

Effect of Irrigation Regime and Emitter Depth on Yield and Water Use for Tomato

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Abstract. The present study is to compare the impact of water regime and emitter depth on growth and yield in relation to water production function of tomato using saline water. A field experiment was conducted at Dirab, during the months of August to February (2004/2005 and 2005/2006 seasons). Four water application rates (irrigation levels) were used namely: 60% of calculated evapotranspiration, ET_c (T1), 80% (T2), 100% (T3) and 120% (T4) and four drip line depths were used namely: surface drip line (D0), 15 cm subsurface drip line (D1), 25 cm (D2) and 35 cm (D3). The experiment was arranged in split-split plot design and the treatments were distributed in randomized complete block design (RCBD) using three replicates and growing tomato (*Lycopersicon esculentum*, L). The results indicated a significant effect of irrigation levels on shoot and root systems weight, root width, % of roots to 25 cm depth. Average fruit weight and gross yield were increased as increasing the irrigation level up to 100% of ET_c , and then decreased at 120% of ET_c . The highest values were 177.9 g and 20.57 t ha⁻¹ for average fruit weight and gross yield in the first season and 120.1 g and 19.3 t ha⁻¹ in the second season, respectively. Increasing the drip line depth significantly increased the average fruit weight, gross yield and water use efficiency. The highest values were attained with 25 cm drip line depth. These values are 177.9 g, 20.57 t ha⁻¹, 5.54 and 4.16 kg m⁻³ for average fruit weight, gross yield, CWUE and IWUE, respectively in the first season. The corresponding values for the second season were 127.4 g, 19.3 t ha⁻¹, 4.57 and 3.49 Kg m⁻³, respectively. The present study recommend a subsurface drip irrigation at 25 cm drip line depth with 80-100% (ET_c) irrigation level to obtain a good growth and yield of tomato under the same conditions. It might be emphasized here that these yields and yields function were obtained under poor quality of irrigation water ($EC_w = 5 \text{ dSm}^{-1}$), in addition to small percentage (15%) of leaching requirement application.

Introduction

Subsurface drip irrigation (SDI) is the latest advanced method of irrigation, which enables the application of the small amounts of water to the soil through the drippers buried below the soil surface with discharge rate generally in the same range of surface drip irrigation, DI (ASAE Standards, 2007). SDI offers many advantages over the surface drip irrigation as reported by many investigators (Camp, 1998).

Both surface and subsurface drip irrigation methods may be managed to decrease deep percolation and surface runoff of water (Phene *et al.*, 1989; Lamm and Trooien, 2003). Drip irrigation has a high actual uniformity, but the detailed soil water distribution in the soil region between the emitters is very non-uniform in subsurface drip irrigation method (Wallach, 1990). Drip irrigation allows uniform delivery of water and nutrient directly to the plant root zone, therefore can increase nutrient efficiency as compared with other irrigation methods

(Sammis, 1980; Miller *et al.*, 1981).

Modern irrigation techniques are needed to increase water-use efficiency. Surface and subsurface drip irrigation methods are the most effective way to save water by efficiently using water and to increase the crop yield (Tiwari *et al.*, 1998; Al-Omran *et al.*, 2005). Many researchers (Hutmacher *et al.*, 1996; Ayars *et al.*, 1999) reported a significant increase in crop yield and water use efficiency. Previous research were done on the effect of drip line depth on growth and yield of tomato. Charlesworth and Muirhead (2003) recommended a drip line depth no greater than 0.2 m on loam soils when germination assistance is an objective of the SDI system. Ayars *et al.* (1999) reported that a drip line depth of 0.45 m was successful for row crops. When tomato seeds were placed directly above drip lines in a Yolo clay loam soil, better germination was obtained with drip line depths of 0.15 or 0.23 m (Schwankl *et al.*, 1990).

The rational irrigation can significantly increase yield (Gajre *et al.*, 1997) and the excessive irrigation

led to decrease of crop water use efficiency (Jin *et al.*, 1999), while deficit irrigation may result in higher yield and definitely higher WUE (Demir *et al.*, 2006). (Kirda *et al.*, 1999) reported that deficit irrigation is one of maximizing WUE for higher yields per unit of irrigation water applied: the crop is exposed to certain level of water deficit during a particular growth stage or throughout the whole growing season.

Many studies have been conducted to determine water production function using evapotranspiration (ET) or water applied (W). The relationship between seasonal ET and yield (Y) showed a linear function (Musick *et al.*, 1994), while the relationship between water applied and yield is curvilinear (Simsek *et al.*, 2005; Sun *et al.*, 2006). However, El-Shafei (1989) found the relationship between Y and W be linear for tomato but up to the irrigation level equal to 80% of pan evaporation.

Therefore, the objective of the present study was to evaluate the effect of irrigation regime and emitters depth on growth, yield, salt distribution, and water use efficiency for tomato crop irrigated by saline irrigation water.

Material and Methods

Location and field experiment

A field experiment was conducted at the Research and Agricultural Experimental Station at Dirab, king

Saud University, (24° 25' N, 46° 34' E), 40 Km southwest of Riyadh, Saudi Arabia during the months of August to March (2004/2005 & 2005/2006, Table (1)). The study area was divided into four equal main plots with a buffer strip of 5 m in the middle (Fig. 1). Each plot was connected to sub plots containing 12 rows through a valve. Each sub plot was further divided into 4 small areas consist of 3 strips of 5.0 m length and 1.0 m width. Each main plot represents a level of irrigation treatment and each sub plot represents a drip line depth treatment. Each replicate was represented by one line (Fig. 1). The experiment was arranged in a split-split plot design and the treatments were distributed in randomized complete block design (RCBD) using three replicates and growing tomato as a test crop.

