip (A) and Gated pipe (B) irrigation systems.

Under drip irrigation, (Fig. 2A), there were no differences in soil salinity due to water stress treatments up to 40 cm depth. However, variations in soil salinity appeared between treatments beyond the 40 cm depth, where the 50% ET_c treatment reflected the lowest soil salinity down to 100 cm depth. Under gated pipe irrigation (Fig. 2B), T1 resulted in higher soil salinity values through the top 40 cm compared with the T2 and T3. It was reported by Assouline et al.,2006 that the salt concentration depends on soil water content, while salt load is a function of the amount of water applied. Beyond this depth, no variations were apparently seen due to the application of the water stress treatments. Also, surface soil salinity (down to 40 cm) was higher under drip irrigation compared with gated pipe irrigation. This may be due to the higher amounts of irrigation water applied through gated pipe irrigation system (Table 4) and hence the greater chance for downward leaching of salts to the subsurface soil layers. Similar results were reported by El-Nagar (1995), Singh-Saggu and Kaushal (1991) and Chartzoulakis and Michelakis (1990).

Generally, the results in Fig. (3A) reveal that applying water stress (T2 and T3) during the flowering stage decreased soil salinity profiles under drip irrigation down to 40 cm depth compared to the no- stress case. Consequently, it would be expected that plant growth during flowering growth stage may decrease at applied irrigation water stress T1 more than other treatments. Below this depth, salinity profiles of the T2 and T3 matched or exceeded the T1 treatment profile, respectively.

Under gated pipe irrigation (Fig. 3B), plots subjected to T2 during the flowering stage were the least in salt accumulation represented by its lowest salinity profile compared to the other irrigation treatments. It was the nearest to the initial state. This might be attributed to the occurrence of equilibrium between the up- and downward flux of soil moisture through the soil profile due to the reduction in evaporation rate from soil surface during flowering stage. Therefore, the efficiency of salt leaching was highest under gated pipe irrigation. On contrast, applying the T3 treatment resulted in the highest salinity profiles that even exceeded the T1 below 40 cm depth. This might be due to the slow percolating saline soil water to the deeper layers of the soil profile under this level of water stress level. These results are in agreement with Chartzoulakis and Drosos (1995) and Dehghanisanij et al. (2006).

Due to the application of irrigation treatments during the harvesting stage (Fig. 4A and B), pronounced effects of the irrigation system type, irrigation intervals and the amount of irrigation water were reflected on soil salinity profiles. When water stress treatments were applied during harvesting, apparently different trends of soil salinity profiles were obtained. All salinity profiles showed greater values with depth and were higher than the initial ones under both irrigation systems. Under drip irrigation (Fig. 4A), soil salinity values for both T2 and T3 treatments were similar through the 40 cm depth and were lower than those of T1 treatment. However, the T2 treatment resulted in obviously lower salinity profile beyond 40 cm depth compared with both T3 and T1. Thus, it can be said that the T2 treatment was the most efficient treatment under drip irrigation during the harvesting stage. Under gated pipe irrigation (Fig. 4B), both T3 and T2 treatments resulted in similar salinity profiles which were slightly higher than those of T1. This might be due to the higher leaching efficiency of the T1 treatment in shifting soil salinity profiles towards lower values.

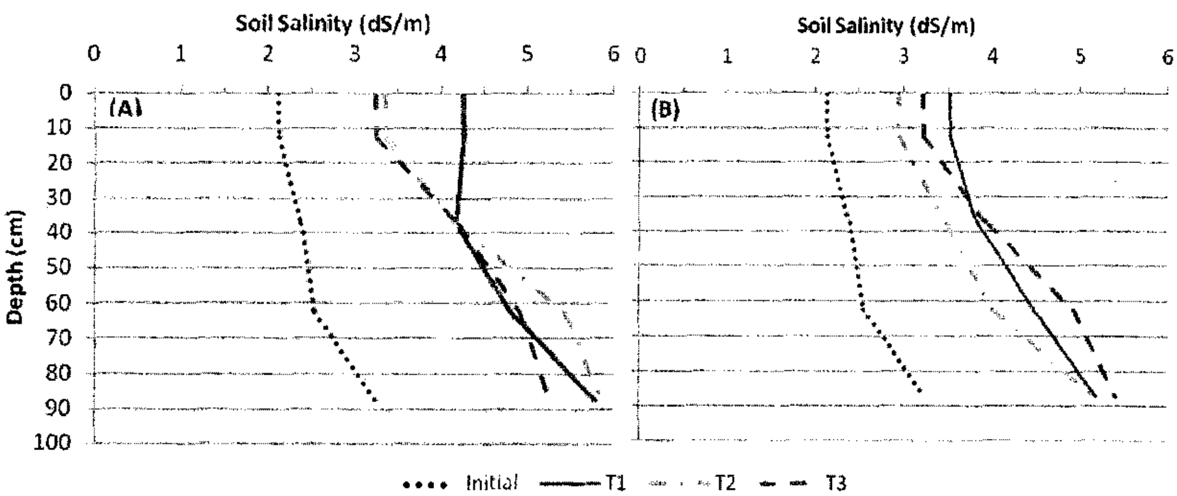

Fig. 3. Soil salinity profiles as affected by irrigation treatments applied during the flowering stage under Drip (A) and Gated pipe (B) irrigation systems.

