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Physiological studies on eggplant (*Solanum melongena*) grown under drought conditions

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***Abstract*---**Field experiment was conducted during the two growing seasons of 2019 and 2021, at Dokki region, El-Giza Governorate, Egypt, in order to investigate the effect of deficit irrigation (DI) treatments: 100% (control), 70% and 50% of ETo (Reference evapotranspiration) and two irrigation systems: Surface drip irrigation (SDI) and Subsurface irrigation (SSI)porous pipe (20.0cm soil depth) on vegetative growth, chemical constituents, fruit yield and quality of eggplant plants (Cultivars : “Classic” “Swad Eleil”). Results revealed that, DI treatments significantly decreased the vegetative growth, total yield ,marketable yield, leaf relative water content (LRWC) and membrane stability index (MSI) of eggplant plants, compared to control treatment (100% ET_0). While, water stress treatments improved leaves proline content, alkaloids and irrigation water use efficiency (IWUE). Using SSI (porous pipe) system significantly increased plant height, fresh weight, total yield, marketable fruit yield of eggplant, LRWC and MSI, “Classic” cv had the highest total yield and total marketable yield under the subsurface irrigation system compared to “Swad El-Layl”cv. Regarding, the effect of interaction between DI treatments and irrigation systems, the results illustrated that application of irrigation water with 100% ET0 by SSI system produced the highest significant values of vegetative growth, fruit yield. It could be also concluded that the vegetative growth, as well as fruit and

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quality of eggplant plants which grown under DI treatments (100, 70 and 50% ET0), can be improved by using SSI system.

***Keywords*---**Deficit Irrigation, Subsurface Drip Irrigation System, Leaf Relative Water Content, Membrane Stability Index, IWUE.
Introduction

1. Introduction

Eggplant (*Solanum melongena L.*) is a distinct crop worldwide, with a cultivated area of 1.86 million ha, producing approximately 54 million Mg. Globally, Egypt ranked third of the largest eggplant producers accounting approximately 2.6% of the world's production [1]. Efficient use of water by irrigation is becoming increasingly important with limited irrigation resources in Egypt with gradually increase of populations [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). In contrast water stress treatments (40% F.C) resulted in a significant decrease in vegetative growth of tomato plants, where plant height was 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, [3] suggested that under drought stress, the contents of chlorophyll were declined in the leaves of tomato plants. In the same trend, [7] and [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, [6] reported 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].on the contrary, [6] indicated that fruit weight and total eggplant yield significantly decreased with minimizing the irrigation water (from100 to 20% F.C).Several studies have shown that the maximum fruit yield of tomatoes was obtained by drip irrigation at 100% ETc treatment [8] and [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] were 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]. These 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[10]. And, Ayars., et al. [11]. Fortunately, salinity is not major in these sandy soil because of the high level of infiltration but a suitable method for irrigation is needed to manage these soils. A successful irrigation method will develop crop coverage which results in the prevention of wind erosion, development of an agricultural economy, and improved health and social affairs. It seems that the porous pipe irrigation technique is one of the best methods applicable to sandy hills, because it discharges a low level of water allowing slow irrigation. Porous pipe works like a clay pot which was used in Central Iran, Pakistan, India and Egypt centuries ago. Porous pipe can be used at the soil surface or subsurface. This pipe is alled by other names such as 'Leaky Pipe' (in USA) and 'Proflex', 'Ecopore' and 'Tuporex' in France The porous pipe irrigation method is currently used in USA, Europe, Australia, China, Japan and other countries and many researchers such as Fok and Willardson [16], et al. (1998), Khorramian et al. Teeluck and Sutton(1998), Cam Tollefson et al. [18], Yoder and Mote (1995), tubing and emitters are expensive and require skilled labor for continuous monitoring and maintenance[14] and Akhoondali [13] have evaluated different aspects of this irrigation method. However, these researchers have used this system with a common condition of horizontal installation of the porous pipe irrigation system, small scale irrigation methods such as drip and porous pipe irrigation methods may produce better results as they provide water to the root system at a minimum level and at an adequate rate thereby minimizing deep percolation. Subsurface irrigation is considered well suited for arid regions due to minimal surface evaporative and deep percolation water losses because with this method required amount of water is directly applied to the root zone. However, people are reluctant to adopt subsurface drip and leaky pipe irrigation methods as they are not only expensive but are also difficult to install, operate and maintain. Therefore, there is a dire need to introduce and practice traditional irrigation methods in water scarce regions with arid climate. One of these methods is porous clay pipe irrigation method. h this method water savings up to 80% were achieved compared to that of surface irrigation methods. Also yield of vegetables irrigated with this system was 5 to 16% more than the normal production obtained with surface irrigation methods. A. Siyal , A. G. Siyal and M. Y. Hasini [20].