The experimental study consisted of four levels of irrigation included:

T1 = as 60% of calculated evapotranspiration ($0.60ET_c$),

T2 = as 80% of calculated evapotranspiration ($0.80ET_c$),

T3 = as 100% of calculated evapotranspiration ($1.00ET_c$), and

T4 = as 120% of calculated evapotranspiration ($1.20ET_c$)

and four treatments of drip line depth including:

D0 = as surface drip irrigation (0.0 cm depth),

D1 = as subsurface drip line depth of 15.0 cm,

Table 1: Meteorological data of the experimental site at Dirab

Month Year	Average Air Temperature C°	Average Relative Humidity %	Rainfall mm	Solar Radiation X 10^4 W m ⁻²	Wind Speed m sec ⁻¹	ET ₀ mm day ⁻¹
First Season						
September, 2004	30.65	17.10	-	38.89	5.43	6.53
October, 2004	25.30	23.29	-	34.09	4.74	4.92
November, 2004	21.22	32.14	-	27.11	4.62	3.66
December, 2004	14.11	53.76	0.34	22.42	4.43	2.27
January, 2005	13.78	46.57	0.26	25.10	4.46	2.65
February, 2005	16.41	50.52	1.52	28.34	5.18	3.03
Second Season						
September, 2005	30.35	17.51	-	38.76	5.45	6.58
October, 2005	25.15	23.25	-	34.05	4.78	4.97
November, 2005	21.28	32.18	-	27.15	4.58	3.72
December, 2005	14.15	53.92	0.38	22.49	4.40	2.25
January, 2006	13.85	47.09	0.28	25.18	4.41	2.69
February, 2006	16.48	50.94	1.49	28.40	5.08	3.09

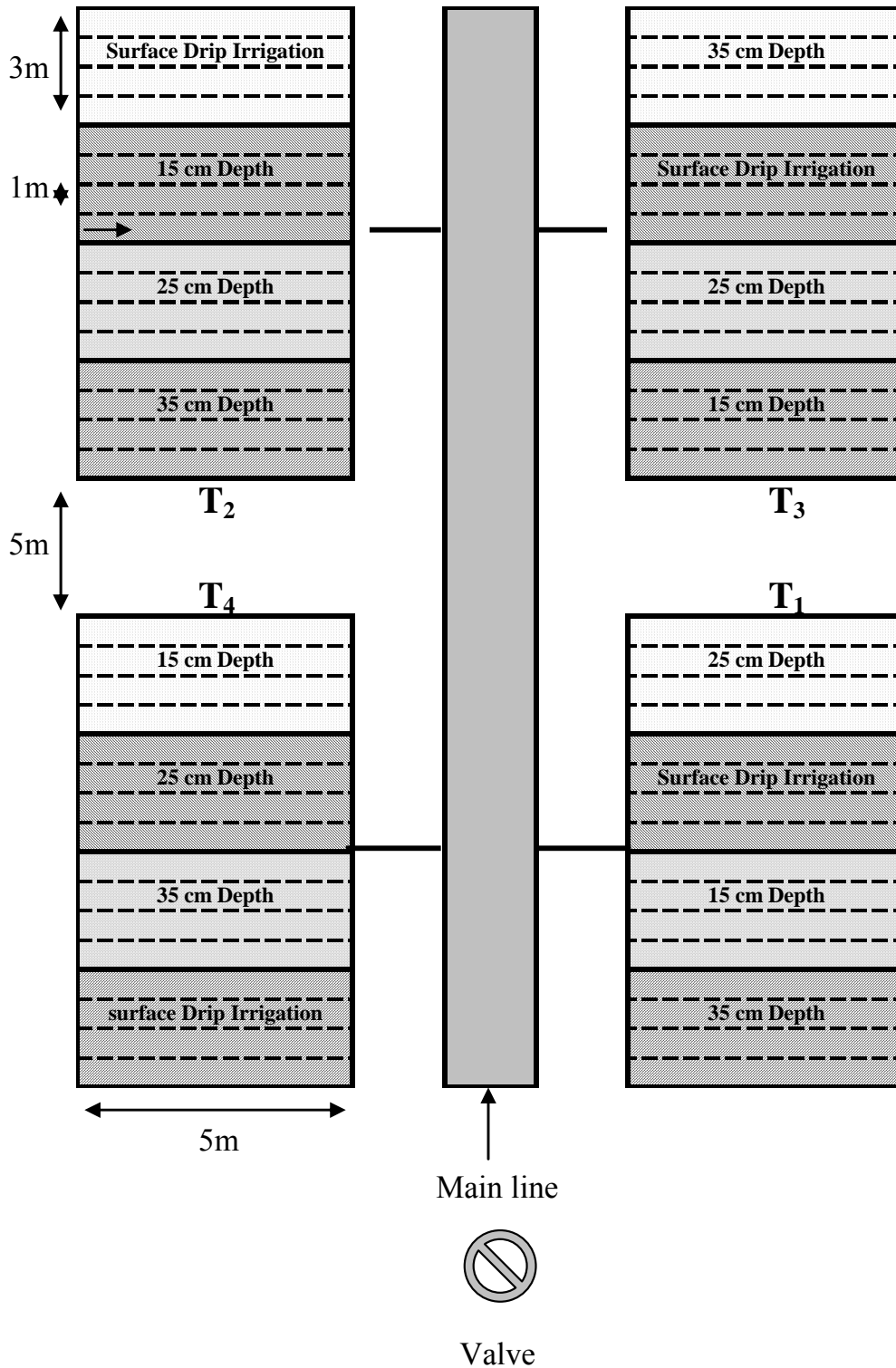


Fig. 1. Field experiment layout with four irrigation regimes and four emitters' depth.

