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Increasing the Productivity of Tomato Plants Grown in Sandy Soil Under Deficit Irrigation Water Conditions

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Research Article

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Keywords: Tomato, Deficit irrigation, Irrigation systems, Subsurface drip irrigation, Glycine betaine, Fruit yield, Fruit quality.

ABSTRACT

Studying the alleviating of water stress for tomato plants cultivated in a sandy soil and were exposed to deficit irrigation (DI) treatments; 100%, 85%, 70% and 55% of ET_o, using two irrigation systems (surface drip irrigation (SDI) and subsurface drip irrigation (SSDI), and spraying the plants by glycine betaine (GB) (0, 5, 10 and 20 mM/l) as a foliar application. Results clearly reported that the full irrigation treatment 100% ET_o produced the highest significant values of total leaves area and fresh and dry weights of tomato leaves per plant, number of flowers per plant and total marketable yield, while DI treatments (85%, 70% and 55% of ET_o) significantly decreased all of these characteristics. There was a positive effect on many tomato fruit quality characteristics; TSS, total sugars and ascorbic acid content. Tomato plants grown under subsurface drip irrigation system have the highest significant values for vegetative growth, flowering and fruit yield and quality parameters, compared to SDI system. Glycine betaine treatments enhanced the growth of tomato plants grown under deficit irrigation water, where plants received GB at 10 mM/l had the maximum values for studying characteristics. While, fruit quality characteristics not significantly affected by GB treatments. Results reported that, When DI treatments (85%, 70% and 55% ET_o) decreased total marketable yield by (14.38%, 25.08% and 48.77%) and (14.23%, 24.78% and 47.03%), spraying the plants by GB at 10 mM/l increased it by (10.95%, 10.11% and 22.85%) and (12.92%, 9.26% and 20.74%), in the first and second seasons, respectively.

INTRODUCTION

Increasing the productivity of vegetable crops as well as saving the water resource is an urgent needs in Egypt which located in the arid and semi-arid regions. Plants grown in these regions face water stress conditions which cause a reduction in the growth and fruit production of vegetable crops [1]. On the other hand, Ozbahce and Tari [2] concluded that successful production of vegetables demands efficient water application.

Producing tomato plants with higher fruit yield and good quality can only be reached in the conditions of optimal soil moisture. In addition, Viswanatha et al., [3] reported that the reduction in crop yields achieved with decreasing irrigation water amount. Thereupon, many studies clearly indicated that decreasing irrigation water reduced the vegetative growth parameters and dry matter accumulation for tomato and sweet corn plants [1,4].

Therefore, irrigation system plays a vital role for vegetable growth and production, where the water should be given in a proper amount and accurate time application. Subsurface drip irrigation system (SSDI) can be used as an effective method for improving water use efficiency [5] and water conservation [6]. This technique (SSDI) may provide a tool for controlling of crop evapotranspiration (ET) in tomato plants and increase saving irrigation water in drought areas [7]. Also, SSDI system increased tomato yield by 66.5% [8] and 41% [9,10] compared to the SDI system. Furthermore, SSDI system improved the vegetable crops production (tomato, sweet corn and cantaloupe), compared to SDI system [10,11].

Glycine betaine (GB) is a small organic molecule [12], which accumulates in plants under environmental stresses (drought stress). While, potato and tomato plants are unable to accumulate GB [13]. Many investigators found that spraying the plants by GB increased the plant tolerance to environmental stress [14,15].

In support, Rezaei et al. [16] concluded that the vegetative growth of tomato plants decreased under drought stress conditions and spraying the plants by GB with 10 mM concentration alleviated the worse effects of drought stress. Furthermore, Gao et al. [17] mentioned that GB treatments increased the processing tomato yield for plants grown under irrigation water shortage. As well as, Rezaei et al. [16] revealed that drought stress decreased the yield of tomato (fruit number and weight) by the reduction in vegetative growth and flowering. While exogenous application of glycine betaine significantly increased the number of flowers by 86%, number of fruits by 115% and fruit weight by 125%.

The aim of this study to investigate the role of GB for ameliorating the worse effects of deficit irrigation water on tomato plants, as well as studying different irrigation systems in the sandy soil and their impacts on the vegetative growth and fruit yield of tomato plants.

MATERIALS AND METHODS

Studying the effect of deficit irrigation treatments (DI), irrigation systems and foliar application of glycine betaine (GB) on tomato plants (*Solanum lycopersicum* L.) has been done in a field experiment in Bani Salama region, El-Giza Governorate, Egypt, in 2013 and 2014. **Figure 1** shows the geographical position of the experimental site. **Tables 1-3** illustrate the analyses of soil and irrigation water samples.

Treatments

Plants of both seasons were subjected to:

Deficit irrigation treatments: 100%, 85%, 70% and 55% of ET_o (Reference evapotranspiration)

Using Penman–Montieth modified equation for calculating the total amounts of irrigation water [18] and data are showed in **Table 3**.

Irrigation systems

Surface drip irrigation system (SDI) and Subsurface drip irrigation system (SSDI), where drip tubes were buried manually at depth of 20.0 cm in the middle of beds before cultivation).

Glycine betaine concentrations: Tomato plants were treated by GB after 2 and 6 weeks from transplanting date at concentrations of 0, 5, 10 and 20 mM/l, as a foliar application.

Tomato plants were cultivated on 27th of September and 1st of October in the first and second seasons, respectively. As well as all tomato plants during the growing season, received the same quantity of fertilizers as; 230 units of nitrogen, 45 units of P_2O_5 and 70 units of K_2O/fed.

Experimental design

The design lay out for this experiment was split- split plot with three replicates. Where in the main plots the deficit irrigation treatments were distributed, and in the sub-plots irrigation systems were randomly arranged, while in the sub-sub plots the GB concentrations were assigned. Tomato plants were cultivated in row with 15 m length and 1.5 m width and the spaces between plants were 50 cm in the rows.

Measured characteristics

Vegetative growth: 1. Number of leaves per plant.

2. Total leaves area (m^2)/plant:

20 leaf discs were taken by a cork borer to estimate total leaves area, according to Koller [19].

3. Fresh and dry weight of leaves (g) per plant.

Flowering and fruit yield: 1. Number of flowers per plant.

2. Total marketable yield (red ripe fruits) ton/fed.

Physical and chemical fruit quality: 1. Average fruit weight (g)

2. Total soluble solids (TSS %): using hand refractometer for determining TSS in tomato fruits.

Determination of total sugars percentage: Total sugars in tomato fruits were measured on the basis of fruits dry matter, colorimetrically using spectrophotometer with the phenol-sulphuric acid according to the method of Dubois et al. [20].