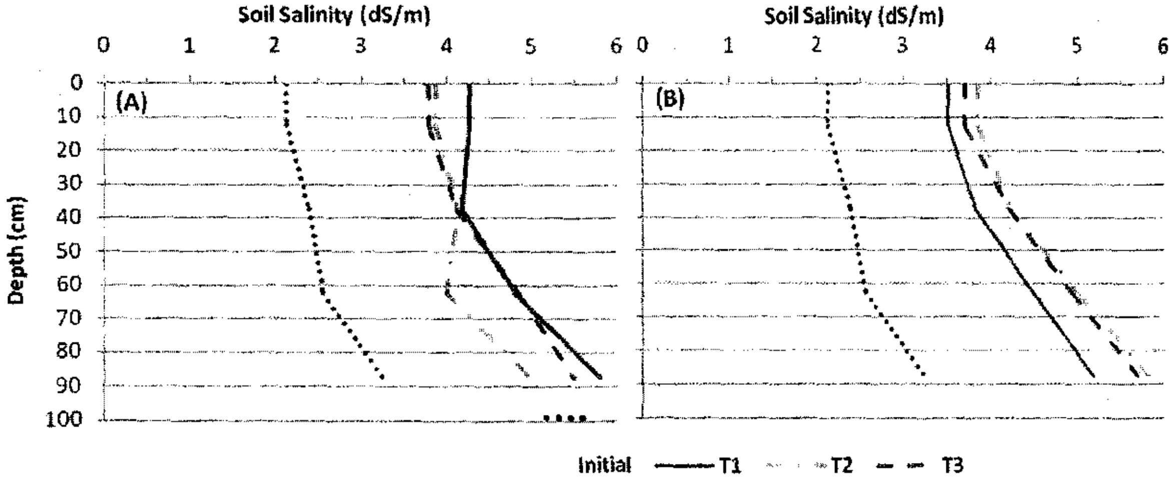

Fig.4. Soil salinity profiles for different irrigation treatments applied during the harvesting stage under drip (A) and gated pipe (B).

Soil salinity profiles obtained for the T2 and T3 water stress treatments compared at the three different growth stages are presented in Figs. 5 and 6, respectively. For the T2 treatment under drip irrigation (Fig. 5A), applying this treatment during the flowering stage resulted in the lowest salinity profile down to 40 cm depth. However soil salinity exceeded other treatments beyond this depth indicating the accumulation of salts down the profile. While applying this treatment during the harvesting stage resulted in an intermediate homogenous salinity profile down to 60 cm depth indicating dominant steady leaching pattern along the profile. The conversion points of all salinity profiles at the 40 cm depth for all treatments under drip irrigation coincide with the effective wetted sphere of the used emitters under the soil field condition. The same trend was observed for the T3 treatment during the three growth stages under drip irrigation system (Fig. 6A). These trends reflect the wetting patterns during irrigation and the subsequent redistribution of soil water. Hanson and May (2011) and Dehghanisanij et al. (2006) reported that irrigation with saline water (up to 2.0 dSm^{-1}) resulted in relatively low salinity levels in the area extending downward from surface drip lines. It can be also noted from Figs 5A and 6A that soil salinity of the surface 40 cm was the lowest when both T2and T3 water stress treatments were applied during the flowering stage. This could be explained in the light of the fact that the flowering stage is the longest period of the growing season and is the stage in which the crop consumes the lowest amount of applied irrigation water and hence the smallest amount of soluble salts. In addition, applying water stress during this stage resulted in the most efficient salt leaching, as most leached salts were pushed downwards beyond the effective root zone (Figs. 5A and 6A).