Subsurface irrigation is said to be most efficient irrigation method in which small volume of water is supplied from below the soil surface to crop resulting in reduction of evaporative and deep percolation water losses at the farm level. It has been practiced in various forms such as pitcher or pot irrigation since ancient times Bainbridge [23] and Siyal et al. [22] and perforated or porous clay pipe irrigation (Ashrafi et al.[24] and Qiaosheng et al [21]. The development of plastic micro-irrigation technology in the last century led to increased use of subsurface irrigation. Today, subsurface drip irrigation is being used throughout the world to irrigate field crops, vegetables, and orchards. However, installation and maintenance of subsurface plastic drip. Also plastic drip tubing and emitters sometimes clog when used in clay soil or if muddy water is used. Therefore, there is great need to practice water use efficient, simple and low cost traditional irrigation methods, such as pitcher and clay pipe for irrigation and water conservation in arid areas of Pakistan. The present study was conducted to investigate the effect of deficit irrigation treatments and irrigation systems on the vegetative growth, fruit yield and marketable yield, IWUE, MSI and LRWC of two eggplant cultivars grown under clay soil conditional.

2. Materials and Methods

Field experiment was carried out on eggplant plants *(Solanum melongena L.)* during the summer seasons of 2019 and 2021 under open field conditions at Dokki experimental location, Agriculture Research Center, El-Giza Governorate, Egypt. The experimental site is located at latitude: 30°05"N, longitude: 31°20"E. The study aimed to investigate the effect of deficit irrigation treatments (DI levels were 100%, 70% and 50% of ETo (Reference evapotranspiration), irrigation systems (Surface drip irrigation (SDI) and Subsurface drip irrigation (SSI) (porous pipe) and their interaction on vegetative growth and fruit yield and quality of eggplant plants. The subsurface drip irrigation (SSI) (porous pipe) was conducted by were burring the drip tubes manually at depth of 20.0 cm in the middle of beds before cultivation). The total amounts of irrigation water during the growing seasons were calculated by using Penman–Montieth modified equation and data are showed in Table 4. The experimental site is located at latitude: 30°05"N, longitude: 31°20"E. Samples analyses of soil and irrigation water are shown in Tables 1 and Metrological data were calculated as monthly means such as maximum and minimum temperatures, relative humidity, soil temperature and wind speed are shown in Table 3.

2.1. Plant materials and cultivation

Eggplant seedlings “Swad El-layl" and “Classic" were used in these experiments. Seedlings were transplanted on 7th of April in the first and second seasons. Eggplant cultivation was performed under open field conditions.

2.2. Experimental design

The experiment was laid out in a split- split plot design with three replicates. Irrigation systems treatments were arranged in the main plots, while, deficit irrigation were randomly distributed in the sub-plots and cultivars were randomly assigned in the sub-sub plots.

Measured characteristics:

- Vegetative growth characteristics after 120 days from transplanting.
    1. Plant height (cm).
    2. Fresh weight of leaves per plant (g).
- Fruit yield:
    1. Total yield (ton/fed.).
    2. Total marketable yield (ton/fed.).

Chemical analyses:

1. Proline content in leaf-
2. Alkaloids in fruits.
    - chlorophyll (spad)
    - Water measurements:

Leaf relative water content

1. **(LRWC) percentage**.
   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 70oC 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.
2. **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. Membrane stability index was calculated as percentage:
   MSI (%) = 1-(EC1/EC2) × 100
3. **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 (m^3/fed).

Statistical analysis

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

Table 1. Chemical properties of experimental soil analysis.

Depth	SP	pH	ECe (dS/m)	meq/l							
				Cations				Anions			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	CO_3^{--}	HCO_3^{-}	SO_4^{--}
0-15	43	7.7	0.6	2.20	1.86	1.83	0.27	1.35	-	2.06	2.55
15-30	45	7.7	0.7	3.00	2.32	1.3	0.37	1.35	-	1.90	3.79
30-45	48	7.7	0.5	4.05	1.50	1.76	0.27	1.35	-	0.95	2.73
45-60	50	7.7	0.5	4.10	1.33	1.66	0.35	1.35	-	0.95	2.75

Table 2. Soil hydro-physical parameters at experimental site

location	Depth (cm)	Field capacity (%, w/w)	Wilting point (%, w/w)	Available water (mm)	Bulk density (g/cm^3)
Giza	0 – 15	39.85	18.61	40.0	1.15
	15 – 30	33.68	17.55	30.1	1.22
	30 – 45	28.36	16.92	20.6	1.20
	45 – 60	27.75	15.58	21.1	1.18
Average		32.41	17.16	27.9	1.18

Table 3. Metrological data (monthly maximum and minimum air temperatures, relative humidity) in 2019 and 2021 seasons