D2 = as subsurface drip line depth of 25.0 cm, and
D3 = as subsurface drip line depth of 35.0 cm

Before starting the experiment, a composite soil sample was taken from surface and subsurface layers from the study area for analysis. Some physical and chemical characteristics of soil samples are shown in Table 2. Recommended methods as outlined in Klute (1986) were used for analyzing the soil samples.

Table 2. Some physical and chemical characteristics of experimental soil

Parameters	Soil depth, cm			
	0 - 15	15 - 30	30 - 50	50 - 70
Particle size distribution, %				
Sand	93.0	89.0	89.0	89.0
Silt	1.0	6.0	4.0	6.0
Clay	6.0	5.0	7.0	5.0
Textural Class	sand	sand	sand	sand
Organic matter content, %	0.03	0.13	0.16	0.02
CaCO ₃ , %	32.0	27.0	24.0	30.0
Saturation water content, % (w/w)	27.2	28.3	29.3	29.8
Field capacity, % (w/w)	14.8	16.4	17.1	16.8
Permanent wilting point, % (w/w)	6.4	7.2	6.7	6.3
Available water, % (w/w)	8.4	9.2	10.4	10.5
pH	7.51	7.72	7.92	8.05
Electrical conductivity (EC _c , dS m ⁻¹)	2.75	2.65	2.00	1.80
SAR (-)	3.29	4.83	2.18	2.41
Soluble Cations, me l⁻¹				
Ca ²⁺	16.4	11.1	11.1	9.1
Mg ²⁺	6.0	6.7	5.6	5.0
Na ⁺	11.0	14.4	6.5	6.4
K ⁺	1.5	2.1	1.7	1.5
Soluble Anions, me l⁻¹				
CO ₃ ⁻	Tr.	Tr.	Tr.	Tr.
HCO ₃ ⁻	3.9	4.0	2.0	4.0
Cl ⁻	9.8	10.5	7.0	5.0
SO ₄ ⁻	12.8	13.9	10.9	8.7

A strip with 30 cm width along the drip lines was excavated to the drip line depth. Organic fertilizer was added for each line at rate of 20.0 Kg ha⁻¹ mixed with super-phosphate at rate of 250 Kg ha⁻¹. These fertilizers were added actually at the bottom of the drip line depth and then drip line was buried and covered with the same soil. The drippers have a capacity of 4.0 L hr⁻¹ and each dipper was placed at 40.0 cm distance (plant to plant distance). Each drip line contained 12 tomato plants. Tomato seeds (Bascal cv.) were sown in nursery on 25th August, 2004. One month old seedlings were transplanted in the field on 26th September, 2004 in the first season. For the second season the seeds were sown in green house on 1st September, 2005 and transplanted on 1st October, 2005. Nitrogen as urea (46%, N), potassium as potassium sulfate (48%, K₂O) and micro nutrients

were weekly applied with irrigation water at recommended doses. Surface drip irrigation was applied to all treatments to establish the plants and to avoid any accumulation of salts affecting early growth. The irrigation treatments were applied for all the treatments from first of November, 2004 & 2005 by providing the irrigation water through the irrigation network. The water quality of the irrigation water was measured (Table 3), the classification of water is (C₄-S₂) according to Richards (1954) and the degree of restriction on water us for irrigation is severe according to Ayers and Westcot (1985). The flow rate metered to provide exactly the water required for each treatment. The quantity of irrigation water supplied for each irrigation treatment was determined as percentage of calculated evapotranspiration (ET_c) calculated by Penman-Monteith Eq. using the meteorological data collected from the meteorological station located nearby the study area (Table 1), and the kc values of tomato for the region are estimated according to Allen *et al.* (1998).

Table 3. Analysis of irrigation water used in the experiment

Parameters	Values*
pH	7.7
Electrical conductivity (dS m ⁻¹)	4.90
Soluble Cations, me l⁻¹	
Ca ²⁺	16.65
Mg ²⁺	10.91
Na ⁺	21.51
K ⁺	0.55
Soluble Anions, me l⁻¹	
CO ₃ ⁻	-
HCO ₃ ⁻	5.68
Cl ⁻	22.51
SO ₄ ⁻	21.08
Sodium Adsorption Ratio (SAR)	5.79
NO ₃ ⁻ , mg l ⁻¹	0.76

$$ET_c = K_c * ET_0$$

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

Where:

- ET₀ = reference evapotranspiration (mm day⁻¹)
ET_c = crop evapotranspiration (mm day⁻¹)
k_c = crop coefficient (dimensionless)
R_n = net radiation at the crop surface (MJ m⁻² day⁻¹)
G = soil heat flux density (MJ m⁻² day⁻¹)
T = mean daily air temperature at 2 m height (C°)
U₂ = wind speed at 2 m height (mS⁻¹)
e_s = saturation vapor pressure (kPa)

- e_a = actual vapor pressure (kPa)
 $(e_s - e_a)$ = saturation vapor pressure deficit (kPa)
 Δ = slope of saturation vapor pressure - temperature curve (kPa °C⁻¹)
 γ = psychrometric constant (kPa °C⁻¹)

The values of water consumptive use were 2500, 3333, 4167 and 5000 m³ ha⁻¹ corresponding to 60, 80, 100 and 120% of the ET_c, respectively for the first season. The corresponding values for the second season were 2625, 3500, 4400 and 5300 m³ ha⁻¹, respectively. Whereas the gross irrigation requirements were calculated taking the leaching requirements and efficiency of irrigation system into consideration using the following Eq. (assuming that deep percolation equal zero):

$$GIR = \frac{ET_c}{(1 - LR) * E_i} \quad (2)$$

Where

- GIR = the gross irrigation requirements (mm day⁻¹)
 LR = the leaching requirement was taken 15% for sandy soils.
 E_i = the efficiency of irrigation system (assumed as 90% for drip and subsurface drip irrigation) (%)

The applied water (W) which is equal to GIR was measured using flow meter and applied in term of (m³ ha⁻¹) through the irrigation network. The values of applied water were 3325, 4433, 5541 and 6650 m³ ha⁻¹ in the first season and were 3400, 4500, 5650 and 6900 m³ ha⁻¹ for the second season.

