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Research Article

Effect of Irrigation Systems on Vegetative Growth, Fruit Yield, Quality and Irrigation Water Use Efficiency of Tomato Plants (*Solanum lycopersicum* L.) Grown under Water Stress Conditions

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Abstract

Field experiment was conducted during the two growing seasons of 2012/2013 and 2013/2014, at BaniSalama region, El-Giza Governorate, Egypt, in order to investigate the effect of deficit irrigation (DI) treatments: 100% (control), 85%, 70% and 55% of ET_o (Reference evapotranspiration) and two irrigation systems: Surface drip irrigation (SDI) and Subsurface drip irrigation (SSDI) (20.0cm soil depth) on vegetative growth, chemical constituents, flowering, fruit yield and quality of tomato plants (Marwa hybrid), grown under sandy soil conditions. Results revealed that, DI treatments significantly decreased the vegetative growth, flowering, fruit yield parameters, photosynthetic pigments (chl. a, b and carotenoids), leaves mineral content (N, P, K and Fe %), leaf relative water content (LRWC) and membrane stability index (MSI) of tomato plants, compared to control treatment (100% ET_o). While, water stress treatments improved leaves proline content, irrigation water use efficiency (IWUE) and some fruit quality characteristics for tomatoes. Using SSDI system significantly increased plant length, number of leaves/plant, total leaves area/plant, number of flowers and fruits/plant, marketable fruit yield of tomatoes, LRWC and MSI, but there were no significant differences were observed on the TSS of tomato fruits with the both of irrigation systems. Regarding, the effect of interaction between DI treatments and irrigation systems, the results illustrated that application of irrigation water with 100% ET_0 by SSDI system produced the highest significant values of vegetative growth, flowering, fruit yield and quality parameters. It could be also concluded that the vegetative growth and flowering parameters, as well as fruit and quality of tomato plants which grown under DI treatments (85, 70 and 55% ET_0), can be improved by using SSDI system.

Keywords: Deficit Irrigation; Subsurface Drip Irrigation System; Leaf Relative Water Content; Membrane Stability Index; IWUE

Abbreviations

DI: Deficit Irrigation; ET: Evapotranspiration; I:S Irrigation System; ETc: Crop evapotranspiration; SDI: Surface Drip Irrigation System; SSDI: Subsurface Drip Irrigation System; LRWC: Leaf Relative Water Content; ETo: Reference Evapotranspiration; IWUE: Irrigation Water Use Efficiency; kpc: Class A Pan Evaporation; WUE: Water Use Efficiency; mM/l: Millimolar/liter; TSS: Total Soluble Solids; F.Wt: Fresh weight; MSI: Membrane Stability Index; T.Wt; Turgid Weight; ABA: Abscisic Acid; D.Wt: Dry Weight.

Introduction

Tomato (*Solanum lycopersicum* L.), a warm season crop, is sensitive to water stress and it has a high correlation between evapotranspiration (ET) and crop yield [1]. It's widely cultivated in hotareas, where the plants experience combinations of heat, water and salt stresses, so its needs enough irrigation water based on climatic conditions and soil type [2].

Among various abiotic stresses, drought is one of the basic factors for restricting crops production [3]. In this concern, Ibrahim [4] reported that increasing the irrigation regime, positively increased all vegetative growth parameters of tomato plants (plant height, number of branches, fresh and dry weight/plant). Where water stress treatments (40% F.C) resulted in a significant decrease in vegetative growth of tomato plants, where plant height reduced by 24% compared to the control treatment 100% F.C. In addition, several studies have shown that a great reduction of leaf area in tomato plants and other vegetable crops was observed with deficit irrigation treatment [5,6]. In the trend Ghorbanli., *et al*. [3] suggested that under drought stress, the contents of chlorophyll are decline in the leaves of tomato plants. In the same trend, Mutava., *et al*. [7] and Mohawesh [6] reported that drought stress reduces photosynthetic rate in soybean and eggplant compared to full irrigation treatment. Water stress treatments significantly reduced the uptake of nitrogen, phosphorus and potassium in tomato plants where the highest percentage was noticed in case of 100% F.C. Moreover, Mohawesh [6] recommended that the most stressful deficit irrigation treatments (20 and 40% based on field capacity) significantly decreased leaf mineral content of eggplant. In contrast, drought stress treatments significantly increased the amount of proline in tomato laves [3] and eggplant leaves [6].

Regarding the effect of deficit irrigation water on flowering and fruit yield, Osipitan (2012) found that the highest values for number of flowers per plant for tomato plants were obtained with increasing water stress regimes. While, Mohawesh [6] recommended that fruit weight and total eggplant yield significantly decreased with minimizing the irrigation water (from100 to 20% F.C). On the other hand, Liu., *et al*. [8] reported that, higher irrigation amount increased number of tomato fruits per plant. Several studies have shown that the maximum fruit yield of tomatoes was obtained by drip irrigation at 100% ETc treatment [9]. The same results were found by Onder., *et al*. [10] on potato plants.

Concerning the fruit quality, when higher irrigation treatment increased mean fruit weight, fruit diameter and fruit length of tomatoes [8] and eggplants [6] decreased the TSS. In addition, several studies have shown that DI treatments improved total soluble solids content for tomatoes and improved the fruit quality [9].

Water stress treatments induced a decrease in leaf relative water content (LRWC) in tomato plants. Mohawesh [6] reported that decreasing water level under open field conditions led to progressively decreased LRWC and membrane stability index (MSI), where deficit irrigation treatments (40 and 20% F.C.) showed significant negative effects on leaf relative water content and increased leaf water potential. On the other hand, deficit irrigation treatments applied to tomato plants have positive effects on water use efficiency [9]. This results are in harmony with those obtained by Onder., *et al*. [10] on potato plants and Mohawesh [6] on eggplants.

Subsurface drip irrigation (SSDI) is considered to be the most modern irrigation system, which effectively used when water is supplied under low pressure directly to the plant roots (Nalliah., *et al*. 2009). As well as, Ayars., *et al.* [11] suggested that SSDI system will be a tool that is available to improve water management and water productivity for sustainable agriculture in the future.