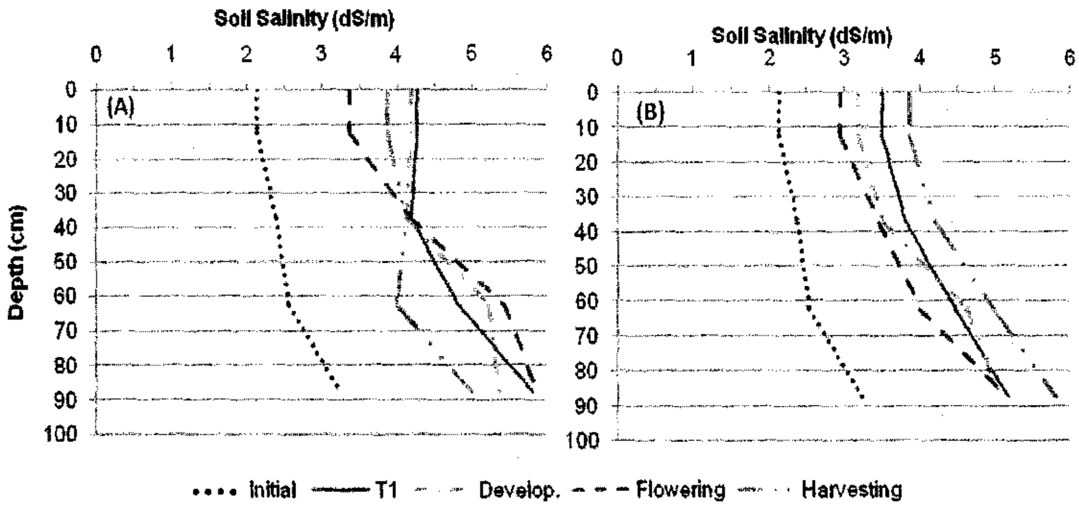

Fig.5. Soil salinity profiles at the end of season as affected by Irrigation treatment T2 applied during different growth stages under drip (A) and gated pipe (B) irrigation systems.

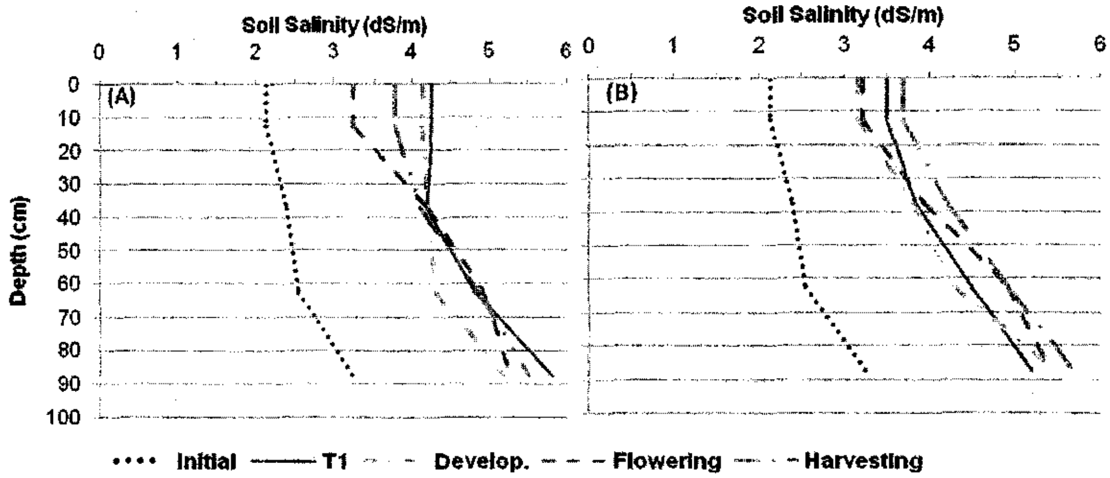

Fig. 6. Soil salinity profiles at the end of season as affected by Irrigation treatment T3 applied during different growth stages under drip (A) and gated pipe (B) irrigation systems.

Under gated pipe irrigation system, the highest salinity profile was obtained when both T2 and T3 water stress treatments were applied during the harvesting stage (Figs. 5B and 6B). This might be due to the reduction of the amount of applied irrigation water during this last stage that lead to lower salinity leaching. On the other hand, the lowest salinity profiles were obtained when those treatments were applied during the flowering stage, having the lowest amount of applied irrigation water (Table 4). It was also found that applying both water stress treatments during flowering resulted in the most efficient salinity leaching pattern following drip irrigation. In addition, the amount of applied irrigation water during the previous and proceeding stages helped to some extent to achieve these results. Abou El-Azem (2005) reported that most of salts movement under surface trickle for both low and medium pressure sprinklers and modified furrow irrigation systems were in the first two layers 0-20 and 20-40 cm and concentrated in the third layer 40-60 cm. Results also showed that irrigation system type had significant effect on salt accumulation rate within the soil profile.