The water utilization by the crop is generally described in terms of water-use efficiency (WUE) was calculated according to the following formula:

$$CWUE = Y/CU \quad (3)$$

$$IWUE = Y/W \quad (4)$$

where:

- Y = Fruit yield (Kg ha⁻¹)
 CU = Consumptive use as percent of ET_c
 $CWUE$ = the consumptive water use efficiency (kg m⁻³)
 $IWUE$ = the irrigation water use efficiency (kg m⁻³)

Nine soil samples were collected before irrigation from the root zone area on a grid bases (15 cm apart) around the dripper at different time of the growth stages, namely vegetative stage, flowering stage and at the end of the season. Soil water contents were determined by gravimetric method after oven drying at 105 °C and salt distributions were assessed by

measuring ECe in soil paste extract.

At the end of growing seasons, tomato growth parameters such as plant weight, shoot system weight, root system weight, weight of tomato fruits per plant and the weight of 10 cm segments of root system were recorded and the gross yield was recorded (t ha⁻¹). Total fruit yield for each replicate was recorded to obtain the gross yield (t ha⁻¹). The distribution of root system was calculated for each treatment by digging a soil block of 50 cm x 50 cm x 70 cm and excavating the soil around the plant, then the plant was picked and the adhesive soil was removed. The root system was weighed and the root density system was calculated for each plant according to (Machado *et al.*, 2003). In the second season, only the average fruit weight of tomato and the gross fruit yield were recorded as important crop parameters.

Crop water production function (CWPF) reflects the beneficial of applied water in production of dry matter or yield. It presents the relationship between the quantity of applied water and the yield production of crop. The quadratic polynomial function of Helweg (1991) was used in the form:

$$Y_a = b_0 + b_1 W + b_2 W^2 \quad (5)$$

Where:

- Y_a = the crop production or yield, ton ha⁻¹
 W = the applied irrigation water, m³ ha⁻¹
 b_0, b_1 and b_2 are fitting coefficients.

Maximum applied water (W_{max}) was calculated by differentiating the CWPF (Eq. 5) and equalized with zero, Then the maximum predicted yield (Y_{max}) can be calculated by substituted the W_{max} in the Eq. (5):

$$\begin{aligned} \delta Y / \delta W &= +b_1 + 2b_2 W = 0 \quad (6) \\ W_{max} &= -b_1 / 2 b_2 \\ Y_{max} &= b_0 + b_1 W_{max} + b_2 W_{max}^2 \end{aligned}$$

The collected data was tabulated and subjected to analysis of variance and least significant difference (LSD) using SAS package (SAS Institute Inc., 1996).

Results and Discussion

Tomato growth parameters

Table 4 showed that tomato growth parameters were affected by both irrigation level and drip line depth. The results indicated a significant effect of

Table 4. Tomato growth parameters as affected by irrigation regime and drip line depth

Irrigation regime (% of ET _c)	Depth of drip line (cm)	Shoot system weight (g)	Root system weight (g)	Root length (cm)	Root Width (cm)	Root system to shoot system %	% of root to 30 cm depth	Root system density (g m ⁻³)
60	Surface	342.0	40.2	58.3	71.7	11.75	89.56	230.1
	15	322.7	42.2	56.0	63.3	13.08	92.19	241.3
	25	310.4	40.2	68.3	70.3	12.95	95.62	229.7
	35	290.0	38.3	46.7	59.3	13.21	93.10	218.9
80	Surface	548.0	56.7	69.7	99.7	10.35	94.14	323.8
	15	441.6	42.2	74.7	104.7	9.56	96.50	241.3
	25	509.6	43.7	62.3	87.3	8.57	95.87	249.5
	35	509.4	46.2	67.0	83.0	9.07	95.74	264.2
100	Surface	343.1	38.5	70.3	84.0	11.22	90.93	220.2
	15	319.6	36.7	69.0	79.7	11.48	94.02	209.9
	25	464.0	48.4	83.3	92.7	10.43	94.84	276.6
	35	349.3	46.4	76.3	88.7	13.28	93.87	265.1
120	Surface	320.8	39.7	68.7	86.0	12.37	94.15	226.7
	15	377.7	45.5	65.7	73.3	12.05	94.13	260.0
	25	340.3	38.4	65.3	63.3	11.28	93.52	219.4
	35	353.5	39.4	77.0	72.3	11.15	92.79	225.1
Mean effect of irrigation level (%)								
60		316.3b	40.2b	57.3b	66.2bc	12.7a	92.62b	230.0a
80		502.2a	47.2a	68.4ab	93.7a	9.4a	95.56a	269.7a
100		369.0ab	42.5ab	74.7a	86.3ab	11.6a	93.42ab	243.0a
120		348.1b	40.8b	69.2ab	73.7b	11.7a	93.65ab	232.8a
Mean effect of drip line depth (cm)								
surface		388.5a	43.8a	66.8a	85.4a	11.42a	92.20a	250.2a
15		365.4a	41.7a	66.4a	80.3a	11.54a	94.21a	238.1a
25		406.1a	42.7a	69.8a	78.4a	10.81a	94.96a	243.8a
35		375.6a	42.6a	66.8a	75.8a	11.68a	93.88a	243.3a
Interaction effect : irrigation level* drip line depth								
L.S.D.(0.05)		n.s.	*	*	*	n.s.	*	*