Subsurface drip irrigation system convey directly water and nutrients to plants, leading to increasing of vegetative growth and yields of vegetable crops. In this concern, EL-Gindy and EL-Araby [12] confirmed that there is a significant response of tomatoes and cucumber for SSDI when using equal quantities of irrigation water. Moreover, Machado., *et al*. [13] concluded that slightly higher values were observed with SSDI system (with tubes at 20 cm depth) for tomato plants. Furthermore, SSDI system was more efficient on enhancing nutrients concentration in potato tubers [14] and increased chlorophyll content, K+, Ca2+ and Mg2+ percentage in tomato plants compared to surface SDI system [5]. In addition, El-hindi [15] reported that SSDI system is important in increasing the availability and absorption of nitrogen and other minerals in the plant, thereby increasing the total chlorophyll content in the leaves.

Fruit yield influenced by irrigation systems, where Miguel., *et al*. [16] reported that when irrigation was reduced by 50% ETc with SSDI treatment, processing tomato yield increased by 66.5% compared to the surface treatment. On potato plants, Selim., *et al*. [14] found that tubers yield was higher under SSDI system than SDI system and the maximum yield was recorded when drip tape was buried at 10.0 cm. In the same trend, Ahmed [17] found that SSDI system increased the tomato yield by 41% over the SDI system. Furthermore, Ayars., *et al*. [11] reported that SSDI system has resulted in increased yields of vegetable crops (tomato, sweet corn and cantaloupe), compared to SDI system. In addition, Ahmed [17] and Ayars., *et al*. [11] found that SSDI system improved the fruit quality of vegetable crops (tomato, sweet corn and cantaloupe), compared to SDI system. On the other hand, Machado., *et al*. [13] reported that fruit quality for tomatoes was not significantly affected by irrigation methods (SDI and SSDI systems).

SSDI system may achieve higher production and water use efficiency than any other irrigation systems [18]. Moreover, Ahmed [17] found that SSDI system increased WUE by 33.7% compared to SDI system. In addition, Ayars., *et al*. [11] recommended that SSDI system has resulted in reduced water application.

The present study was conducted to investigate the effect of deficit irrigation treatments and irrigation systems on the vegetative growth, fruit yield and quality and IWUE of tomato plants grown under sandy soil conditions.

Materials and Methods

Field experiment was carried out on tomato plants (*Solanum lycopersicum* L.) during 2012/2013 and 2013/2014 seasons, in a private farm at Bani Salamaregion, El-Giza Governorate, Egypt, in order to investigate the effect of deficit irrigation treatments (DI levels were 100%, 85%, 70% and 55% of ET_o (Reference evapotranspiration)), irrigation systems (Surface drip irrigation (SDI) and Subsurface drip irrigation (SSDI), where drip tubes were buried manually at depth of 20.0 cm in the middle of beds before cultivation) and their interaction on vegetative growth and fruit yield and quality of tomato plants grown under sandy soil conditions. The total amounts of irrigation water during the growing seasons were calculated by using Penman–Montieth modified equation [19] and data are showed in Table 3. The experimental site is located at latitude: 30°15"N, longitude: 30°47"E. Geographical position of the experimental site is shown in Figure 1. Samples analyses of soil and irrigation water are shown in Tables 1 and 2. Metrological data were calculated as monthly means such as maximum and minimum temperatures, relative humidity and the total rain are shown in Table 4.

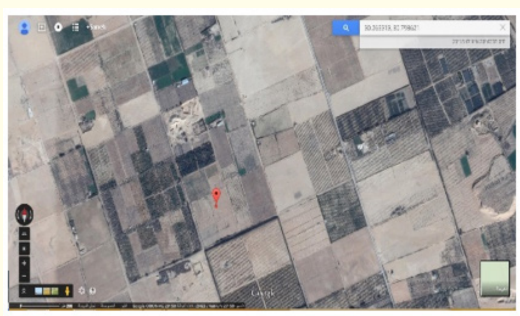

Figure 1: Experimental site (Google map, Satellite).

Tomato hybrid "Marwa" was used as test crop. Transplanting dates were on 27th of September and 1st of October in the first and second seasons, respectively. All agriculture practices were performed as recommended by Egyptian Ministry of Agriculture and Land Reclamation for tomato cultivation under open field conditions. Plants were fertilized with 230 units of N, 45 units of P_2O_5 and 70 units of K_2O/fed. during the growing season.

Physical properties		Values
Very coarse sand, % (2-1 mm)		16.60
Coarse sand, % (1-0.5 mm)		54.80
Medium sand, % (0.5-0.25 mm)		1.14
Fine sand, % (0.25-0.1 mm)		16.48
Very fine sand, % (0.1-0.05 mm)		9.64
Silt + Clay, % (0.05> mm)		1.34
Soil texture		Sandy
Field capacity, (%)		12
Wilting point, (%)		3.7
Saturation percent, (%)		29
Chemical properties		
pH		8.12
EC (dS/m)		1.81
Soluble cations (meq./L)	Ca^{++}	7
	Mg^{++}	3.2
	Na^{+}	7.6
	K^{+}	0.41
Soluble anions (meq./L)	CO_3^{--}	Nil
	HCO_3^{-}	2.5
	Cl^{-}	9
	SO_4^{--}	6.71

Table 1: Physical and chemical properties of experimental soil analysis.

Items		Values
pH		7.97
EC (dS/m)		1.36
Soluble cations (meq./L)	Ca^{++}	6.35
	Mg^{++}	4.11
	Na^{+}	5.95
	K^{+}	0.23
Soluble anions (meq./L)	CO_3^{--}	0
	HCO_3^{-}	2.97
	Cl^{-}	4.36
	SO_4^{--}	5.12

Table 2: Chemical properties of experimental water analysis.

Experimental design

The experiment was arranged in a split-plot design with three replications. Deficit irrigation treatmentswere arranged in the main plots and irrigation systems were assigned in the sub-plots. The area of the experimental plot was 22.5 m^2 consisted of one row with 15 m length and 1.5 m width and the plants were transplanted 75 cm spaced in the rows (Table 3).