Date/Time	Air temperature [°C]			Relative humidity [%]	Wind speed [m/s]		Soil temperature [°C]		
	avg	max	min	avg	avg	max	avg	max	min
	First season (2019)								
Apr	21.00	27.39	14.83	48.39	0.63	2.25	22.44	27.58	17.46
May	27.30	34.89	19.75	38.28	0.60	2.22	27.62	32.47	22.41
Jun	29.61	36.11	23.89	50.37	0.64	2.10	29.58	33.04	25.11
Jul	30.33	36.66	24.79	52.79	0.58	2.01	30.26	33.26	27.56
Aug	30.40	36.69	24.86	53.87	0.63	1.97	31.07	35.40	27.85
Sep	28.04	33.81	23.43	57.64	0.71	2.08	29.60	36.63	25.27
Oct	25.81	31.18	20.64	58.66	0.49	2.03	26.93	41.09	18.24
Nov	21.59	27.42	15.88	57.88	0.32	1.79	21.70	36.78	12.10
	Second season (2021)								
Apr	21.39	27.85	15.39	54.20	0.81	2.40	22.77	40.70	11.86
May	26.20	33.36	19.36	46.06	0.72	2.22	27.81	41.95	17.52
Jun	28.43	35.90	21.90	47.41	0.67	2.07	30.48	44.06	19.76
Jul	29.72	37.04	24.05	58.37	0.62	1.97	32.01	47.05	22.61
Aug	30.32	36.91	24.99	57.87	0.64	1.96	31.75	46.66	23.44
Sep	29.81	35.51	25.23	61.11	1.02	2.40	29.01	36.94	24.12
Oct	26.62	31.48	22.61	61.87	0.83	2.22	26.23	32.09	21.29
Nov	19.79	25.11	15.24	68.43	0.36	1.89	20.17	27.06	15.60

Table 4. Irrigation requirements (L/plant per day) for irrigation treatments (100%, 70% and 50% of ET_o) for eggplant plants in open field cultivation in two seasons of 2019 and 2021

	first season			second season		
Weeks	100%	70%	50%	100%	70%	50%
1	1.31	1.01	0.655	1.31	1.01	0.655
2	1.53	1.23	0.765	1.53	1.23	0.765
3	1.76	1.46	0.88	1.66	1.36	0.83
4	2.01	1.71	1.005	2.01	1.71	1.005
5	2.27	1.97	1.135	2.27	1.97	1.135
6	2.78	2.48	1.39	2.78	2.48	1.39
7	3.4	3.1	1.7	3.4	3.1	1.7
8	3.88	3.58	1.94	3.88	3.58	1.94
9	4.46	4.16	2.23	4.26	3.96	2.13
10	4.5	4.2	2.25	4.5	4.2	2.25
11	4.54	4.24	2.27	4.54	4.24	2.27
12	4.74	4.44	2.37	4.74	4.44	2.37
13	4.61	4.31	2.305	4.61	4.31	2.305
14	4.55	4.25	2.275	4.65	4.35	2.325
15	3.98	3.68	1.99	3.98	3.68	1.99
16	3.84	3.54	1.92	3.84	3.54	1.92
17	3.55	3.25	1.775	3.55	3.25	1.775
18	3.28	2.98	1.64	3.28	2.98	1.64
19	2.98	2.68	1.49	2.98	2.68	1.49
20	2.65	2.35	1.325	2.65	2.35	1.325
21	2.35	2.05	1.175	2.35	2.05	1.175
22	2.07	1.77	1.035	2.17	1.87	1.085

Results

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 (plant height and fresh weights of eggplant leaves per plant) of two eggplant cultivars. Results clearly indicated that DI treatments significantly decreased all vegetative growth parameters of eggplant plants during the both studied seasons. Where the lowest values were obtained by 50% ET_o treatment. Conversely, the highest significant values were obtained by (100% ET_o) followed by 70% ET_o treatment with significant differences between them. Concerning the effect of irrigation systems (subsurface and surface drip irrigation) on vegetative growth parameters of eggplant plants, the obtained data revealed that subsurface irrigation system (SSI) showed superiority upon surface drip irrigation system (SDI) with all vegetative growth characteristics especially with "Sawad El-Layl" cultivar. Upon surface drip irrigation system (SDI). In this respect, SSI (porous pipe) system produced higher significant values for plant height, and fresh weight of eggplant leaves per plant both tested seasons, as compared surface drip irrigation system

(SDI. Regarding the interaction between deficit irrigation treatments and irrigation systems, plants that were irrigated by 100% ET_o with SSI system produced the highest significant values for plant height, and fresh weights of eggplant leaves per plant. In general, there were significant differences between the cultivars. The Classic cv was better in the first season, and the "Sawad El-Layl" was better in the second season. Also, there were significant differences between the cultivars within the drip irrigation systems in the two seasons, and the "Sawad El-Layl" cv was better under the subsurface irrigation system in the two seasons. "Sawad El-Layl" gave higher values of plant height and fresh weight with surface drip irrigation. Classic cultivar showed the lowest fresh weight at the 50% ET_o by using subsurface irrigation and the lowest plant height at the 50% ET_o by using drip irrigation.