Determination of ascorbic acid content (V.C): Ascorbic acid was determined in fruit tissues blended in 10 ml of 3% oxalic acid solution, then 10 ml of blended fruit juice was titrated against 2, 6 dichloro- phenol indophenol [21].

Determination of lycopene: Lycopene in tomato fruits was measured by spectrophotometer at the wavelength of 503 nm, based on the method of Fish et al., [22].

Determination of nitrate (NO3) percentage: Nitrate (NO_3) percentage was measured in the dry fruit samples using spectrophotometer at 410 nm, as described by Cataldo et al. [23].

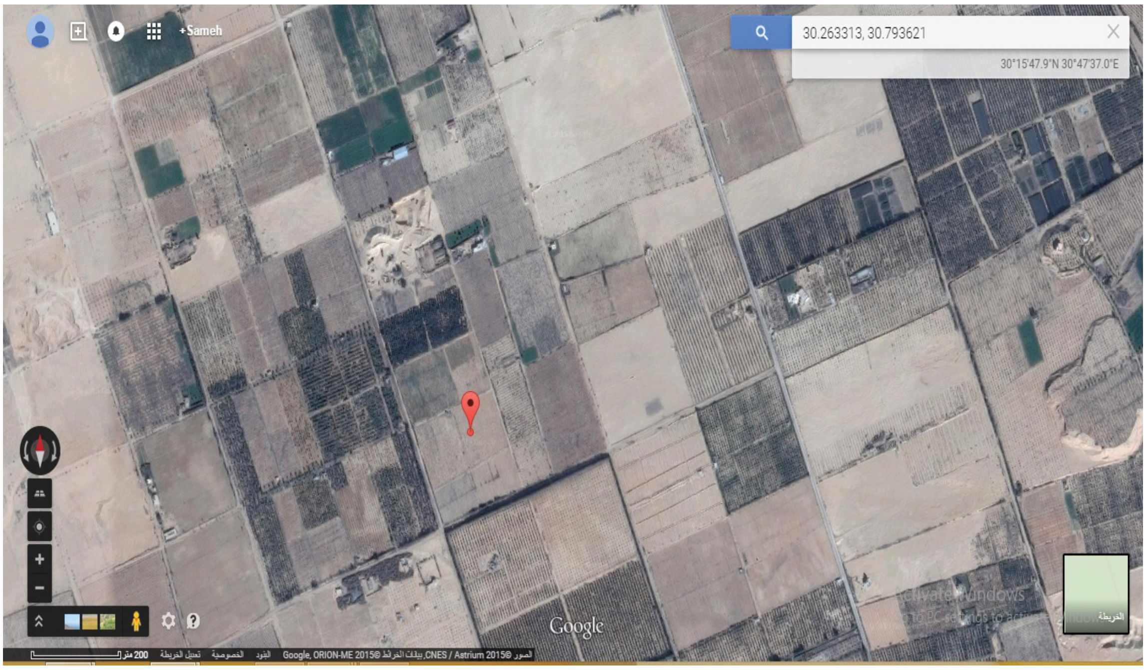

Figure 1. Experimental site (Google map, Satellite).

Table 1. Physical properties of experimental soil analysis.

Very coarse sand %	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand %	Silt + Clay (%)	Soil texture	Field capacity (%)	Wilting point (%)	Saturation percent (%)
16.60	54.80	1.14	16.48	9.64	1.34	Sandy	12	3.7	29

Table 2. Chemical properties of experimental soil analysis.

pH	EC (dS/m)	Soluble cations (meq./L)				Soluble anions (meq./L)			
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}	SO_4^{-}
8.12	1.81	7	3.2	7.6	0.41	Nil	2.5	9	6.71

Table 3. Chemical properties of experimental water analysis.

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

Statistical analysis

The obtained data was computed using the MSTAT Computer Program [24] for analyzing the variance to each attribute. The significance of differences among mean values was tested under Duncan's New Multiple Range test at 5% level of probability [25] **(Table 4)**.

Table 4. Irrigation water requirements (minute/plant per day) for tested irrigation treatments, starting from 1st of October.

*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

RESULTS AND DISCUSSION

Tomato plants were exposed to different irrigation treatments using surface and subsurface drip irrigation systems as well as the plants spayed by the osmo protectant component (GB), for testing the plants behavior under these conditions and the effects on the growth and fruit yield.

Tomato plants significantly affected by the deficit irrigation treatments, as shown in **Tables 5 and 6** all vegetative growth parameters significantly decreased with decreasing the amount of irrigation water. Where the highest significant values for the number of leaves per plant, total leaves area per plant, fresh and dry weights of tomato leaves per plant were obtained by the full irrigation treatment 100% ET_o, while 55% ET_o treatment produced the small vegetable growth, during the two growing seasons. In the same trend, Bhardwaj and Yadav and Mutava et al. [26] mentioned that, water plays a main role for moving the mineral elements from the soil to the leaves of the plant as well as translocating the photosynthetic assimilates from the leaves to the other parts in the plant, which reflect to increment in the plant vegetative growth [27]. On the other hand, drought stress treatments caused a reduction in the vegetative growth.

The effect of irrigation systems (SDI and SSDI) on the vegetative growth of tomato plants, results clearly revealed that SSDI system produced the highest significant values for the studied vegetative growth characteristics compered to SDI system. These findings are agreed with the results of Schwankl et al. [28].

Table 5. Effect of deficit irrigation, irrigation systems and glycine betaine concentrations on number of leaves and total leaf area (m^2) of tomato plant.