Measured characteristics

Vegetative growth characteristics

Five plants were randomly chosen from three replications at 65 days from transplanting date to determine the following Characteristics: plant length (cm), number of leaves per plant, total leaves area (m^2)/plant (total leaves area was estimated with a 20 disc sampling per plant, dried and weighted separately. A relationship between disk dry matter and disk area was applied to total leaf dry matter to find total leaf area, according to Koller [20]), fresh weight and dry weight of leaves (g) per plant.

Chemical contents of the tomato leaves

- **Estimation of photosynthetic pigments:** Photosynthetic pigments (chlorophyll a, chlorophyll b and carotenoids (mg/g fresh weight)) in leaves were assayed according to [21]. Fifth leaf from the top of the plant (the fully expended leaf) was chosen to take 0.5g sample fresh weight. The pigments were extracted by using 10 ml N, N dimethyl formamide. The absorbance of the solution was measured at 470, 647 and 664 nm by UV/VIS spectrophotometer (CT 200 spectrophotometer), for chlorophyll a, b and carotenoids, respectively.
- **Determination of proline content in the tomato leaves*:*** Free proline content was extracted using 3% (w/v) aqueous sulphosalycylic acid and estimated by ninhydrin reagent according to the method of Bates., *et al* [22].
- **Nutrient analysis:** Nitrogen percent (N%) was determined using micro-Kjeldahl method as explained by Hesse [23]. Phosphorus percent (P%) was determined colorimetrically at wavelength 680 nm using Spectrophotometer (UV/VIS Spectrophotometer, CT 200) as described by Cottenie., *et al* [24]. Potassium percent (K%) was determined by using Flame photometer as mentioned by Cottenie., *et al.* [24]. Also, Fe concentration was measured using Atomic absorption Spectrophotometer PerkinElmer model 5000, as described by Chapman and Pratt [25].

Flowering and fruit yield

- Number of flowers and number of fruits per plant were also measured.
- **Yield:** Tomato fruits were hand harvested when reached to red ripe stage. At harvesting, total marketable yield was measured considering red and disease-free fresh fruits.
- **Fruit quality:** Random samples of fruits were taken from each experimental plot to determine the average fruit weight, fruit diameter and total soluble solids (TSS %) using hand refractometer.

Water measurements

Leaf relative water content (LRWC) (%)

For the estimation of LRWC, 20 leaf discs samples (10 mm in diameter) were taken with a cork borer (the fifth leaf from the top) and placed in a reweighed Petri dish to determine fresh weight (F.Wt.), discs were floated for 24 hours in distilled water inside a closed Petri dish until the discs became fully turgid. Discs samples were weighted after gently wiping the water to determine turgid weight (T.Wt.). Finally, the leaf discs were placed in a per-heated oven at 70°C to a constant weight (almost 48h) and weighted again to obtain discs dry weight (D.Wt.). So, LRWC % was calculated according to the equation of Kaya., *et al*. [26] as:

LRWC % = [(FW-DW)/(TW-DW)[× 100.

*Weeks	First season (2012/2013)				First season (2013/2014)			
	100%	85%	70%	55%	100%	85%	70%	55%
1	13.00	11.05	9.10	7.15	14.00	11.90	9.80	7.70
2	13.50	11.48	9.45	7.43	14.00	11.90	9.80	7.70
3	14.50	12.33	10.15	7.98	15.00	12.75	10.50	8.25
4	15.00	12.75	10.50	8.25	15.50	13.18	10.85	8.53
5	16.00	13.60	11.20	8.80	16.50	14.03	11.55	9.08
6	17.30	14.71	12.11	9.52	17.80	15.13	12.46	9.79
7	18.80	15.98	13.16	10.34	19.00	16.15	13.30	10.45
8	20.50	17.43	14.35	11.28	20.50	17.43	14.35	11.28
9	23.30	19.81	16.31	12.82	23.00	19.55	16.10	12.65
10	26.00	22.10	18.20	14.30	27.00	22.95	18.90	14.85
11	29.00	24.65	20.30	15.95	28.80	24.48	20.16	15.84
12	32.20	27.37	22.54	17.71	32.70	27.80	22.89	17.99
13	33.50	28.48	23.45	18.43	34.00	28.90	23.80	18.70
14	34.60	29.41	24.22	19.03	35.40	30.09	24.78	19.47
15	36.00	30.60	25.20	19.80	37.00	31.45	25.90	20.35
16	38.40	32.64	26.88	21.12	39.50	33.58	27.65	21.73
17	41.00	34.85	28.70	22.55	42.30	35.96	29.61	23.27
18	38.60	32.81	27.02	21.23	40.60	34.51	28.42	22.33

Table (3): Irrigation requirements (minute/plant per day) for irrigation treatments (100%, 85%, 70% and 55% of ET_o) for tomato plants in open field cultivation in both seasons of 2012-2013 and 2013-2014.

* Starting from 1st of October (2012 and 2013 for the first and second seasons, respectively)

Membrane stability index (MSI)

Ten leaf discs (10mm in diameter) were obtained from the fifth leaf from the top and placed in the tube containing 10 ml of distilled water in two sets. One set was subjected to 40°C for 30 min and its electrical conductivity (EC1) was determined at the end of incubation period using an electrical conductivity meter (HANNA H199301). Second set tubes were boiled in a temperature controlled water bath at 100°C for 15 min, and then the electrical conductivity (EC2) was measured [27]. Membrane stability index was calculated as percentage:

MSI (%) = 1-(EC1/EC2) × 100

Irrigation water use efficiency (IWUE) (kg/m3)

IWUE under deficit irrigation treatments were determined using the following equations given by Howell., *et al*. [28]:

IWUE = Yield (kg/fed.)/Applied irrigation water amount (m3/fed)(Table 4).