Chemical contents for eggplant leaves

Data presented in Tables 7-8 reveal the effect of deficit irrigation treatments, irrigation systems and their interactions on chemical contents for eggplant leaves (N, P, K, Ca and chlorophyll). Results illustrated that decreasing irrigation water from 100% ET_o to 50% ET_o significantly decreased photosynthetic pigments and mineral constituents of eggplant leaves. Where, the highest significant values for N, P, K, Ca and chlorophyll content were obtained with 100% ET_o (control) treatment. While the lowest values were gained with 50% ET_o treatment in both tested seasons. As for the irrigation systems, the results of subsurface irrigation were better in improving nutrients and chlorophyll and delivering them to the plant better. The "Classic" cv showed a better improvement against stress conditions than "Sawad El-Layl" cv. The result of an interaction between irrigation systems and irrigation levels showed treatment 100% ET_o was the best under the subsurface irrigation system, which was the best treatment to improve nutrients (N, P, K, Ca) and chlorophyll. And the interaction between irrigation systems and cultivars was that the "Classic" cv showed the best results with the subsurface irrigation system in both seasons. 100 % ET_o (control) treatment was the best treatment with the "Classic" cv and improved nutrients and chlorophyll in both seasons.

On the contrary, drought stress significantly increased proline content in eggplant leaves. Where, the highest significant values were obtained by 50% ET_o treatment. While, the lowest values were noticed with 100% ET_o treatment, in the two studied seasons. In contrast, surface drip irrigation system produced the highest significant values of proline content in eggplant leaves compared to subsurface irrigation system, in the both tested seasons. As for the interaction between cultivars and irrigation systems, the “Sawad El-Layl” cv had the highest value of proline in leaves under the surface drip irrigation system, While the interaction between the cultivars and the irrigation levels was the "Sawad El-Layl" cv which had the highest value of proline in the leaves with 50% ET_o treatment. The result of the interaction between irrigation systems and irrigation levels and cultivars was an increase in the values of proline in the leaves of the "Sawad El-Layl" cv with 50% ET_o treatment and a surface drip irrigation system(Table 9).

Chemical contents for eggplant fruits

On the other hand, drought stress significantly increased alkaloids content in eggplant fruits. Where, the highest significant values were obtained by 50% ET_o treatment. While, the lowest values were noticed with 100% ET_o treatment, in the two studied seasons. In contrast, surface drip irrigation system produced the highest significant values of alkaloids content in eggplant fruits compared to subsurface irrigation system, in the both tested seasons. As for the interaction between cultivars and irrigation systems, the “Sawad El-Layl” cv had the highest value of alkaloids in fruits under the surface drip irrigation system, While the interaction between the cultivars and the irrigation levels was the "Sawad El-Layl" cv which had the highest value of alkaloids in fruits with 50% ET_o treatment. The result of the interaction between irrigation systems and irrigation levels and cultivars was an increase in the values of alkaloids in the fruits of the "Sawad El-Layl" cv with 50% ET_o treatment and a surface drip irrigation system. Thus, it affects the quality of the characteristics of the fruits (Table 9).

Table 5. Effect of irrigation systems, irrigation levels, cultivars and the interaction on fresh weight(g/plant) of eggplant plants after 120 days from transplanting

			First Season (2019)				Second Season(2021)		
Irrigation system(A)	Irrigation levels(B)	(C) Cultivars							
		Sawad El-Lil	Classic	A×B	A	Sawad El-Lil	Classic	A×B	A
Surface Drip Irrigation (SDI)	100%	855.17	1155.77	1005.47	820.85	865.17	1165.77	1015.47	825.85
	70%	877.81	678.20	778.01		877.81	678.20	778.01	
	50%	676.90	681.27	679.08		676.90	691.27	684.08	
	Mean	803.29	838.41			806.63	845.08		
Sub Surface Irrigation (SSI)	100%	1032.73	1048.00	1040.37	847.37	1058.40	1048.00	1053.20	854.54
	70%	815.83	827.20	821.52		831.57	828.87	830.22	
	50%	738.43	622.00	680.22		738.43	622.00	680.22	
	Mean	862.33	832.40			876.13	832.96		
	C	832.81	835.41			841.38	839.02		
		B×C			B	B×C			B
	100%	943.95	1101.88		1022.92	961.78	1106.88		1034.33
	70%	846.82	752.70		799.76	782.45	853.34		817.89
	50%	707.67	651.63		679.65	707.67	656.63		682.15
L.S.D at 5% ($P \leq 0.05$)	A	B	C	A×B	A×C	B×C	A×B×C		
First season	8.54	1.53	1.17	5.90	1.66	2.03	2.88		
Second season	1.31	1.06	0.35	5.37	0.49	0.60	0.85		

Table 6. Effect of irrigation systems, irrigation levels, cultivars and the interaction on plant height (cm) of eggplant plants after 120 days from transplanting

		First season (2019)					Second season (2021)			
Irrigation system (A)	Irrigation levels	Cultivars©				Irrigation levels	Cultivars©			
		Sawad El-Lil	Classic	A*B	A		Sawad El-Lil	Classic	A*B	A
Surface Drip Irrigation (SDI)	100%	86.37	91.00	88.68		100%	83.60	85.45	84.53	74.66
	70%	72.57	77.57	75.07	75.93	70%	76.31	69.35	72.83	
	50%	66.60	61.50	64.05		50%	72.10	61.17	66.63	
	Mean	75.18	76.69			Mean	77.34	71.99		
Sub Surface Irrigation (SSI)	100%	89.50	94.30	91.90		100%	88.33	90.18	89.26	79.82
	70%	79.70	83.73	81.72	81.61	70%	82.00	78.68	80.34	
	50%	69.53	72.90	71.22		50%	68.30	71.40	69.85	
	Mean	79.58	83.64			Mean	79.54	80.09		
	C	77.38	80.17			C	78.44	76.04		
		B×C			B			B×C		B
	100%	87.93	92.65		90.29	100%	85.97	87.82		86.89
	70%	76.13	80.65		78.39	70%	79.15	74.02		76.59
	50%	68.07	67.20		67.63	50%	70.20	66.28		68.24

Table 7. Effect of irrigation systems, irrigation levels, cultivars and the interaction on chlorophyll (spad) of eggplant plants after 120 days from transplanting.