Treatments			Season (2012/2013)				Season (2013/2014)			
Deficit irrigation (DI)	Irrigation systems	Glycine betiane (GB)	Number of leaves/ plant		Total leaf area (m^2)		Number of leaves/ plant		Total leaf area (m^2)	
100% ET_o	Surface	0 mM/l	85.00	b-d	4.00	c-f	86.33	cd	4.20	bc
		5 mM/l	85.00	b-d	4.07	c-f	86.00	d	4.17	bc
		10 mM/l	91.00	b	4.34	a	92.27	b	4.39	ab
		20 mM/l	89.00	bc	3.96	d-f	90.77	bc	4.18	bc
	Subsurface	0 mM/l	88.67	bc	4.10	b-d	87.53	cd	4.28	a-c
		5 mM/l	91.00	b	4.20	a-c	92.74	b	4.27	a-c
		10 mM/l	102.70	a	4.28	ab	103.70	a	4.49	a
		20 mM/l	88.67	bc	4.00	c-f	87.13	cd	4.32	a-c
85% ET_o	Surface	0 mM/l	76.00	e-i	3.50	g	78.00	hi	3.64	f
		5 mM/l	77.33	d-i	3.87	ef	77.06	h-j	3.91	e
		10 mM/l	84.33	b-e	3.93	d-f	83.50	d-g	4.06	c-e
		20 mM/l	80.00	d-h	3.96	d-f	81.08	f-h	4.16	b-d
	Subsurface	0 mM/l	77.33	d-i	3.86	f	78.00	hi	3.92	de
		5 mM/l	82.33	b-f	4.09	b-d	84.41	d-f	4.23	bc
		10 mM/l	84.67	b-e	4.06	c-f	85.74	de	4.19	bc
		20 mM/l	81.67	c-g	4.08	b-e	81.31	e-h	4.16	b-d
70% ET_o	Surface	0 mM/l	61.33	kl	2.34	ij	62.74	m-p	2.46	ij
		5 mM/l	69.33	i-k	2.48	i	70.63	kl	2.59	i
		10 mM/l	77.00	d-i	3.29	h	80.33	f-h	3.37	gh
		20 mM/l	72.00	h-j	3.24	h	73.08	jk	3.25	h
	Subsurface	0 mM/l	65.33	j-l	2.40	i	66.08	mn	2.50	ij
		5 mM/l	73.33	g-j	2.53	i	74.56	i-k	2.66	i
		10 mM/l	78.00	d-h	3.28	h	79.00	g-i	3.46	f-h
		20 mM/l	75.00	f-i	3.50	g	75.41	ij	3.58	fg

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55% ET_o	Surface	0 mM/l	59.00	l	1.40	o	58.00	q	1.49	o
		5 mM/l	61.83	kl	1.70	mn	60.77	o-q	1.68	no
		10 mM/l	61.80	kl	2.13	k	63.00	m-p	1.99	lm
		20 mM/l	61.17	kl	1.59	n	62.00	n-q	1.66	no
	Subsurface	0 mM/l	60.67	l	1.87	lm	60.00	pq	1.86	mn
		5 mM/l	42.00	m	1.85	lm	64.00	m-p	1.93	lm
		10 mM/l	65.67	j-l	2.19	jk	66.83	lm	2.30	jk
		20 mM/l	65.10	j-l	2.03	kl	65.33	m-o	2.12	kl
100% ET_o			90.13	A	4.12	A	90.81	A	4.29	A
85% ET_o			80.46	B	3.92	B	81.14	B	4.03	B
70% ET_o			71.42	C	2.88	C	72.73	C	2.98	C
55% ET_o			59.65	D	1.84	D	62.49	D	1.88	D
Subsurface			74.45	A	3.11	B	75.35	B	3.20	B
Surface			76.38	A	3.27	A	78.24	A	3.39	A
0 mM/l			71.67	C	2.93	D	72.09	C	3.04	D
5 mM/l			72.77	C	3.10	C	76.27	B	3.18	C
10 mM/l			80.64	A	3.44	A	81.80	A	3.53	A
20 mM/l			76.57	B	3.30	B	77.01	B	3.43	B

The same letter (s) in the same column meaning not significantly different among the values (P<0.05)

Table 6. Effect of deficit irrigation, irrigation systems and glycine betaine concentrations on fresh and dry weights of leaves (g) of tomato plant.

Treatments			Season (2012/2013)				Season (2013/2014)			
Deficit irrigation (DI)	Irrigation systems	Glycine betiane (GB)	Fresh weight of leaves (g)		Dry weight of leaves (g)		Fresh weight of leaves (g)		Dry weight of leaves (g)	
100% ET_o	Surface	0 mM/l	666.00	c	28.85	d	667.70	c	30.54	c
		5 mM/l	657.00	cd	29.06	d	661.20	cd	30.77	c
		10 mM/l	706.70	b	30.87	b	709.40	b	32.42	b
		20 mM/l	668.70	c	30.06	b-d	671.90	c	31.78	bc
	Subsurface	0 mM/l	671.70	c	29.33	cd	675.50	c	31.40	bc
		5 mM/l	667.00	c	30.40	bc	670.00	c	32.30	b
		10 mM/l	754.30	a	32.78	a	752.80	a	34.63	a
		20 mM/l	671.30	c	30.99	b	674.50	c	32.67	b
85% ET_o	Surface	0 mM/l	591.00	f	21.03	h	596.20	h	22.23	g
		5 mM/l	608.00	ef	23.31	c	609.10	f-h	25.05	f
		10 mM/l	626.00	e	27.20	e	628.50	ef	28.73	d
		20 mM/l	606.00	ef	25.46	f	611.40	f-h	27.09	e
	Subsurface	0 mM/l	591.00	f	23.27	g	597.40	gh	25.04	f
		5 mM/l	615.00	ef	25.03	f	620.10	e-h	26.22	ef
		10 mM/l	634.00	de	28.98	d	638.00	de	30.63	c
		20 mM/l	619.00	e	27.30	e	623.50	e-g	28.98	d
70% ET_o	Surface	0 mM/l	349.30	i	15.35	kl	353.60	k	16.86	jk
		5 mM/l	360.00	hi	16.53	jk	362.90	k	18.08	ij
		10 mM/l	384.00	gh	18.11	i	389.10	ij	19.57	h
		20 mM/l	353.30	i	16.05	jk	357.60	k	17.55	ij
	Subsurface	0 mM/l	357.30	hi	15.91	jk	363.00	k	17.34	i-k
		5 mM/l	363.70	hi	16.77	j	368.00	j-k	18.33	hi
		10 mM/l	397.70	g	20.67	h	400.70	i	22.20	g
		20 mM/l	363.30	hi	16.68	jk	367.40	jk	18.39	hj
55% ET_o	Surface	0 mM/l	182.30	m	12.36	no	186.50	o	13.88	no
		5 mM/l	201.70	k-m	13.05	m-o	206.70	m-o	13.79	no
		10 mM/l	222.00	jk	13.64	mn	226.40	lm	15.13	l-n
		20 mM/l	205.70	k-m	12.99	m-o	210.00	m-o	14.53	m-o
	Subsurface	0 mM/l	191.00	lm	12.10	o	195.60	no	13.66	o
		5 mM/l	215.30	j-l	13.60	mn	220.40	l-n	15.30	lm
		10 mM/l	236.70	j	15.37	kl	240.80	l	16.92	jk
		20 mM/l	214.30	j-l	14.27	lm	218.00	l-n	16.09	kl
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

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Subsurface	461.70	B	20.87	B	465.50	B	22.38	B
Surface	472.70	A	22.09	A	476.60	A	23.76	A
0 mM/l	450.00	C	19.77	D	454.40	C	21.37	D
5 mM/l	461.00	B	20.97	C	464.80	B	22.48	C
10 mM/l	495.20	A	23.45	A	498.20	A	25.03	A
20 mM/l	462.70	B	21.73	B	466.80	B	23.38	B

The same letter (s) in the same column meaning not significantly different among the values ($P<0.05$)

Al-Omran et al. [9] and Elhindi [29], which referred to SSDI enhanced vegetative growth, this may be due to SSDI create more suitable conditions by adding the water and fertilizers in the crop root zone.