Month	Minimum air temp. (C)	Maximum air temp. (C)	Total rain (mm)	Maximum relative humidity (%)	Minimum relative humidity (%)
2012/2013					
October	19.60	31.20	0.000	82.90	34.45
November	14.60	26.20	0.178	84.10	38.05
December	13.00	23.90	0.201	82.90	41.65
January	9.70	20.60	0.169	85.30	38.15
February	11.50	22.20	0.254	82.50	36.85
2013/2014					
October	18.40	30.00	0.000	51.80	42.15
November	13.20	24.40	0.250	53.20	44.15
December	10.80	21.80	0.330	85.80	47.35
January	9.20	20.20	0.148	86.30	45.05
February	10.90	22.50	0.266	83.70	40.45

Table 4: Metrological data* (monthly maximum and minimum air temperatures, relative humidity and total rain) in 2012/2013 and 2013/2014 seasons.

* Metrological data were obtained from Central Laboratory for Agricultural Climate (CLAC).

Statistical analysis

Analysis of variance of the obtained data from each attribute was computed using the MSTAT Computer Program [29]. The Duncan's New Multiple Range test at 5% level of probability was used to test the significance of differences among mean values [30].

Results and Discussion Results and Discussion

Vegetative growth characteristics

Data in Tables 5 and 6 present the effect of deficit irrigation (DI), irrigation systems (IS) and their interactions on vegetative growth characteristics of tomato plants, i.e., plant length, number of leaves per plant, total leaves area per plant and fresh and dry weights of tomato leaves per plant. Results clearly indicated that DI treatments significantly decreased all vegetative growth parameters of tomato plants during the both studied seasons. Where the highest significant values were obtained by the full irrigation treatment (100% ET_o), followed by 85% ET_o treatment with significant differences between them, whereas, the lowest values were obtained by 55% ET_o treatment. These results are in harmony with those obtained by El-Dakroury [31], which recommended that increasing irrigation level from 60% and up to 100% ET_o significantly increased the vegetative growth parameters. This may be due to the role of water in increasing the uptake of mineral elements from soil and translocation of photosynthetic assimilates, thus reflected increases in the leaf number and leaf area as well as foliage weight per plant [32]. Moreover, drought stress causes various physiologic and biochemical effects in plants [33,34]. Furthermore, the reduction in shoot fresh and dry biomass, shoot length, leaf area per plant, transpirationrates, stomatal conductance, photosynthetic rate, relative water content and leaf water potential were accompanied to drought water stress [7], especially for plants were grown under sandy soil conditions. Ultimately, it destabilizes the membrane structure and permeability, protein structure and function, leading to cell death.

Treatments		2012/2013						2013/2014					
Deficit irrigation (DI)	Irrigation systems (IS)	Plant length (cm)		Number of leaves/plant		Total leaves area (m^2)/plant		Plant length (cm)		Number of leaves/plant		Total leaves area (m^2)/plant	
100% ET_o	Surface	90.25	b	87.50	b	4.09	ab	90.45	b	88.84	b	4.24	ab
	Subsurface	93.42	a	92.75	a	4.14	a	93.85	a	92.79	a	4.34	a
85% ET_o	Surface	84.17	c	79.42	c	3.82	c	84.69	c	79.91	d	3.94	c
	Subsurface	87.83	b	81.50	c	4.02	b	88.33	b	82.37	c	4.13	b
70% ET_o	Surface	80.75	d	69.92	d	2.84	d	81.57	d	71.70	f	2.92	e
	Subsurface	82.42	cd	72.92	d	2.93	d	83.25	cd	73.76	e	3.05	d
55% ET_o	Surface	66.00	f	60.95	e	1.71	f	66.78	f	60.94	h	1.70	g
	Subsurface	69.25	e	58.36	e	1.98	e	70.13	e	64.04	g	2.05	f
Deficit irrigation (DI)	100% ET_o	91.83	A	90.13	A	4.12	A	92.15	A	90.81	A	4.29	A
	85% ET_o	86.00	B	80.46	B	3.92	B	86.51	B	81.14	B	4.03	B
	70% ET_o	81.58	C	71.42	C	2.88	C	82.41	C	72.73	C	2.98	C
	55% ET_o	67.63	D	59.65	D	1.84	D	68.45	D	62.49	D	1.88	D
Irrigation systems (IS)	Surface	80.29	B	74.45	A	3.11	B	80.87	B	75.35	B	3.20	B
	Subsurface	83.23	A	76.38	A	3.27	A	83.89	A	78.24	A	3.39	A
Values followed by the same letter (s) within column are not significantly different (P<0.05)													

Table 5: Effect of deficit irrigation and irrigation systems on some vegetative attributes of tomato plants during 2012/2013 and 2013/2014 seasons.

Concerning the effect of irrigation systems (surface and subsurface drip irrigation) on vegetative growth parameters of tomato plants, the obtained data revealed that subsurface drip irrigation system (SSDI)showed superiority upon surface drip irrigation system (SDI) with all vegetative growth characteristics. Where, the highest significant values for plant length, number of leaves per plant, total leaves area per plant and fresh and dry weights of tomato leaves per plant were produced by SSDI system in the both tested seasons. In this concern, many investigators reported that SSDI system enhanced vegetative growth, this improvement due to the timing and placement of water and nutrients in the crop root zone, furthermore, the salt distribution in the soil profile under SSDI system in the sandy soil type was better than SDI system, where the harmful effects of salt in the root zone and evaporation from the soil surface were reduced [15,35].

Regarding the interaction between deficit irrigation treatments and irrigation systems, plants were irrigated by 100% ET_o with SSDI system produced the highest significant values for plant length, number of leaves per plant and fresh and dry weights of tomato leaves per plant. While the highest significant values of total leaves area per plant were obtained by 100% ET_o treatment with both irrigation systems (SDI and SSDI) in the two growing seasons.