		First season (2019)				Second season (2021)			
Irrigation systems(A)	Irrigation levels(B)	(C) Cultivars							
		Sawad El-Layl	Classic	A×B	A	Sawad El-Layl	Classic	A×B	A
Surface Drip Irrigation (SDI)	100%	34.00	41.70	37.85	37.66	35.00	41.00	38.00	37.12
	70%	33.33	42.00	37.67		35.73	38.33	37.03	
	50%	36.23	38.70	37.47		35.00	37.67	36.33	
	Mean	34.52	40.80			35.24	39.00		
Sub Surface Irrigation (SSI)	100%	39.00	43.00	41.00	39.44	38.00	45.00	41.50	39.34
	70%	39.27	42.30	40.78		38.00	43.00	40.50	
	50%	36.00	37.07	36.53		35.60	36.43	36.02	
	Mean	38.09	40.79			37.20	41.48		
	C	36.31	40.79			36.22	40.24		
		B×C			B	B×C			B
	100%	36.50	42.35		39.43	36.50	43.00		39.75
	70%	36.30	42.15		39.23	36.87	40.67		38.77
	50%	36.12	37.88		37.00	35.30	37.05		36.18

L.S.D at 5% (P≤0.05)	A	B	C	A×B	A×C	B×C	A×B×C
First season	0.75	0.85	0.52	10.22	0.74	0.91	1.29
Second season	0.47	0.56	0.59	9.14	N.S	1.02	1.45

Table 8. Effect of irrigation systems, irrigation levels, cultivars and the interaction on (N, P, K and Ca) contents in eggplant fruits after 120 days from transplanting

Irrigation system (A)	Irrigation levels(B)	Cultivars ©	First Season N	P	K	Ca
Surface Drip Irrigation (SDI)	100%	Sawad El-Layl	2.38	0.81	1.26	2.20
		Classic	2.80	0.75	1.29	1.90
		Mean	2.59	0.78	1.27	2.05
	70%	Sawad El-Layl	2.48	0.68	1.18	2.03
		Classic	2.11	0.74	1.30	2.27
		Mean	2.30	0.71	1.24	2.15
	50%	Sawad El-Layl	1.75	0.32	1.08	1.77
		Classic	1.60	0.40	1.12	1.91
		Mean	1.68	0.36	1.10	1.84
Sub Surface Irrigation (SSI)	100%	Sawad El-Layl	2.58	0.73	1.79	2.60
		Classic	2.91	0.94	2.02	2.70
		Mean	2.75	0.83	1.91	2.65
	70%	Sawad El-Layl	2.06	0.81	1.32	2.00
		Classic	2.03	0.99	1.37	2.20
		Mean	2.04	0.90	1.35	2.10
	50%	Sawad El-Layl	1.81	0.51	1.04	2.00
		Classic	2.00	0.67	1.22	2.08
		Mean	1.90	0.59	1.13	2.04
	SDI	Mean	2.19	0.62	1.20	2.01
	SSI	Mean	2.23	0.77	1.46	2.26
B			2.67	0.81	1.59	2.35
			2.17	0.80	1.29	2.13
			1.79	0.47	1.11	1.94
B*C	100%	Sawad El-Layl	2.48	0.77	1.52	2.40
		Classic	2.86	0.84	1.66	2.30
	70%	Sawad El-Layl	2.27	0.74	1.25	2.02
		Classic	2.07	0.87	1.34	2.23
	50%	Sawad El-Layl	1.78	0.49	1.06	1.89
		Classic	1.80	0.46	1.17	1.99
LSD	A		0.005	0.001	0.006	0.005
	B		0.030	0.010	0.040	0.020
	C		0.030	0.010	0.030	0.034
	B*C		0.043	0.120	0.240	0.046