Glycine betaine has a positive effect on the vegetative growth of tomato plants, where the plants enhanced with the foliar application of GB. Using GB at 10 mM/l produced the highest vegetable growth for tomato plants, compared to the other concentrations in the both tested seasons. In the same trend, Abbas et al. revealed that the vegetative growth of eggplant improved by GB application and this improvement attributed to the role of GB in enhancing the stomatal conductance and photosynthetic rate in plant leaves [30]. In addition, many scientists reported that translocating GB to the plant organs enhanced their growth and reproduction, where GB plays a role as an osmoprotectant in the cells of these organs [14,15].

As for the interaction among the studied treatments, results illustrated that tomato plants were treated by 100% ET_o using SSDI system and 10 mM/l of GB, produced the highest number of leaves per plant as well as had the biggest fresh and dry weights of tomato leaves per plant in the both tested seasons. While the total leaves area per plant increased significantly with treatments of 100% ET_o using SDI system (and 10 mM/l GB) and SSDI system (and 5 and 10 mM/l GB), compared to the other treatments.

Flowering and fruit yield

Increasing the irrigation water from 55% ET_o to 100% ET_o produced a good vegetable growth of tomato plants which affected positively on the flowering and fruit yield. Where data in **Table 7** clearly indicated the highest significant values of number of flowers per plant and total marketable yield were obtained with 100% ET_o treatment. In support, Farooq et al. [31] and Kahlaoui et al. [32] indicated that deficit irrigation water leading to a reduction in plant growth and decreasing in the flowering and fruit production. Furthermore, Earl and Davis [33] and Aldesuquy et al. [34] suggested that plants grown in soil water deficit produced a small plant canopy and decreased photosynthetic pigments, carbohydrates accumulation and total nitrogen and protein, leading to a reduction in crop yield.

Regarding the irrigation systems, SSDI system showed significant superiority upon SDI system. Where tomato plants produced the maximum number of flowers per plant with SSDI system which led to an increasing in the total marketable yield of tomatoes compared to SDI system. The same findings were observed on tomato plants by Al-Omran et al. [9] and on different vegetable crops by Ayars et al. [11]. In addition, Selim et al. [35] mentioned that subsurface drip irrigation system decreased the losing water through evaporation from the soil surface, which resulted in improving the growth of tubers and produced the optimum crop yield. Moreover, SSDI system keeps the optimum level of soil water content in the root zone, which increase the water and fertilizers use efficiency and produce a good vegetative growth as well as increase the fruit yield production [36].

Tomato flowering and fruit yield affected by GB treatments, the results showed that spraying the plants by GB at 10 mM/l had the maximum number of flowers as well as the biggest marketable yield in two tested seasons. The same results were obtained by Gao et al. [17], Rezaei et al. [16] and Yan et al. [17] on tomato plants.

Concerning the interaction among studied treatments, data illustrated that plants were received irrigation water at 100% ET_o under both irrigation systems and treated by 10 mM/l GB had the maximum number of flowers per plant, with no significant differences with other concentrations (0 and 5 mM/l GB). While treatment of 100% ET_o using SSDI system and 10 or 20 mM/l GB produced the maximum total marketable yield of tomatoes in the two tested seasons.

Table 7. Effect of deficit irrigation, irrigation systems and glycine betaine concentrations on the number of flowers per plant and total marketable yield (ton/fed.) of tomatoes.

Treatments			Season (2012/2013)				Season (2013/2014)			
Deficit irrigation (DI)	Irrigation systems	Glycine betiane (GB)	Number of flowers/ plant		Total marketable yield (ton/fed.)		Number of flowers/ plant		Total marketable yield (ton/fed.)	
100% ET_o	Surface	0 mM/l	111.00	bc	43.07	e	114.10	ab	43.77	de
		5 mM/l	110.30	bc	45.00	d	112.10	bc	44.30	d
		10 mM/l	116.70	ab	47.97	c	121.10	a	49.20	b
		20 mM/l	105.30	cd	48.63	bc	108.10	bc	49.83	b
	Subsurface	0 mM/l	113.30	a-c	44.57	d	115.50	ab	43.80	de
		5 mM/l	113.00	a-c	44.17	d	115.20	ab	46.10	c
		10 mM/l	120.70	a	49.63	a	122.90	a	51.20	a
		20 mM/l	108.30	b-d	49.00	ab	110.80	bc	50.30	ab