Chemical contents for tomato leaves

Data presented in Tables 7-8 reveal the effect of deficit irrigation treatments, irrigation systems and their interactions on-chemical contents for tomato leaves (chlorophyll a, chlorophyll b, carotenoids, proline content and mineral elements: N, P, K and Fe). Results illustrated that decreasing irrigation water from 100% ET_o to 55% ET_o significantly decreased photosynthetic pigments

Data presented in Tables 7-8 reveal the effect of deficit irrigation treatments, irrigation systems and their interactions onchemical contents for tomato leaves (chlorophyll a, chlorophyll b, carotenoids, proline content and mineral elements: N, P, K and Fe). Results illustrated that decreasing irrigation water from 100% ET_o to 55% ET_o significantly decreased photosynthetic pigments and mineral constituents of tomato leaves. Where, the highest significant values for chlorophyll a, chlorophyll b, carotenoids and leaf N, P, K and Fe contents were obtained with 100% ET_o (control) treatment. While the lowest values were gained with 55% ET_o treatment in both tested seasons. In the second season, no significant differences were realized between with 100% ET_o and 85% ET_o treatments for chlorophyll b. On the other hand, drought stress significantly increased proline content in tomato leaves. Where, the highest significant values were obtained by 55% ET_o treatment. While, the lowest values were noticed with 100% ET_o treatment, in the two studied seasons. These results are in harmony with those obtained by Ghorbanli., *et al*. [3], which reported that leaf chlorophyll a and b significantly decreased in mild and severe stress conditions. In the same trend, Gao., *et al*. [36] reported that under drought stress, the content of chlorophyll is decline in the leaves of processing tomato. In addition, Mutava., *et al*. [7] reported that drought stress reduces photosynthetic rate in soybean which mainly due to the reduction in stomatal conductance caused by increased ABA concentration in the leaves. Furthermore, El-Fawakhry [37] suggested that drip irrigation system is important in increasing the availability and absorption of nitrogen and other minerals in the plant, thereby increasing the total chlorophyll content in the leaves. While, Yadav., *et al*. [38] mentioned that water stress induced an accumulation in proline concentration in wheat plants. Proline accumulates under stressed conditions supplies energy for growth and survival and thereby helps the plant to tolerate stress. As well as, Gao., *et al*. [36] reported that under drought stress, the contents of proline and soluble sugar are increased in the leaves of processing tomato. Therefore, Ghorbanli., *et al*. [3] concluded that in tomato plants osmolyte such as proline increased against drought stress.

Respecting the effect of irrigation systems (SDI and SSDI) on photosynthetic pigments and mineral elements in tomato leaves, the obtained data revealed that SSDI system produced the highest significant values for chlorophyll a, chlorophyll b, carotenoids and leaf N, P, K and Fe contents compared to SDI system. In contrast, surface drip irrigation system produced the highest significant values of proline content in tomato leaves compared to subsurface drip irrigation system, in the both tested seasons. In connection with these results El-Shawadfy [35] found that SSDI systems exhibited the highest values of pod colour (Chl.a, Chl.b and Chl.a+b) for bean plants compared to other irrigation systems. In addition, Elhindi [15] reported that SSDI system is important in increasing the availability and absorption of minerals in the plant, thereby increasing the total chlorophyll content in the leaves. Furthermore, Cooper and Chunhua [39] suggested that use of SSDI system slightly increased the nutrient concentration in the marigold plant, which was reflected through increased nutrient uptake in the plants. Moreover, Oktem [40] reported that water plays a significant role in mobilization of mineral elements. Similarly, Selim., *et al*. [14] mentioned that SSDI system slightly increased nutrients concentration in potato tubers as compared with SDI system.

Treatments		2012/2013				2013/2014			
Deficit irrigation (DI)	Irrigation systems (IS)	Fresh weight of leaves (g)		Dry weight of leaves (g)		Fresh weight of leaves (g)		Dry weight of leaves (g)	
100% ET_o	Surface	674.60	b	29.71	b	677.50	b	31.38	b
	Subsurface	691.10	a	30.88	a	693.20	a	32.75	a
85% ET_o	Surface	607.80	c	24.25	d	611.30	c	25.78	d
	Subsurface	614.80	c	26.15	c	619.70	c	27.72	c
70% ET_o	Surface	361.70	d	16.51	f	365.80	d	18.01	f
	Subsurface	370.50	d	17.51	e	374.80	d	19.06	e
55% ET_o	Surface	202.90	e	13.01	h	207.40	e	14.33	h
	Subsurface	214.30	e	13.83	g	218.70	e	15.49	g
Deficit irrigation (DI)	100% ET_o	682.80	A	30.29	A	685.40	A	32.06	A
	85% ET_o	611.30	B	25.20	B	615.50	B	26.75	B
	70% ET_o	366.10	C	17.01	C	370.30	C	18.54	C
	55% ET_o	208.60	D	13.42	D	213.10	D	14.91	D
Irrigation systems (IS)	Surface	461.70	B	20.87	B	465.50	B	22.38	B
	Subsurface	472.70	A	22.09	A	476.60	A	23.76	A
Values followed by the same letter (s) within column are not significantly different (P<0.05)									

Table 6: Effect of deficit irrigation and irrigation systems on fresh and dry weights of leaves (g) of tomato plants during 2012/2013 and 2013/2014 seasons.

Concerning the combination between deficit irrigation treatments and irrigation systems data showed that, plants were irrigated by 100% ET_o with SSDI system produced the highest significant values for chlorophyll a chlorophyll b, carotenoids and leaf N, P, K, and Fe contents in tomato leaves, with no significant differences with 85% ET_o and SSDI system for chlorophyll b only in the both tested seasons. While, plants were irrigated by 55% ET_o with SDI system produced the highest significant values for proline content in tomato leaves, compared to the other treatments.