A*B	0.050	0.130	0.050	0.160
A*C	0.030	0.170	N.S	0.060
A*B*C	0.050	0.020	0.080	0.083

Table 9. Effect of irrigation systems, irrigation levels, cultivars and the interaction on Alkaloids and Proline contents in eggplant fruits after 120 days from transplanting

			first season(2019)		second season(2021)	
A	B	C	Alkaloids	proline	Alkaloids	proline
			(mg/100g)	(ppm)	(mg/100g)	(ppm)
Surface Drip Irrigation (SDI)	100%	Sawad El-Layl	157.50	131.00	236.50 120.97	
		Classic	145.87	126.30	124.87	116.27
		Mean	151.68	128.65	180.68	118.62
	70%	Sawad El-Layl	327.20	194.87	265.00	184.84
		Classic	286.00	215.33	306.20	205.30
		Mean	306.60	205.10	285.60	195.07
	50%	Sawad El-Layl	533.00	367.97	533.00	357.94
		Classic	519.30	302.63	498.30	334.00
		Mean	526.15	335.30	515.65	345.97
Subsurface Irrigation (SSI)	100%	Sawad El-Layl	185.64	115.23	215.84	119.00
		Classic	136.84	106.00	164.64	105.20
		Mean	161.24	110.62	190.24	112.10
	70%	Sawad El-Layl	279.50	188.07	258.50	225.97
		Classic	324.97	146.00	303.97	119.00
		Mean	302.23	167.03	281.23	172.49
	50%	Sawad El-Layl	489.67	269.17	368.67	259.14
		Classic	324.87	295.37	321.20	185.34
		Mean	407.27	282.27	344.93	222.24
	SDI	Mean	328.14	223.02	327.31	219.89
L.S.D at 5% (P≤0.05)						
	SSI	Mean	290.25	186.64	272.14	168.49

A*B*C	A*C	A*B	B*C	C	B	A
1.290	0.740	89.050	0.910	0.520	0.670	4.170
2.520	1.960	38.700	1.600	2.030	1.300	2.980

1.900	0.770	98.020	0.770	1.350	0.700	3.310
2.520	1.760	39.600	1.450	1.310	0.810	6.570

Table 10. 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 eggplant plants after 120 days from transplanting

A	B	C	First Season		2019	Second Season		2021
			IWUE (kg/m³)	MSI	LRWC (%)	IWUE (kg/m³)	MSI	LRWC (%)
Surface Drip Irrigation (SDI)	100%	Sawad El-Layl	46.37	85.07	80.85	43.45	82.07	82.51
		Classic	48.63	81.45	85.45	30.21	86.45	87.11
		Mean	47.50	83.26	83.15	36.83	84.26	84.81
	70%	Sawad El-Layl	33.02	74.32	74.03	36.84	66.33	81.53
		Classic	32.88	77.12	80.46	41.88	78.32	79.76
		Mean	32.95	75.72	77.25	39.36	72.33	80.64
	50%	Sawad El-Layl	33.56	62.12	64.00	42.45	58.33	67.08
		Classic	33.11	65.95	68.24	59.29	67.61	69.90
		Mean	33.33	64.03	66.12	50.87	62.97	68.49
SubSurface Irrigation (SSI)	100%	Sawad El-Layl	48.02	86.45	85.45	47.57	85.22	87.11
		Classic	48.77	91.78	90.78	48.27	90.33	92.44
		Mean	48.40	89.12	88.12	47.92	87.78	89.78
	70%	Sawad El-Layl	30.52	84.78	60.31	36.84	75.00	80.67
		Classic	39.03	81.45	80.45	42.41	80.00	83.67
		Mean	34.77	83.12	70.38	39.62	77.50	82.17
	50%	Sawad El-Layl	39.79	71.45	66.00	48.41	70.22	70.33
		Classic	41.97	81.00	74.45	37.14	74.00	83.33
		Mean	40.88	76.23	70.23	42.78	72.11	76.83
	SDI	Mean	37.93	74.34	75.51	42.35	73.19	77.98
	SSI	Mean	41.35	82.82	76.24	43.44	79.13	82.39
B			47.95	86.19	85.63	42.38	86.02	87.29
			33.86	79.42	73.81	39.49	74.91	81.41
			37.11	70.13	68.17	46.82	67.54	72.66
B*C	100%	Sawad El-Layl	47.20	85.76	83.15	45.51	83.64	84.81
		Classic	48.70	86.62	88.12	39.24	88.39	89.78
	70%	Sawad El-Layl	31.77	79.55	67.17	36.84	70.67	81.10
		Classic	35.95	79.28	80.46	42.14	79.16	81.71
	50%	Sawad El-	36.67	66.78	65.00	45.43	64.28	68.71

		Layl Classic	37.54	73.48	71.35	48.21	70.81	76.62
L.S.D at 5% (P≤0.05	A		1.310	2.880	0.170	1.040	5.890	3.580
	B		1.080	1.580	1.550	1.390	1.780	1.820
	C		0.730	1.140	1.230	0.370	0.840	1.450
	B*C		1.030	1.970	1.750	1.260	1.450	2.510
	A*B		4.970	5.520	18.660	1.380	8.510	10.240
	A*C		1.260	1.610	2.140	1.420	1.400	2.060
	A*B*C		1.780	2.970	3.030	1.490	2.060	3.550

presented in Table 10 reveal the effect of deficit irrigation treatments, irrigation systems and their interactions on water measurements for eggplant 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 50% ETo to 100% ET_o significantly increased leaf relative water content (LRWC) and membrane stability index (MSI) in the both tested seasons. The highest significant values were obtained by 100% ET_o treatment, while, the lowest values were obtained by 50% ET_o treatment. In contrast, irrigation water use efficiency (IWUE) significantly decreased with increasing irrigation water, where the maximum values were observed with 50%ET_o treatment, in the two studied seasons.