85% ET_o	Surface	0 mM/l	83.33	g-i	36.14	lm	85.54	f-h	36.70	i
		5 mM/l	85.67	gh	38.17	k	87.88	fg	38.50	h
		10 mM/l	92.00	e-g	41.27	fg	94.47	ef	41.97	f
		20 mM/l	88.00	fg	39.47	ij	90.21	ef	40.00	g
	Subsurface	0 mM/l	88.00	fg	38.90	jk	90.21	ef	38.40	h
		5 mM/l	91.00	fg	40.00	hi	93.21	ef	39.63	g
		10 mM/l	100.70	de	42.00	f	104.10	cd	42.83	ef
		20 mM/l	95.67	ef	40.83	gh	97.88	de	40.20	g
70% ET_o	Surface	0 mM/l	62.67	lm	31.08	q	65.14	kl	31.87	n
		5 mM/l	72.00	jk	33.88	p	74.21	ij	33.60	m
		10 mM/l	83.67	g-i	35.53	m-o	85.88	f-h	34.90	kl
		20 mM/l	71.00	j-l	34.82	n-p	73.21	i-k	34.73	kl
	Subsurface	0 mM/l	66.67	k-m	34.57	op	68.88	jk	34.00	lm
		5 mM/l	77.33	h-j	34.80	n-p	79.54	g-i	35.40	jk
		10 mM/l	86.00	gh	36.76	l	88.21	fg	37.07	i
		20 mM/l	75.33	i-k	35.73	mn	77.54	h-j	36.13	ij
55% ET_o	Surface	0 mM/l	41.67	q	22.37	v	43.81	o	22.92	r
		5 mM/l	43.33	pq	23.97	u	45.14	o	24.93	q
		10 mM/l	51.67	n-p	27.07	s	54.14	mn	26.73	p
		20 mM/l	50.33	n-q	25.20	t	52.14	m-o	24.64	q
	Subsurface	0 mM/l	47.33	o-q	22.53	v	49.81	no	23.47	r
		5 mM/l	50.00	n-q	25.17	t	51.47	m-o	25.60	q
		10 mM/l	58.00	mn	28.10	r	59.81	lm	29.27	o
		20 mM/l	53.33	no	27.13	s	55.81	mn	26.67	p
100% ET_o			112.30	A	46.51	A	115.00	A	47.31	A
85% ET_o			90.54	B	39.60	B	92.94	B	39.78	B
70% ET_o			74.33	C	34.65	C	76.58	C	34.71	C
55% ET_o			49.46	D	25.19	D	51.51	D	25.53	D
Subsurface			79.29	B	35.85	B	81.71	B	36.16	B
Surface			84.04	A	37.12	A	86.31	A	37.50	A
0 mM/l			76.75	C	34.15	D	79.13	C	34.37	D
5 mM/l			80.33	B	35.64	C	82.35	B	36.01	C
10 mM/l			88.67	A	38.54	A	91.33	A	39.15	A
20 mM/l			80.92	B	37.60	B	83.22	B	37.81	B

The same letter (s) in the same column meaning not significantly different among the values ($P<0.05$).

Fruit quality

Data in **Tables 8-10** present the effect of studied treatments on the fruit quality of tomatoes i.e., average fruit weight, total soluble solids (TSS %), total sugars, ascorbic acid content, lycopene content and nitrate (NO_3) percentage.

Decreasing irrigation water significantly increased TSS, total sugars and ascorbic acid content in tomato fruits, where 55% ET_o treatment produced the highest significant values. On the other hand, average fruit weigh, lycopene content and NO_3 percentage in tomatoes increased with increasing the irrigation water, where 100% ET_o treatment had the highest significant values. Similar findings were obtained by Cetin et al. [37] and Patane and Cosentino [38], they reported that the full irrigated treatment produced the highest fruit weight, diameter and fruit colour, while decreased the soluble and total solids. Moreover, Branthome et al. [39] and Patane et al. [40] found that DI treatment (0.7k pc) produced a good yield and fruit quality (colour and TSS) of tomatoes.

Respecting the irrigation systems, data showed that the both of irrigation systems had no significant effects on average fruit weight and TSS. While SSDI system had the maximum values of lycopene content and nitrate (NO_3) percentage. For the total sugars and ascorbic acid content, SDI system had superiority upon SSDI system. In the same trend, Ahmed [10] concluded that SSDI system produced the higher production yield and fruit quality for vegetable crops compared to SDI system. In addition, Oron et al. [41] suggested that SSDI system plays a role in decreasing the salts accumulation at the root zone and this improves the yield and fruit quality. On the other hand, Ayars et al. [42] mentioned that irrigation methods have no significant effects on tomato fruit quality parameters (fruit weight and colour).

Concerning the GB treatments, data indicated that the average fruit weight and TSS parameters not significantly affected by all GB concentrations. While the maximum significant values for total sugars and ascorbic acid content were observed with treatment of 0 mM/l GB. Whereas 0 and 5 mM/l of GB treatments produced the maximum significant values for NO_3 percentage. For the lycopene content, in the first season tomato plants sprayed by GB at 20 mM/l produced the highest values, while in the second seasons there were no significant differences between 10 and 20 mM/l of GB treatments. The same results were found by Arafa et al. [43] and Rezaei et al. [16], where average fruit of tomatoes decreased with drought stress treatment and treated the plants by GB significantly increased it by 125%.

Regarding the interaction among the studied treatments, results illustrated that tomato plants were subjected to 55% ET_o using SDI system and spayed by GB at 0 mM/l produced the maximum significant values for total sugars. While treatment of 55% ET_o using SDI system produced the maximum significant values for TSS with all GB concentrations and ascorbic acid content with GB at 0 and 5 mM/l. The combination among 100% ET_o and SSDI system with 10 and 20 mM/l GB achieved the maximum significant numbers for lycopene content and NO_3 percentage in tomato fruits. For average fruit weight, results revealed that no clear trend was observed in most cases among the studied treatments.

Table 8. Effect of deficit irrigation, irrigation systems and glycine betaine concentrations on average fruit weight (g) and TSS (%) of tomato fruits.

