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EFFECT OF DRIP IRRIGATION SYSTEMS AND WATER QUANTITY ON GROWTH, YIELD AND WATER USE EFFICIENCY OF SWEET POTATO PLANT GROWN UNDER SANDY SOIL CONDITIONS

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ABSTRACT

This research was carried out to evaluate the effect of drip irrigation systems; *i.e.*, surface (SD), subsurface (SSD) and irrigation water quantities; *i.e.*, 1000, 1500, 2000 and 2500 m^3/fed., as well as their interactions on sweet potato plant growth, plant water relationships, water use efficiency (WUE) and root tuber yield and its quality under sandy soil conditions.

All studied plant growth characters, free water, total water in leaves and N percentages in shoots as well as N, P and K uptakes by shoots were significantly enhanced by subsurface drip irrigation system. Also, it recoded significant increases in root tuber yield and its quality. While, (SD) significantly increased bound water percentage, cell sap, osmotic pressure, transpiration rate (TR) and proline amino acid content in leaves.

The highest tested water quantity (2500 m^3/fed.) recorded the maximum values for all plant growth traits, total and free water (%) in leaves, N, P and K contents and their uptakes by shoots, total tuber root yield/ plant and per fed. as well as tuber root chemical constituents. While, 1000 m^3/fed. resulted in increases of bound water%, cell sap and osmotic pressure and proline amino acid.

In addition, 2500 m^3/ fed. as SSD irrigation system gave the highest values for all plant growth characters and recorded the highest yield quantity and quality.

Keywords: Sweet potato, irrigation system, water quantity, growth, yield , water use efficiency and tuber root quality.

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INTRODUCTION

Sweet potato *(Ipomoea batatas* (L.) Lam.) is considered as one of the very important crops in tropical and subtropical regions as well as in developing countries. Its chief use is for human consumption and for starch manufacturing. Its roots and leaves have high nutritious value. So, the same plant produces two useful food types; namely, tuberous roots and green tops which can be used for human and animal feeding, respectively.

Excessive permeability and low water and nutrient holding capacities are the major problems in sandy soils (Suganya and Sivasamy, 2006). Hence, managing irrigation water and plant nutrients are the major challenge of sandy soil amelioration efforts. Since, insufficient irrigation water results of high soil moisture tension, which fall plant under stress and, in turn, reduce its yield. While, excess irrigation water may reduce crop yield due to leaching of applied nutrients, increased disease incidence and/or failure to stimulate growth of the commercially valuable parts of the plant (Solomon, 1993).

Drip irrigation system allows water to be applied uniformly and slowly at the plant location, so that essentially all the water is placed in the root zone (Johnson *et al.*, 1991). Drip irrigation is categorized to two systems; *i.e.,* surface drip irrigation SD: water is applied directly to the soil surface or subsurface drip irrigation SSD: Water is applied below the soil surface through perforated pipes (Viola, 2009). In SSD system, water infiltration takes place in the region directly around the dripper, which is small compared with the total area of irrigated field. According to Ruskin (2000), SSD system must be used to supply water in small amounts and at higher frequency.

Subsurface drip irrigation is considered to be the most modern irrigation system with high efficient water delivery that can contribute in conserving water (Hanson and May, 2004). Additionally, SSD system has proved to be an efficient irrigation method with potential advantages of high water use efficiency; fewer weed and disease problems; less soil erosion; efficient fertilizer application; maintenance of dry areas for tractor movement at any time; flexibility in design; and lower labor costs than at in a conventional SD system (Camp *et* *al.*, 2000; Lamm, 2002; Raine and Foley, 2001). Also, SSD system reduces water loss through evaporation and deep percolation (Camp, 1998). Simultaneously, SSD system ensures long life of the system because pipes and drippers don't expose to the sun and extreme weather conditions. Contrary, there are potential disadvantages with SD system, which mainly relate to poor or uneven surface wetting and risky crop establishment (Camp *et al.*, 2000; Lamm, 2002; Raine and Foley, 2001).

Of sweet potato plant, water stress reduced growth as: main stem length, number of branches, leaf area and shoot dry weight per plant; yield as: tubers number/ plant, total and marketable yield; and quality as: total carotene and total soluble sugar, starch, total carbohydrates, N, protein as well as mineral contents in tuber tissues comparing to unstressed plants (Abdel -Fattah *et al.*, 2002). Al-Easily (2006) found that drip irrigation rate of 3000 m^3/fed. being the superior for enhancing all plant growth characters, dry weight of different plant parts, plant chemical constituents and yield and its components. Selim *et al.* (2009) added that subsurface drip irrigation was more efficient than surface drip irrigation on enhancing tubers yield quantity and quality parameters and nutrients concentrations in potato tubers.

Similarly, subsurface drip irrigation system led to greater sugar beet yield with higher sugar content and also increased water savings compared with surface drip irrigation Sakellariou *et al.* (2002).

So, the objective of this research was to evaluate the effects of surface and subsurface drip irrigation systems and irrigation water quantities on plant growth, water relations, water use efficiency, yield and its quality of sweet potato plant grown under sandy soil conditions.

MATERIALS AND METHODS

This experiment was carried out during the two successive summer seasons of 2009 and 2010 in a Private Farm in El-Salhyia El-Gadida Region, Sharkia Governorate, on sweet potato plant, to study the effect of irrigation systems and water quantities as well as their interactions on growth, plant water relationships, yield and its quality as well as water use efficiency under sandy soil conditions.