* Significant at 0.05 probability level n.s. non-significant at 0.05 probability level

Values followed by the same letters are not significant.

irrigation levels on growth parameters. The 80% level of reference evapotranspiration was superior over the other treatments in increasing shoot and root systems weight, root width, % of roots to 30 cm depth and root system density. If we consider 100% as reference level, then the change of shoot weight accounted as -14.28, 36.1 and -5.62% for irrigation levels of 60, 80 and 120%, respectively over the 100% irrigation level (100% of ET_c). The corresponding changes in root system weight were -5.4, 11.06 and -4.0%, respectively. Spread of root system in horizontal direction was significantly affected by irrigation regime but the 80% level was more pronounced in increasing the root width by about 8.57% compared to 100% irrigation level. The other treatments decreased the root width. The ratio of root system related to shoot system varied according to the irrigation levels, but it reached to maximum value at 60% irrigation level, an increase of about 9.91% when compared with 100% irrigation level. The percent of root system was concentrated at surface layer of soil (30.0 cm depth) and reached more than 90%, but the maximum value was recorded at 80% irrigation level. The root system

density (g m⁻³ soil) followed the same trend.

Increasing the depth of drip line did not show any significant effect on tomato growth parameters. Generally, the data showed that the 25 cm depth of drip line (subsurface drip irrigation) was more suitable and gave the best results over the other depths. The shoot system weight increased by 4.53% over the surface drip irrigation. The corresponding values for root system weight and root length were 2.10 and 4.49%, respectively. The behavior of root percent to 30 cm depth and root system density (g m⁻³ of soil) were similar where the increases were 2.99 and 1.44%, respectively.

The effect of irrigation levels may be explained on the basis that a decrease in moisture level in the root zone was responsible for decreasing the growth parameters especially at lower irrigation level (60% of ET_c). The decrease of soil aeration with high levels of irrigation such as 100 and 120% may be the reason for decreasing the growth parameters. This means a proper balance between the moisture and the aeration levels in the root zone depth improved the plant growth, consequently increasing the yield.

An increase in the drip line depth gave a good balance of moisture and aeration in the root zone depth allowing a good growth of shoot and root systems when compared with surface drip irrigation, which in some conditions may increase the moisture level in surface layer of soil, resulting in restricted root system spreading. A decrease in the root system resulted in a decrease in shoot system growth, which in turn led in decreasing the vegetative growth and yield. Many studies showed an increase in root system in soil surface layer of 30 cm depth (Oliveira *et al.*, 1996)

Generally, the subsurface drip irrigation was better than surface drip irrigation when comparing the growth parameters (Ayars *et al.*, 1999; Machado *et al.*, 2003; EL-Damry, 2006). This trend may be due to the increased soil evaporation from soil surface layer (Lamm and Trooien, 2003) which is reduced for subsurface drip irrigation (Phene *et al.*, 1991).

Tomato yield and water use efficiency

Tables 5 & 6 illustrated the effects of irrigation level and drip line depth on tomato fruit yield and water-use efficiency for both seasons. Irrigation level

has a significant effect on average fruit weight and fruit yield. Average fruit weight and gross yield were increased as increasing the irrigation level up to 100% of ETc, and then decreased at 120% of ETc. The irrigation level of 100% has a superior value, in which the highest values were 177.9 g and 20.57 t ha⁻¹ for average fruit weight and gross yield in the first season and 120.1 g and 19.29 t ha⁻¹ in the second season, respectively.

Irrigation levels significantly affected the water-use efficiency of tomato crop. The values of CWUE and IWUE decreased with increasing the irrigation level. The highest values were attained with 60% irrigation level. The values were 6.51 and 6.20 Kg m⁻³ in the first season, respectively. The corresponding values for the second season were 5.60 and 4.23 Kg m⁻³, respectively. The decreasing of water use efficiency with increasing the irrigation level is attributed to the increasing of applied irrigation water. From the production value viewpoint, the 100% irrigation level was the best rate of irrigation (20.57 and 19.29 t ha⁻¹ gross yield for both seasons).

Increasing the drip line depth, significantly affected the average fruit weight, gross yield and

Table 5. Tomato fruit yield, water used and water-use efficiency as affected by both irrigation regime and drip line depth for first season (2004/2005)