Treatments			Season (2012/2013)				Season (2013/2014)			
Deficit irrigation (DI)	Irrigation systems	Glycine betiane (GB)	Average fruit weight (g)		TSS (%)		Average fruit weight (g)		TSS (%)	
100% ET_o	Surface	0 mM/l	103.40	a	5.76	l	97.30	a	5.75	j
		5 mM/l	95.34	a-e	5.73	l	92.53	a-d	5.73	j
		10 mM/l	98.87	ab	5.93	kl	97.33	a	5.90	ij
		20 mM/l	91.83	b-f	6.03	i-l	90.95	a-e	6.18	g-i
	Subsurface	0 mM/l	96.14	a-d	6.53	d-h	93.90	a-c	6.63	d-f
		5 mM/l	88.77	b-f	6.30	g-j	93.26	a-c	6.32	f-h
		10 mM/l	97.22	a-c	6.37	e-i	92.50	a-d	6.46	e-h
		20 mM/l	87.26	c-f	6.23	h-k	88.30	a-e	6.53	d-g
85% ET_o	Surface	0 mM/l	84.50	d-h	6.70	d-f	88.75	a-e	6.86	c-e
		5 mM/l	85.58	c-g	6.47	d-h	88.10	a-e	6.60	d-f
		10 mM/l	87.92	b-f	6.73	d-f	85.97	b-e	6.37	f-h
		20 mM/l	85.72	c-g	6.30	g-j	88.35	a-e	6.67	d-f
	Subsurface	0 mM/l	87.68	b-f	6.37	f-i	84.43	b-e	6.47	e-h
		5 mM/l	85.40	d-g	6.31	g-j	85.20	b-e	6.45	f-h
		10 mM/l	88.15	b-f	6.02	i-l	85.87	b-e	6.10	h-j
		20 mM/l	86.38	c-g	6.00	j-l	87.10	a-e	6.13	g-i
70% ET_o	Surface	0 mM/l	80.01	f-j	6.63	d-g	81.92	d-f	6.63	d-f
		5 mM/l	82.17	f-j	6.65	d-g	81.38	e-g	6.69	d-f
		10 mM/l	82.55	f-i	6.77	cd	83.73	c-f	6.90	cd
		20 mM/l	83.63	e-i	6.73	de	86.98	a-e	6.90	cd
	Subsurface	0 mM/l	84.32	e-h	7.16	b	84.76	b-e	7.30	b
		5 mM/l	85.19	d-g	7.25	b	87.65	a-e	7.38	b
		10 mM/l	87.40	b-f	7.23	b	95.06	ab	7.45	b
		20 mM/l	82.65	f-i	7.30	b	87.60	a-e	7.40	b
55% ET_o	Surface	0 mM/l	68.51	k	8.14	a	66.98	h	8.33	a
		5 mM/l	73.17	h-k	8.00	a	69.46	h	8.29	a
		10 mM/l	73.25	h-k	7.96	a	71.66	h	8.33	a
		20 mM/l	70.80	jk	7.99	a	69.41	h	8.09	a
	Subsurface	0 mM/l	72.56	i-k	7.21	b	68.35	h	7.39	b
		5 mM/l	74.80	g-k	7.20	b	74.28	f-h	7.35	b
		10 mM/l	73.30	h-k	7.31	b	71.20	h	7.22	bc
		20 mM/l	72.97	h-k	7.08	bc	72.30	gh	7.21	bc
100% ET_o			94.85	A	6.11	D	93.26	A	6.19	D
85% ET_o			86.42	B	6.36	C	86.72	B	6.46	C
70% ET_o			83.49	B	6.97	B	86.13	B	7.08	B
55% ET_o			72.42	C	7.61	A	70.45	C	7.78	A
Subsurface			84.20	A	6.78	A	83.80	A	6.89	A
Surface			84.39	A	6.74	A	84.49	A	6.86	A
0 mM/l			84.64	A	6.81	A	83.30	A	6.92	A
5 mM/l			83.80	A	6.74	A	83.98	A	6.85	A
10 mM/l			86.08	A	6.79	A	85.42	A	6.84	A
20 mM/l			82.66	A	6.71	A	83.87	A	6.89	A

The same letter (s) in the same column meaning not significantly different among the values ($P<0.05$)

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Table 9. Effect of deficit irrigation, irrigation systems and glycine betaine concentrations on V.C (mg ascorbic acid/100 ml juice) and total sugar (%) of tomato fruits.

Treatments			Season (2012/2013)				Season (2013/2014)			
Deficit irrigation (DI)	Irrigation systems	Glycine betiane (GB)	V.C (mg ascorbic acid/100 ml juice)		Total sugar (%)		V.C (mg ascorbic acid/100 ml juice)		Total sugar (%)	
100% ET_o	Surface	0 mM/l	22.76	kl	6.82	kl	22.79	p	6.86	jk
		5 mM/l	22.30	lm	6.77	lm	22.45	q	6.79	lm
		10 mM/l	21.96	mn	6.74	m	22.02	r	6.75	m
		20 mM/l	21.65	n	6.74	m	21.59	s	6.75	m
	Subsurface	0 mM/l	20.84	o	6.60	n	20.86	t	6.62	n
		5 mM/l	20.54	op	6.56	n	20.54	t	6.53	o
		10 mM/l	19.98	pq	6.44	p	20.05	u	6.44	p
		20 mM/l	19.85	q	6.37	q	19.92	u	6.36	q
85% ET_o	Surface	0 mM/l	26.52	f	7.49	g	26.38	ij	7.50	f
		5 mM/l	25.74	g	7.37	h	26.21	ij	7.40	g
		10 mM/l	25.75	g	7.29	i	25.35	l	7.27	h
		20 mM/l	24.01	hi	7.30	i	24.21	m	7.30	h
	Subsurface	0 mM/l	24.44	h	6.87	k	24.48	m	6.88	j
		5 mM/l	23.93	hi	6.77	lm	23.86	n	6.81	kl
		10 mM/l	23.43	ij	6.50	o	23.46	o	6.51	o
		20 mM/l	23.09	jk	6.45	op	23.16	o	6.50	o
70% ET_o	Surface	0 mM/l	28.81	c	7.91	cd	28.79	d	7.90	cd
		5 mM/l	28.41	cde	7.86	de	28.43	e	7.88	d
		10 mM/l	28.00	de	7.82	ef	28.06	f	7.83	e
		20 mM/l	27.85	e	7.78	f	27.84	fg	7.77	e
	Subsurface	0 mM/l	27.86	e	7.45	g	26.89	h	7.49	f
		5 mM/l	26.46	f	7.30	i	26.41	i	7.29	h
		10 mM/l	26.08	fg	7.10	j	26.06	jk	7.11	i
		20 mM/l	25.69	g	7.12	j	25.74	k	7.12	i
55% ET_o	Surface	0 mM/l	30.70	a	8.20	a	30.80	a	8.24	a
		5 mM/l	30.50	a	8.01	b	30.45	b	8.05	b
		10 mM/l	29.85	b	7.94	c	29.89	c	7.95	c
		20 mM/l	29.52	b	7.94	c	29.58	c	7.95	c
	Subsurface	0 mM/l	28.73	c	7.86	de	28.79	d	7.88	d
		5 mM/l	28.55	cd	7.82	ef	28.58	de	7.82	e
		10 mM/l	27.95	de	7.78	f	27.68	g	7.77	e
		20 mM/l	27.80	e	7.78	f	27.85	fg	7.78	e
100% ET_o			21.24	D	6.63	D	21.28	D	6.64	D
85% ET_o			24.61	C	7.00	C	24.64	C	7.02	C
70% ET_o			27.40	B	7.54	B	27.28	B	7.55	B
55% ET_o			29.20	A	7.92	A	29.20	A	7.93	A
Subsurface			26.52	A	7.50	A	26.55	A	7.51	A
Surface			24.70	B	7.05	B	24.65	B	7.06	B
0 mM/l			26.33	A	7.40	A	26.22	A	7.42	A
5 mM/l			25.80	B	7.31	B	25.87	B	7.32	B
10 mM/l			25.38	C	7.20	C	25.32	C	7.21	C
20 mM/l			24.93	D	7.19	C	24.99	D	7.19	C

The same letter (s) in the same column meaning not significantly different among the values ($P<0.05$).