Treatments		2012/2013								2013/2014							
Deficit irrigation (DI)	Irrigation systems (IS)	Chlorophyll a (mg/g fresh weight)		Chlorophyll b (mg/g fresh weight)		Carotenoids (mg/g fresh weight)		Proline content (µg/g DW)		Chlorophyll a (mg/g fresh weight)		Chlorophyll b (mg/g fresh weight)		Carotenoids (mg/g fresh weight)		Proline content (µg/g DW)	
100% ET_o	Surface	2.30	b	1.52	b	1.57	b	36.50	g	2.35	b	1.57	b	1.63	b	36.38	f
	Sub surface	2.47	a	1.70	a	1.67	a	36.39	g	2.57	a	1.73	a	1.74	a	36.17	f
85% ET_o	Surface	1.94	d	1.43	c	1.28	d	39.03	e	2.03	d	1.55	bc	1.37	d	38.90	e
	Sub surface	2.18	c	1.63	a	1.44	c	38.31	f	2.28	c	1.68	a	1.50	c	38.74	e
70% ET_o	Surface	1.60	f	1.29	d	0.99	f	47.53	c	1.71	f	1.41	d	1.08	f	48.10	c
	Sub surface	1.70	e	1.45	bc	1.08	e	45.88	d	1.79	e	1.47	cd	1.14	e	46.36	d
55% ET_o	Surface	1.47	g	0.97	f	0.69	g	58.71	a	1.54	h	1.06	f	0.73	g	58.67	a
	Sub surface	1.58	f	1.07	e	0.73	g	56.74	b	1.62	g	1.15	e	0.76	g	56.77	b
Deficit irrigation (DI)	100% ET_o	2.39	A	1.61	A	1.62	A	36.45	D	2.46	A	1.65	A	1.68	A	36.27	D
	85% ET_o	2.06	B	1.53	B	1.36	B	38.67	C	2.16	B	1.62	A	1.43	B	38.82	C
	70% ET_o	1.65	C	1.37	C	1.04	C	46.71	B	1.75	C	1.44	B	1.11	C	47.23	B
	55% ET_o	1.52	D	1.02	D	0.71	D	57.72	A	1.58	D	1.11	C	0.75	D	57.72	A
Irrigation systems (IS)	Surface	1.83	B	1.30	B	1.13	B	45.44	A	1.91	B	1.40	B	1.20	B	45.51	A
	Sub surface	1.98	A	1.46	A	1.23	A	44.33	B	2.06	A	1.51	A	1.28	A	44.51	B
Values followed by the same letter (s) within column are not significantly different (P<0.05)																	

Table 7: Effect of irrigation levels and foliar application of glycine betaine on chlorophyll a, b and carotenoids contents (mg/g fr.wt) of tomato leaves during 2012/2013 and 2013/2014 seasons.

Treatments		2012/2013								2013/2014							
Deficit irrigation (DI)	Irrigation systems (IS)	N (%)		P (%)		K (%)		Fe (ppm)		N (%)		P (%)		K (%)		Fe (ppm)	
100% ET_o	Surface	3.99	b	0.42	b	4.83	c	165.00	b	4.05	b	0.42	b	4.88	b	168.50	b
	Subsurface	4.48	a	0.44	a	5.08	a	178.40	a	4.51	a	0.45	a	5.19	a	182.70	a
85% E_To	Surface	3.57	d	0.37	cd	4.55	d	158.90	c	3.61	d	0.38	cd	4.60	c	160.10	d
	Subsurface	3.81	c	0.39	bc	4.86	b	159.60	c	3.90	c	0.39	c	4.90	b	163.30	c
70% ET_o	Surface	2.79	f	0.33	e	4.04	f	131.90	e	2.84	f	0.33	e	4.10	e	134.10	f
	Subsurface	3.37	e	0.36	d	4.27	e	142.80	d	3.50	e	0.36	d	4.30	d	145.10	e
55% ET_o	Surface	2.23	h	0.25	f	2.67	h	115.80	g	2.29	h	0.26	f	2.69	g	117.60	h
	Subsurface	2.58	g	0.32	e	3.23	g	117.90	f	2.63	g	0.32	e	3.27	f	122.40	g
Deficit irrigation (DI)	100% ET_o	4.24	A	0.43	A	4.96	A	171.70	A	4.28	A	0.43	A	5.04	A	175.60	A
	85% ET_o	3.69	B	0.38	B	4.70	B	159.20	B	3.75	B	0.38	B	4.75	B	161.70	B
	70% ET_o	3.08	C	0.34	C	4.15	C	137.30	C	3.17	C	0.35	C	4.20	C	139.60	C
	55% ET_o	2.41	D	0.28	D	2.95	D	116.80	D	2.46	D	0.29	D	2.98	D	120.00	D
Irrigation systems (IS)	Surface	3.14	B	0.34	B	4.02	B	142.90	B	3.19	B	0.35	B	4.07	B	145.10	B
	Subsurface	3.56	A	0.38	A	4.36	A	149.70	A	3.63	A	0.38	A	4.42	A	153.40	A
Values followed by the same letter (s) within column are not significantly different (P<0.05)																	

Table 8: Effect of deficit irrigation and foliar application of glycine betaine on some vegetable attributesof tomato plants during 2012/2013 and 2013/2014 seasons.

Flowering and fruit yield

Data in Tables 9 reveal the influence of deficit irrigation, irrigation systems and their interactions on number of flowers per plant, number of fruits per plant and total marketable yield. Results showed that decreasing irrigation water from 100% ET_o to 55% ET_o significantly reduced number of flowers per plant, number of fruits per plant and total marketable yield during both tested seasons. Where the highest significant values were obtained with 100% ET_o treatment, followed by 85% ET_o treatment with significant differences between them. While the lowest values were noticed with plants irrigated by 55% ET_o. These results are in agreement with those obtained by Colla., *et al*. [41] affirmed that deficit irrigation reduced the number of flowers leading to decrease the number of fruits. In addition, Farooq., *et al*. [33] indicated that water deficit reduced plant growth and development, leading to the production of smaller organs, and reduction the number of flowersper plant. As well as, Kahlaoui., *et al*. [5] mentioned that deficit irrigation at 70% of tomato water requirement decreased the number of flowers per plant. Furthermore, Earl and Davis [42] suggested that soil water deficit reduced crop yield by reducing canopy absorption of photosynthetically active radiation, leading to decreasing radiation-use efficiency. Moreover, Aldesuquy., *et al.* [43] reported that the reduction in yield can be attributed to the decrease in photosynthetic pigments, carbohydrates accumulation (polysaccharides) and nitrogenous compounds (total nitrogen and protein).