Irrigation Regime (% of ET _c)	Depth of drip line (cm)	Average fruit weight g	Gross yield Ton ha ⁻¹	Water use m ³ ha ⁻¹	Applied water m ³ ha ⁻¹	CWUE kg m ⁻³	IWUE kg m ⁻³
60	Surface	56.9	13.65	2500	3325	5.46	5.20
	15	83.8	16.34	2500	3325	6.54	6.22
	25	114.5	18.28	2500	3325	7.31	6.96
	35	94.3	16.87	2500	3325	6.75	6.43
80	Surface	94.4	16.85	3333	4433	5.06	4.81
	15	112.4	18.98	3333	4433	5.69	5.42
	25	175.1	20.86	3333	4433	6.26	5.96
	35	125.3	19.65	3333	4433	5.90	5.61
100	Surface	139.8	18.08	4167	5541	4.34	4.11
	15	161.4	20.80	4167	5541	4.99	4.73
	25	230.5	22.32	4167	5541	5.36	5.07
	35	180.0	21.06	4167	5541	5.05	4.79
120	Surface	88.1	16.12	5000	6650	3.22	3.04
	15	121.3	19.75	5000	6650	3.95	3.73
	25	191.3	21.58	5000	6650	4.32	4.07
	35	131.5	20.52	5000	6650	4.10	3.87
Mean effect of irrigation level (%)							
	60	87.4	16.29	2500	3325	6.51	6.20
	80	126.8	19.09	3333	4433	5.73	5.45
	100	177.9	20.57	4167	5541	4.94	4.67
	120	133.1	19.49	5000	6650	3.90	3.68
Mean effect of drip line depth (cm)							
	Surface	94.8c	16.18d	3750	4987	4.52d	4.29d
	15	119.7bc	18.97c	3750	4987	5.29c	5.03c
	25	177.9a	20.76a	3750	4987	5.81a	5.52a
	35	132.8b	19.53b	3750	4987	5.45b	5.17b
Interaction effect : irrigation level* drip line depth							
	L.S.D.(0.05)	35.4*	1.46*	-	-	0.43*	0.41*

* Significant at 0.05 probability level n.s. non-significant at 0.05 probability level
Values followed by the same letters are not significant.

Table 6. Tomato fruit yield, water used and water-use efficiency as affected by both irrigation regime and drip line depth for second season (2005/2006)

Irrigation Regime (% of ET _c)	Depth of drip line (cm)	Average fruit weight (g)	Gross yield Ton ha ⁻¹	Water use m ³ ha ⁻¹	Applied water m ³ /ha ⁻¹	CWUE kg m ⁻³	IWUE kg m ⁻³
60	Surface	65.7	13.42	2625	3400	5.11	3.95
	15	107.3	15.15	2625	3400	5.77	4.46
	25	99.3	15.75	2625	3400	6.00	4.63
	35	109.7	14.52	2625	3400	5.53	4.27
80	Surface	79.7	15.61	3500	4500	4.46	3.47
	15	89.7	17.10	3500	4500	4.89	3.80
	25	129.7	18.13	3500	4500	5.18	4.03
	35	110.3	16.47	3500	4500	4.71	3.66
100	Surface	109.3	18.01	4400	5650	4.09	3.19
	15	115.0	19.78	4400	5650	4.50	3.50
	25	150.6	20.83	4400	5650	4.73	3.69
	35	105.3	18.53	4400	5650	4.21	3.28
120	Surface	80.0	17.35	5300	6900	3.27	2.51
	15	109.5	18.95	5300	6900	3.58	2.75
	25	130.0	19.92	5300	6900	3.76	2.89
	35	110.3	18.10	5300	6900	3.42	2.62
Mean effect of irrigation level (%)							
	60	95.5b	14.71d	2625	3400	5.60a	4.33a
	80	102.4b	16.83c	3500	4500	4.81b	3.74ab
	100	120.1a	19.29a	4400	5650	4.38c	3.41ab
	120	107.5ab	18.58ab	5300	6900	3.51d	2.69b
Mean effect of drip line depth (cm)							
	Surface	83.7b	16.10c	3956	5112.5	4.23d	3.28d
	15	105.4a	17.75b	3956	5112.5	4.68b	3.63b
	25	127.4a	18.66a	3956	5112.5	4.92a	3.81a
	35	108.9a	16.91c	3956	5112.5	4.47c	3.46c
Interaction effect : irrigation level* drip line depth							
	L.S.D.(0.05)	28.2*	1.72*	-	-	0.39*	0.34*

* Significant at 0.05 probability level n.s. non-significant at 0.05 probability level

Values followed by the same letters are not significant.

water use efficiency. Increasing the depth of drip line increased the fruit weight from 94.8 g for surface drip irrigation to 177.9 g for subsurface drip irrigation at 25 cm depth in the first season and from 83.7 to 127.4 g for the second season. The other values were 119.7 and 132.8 g for 15 and 35 cm drip line depths in the first season and 105.4 and 108.9 g for the second season, respectively. Also, gross yield was 16.18, 18.97, 20.76 and 19.53 t ha⁻¹ for surface, 15, 25 and 35 cm drip line depths, respectively in the first season. The corresponding values for the second season were 16.10, 17.75, 18.66 and 16.91 t ha⁻¹, respectively. The highest values were attained with 25 cm drip line depth. The same trend was noticed for WUE, in which the highest value was attained with 25 cm drip line depth, i.e. 5.81 and 4.92 Kg m⁻³ of water consumed (CWUE) and 5.52 and 3.81 Kg m⁻³ of applied water (IWUE) for both seasons, respectively (Table 5 & 6).

Water production function

It was clear from the present results that the 25 cm drip line depth was suitable under the present conditions, may be due to the good balance of the soil

moisture and aeration in the root zone depth. Many researchers have reported similar increases in water-use efficiency for subsurface drip irrigation as compared with surface drip irrigation due to decreasing the evapotranspiration (Kashyap and Panda, 2003; Onder *et al.*, 2005; Patel and Rajput, 2007).