Table 11. Effect of irrigation systems, irrigation levels, cultivars and the interaction on total yield(ton/fed) of eggplant plants after 120 days from transplanting

		First Season (2019)				Second Season(2021)			
		(C) Cultivars							
Irrigation system (A)	Irrigation levels(B)	Sawad El-Layl	Classic	A×B	A	Sawad El-Layl	Classic	A×B	A
Surface Drip Irrigation (SDI)	100%	45.91	48.14	47.03		29.91	45.91	37.91	
	70%	24.47	31.15	27.81	30.80	27.30	31.04	29.17	28.42
	50%	17.03	18.06	17.55		15.71	20.67	18.19	
	Mean	29.14	32.45			24.31	32.54		
Sub Surface Irrigation (SSI)	100%	47.54	48.28	47.91		47.09	47.79	47.44	
	70%	41.00	45.62	43.31	36.90	43.30	45.43	44.36	35.87
	50%	18.20	20.78	19.49		15.37	16.21	15.79	
	Mean	35.58	38.22			35.26	36.48		
	C	32.36	35.34			29.78	34.51		
		B×C			B	B×C			B
	100%	46.72623	48.21		47.46901	38.5021	46.85		42.67559
	70%	32.73723	38.38241		35.55982	35.3	38.2312		36.7656
	50%	17.61305	19.4194		18.51623	15.5428	18.44128		16.99204
L.S.D at5%	A	B	C	A×B	A×C	B×C	A×B×C		
First season	0.223	0.268	0.212	6.78	0.299	0.36	0.519		
Second season	0.057	0.145	0.11	2.116	0.164	0.201	0.285		

Table 12. Effect of irrigation systems, irrigation levels, cultivars and the interaction on marketable yield (ton/fed) of eggplant plants after 120 days from transplanting

		First Season (2019)				Second Season(2021)			
		(C) Cultivars							
Irrigation system (A)	Irrigation levels(B)	Sawad El-Layl	Classic	A×B	A	Sawad El-Layl	Classic	A×B	A
Surface Drip Irrigation (SDI)	100%	45.02	47.25	46.13	29.90	29.36	45.35	37.36	29.31
	70%	23.58	30.26	26.92		26.75	30.48	28.61	
	50%	16.14	17.17	16.65		15.16	28.79	21.97	
	Mean	28.25	31.56			23.75	34.88		
Sub Surface Irrigation (SSI)	100%	46.65	47.39	47.02	36.13	46.54	47.23	46.89	35.31
	70%	40.73	44.82	42.77		42.75	44.87	43.81	
	50%	17.30	19.88	18.59		14.82	15.66	15.24	
	Mean	34.89	37.36			34.70	35.92		
	C	31.57	34.46			29.23	35.40		
		B×C			B	B×C			B
	100%	45.83	47.32		46.58	37.9475	46.29		42.12099
	70%	32.15	37.54		34.84	34.7454	37.6766		36.211
	50%	16.72	18.53		17.62	14.9882	22.22498		18.60659
L.S.D at 5%	A	B	C	A×B	A×C	B×C	A×B×C		
First season	0.02	0.06	0.10	6.58	0.15	0.18	0.26		
Second season	0.05	0.26	0.20	10.22	0.29	0.36	0.51		

Data in Tables 11, 12 reveal the influence of deficit irrigation, irrigation systems and their interactions on total yield and total marketable yield. Drought stress significantly decreased total yield and total marketable. The highest total yield and total marketable yield were obtained by 100% ET_o treatment. While, the lowest values were noticed with 50% ET_o treatment, in the two studied seasons. Surface drip irrigation system produced the lowest total yield and total marketable yield compared to subsurface irrigation system (porous pipe), in the both tested seasons. As for the interaction between cultivars and irrigation systems, “Classic” cv had the highest total yield and total marketable yield under the subsurface irrigation system, While the interaction between the cultivars and the irrigation levels was “Classic” cv was better with the 100% ET_o and 70 ET_o treatment. The result of the interaction between irrigation systems and irrigation levels and cultivars was an increase total yield and total marketable yield with "Classic" cv and 100% ET_o treatment with a subsurface irrigation system (porous pipe).