Treatments		2012/2013						2013/2014					
Deficit irrigation (DI)	Irrigation systems (IS)	Number of flowers/plant		Number of fruits/plant		Total marketable yield (ton/fed.)		Number of flowers/plant		Number of fruits/plant		Total marketable yield (ton/fed.)	
100% ET_o	Surface	110.80	a	78.33	b	46.17	b	113.90	a	80.15	b	46.78	b
	Subsurface	113.80	a	86.33	a	46.84	a	116.10	a	88.15	a	47.85	a
85% ET_o	Surface	87.25	c	63.92	d	38.76	d	89.53	c	65.74	d	39.29	d
	Subsurface	93.83	b	68.33	c	40.43	c	96.36	b	70.15	c	40.27	c
70% ET_o	Surface	72.33	d	42.75	f	33.83	f	74.61	d	44.57	f	33.78	f
	Subsurface	76.33	d	57.33	e	35.47	e	78.54	d	59.15	e	35.65	e
55% ET_o	Surface	46.75	f	36.58	g	24.65	h	48.81	f	38.40	g	24.81	h
	Subsurface	52.17	e	40.92	f	25.73	g	54.22	e	42.74	f	26.25	g
Deficit irrigation (DI)	100% ET_o	112.30	A	82.33	A	46.51	A	115.00	A	84.15	A	47.31	A
	85% ET_o	90.54	B	66.13	B	39.60	B	92.94	B	67.94	B	39.78	B
	70% ET_o	74.33	C	50.04	C	34.65	C	76.58	C	51.86	C	34.71	C
	55% ET_o	49.46	D	38.75	D	25.19	D	51.51	D	40.57	D	25.53	D
Irrigation systems (IS)	Surface	79.29	B	55.40	B	35.85	B	81.71	B	57.22	B	36.16	B
	Subsurface	84.04	A	63.23	A	37.12	A	86.31	A	65.05	A	37.50	A
Values followed by the same letter (s) within column are not significantly different ($P<0.05$)													

Table 9: Effect of deficit irrigation and irrigation systems on the number of flowers and fruits of tomato plant and the total marketable yield (ton/fed.) of tomatoes during 2012/2013 and 2013/2014 seasons**.**

Concerning the effect of irrigation systems (SDI and SSDI) on flowering and fruit yield characteristics, the obtained data revealed that SSDI system showed significant superiority upon SDI system. Where, the highest significant values for number of flowers per plant, number of fruits per plant and total marketable yield were obtained by SSDI system compared to SDI system in the both tested seasons. These results are in harmony with those obtained by Selim., *et al*. [14] on potato, El-Shawadfy [35] on snap bean and Ayars., *et al*. [11] on many vegetable crops. Furthermore, Selim., *et al*. [14] mentioned that the ability of SSDI system to improve tubers yield could be attributed to the less water lost from soil surface through evaporation, which resulted in optimum crop yield. Moreover, SSDI system allows maintenance of optimum soil moisture content in the root zone, which improved the efficiency of water and fertilizers use, which reflected on the increase of vegetative growth and fruit yield [44].

Respecting the studied combination between deficit irrigation treatments and irrigation systems, plants were irrigated by 100% ET_o with both of irrigation systems (SDI and SSDI) showed the highest numbers of flowers per plant with significant differences to the other treatments. While the highest significant values for number of fruits per plant and total marketable yield for tomatoes were obtained by 100% ET_o with SSDI system in the both tested seasons.

Fruit quality

Data in Tables 10 illustrate the effect of deficit irrigation, irrigation systems and their interactions on fruit quality characteristics of tomatoes (average fruit weight, fruit diameter and total soluble solids (TSS %)). Results showed that decreasing irrigation water from 100% ET_o to 60% ET_o significantly affected on fruit quality characteristics. Where, the highest significant values of average fruit weight were obtained by 100% ET_o treatment. While, the maximum fruit diameter were observed with 100, 85 and 70% ETo treatments, without significant differences among them. On the other hand, decreasing irrigation water increased TSS of tomatoes, where the highest significant values were obtained by 55% ET_o treatment in the two studied seasons. Similar findings were obtained by Cetin., *et al.* (2002), where the highest fruit weight and diameter were noticed with full irrigated treatment. In this respect, Patane., *et al.* [9] concluded that a proper application of DI strategy may contribute to obtain a good compromise between yield and fruit quality in tomato. Moreover, Branthome., *et al.* [45] recommended that the highest values of total soluble solids content (TSS) were determined in the deficit irrigation conditions (0.7k pc). Similarly, irrigation for maximum yield was found to reduce TSS of processing tomatoes [41,46].

Treatments		2012/2013						2013/2014					
Deficit irrigation (DI)	Irrigation systems (IS)	Average fruit weight (g)		Fruit diameter (cm)		TSS (%)		Average fruit weight (g)		Fruit diameter (cm)		TSS (%)	
100% ET_o	Surface	97.35	a	5.33	a	5.86	f	94.53	a	5.02	bc	5.89	f
	Subsurface	92.35	b	5.12	ab	6.36	d	91.99	ab	5.05	bc	6.49	d
85% ET_o	Surface	85.93	c	4.95	b	6.55	c	87.79	bcd	5.38	a	6.62	cd
	Subsurface	86.90	c	5.06	b	6.17	e	85.65	cd	4.99	bc	6.29	e
70% ET_o	Surface	82.09	c	5.00	b	6.70	c	83.50	d	4.96	c	6.78	c
	Subsurface	84.89	c	4.98	b	7.24	b	88.77	bc	5.20	ab	7.38	b
55% ET_o	Surface	71.43	d	4.11	c	8.02	a	69.38	e	4.24	d	8.26	a
	Subsurface	73.40	d	4.24	c	7.20	b	71.53	e	4.32	d	7.29	b
Deficit irrigation (DI)	100% ET_o	94.85	A	5.23	A	6.11	D	93.26	A	5.04	A	6.19	D
	85% ET_o	86.42	B	5.01	A	6.36	C	86.72	B	5.18	A	6.46	C
	70% ET_o	83.49	B	4.99	A	6.97	B	86.13	B	5.08	A	7.08	B
	55% ET_o	72.42	C	4.18	B	7.61	A	70.45	C	4.28	B	7.78	A
Irrigation systems (IS)	Surface	84.20	A	4.85	A	6.78	A	83.80	A	4.90	A	6.89	A
	Subsurface	84.39	A	4.85	A	6.74	A	84.49	A	4.89	A	6.86	A
Values followed by the same letter (s) within column are not significantly different ($P<0.05$)													

Table 10: Effect of deficit irrigation and irrigation systems on average fruit weight (g) and fruit diameter (cm) and TSS (%) of tomato fruits during 2012/2013 and 2013/2014 seasons.