Fitting the present data to the polynomial function for the different treatments was done and presented in Table (7) and Figure (2). According to the mathematical analysis of the CWPF, the predicted maximum yield with applied water was 21.60 and 18.72 t ha⁻¹ for both seasons, respectively. The corresponding calculated applied water was 5571 and 5714 m³ ha⁻¹, respectively. It differed slightly (+11.71 and +11.77 % for both seasons, respectively) from the actual value applied under field conditions (4987 and 5112 m³ ha⁻¹, respectively). The mathematical analysis proved the superiority of 25 cm drip line depth in increasing the fruit yield and water use efficiency of tomato crop. While, the fitting data of yield and calculated (ET_c) showed that maximum yield was 22.0 and 20.5 t ha⁻¹ for the first and second seasons, respectively, at 25 cm drip line depth.

Table 7. Tomato water production function according to applied irrigation water (W) as affected by depth of drip line

Drip line Depth (cm)	Crop water production function	r ²	Maximum yield * Ton ha ⁻¹	Applied water m ³ ha ⁻¹	IWUE kg m ⁻³
First season					
Surface	$Y = -1E-06 * AW^2 + 0.0113 * W - 12.2250$	0.9929	19.70	5650	3.49
15	$Y = -8E-07 * AW^2 + 0.0086 * W - 3.9872$	0.9807	19.13	5375	3.56
25	$Y = -7E-07 * AW^2 + 0.0078 * W - 0.1260$	0.9937	21.60	5571	3.88
35	$Y = -7E-07 * AW^2 + 0.0079 * W - 1.8111$	0.9984	20.48	5643	3.63
Second season					
Surface	$Y = -6E-07 * AW^2 + 0.0071 * W - 3.8322$	0.9577	16.27	5833	2.79
15	$Y = -6E-07 * AW^2 + 0.0069 * W - 1.8032$	0.9295	17.63	5750	3.07
25	$Y = -7E-07 * AW^2 + 0.0081 * W - 3.8218$	0.9487	18.72	5714	3.28
35	$Y = -5E-07 * AW^2 + 0.0060 * W - 0.1659$	0.9660	17.54	6000	2.92

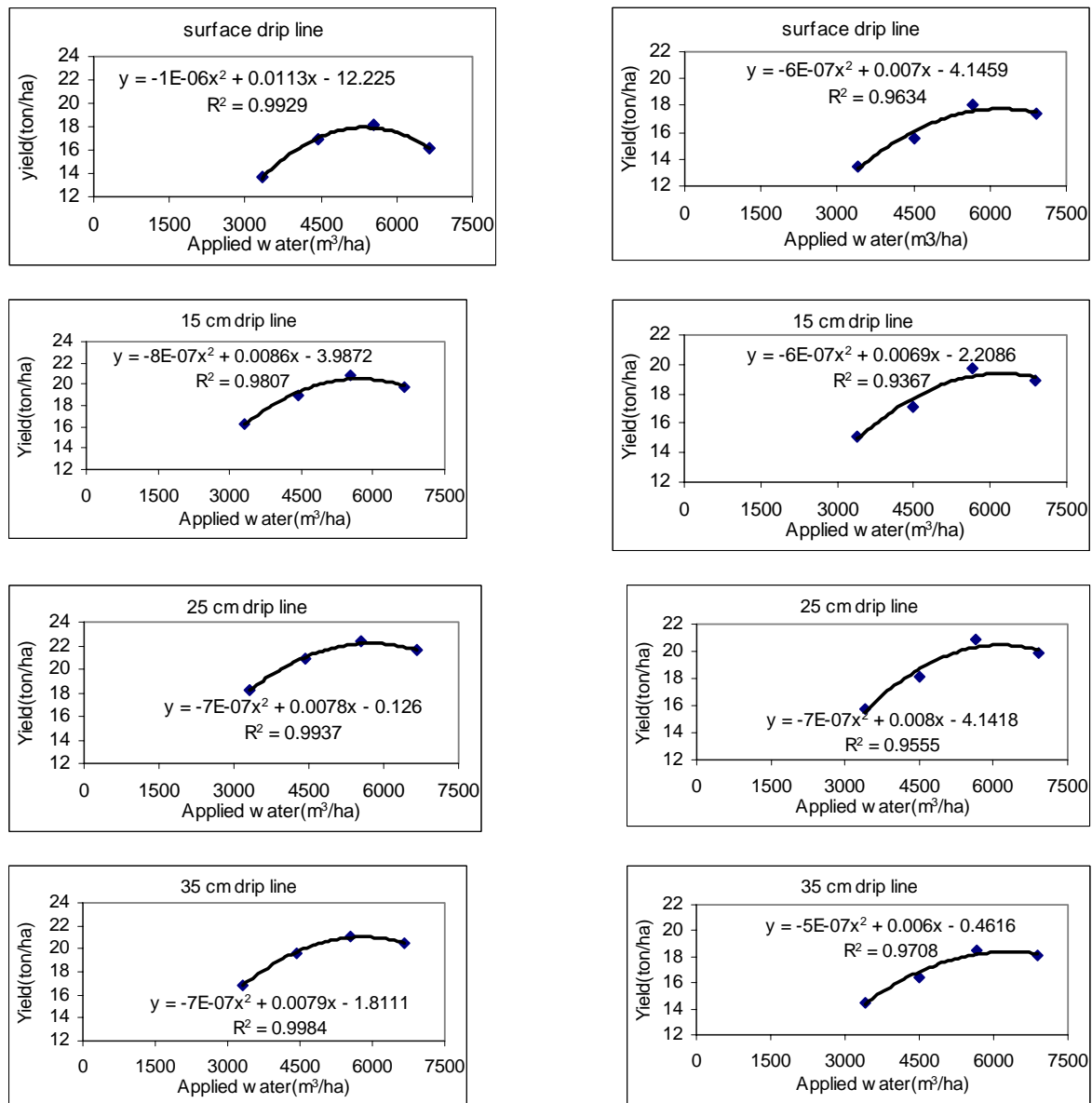


Fig.2: Tomato water production functions for first (left) and second(right) seasons