Discussion

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, transpiration rates, stomatal conductance, photosynthetic rate, relative water content and leaf water potential were accompanied to drought water stress [7] Ultimately, it destabilizes the membrane structure and permeability, protein structure and function, leading to cell death). In this concern, many investigators reported that SSI 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 SSI system in the soil was better than SDI system [15, 35]. Different responses of different cultivars to water stress and these differences were possibly due to the difference in genotype genetic structure [54, 55]. Eggplant cultivars showed different responses to water stress in leaf area, number of leaves, and number of branches[56]. Drought reduced stem diameter of all eggplant cultivars and the response of eggplant cultivars to drought was variable. In connection with these results El-Shawadfy [35]. SSI 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, SSDI system is important in increasing the availability and absorption of minerals in the plant [15], thereby increasing the total chlorophyll content in the leaves. Furthermore, SSDI system slightly increased the nutrient concentration in the marigold plant, which was reflected through increased nutrient uptake in the plants[39]. Moreover water plays a significant role in mobilization of mineral elements [40]. SSDI system slightly increased nutrients concentration in potato tubers as compared with SDI system [14]. Concerning the combination between deficit irrigation treatments and irrigation systems data showed that, plants were irrigated by 100% ET_o with SSI (porous pipe) system produced the highest significant values for chlorophyll content in eggplant leaves. While, plants were irrigated by 50% ET_o with SDI system produced the highest significant values for proline content in eggplant leaves, compared to the other treatments. Leaf chlorophyll and significantly decreased in mild and severe stress conditions [3]. In the same trend, under drought stress, the content of chlorophyll is decline in the leaves of processing tomato [36]. And plants were irrigated by 100% ET_o with SDI system produced the lowest significant values for alkaloids contents in eggplant fruits, compared to the other treatments While, plants were irrigated by 50% ETo with SDI system produced the highest significant values for alkaloids contents in eggplant fruits, compared to the other treatments. Drought stress reduces photosynthetic rate in soybean which mainly due to the reduction in stomatal conductance caused by increased ABA concentration in the leaves [7]. Water stress induced an accumulation in proline concentration in wheat plants[38]. Proline accumulates under stressed conditions supplies energy for growth and survival and thereby helps the plant to tolerate stress. Under drought stress, the contents of proline and soluble sugar are increased in the leaves of processing tomato [36]. Eggplant plants osmolyte such as proline increased against drought stress [3]. Water stress reduced the three photosynthetic pigments, increased proline, malondialdehyde, total phenolics, and total flavonoids, although some varietal differences were observed. Different patterns were also detected in the activities of the four enzymes evaluated, but few differences were observed for individual varieties between the control and water stress treatments. Many significant phenotypic correlations were observed among the traits studied, but only eight environmental correlations were detected. proline could be used as a marker for drought stress tolerance in this species. The information obtained provides new insight on the physiological and biochemical responses of eggplant to drought stress [52]. When plants are exposed to various stress situations, their alkaloid concentration frequently is enhanced. This well-known phenomenon is presumably due to a passively enhanced rate of biosynthesis, caused by greatly elevated concentrations of NADPH in stressed plants. Here, we used Chelidonium majus L. plants, which accumulate high concentrations of dihydrocoptisine in their leaves, to study the impact of drought and salt stress on the biosynthesis and accumulation of alkaloids. In comparison to well-watered controls, in the transcriptome of the gene encoding the key enzyme in alkaloid biosynthesis, stylopine synthase, is enhanced in stressed C. majus plants. If we presuppose that increased transcript levels correlate with increased enzymatic activity of the gene products, these data indicate, for the first time, that stress-related increases in alkaloid concentration might not only be caused by the well-known stress-related passive shift, but may also be due to an enhancement of enzymatic capacity [51]. Using of DI strategy is very important to increase crop water use efficiency (WUE) [50]. The adoption of DI strategies at 50% reduction of ETc could be suggested for processing tomato under open field conditions, for increasing WUE [9]. Respecting the effect of irrigation systems (SDI and SSI) on water measurements for eggplant plants, the obtained data revealed that SSI system showed significant superiority to SDI system under field conditions in the both tested seasons. The highest significant values for LRWC, MSI and IWUE were showed with SSDI system compared to SDI system. Water use efficiency under SSDI system was much more than SDI system with cultivated tomato plants [50]. 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 eggplant crop production under water limited conditions. Concerning the combination between deficit irrigation treatments and irrigation systems, plants were irrigated by 100% ET_o with SSI 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 50% ET_o and both of irrigation systems (in the first season) as well as with SSI system only in the second season. Deficit irrigation reduced the number of flowers leading to decrease the number of fruits [41]. Deficit irrigation at 70% of tomato water requirement decreased the number of flowers per plant [5, 33]. Furthermore, soil water deficit reduced crop yield by reducing canopy absorption of photo synthetically active radiation, leading to decreasing radiation-use efficiency [42]. Moreover, the reduction in yield can be attributed to the decrease in photosynthetic pigments, carbohydrates accumulation (polysaccharides) and nitrogenous compounds (total nitrogen and protein) [43]. 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 total yield and total marketable yield were obtained by SSDI system compared to SDI system in the both tested seasons [53]. 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, 35, 11]. 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 total yield and total marketable yield significant differences to the other treatments. While the highest significant values for total yield and total marketable yield for eggplant were obtained by 100% ET_o with SSDI system in the both tested seasons.

Conclusion

It's concluded that, minimizing the amount of irrigation water significantly decreased the vegetative growth and fruit yield of eggplant plants. Using SSI (porous pipe) system enhanced the vegetative growth parameters; fresh weight and plant height, which reflected in an increasing of the total yield of eggplant. Finally, eggplant plants grown in Egyptian conditions and open field conditions can grow well under deficit irrigation water (70% ETo) by using SSI system (porous pipe) And using water stress tolerant cultivars with giving high productivity, especially under the conditions of climatic changes and a lack of water resources.

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