Regarding the effect of irrigation systems (SDI and SSDI) on fruit quality characteristics, data revealed that there were no significant differences between the both of irrigation systems for average fruit weight, fruit diameter and TSS of tomatoes, in the two studied seasons. In connection with these results, Phene., *et al.* [47] and Oron., *et al.* [48] suggested that SSDI system decreases the accumulation of salts at the root zone level of plants, producing an improved yield and fruit quality. This has been observed in tomato [49] and onion [18]. On the other hand, Ahmed [17] concluded that SSDI system was found to be more advanced for using of very small amounts of water and chemicals, which ensures higher yield and quality for vegetable crops compared to the surface irrigation system.

The studied combination between deficit irrigation treatments and irrigation systems indicated that, plants were irrigated by 100% ET_o with SDI system (in the first season) and with both of irrigation systems (in the second season) showed the highest significant values for average fruit weight. However, the highest significant values for fruit diameter were noticed with 100% ET_o treatment with both of irrigation systems in the first season and by 85% ET_o with SDI system and 70% ET_o with SSDI system in the second season. In contrast, the highest significant values for TSS, were noticed with 55% ET_o and SDI system, in the both tested season.

Water measurements of tomato plants

Data presented in Tables 11 reveal the effect of deficit irrigation treatments, irrigation systems and their interactions on water measurements for tomato plants, i.e., leaf relative water content (LRWC), membrane stability index (MSI) and irrigation water use efficiency (IWUE). Results clearly indicated that increasing irrigation water from 55% ET_o to 100% ET_o significantly increased leaf relative water content (LRWC)and membrane stability index (MSI) in the both tested seasons. Where the highest significant values were obtained by 100% ET_o treatment, while, the lowest values were obtained by 55% ET_o treatment. In contrast, irrigation water use efficiency (IWUE) significantly decreased with increasing irrigation water, where the maximum values were observed with 55% ET_o treatment, in the two studied seasons. These results are in harmony with those obtained by Kirda [50], reported that the using of DI strategy is very important to increase crop water use efficiency (WUE). Moreover, Patane., *et al*. [9] concluded that the adoption of DI strategies at 50% reduction of ET_c could be suggested for processing tomato under open field conditions, for increasing WUE.

Treatments		**2012/2013**						**2013/2014**					
Deficit irrigation (DI)	Irrigation systems (IS)	MSI		Leaf relative water content (%) (LRWC)		Irrigation water use efficiency (IWUE) (kg/m3)		MSI		Leaf relative water content (%) (LRWC)		Irrigation water use efficiency (IWUE) (kg/m3)	
100% ET_o	Surface	82.88	b	85.79	b	34.51	f	83.06	b	86.13	b	34.42	h
	Subsurface	91.71	a	87.50	a	38.19	e	91.90	a	87.82	a	39.08	g
85% ET_o	Surface	70.99	d	83.30	d	46.34	d	71.76	c	83.70	c	46.97	f
	Subsurface	82.18	c	83.83	c	53.94	b	82.75	b	84.20	c	55.62	c
70% ET_o	Surface	61.60	f	66.46	f	50.46	c	62.27	e	67.18	e	51.45	e
	Subsurface	69.52	e	67.82	e	53.02	b	70.40	d	68.83	d	53.50	d
55% ET_o	Surface	42.63	h	62.66	h	56.86	a	43.00	g	63.05	g	57.25	b
	Subsurface	51.07	g	63.54	g	57.28	a	51.51	f	63.99	f	58.42	a
Deficit irrigation (DI)	100% ET_o	87.30	A	86.64	A	36.35	D	87.48	A	86.97	A	36.75	D
	85% ET_o	76.59	B	83.56	B	50.14	C	77.26	B	83.95	B	51.29	C
	70% ET_o	65.56	C	67.14	C	51.74	B	66.34	C	68.00	C	52.48	B
	55% ET_o	46.85	D	63.10	D	57.07	A	47.25	D	63.52	D	57.83	A
Irrigation systems (IS)	Surface	64.53	B	74.55	B	47.04	B	65.02	B	75.01	B	47.52	B
	Subsurface	73.62	A	75.67	A	50.61	A	74.14	A	76.21	A	51.65	A
Values followed by the same letter (s) within column are not significantly different (P<0.05)													

Table 11: Effect of deficit irrigation and irrigation systems on leaf relative water content (LRWC) (%), membrane stability index (MSI) and the irrigation water use efficiency (IWUE) (kg/m3) of tomato plants during 2012/2013 and 2013/2014 seasons.

Respecting the effect of irrigation systems (SDI and SSDI) on water measurements for tomato plants, the obtained data revealed that SSDI system showed significant superiority to SDI system under field conditions in the both tested seasons. Where, the highest significant values for LRWC, MSI and IWUE were showed with SSDI system compared to SDI system. These results are in agreement with those obtained by Ahmed [17], who suggested that water use efficiency under SSDI system was much more than SDI system with cultivated tomato plants. This due to, bigger wetted volume in the root zone was observed with SSDI system and all water utilized by plants. It can be concluded that, SSDI method proved a feasible option for tomato crop production under water limited conditions.

Concerning the combination between deficit irrigation treatments and irrigation systems, plants were irrigated by 100% ET_o with SSDI system produced the highest significant values for LRWC and MSI, in the both tested seasons. On the other hand, the maximum significant values for IWUE were observed with 55% ET_o and both of irrigation systems (in the first season) as well as with SSDI system only in the second season.

Conclusion

It could be concluded that, under sandy soil conditions with deficit and limited water resource, tomato plants should be produced using subsurface drip irrigation system to overcome the negative effects of water stress and increase the water use efficiency, as well as improve the vegetative growth, fruit yield and quality.

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