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Table 10. Effect of deficit irrigation, irrigation systems and glycine betaine concentrations on lycopene content (mg/100g F.W.) and nitrate (NO_3) percent (%) of tomato fruits.

Treatments			Season (2012/2013)				Season (2013/2014)			
Deficit irrigation (DI)	Irrigation systems	Glycine betiane (GB)	Lycopene content (mg/100g f.w)		Nitrate percent (%)		Lycopene content (mg/100g f.w)		Nitrate percent (%)	
100% ET_o	Surface	0 mM/l	3.27	d	2.75	f	3.32	d	2.78	d
		5 mM/l	3.37	c	2.81	de	3.39	c	2.81	cd
		10 mM/l	3.39	c	2.86	c	3.40	c	2.87	bc
		20 mM/l	3.39	c	2.86	cd	3.40	c	2.88	bc
	Subsurface	0 mM/l	3.53	b	2.79	ef	3.55	b	2.84	bcd
		5 mM/l	3.53	b	2.85	cd	3.58	b	2.92	b
		10 mM/l	3.66	a	3.11	a	3.71	a	3.12	a
		20 mM/l	3.68	a	3.02	b	3.70	a	3.05	a
85% ET_o	Surface	0 mM/l	2.44	j	1.95	l	2.48	j	1.95	ij
		5 mM/l	2.56	i	1.97	l	2.59	i	2.00	i
		10 mM/l	2.65	h	2.11	k	2.70	h	2.16	h
		20 mM/l	2.69	h	2.16	j	2.68	h	2.22	h
	Subsurface	0 mM/l	2.85	g	2.32	i	2.88	g	2.40	g
		5 mM/l	2.98	f	2.45	h	3.05	f	2.51	f
		10 mM/l	3.12	e	2.54	g	3.16	e	2.62	e
		20 mM/l	3.11	e	2.59	g	3.18	e	2.62	e
70% ET_o	Surface	0 mM/l	1.98	op	1.55	q	1.99	op	1.58	m
		5 mM/l	1.99	nop	1.60	p	2.00	op	1.62	m
		10 mM/l	1.99	nop	1.70	o	2.00	op	1.72	l
		20 mM/l	2.00	nop	1.77	n	1.99	op	1.80	k
	Subsurface	0 mM/l	1.99	nop	1.70	o	2.03	no	1.74	kl
		5 mM/l	2.02	mno	1.75	no	2.06	mn	1.79	kl
		10 mM/l	2.10	l	1.85	m	2.14	l	1.92	j
		20 mM/l	2.18	k	1.84	m	2.21	k	1.90	j
55% ET_o	Surface	0 mM/l	1.95	p	1.12	v	1.96	p	1.18	q
		5 mM/l	1.97	op	1.22	u	1.99	op	1.25	pq
		10 mM/l	2.02	mno	1.31	st	2.04	mno	1.25	pq
		20 mM/l	2.04	mn	1.32	st	2.04	mno	1.34	o
	Subsurface	0 mM/l	2.04	lmn	1.28	t	2.08	lmn	1.31	op
		5 mM/l	2.07	lm	1.35	s	2.09	lm	1.38	no
		10 mM/l	2.17	k	1.42	r	2.19	k	1.45	n
		20 mM/l	2.18	k	1.43	r	2.20	k	1.43	n
100% ET_o			3.48	A	2.88	A	3.51	A	2.91	A
85% ET_o			2.80	B	2.26	B	2.84	B	2.31	B
70% ET_o			2.03	D	1.72	C	2.05	C	1.76	C
55% ET_o			2.06	C	1.31	D	2.07	C	1.32	D
Subsurface			2.48	B	1.94	B	2.50	B	1.96	B
Surface			2.70	A	2.14	A	2.74	A	2.19	A
0 mM/l			2.51	D	1.93	C	2.54	C	1.97	C
5 mM/l			2.56	C	2.00	B	2.59	B	2.04	B
10 mM/l			2.64	B	2.11	A	2.67	A	2.14	A
20 mM/l			2.66	A	2.12	A	2.68	A	2.16	A

The same letter (s) in the same column meaning not significantly different among the values ($P<0.05$).

CONCLUSION

It's concluded that, minimizing the amount of irrigation water significantly decreased the vegetative growth, flowering and fruit yield of tomato plants grown under sandy soil conditions. Using SSDI system enhanced the vegetative growth parameters; number of leaves and total leaves area per plant, which reflected in an increasing of the flowering and fruit yield of tomatoes. In addition, it's clear to notice that using GB as a foliar application had a remarkable effect on alleviating the drought stress for tomato plants, which reflected to an increment in characteristics of vegetative growth, flowering and fruit production. Finally, tomato plants grown in sandy soil and open field conditions can grow well under deficit irrigation water (85% and 70% ET_o) by using SSDI system and spray the plants by GB at 10 mM/l, which help the plants to minimizing the worse effects of water stress and enhance the he vegetative growth, flowering and fruit yield and quality.