Table 8. Soil salinity (EC_e dSm⁻¹) at different dates of growing seasons for surface & subsurface drip irrigation with 100% of ET_c treatment

Depth cm	Date				
	Surface drip irrigation and 100% of ET _c treatment.				
	Aug. 2004	Dec. 2004	March 2005	Dec. 2005	March 2006
0 – 15	3.60	6.24	8.08	6.54	8.46
15 – 30	2.80	3.12	3.38	3.50	6.04
30 - 50	2.40	2.30	2.42	3.20	3.34
	Subsurface drip irrigation and 100% of ET _c treatment.				
0 – 15	2.51	5.89	8.22	7.02	9.2
15 – 30	1.73	3.67	5.36	6.33	6.59
30 - 50	0.45	1.89	1.64	2.96	3.68

Soil salinity

Data of surface (zero depth of emitters) and subsurface drip irrigation (25 cm depth of emitters) with irrigation level of 100% of ET_c are presented in Table (8). It indicated that salt distribution differ between the beginning and the end of the season. The table also, showed that the soluble salt distribution was high on the surface and decreased gradually with depth to the lowest values at 30-50 cm depth. Similar results were reported for salt, soil water content and root distributions (Al-Omran *et al.*, 2005; El-Damry, 2006). It appears that salt accumulation in the field was an important factor in reducing yield in the second season which is in contrast with study reported by Wan *et al.* (2007) where the salinity of 1.1- 4.9 dSm⁻¹ had little effect on tomato yield. However, as Shalhevet (1994) stated that it is still controversial whether the reduction in water uptake with increasing salinity is the cause or the result of reduction in growth.

Conclusion

The study showed the role of subsurface drip irrigation in improving the growth and increasing the yield of tomato crop and resulted in saving of applied irrigation water by creating a good moisture distribution in the root zone depth. Generally, the results suggested that the subsurface drip irrigation at 25 cm drip line depth using 100% of reference evapotranspiration (ET_c) irrigation level obtained a good growth and high fruit yield as well as water-use efficiency. It can be concluded that salinity of irrigation water (4.9 dSm⁻¹) used and to small percentage (15%) of leaching requirement application had resulted in lowering the average tomato yield to 17.0 t ha⁻¹ compared with the average yield of 70-100 ton ha⁻¹ reported using good water quality (EC_w of 1.2 dSm⁻¹).

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: الري بالتنقيط تحت السطحي، كفاءة استخدام المياه، دالة انتاجية المياه، ملوحة مياه الري، اعماق المنقطات.

. يعتبر الاستخدام المستدام لمصادر المياه النادرة في المملكة من الاولويات في التنمية الزراعية، وعليه فأن إيجاد طرق و تقنيات لتحسين ورفع كفاءة استخدام المياه للري مهمة جداً في مجال الزراعة. تركز الدراسة الحالية على تأثير مستوى مياه الري و اعماق المنقطات على نمو وانتاجية الطماطم وكذلك على دالة الانتاجية لمياه الري مرتفعة الملوحة نسبياً. تمت الدراسة في محطة الابحاث و التجارب الزراعية التابعة لكلية علوم الاغذية و الزراعة بديراب خلال الفترة اغسطس - فبراير لموسمي (٢٠٠٤ - ٢٠٠٦ م). لقد تم استخدام اربعة مستويات من الري على اساس البخر- نتح المحسوب عند ٦٠، ٨٠، ١٠٠ و ١٢٠٪ من البخر- نتح المحسوب (ETc)، وارباع اعماق للمنقطات هي صفر، ١٥، ٢٥ و ٣٥ سم. نظمت التجربة من خلال تصميم القطع المنشقة ثنائياً باستخدام التصميم العشوائي الكامل بثلاث مكررات لكل معاملة. لقد اوضحت النتائج ان هناك اختلاف معنوي لتاثير مستويات الري على النمو الخضري و الجذري لعنق ٢٥ سم. لقد زاد معدل الانتاج مع زيادة مستويات الري حتى ١٠٠٪ من البخر- نتح المحسوب (ETc) وانخفاض عند مسوى ١٢٠٪. كانت القيمة الاقصى هي ١٧٧.٩ جم و ٢٠.٥٧ طن/هكتار لمتوسط الثمار و الانتاجية للموسم الاول و ١٢٠.١ جم و ١٩.٣ طن/هكتار في الموسم الثاني، على التوالي. كما اوضحت النتائج ان زيادة اعماق المنقطات زاد من متوسط اوزان الثمار و الانتاجية و كفاءة استخدام المياه وكانت اعلى قيم عند عمق ٢٥ سم حيث قيم متوسط اوزان الثمار و الانتاجية و كفاءة استخدام المياه و الري هي ١٧٧.٩ جم و ٢٠.٧٦ طن/هكتار و ٥٤، ١٦ و ٤ كجم/م^٣ على التوالي للموسم الاول وكانت النتائج للموسم الثاني ١٢٧.٤ جم و ١٩.٣ طن/هكتار و ٥٧، ٤ و ٣ كجم/م^٣. ولقد توصلت النتائج من الدراسة الحالية بان عمق ٢٥ سم لمنقطات كان الانسب وعند مستوى ري ٨٠ - ١٠٠٪ من (ETc). ويجب ملاحظة ان النتائج المتحصل عليها كانت تحت مياه ري منخفضة النوعية ($EC_w = 4.9 \text{ dSm}^{-1}$) ونسبة غسيل لا تتجاوز ١٥٪.