3. Relationship between Moisture and Salt Distribution Profiles:

Correlation coefficients (r) of soil salinity *vs.* moisture profiles for all treatments were calculated 0.771 and 0.714 under drip and gated pipe irrigation systems, respectively. These positive values indicate that there was a direct relationship between the accumulation of leached salts and percolated soil water below the root zone at the end of the growing season. This is likely to be due to the soil factors controlling the redistribution pattern of moisture and salts in soil profile such as water holding capacity, soil water potentials relations, pore - size distribution and downward/upward water flux ratio as well as the reduction of evaporation from soil surface as a result of the covering green canopy of tomato crop. This result supports the findings of Hanson, et al. (2009) who showed that soil salinity, soil-water content and root density all vary around the drip line, resulting in uncertainty about the accuracy of root-zone soil salinity.

4. Effects on Leaf Water Potential:

Data of leaf water potential (LWP, kPa) under both irrigation systems are listed in Table (5). These values were measured at the end of each growing stage subjected to water stress treatments. The results revealed that values of LWP increased significantly with increasing water stress for each growth stage and under both irrigation systems. It was also found that LWP increased with the progress of the plant growth stages. Increasing LWP in both cases is explained by either the soil water deficit due to the applied water stress treatments or the increase in soil salinity and hence its osmotic potential as a result of the accumulation of salts applied with water irrigation.

CONCLUSION

Imposing water and salinity stresses during the different growth stages of tomato plants affected soil moisture and salinity distribution patterns, and significantly increased leaf water potential. Responses to the applied water stress treatments were dependent on the type of irrigation system. Timing of imposing water stress treatments was found to be more influential than their magnitude. Flowering stage was the most sensitive to water and salinity stresses. Surface drip irrigation system was found to be better in coping with the adverse effects of soil moisture and salinity stresses on tomato leaf water potential. Further research is needed for the agricultural sustainability under the conditions of the studied area.

Table 5. Leaf water potential at the end of the three growth stages under different water stress levels.

Stress treatment	LWP, kPa		
	H	F	D
		Drip Irrigation	
T1	-9.80 a	-8.00 a	-7.00 a
T2	-15.20 b	-14.00 b	-12.70 b
T3	-19.00 c	-17.70 c	-16.80 c
		Gated Pipe Irrigation	
T1	-9.00 a	-7.30 a	-6.30 a
T2	-16.70 b	-13.70 b	-13.20 b
T3	-20.20 c	-16.70 c	-16.80 c
$LSD_{.05}$		**1.10**	

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الملخص العربى

تأثير جدولة الرى باستخدام مياه الصرف علي توزيع الرطوبة الأرضية و الملوحة في منطقة الجذور وعلى الجهد المائي لأوراق الطماطم

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إن استخدام مصادر المياه منخفضة الجودة يواجه العديد من المحددات والتحديات. ولذلك أجريت تجربة حقلية بنظام القطع المنشقة في صيف ٢٠٠٧ في أرض جيرية قوامها sandy clay loam لدراسة تأثير الإجهاد المائي لمياه الصرف الزراعي ($EC = 2.81\ dSm^{-1}$) تحت نظام الري بالتنقيط والري المبوب (drip and gated pipe) علي توزيع الرطوبة الأرضية والأملاح في منطقة الجذور وكذلك الجهد المائي لأوراق نبات الطماطم، حيث تمثل T1 ١٠٠%، وT2 ٧٥%، وT3 ٥٠% من البخرنتح لمحصول الطماطم ثلاث معاملات للاجهاد المائي، طبقت خلال مراحل نمو النبات المختلفة (مرحلة النمو الخضري والتزهير والحصاد). وقد أظهرت النتائج اختلافات في توزيع الرطوبة الارضية مع العمق تحت نظامى الرى حتي عمق ٦٠ سم وكانت قطاعات الرطوبة الارضية تحت نظام الرى المبوب أعلي من مثيلاتها تحت الرى بالتنقيط. وقد تم الحصول علي أدنى مستوى من الرطوبة الارضية المتبقية تحت المعاملتين T2 وT3 أثناء فترة الحصاد. كما إزداد الحمل الملحي بقطاع التربة بزيادة معدل إضافة المياه. تبين أن قطاعات ملوحة التربة إعتمدت بصورة واضحة علي معاملات الإجهاد المائي المدروسة ونظام الري المتبع، كما تبين أيضا من تلاقي منحنيات قطاعات ملوحة التربة عند عمق ٤٠ سم تحت نظام الري بالتنقيط أنها تمثل عمق الأبتلال الفعال للمنقطات المستخدمة تحت ظروف الدراسة. كانت مرحلة الازهار هى الاكثر حساسية لتأثير معاملات الإجهاد المائي المختبرة. ونتج من تطبيق المعاملتين T2 و T3 خلال فترة الحصاد الحصول علي أعلى قطاعات ملوحة تحت نظام الري المبوب كما زادت قيم الجهد المائي الورقي تحت نفس المعاملات في كل من نظامي الرى.