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REFERENCES

1. Souza CM, et al. Study on phlebotomine sand fly (Diptera: Psychodidae) fauna in Belo Horizonte, state of Minas Gerais, Brazil. Mem do Inst Oswaldo Cruz. 2004;99:795-803.
2. Ozbahce A and Tari AF. Effects of different emitter space and water stress on yield and quality of processing tomato under semi-arid climate conditions. Agric Water Manag. 2010;97:1405-1410.
3. Viswanatha GB, et al. Soil-plant water status and yield of sweet corn (Zea mays L. cv. Saccharata) as influenced by drip irrigation and planting methods. Agric Water Manag. 2002;55:85-91.
4. Karam F, et al. Evapotranspiration, yield and water use efficiency of drip irrigated corn in the Bekaa Valley of Lebanon. Agric Water Manag. 2003;63:125-137.
5. Nalliah V, et al. Evaluation of a plant controlled subsurface drip irrigation system. Biosys Eng. 2009;102:313-320.
6. Rajkumari Y, et al. Nitrogen management for subsurface drip irrigated cotton. In: Beltwide Cotton Conferences, San Antonio, Texas, January. 2006;pp:3-6.
7. Al-Ghobari HM. The assessment of automatic irrigation scheduling techniques on tomato yield and water productivity under a subsurface drip irrigation system in a hyper arid region. Conference sustainable irrigation and drainage V. Poznan, Poland. 2014;pp:12.
8. Miguel AA and Francisco MA. Response of tomato plants to deficit irrigation under surface or subsurface drip irrigation. J Applied Horticulture. 2007;9(2):97-100.
9. Al-Omran AM, et al. Impact of irrigation water quality, irrigation systems, irrigation rates and soil amendments on tomato production in sandy calcareous soil. Turk J Agric For. 2010;34:59-73.
10. Ahmed TF. Performance assessment of surface and subsurface drip irrigation system for crops and fruit trees (Ph.D Thesis). Department of Civil Engineering Faculty of Civil & Environmental Engineering University of Engineering and Technology Taxila-Pakistan. 2011;p:150.
11. Ayars JE, et al. Subsurface drip irrigation in California-here to stay. Agric Water Manag. 2015;157:39-47.
12. Cha-um S, et al. Glycine betaine alleviates water deficit stress in indica rice using proline accumulation, photosynthetic efficiencies, growth performances and yield attributes. Aust J Crop Sci. 2013;7:213-218.
13. Gorham J. Betaines in higher plants-biosynthesis and role in stress metabolism. In: Amino acids and their Derivatives in Higher Plants (Walls grove RM Edn). University Press, Cambridge. 1995;pp:171-203.
14. Makela P, et al. Uptake and translocation of foliar applied glycinebetaine in crop plants. Plant Sci. 1996;121:221-230.
15. Chen THH and Murata N. Glycinebetaine: an effective protectant against abiotic stress in plants. Trends Plant Sci. 2008;13:499-505.
16. Rezaei MA, et al. Morpho-physiological improving effects of exogenous glycine betaine on tomato (Lycopersicum esculentum Mill.) cv. PS under drought stress conditions. Plant Omics. 2012;5:79-86.
17. Gao Y, et al. Effect of spraying glycine betaine on physiological responses of processing tomato under drought stress. Plant Nutr Fertil Sci. 2012;18:426-432.
18. Allen RG, et al. Crop Evapotranspiration: Guidelines for computing crop water requirements. FAO irrigation and drainage paper 56, Rome, 1998;p:300.
19. Koller HR. Leaf area, leaf weight relationship in the soybean canopy. Crop Sci. 1972;12:180-183.
20. Dubois M, et al. Colorimetric method for determination of sugars and related substances. Anal Chem. 1956;23:350-356.
21. AOAC. Official Methods of Analysis (15th Edn). Association of official analytical chemists, Washington, D.C. USA, 1990.
22. Fish WW, et al. Quantitative assay for lycopene that utilizes reduced volumes of organic solvents. J Food Comp Anal. 2002;15:309-317.
23. Cataldo DA, et al. Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. Commun Soil Sci Plant Anal. 1975;6:71-80.
24. MSTAT Development Team. MSTAT user's guide: A microcomputer program for the design, management and analysis of agronomic research experiments. Michigan State University East Lansing, U.S.A, 1989.
25. Steel RGD and Torrie JH. Principles and procedures of statistics. McGraw Hill, New York, 1960;p:481.
26. Mutava RN, et al. Understanding abiotic stress tolerance mechanisms in soybean: a comparative evaluation of soybean response to drought and flooding stress. Plant Physiol Biochem. 2015;86:109-120.
27. Leilah AA. Physiological response of onion to water stress and bio fertilizers (M.Sc. Thesis). Faculty of Agriculture, Mansoura University, Egypt. 2009;p:121.

 e-ISSN:2347-226X
p-ISSN:2319-9857

28. Schwankl L, et al. Subsurface drip irrigation of tomatoes: drip system design, management promote seed emergence. Calif Agric (Berkeley). 1991;45:21-23.

29. Elhindi KM. Evaluation of composted green waste fertigation through surface and subsurface drip irrigation systems on pot marigold plants (Calendula officinalis L.) grown on sandy soil. Aust J Crop Sci. 2012;6:1249-1259.

30. Tasuku H, et al. Tissue specificity of glycinebetaine synthesis in barley. Plant Sci. 2009;176:112-118.

31. Farooq M, et al. Plant drought stress: effects, mechanisms and management. In: Sustainable Agriculture (Lichtfouse E, et al. Edn). Springer, Netherlands. 2009;pp:153-188.

32. Kahlaoui B, et al. Effects of saline water on tomato under subsurface drip irrigation: nutritional and foliar aspects. J Soil Sci Plant Nutr. 2011;11:69-86.

33. Earl H and Davis RF. Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. Agron J. 2003;95:688-696.

34. Aldesuquy HS, et al. Glycine betaine and salicylic acid induced modification in productivity of two different cultivars of wheat grown under water stress. J Stress Physiol Biochem. 2012;8:72-89.

35. Selim EM, et al. Evaluation of humic substances fertigation through surface and subsurface drip irrigation systems on potato grown under Egyptian sandy soil conditions. Agric Water Manag. 2009;96:1218-1222.

36. Thompson TL and Doerge TA. Nitrogen and water interactions in subsurface trickle irrigated leaf lettuce II. Agronomic, economic and environmental outcomes. Soil Sci Soc Am J. 1996;60:168-173.

37. Cetin O, et al. Effects of different irrigation treatments on yield and quality of drip-irrigated tomatoes under Eskisehirconditions. In: IV Vegetable Agriculture Symposium, Bursa, Turkey, 17–20 September, 2002.

38. Patane C and Cosentino SL. Effects of soil water deficit on yield and quality of processing tomato under a Mediterranean climate. Agric Water Manag. 2010;97:131-138.

39. Branthome XY, et al. Influence of drip irrigation on the technological characteristics of processing tomatoes. Acta Horticulturae. 1994;376:285-290.

40. Patane C, et al. Effects of deficit irrigation on biomass, yield, water productivity and fruit quality of processing tomato under semi-arid Mediterranean climate conditions. Scientia Horticult. 2011;129:590-596.

41. Oron G, et al. Improved saline - water use under subsurface drip irrigation. Agric Water Manag. 1998;39:19-33.

42. Ayars JE, et al. Subsurface drip irrigation of row crops: a review of 15 years of research at the Water Management Research Laboratory. Agric Water Manag. 1999;42:1-27.

43. Arafa AA, et al. The effect of glycine betaine or ascorbic acid on grain germination and leaf structure of sorghum plants grown under salinity stress. Aust J Crop Sci. 2009;3:294-304.