Physical and chemical properties of the used experimental soil were: sandy in texture for the two experimental seasons, it had 0.06 and 0.07% organic matter, 8.14 and 8.16 pH, 1.97 and 2.03 mmhos/cm EC, 4.23 and 4.17 ppm available N, 3.38 and 3.42 ppm available P and 8.91 and 8.74 ppm available K during the 1st and 2nd seasons, respectively. While, The analysis of irrigation water was: 0.52 mmhos/cm for Ec, 7.92 for pH; 1.40, 1.17, 1.67, 0.12, 1.35, 1.12, 2.1 and 1.48 mol/L for Ca, Mg, Na, K, SO_4, Cl, HCO_3 and sodium adsorption ratio, respectively.

The experiment included eight treatments, which were the combinations between two drip irrigation systems (surface and subsurface) and four irrigation water quantities (1000, 1500, 2000 and 2500 m3/fed.). These treatments were arranged in a split plot system in a complete randomized block design with three replicates. The irrigation systems were arranged in the main plots and irrigation water quantities were randomly distributed in the sub plots.

Drippers commercially named GR with flow rate of 2 l/ hour at one bar pressure were used in design the line system and placed 25 cm apart from each other in the two tested irrigation systems. Laterals lines, 16 mm in diameter, were potted at top rim of soil surface in SD system and at 15 cm depth from the soil surface in SSD system.

The experimental unit area was 12.6 m^2. It contains three dripper lines with 6 m length each and 70 cm distance between each two dripper lines. One line was used to measure the morphological and physiological traits and the other two lines were used for yield determinations. In addition, one row was left between each two experimental units as guard area to avoid the overlapping infiltration of irrigation water.

For the two experimental seasons, on April 20th sweet potato (*Ipomoea batatas*, L.) cv. Beauregard stem cuttings, about 20 cm length, were transplanted on the third top of slope ridges at 25 cm apart. Then, all experimental units received 100 m^3 water during the following twentieth days from transplanting. On May 10th, irrigation treatments were begun and repeated at two days interval. Irrigation was stopped on September 1st (ten days before tuber root harvesting). Water counters were used for calculating the tested water quantities. Irrigation numbers over season as well as time (min) and amounts of water (m^3) per plot and per fadden/ irrigation are shown in Schedule 1.

Schedule 1. Irrigation numbers over season, as well as time and quantity per plot and per fed./ irrigation of sweet potato via dripper lines with discharge of 2 L/h for each dripper at 1 bar

Water quantity (m^3/fed.)	Irrigation number	Irrigation Time in every irrigation (min.)	Water quantity (m^3/fed..) in every irrigation	Water quantity (m^3/plot) / irrigation
900	55	20.71	16.364	0.049
1400	55	32.10	25.455	0.076
1900	55	43.70	34.545	0.104
2400	55	55.09	43.636	0.131

All treatments received ammonium sulphate (20.5% N), calcium superphosphate (15.5%) and potassium sulphate (48-52% K_2O) at a rate of 200, 150 and 150 kg/ fed.., respectively. One third of N and K_2O and all P_2O_5 were added during soil preparation with FYM at the rate of 20 m^3/ fed... The rest of N and K_2O (two thirds) were added as fertigation at four days interval beginning one month after planting. The normal agricultural practices were carried out as commonly followed in the district.

Data Recorded

On August 10[th] of the two growing seasons (110 days after transplanting), five plants from each treatment were randomly taken to determine treatments effect on plant growth, water relations and nutrient uptake and percentages in shoot as well as leaf content of proline amino acid. While, on September 10[th] (140 days after transplanting) yield determinations were recorded.

Plant growth

Plant growth records were implicated vine length (cm), number of branches/ plant, shoot dry weight (leaves + stems)/ plant (g) and relative increase in shoot dry weight/ plant. Additionally, leaf area/ plant (m^2) was calculated according to the described formula by Koller (1972) as follows:

$$\text{Leaf area} = \frac{\text{Leaves dry weight/plant} \times \text{No.of disks} \times \text{disk area}}{\text{Dry weight of disks}}$$

Plant water relations

Water relations were recorded in the fourth upper plant leaf as total, free and bound water as well as cell sap and osmotic pressure according to the methods of Gosev (1960). Also, transpiration rate (mg/cm^2/h) was measured using the adopted rapid weighing systems described by Migahid and Amer (1952).

Nutrient uptake and their percentages in shoot

Total Nitrogen, phosphorus and potassium percentages were determined in dried and wet digested shoot according to the methods described by A.O.A.C. (1990), and then uptake of N, P and K by shoots was calculated.

Proline amino acid content

It was determined as mg/100g leaves dry weight according to the method described by Bates (1973).

Yield and its components

At harvesting (140 days after transplanting), tuberous roots of each treatment were classified according to Grang (1963) into two grades; *i.e.*, Marketable roots have a weight 100 to 250gm, while non-marketable roots have a weight of less than 100gm or more than 250gm, then weighted to determine total yield (ton/fed.). In addition average tuber weight (g) and tuber yield/ plant (kg) were calculated.

Water use efficiency (WUE)

It was determined by dividing the tuber roots yield/ fed. by the water quantity/ fed. and expressed as kg tuber root/m^3 water (Begg and Turner 1976).

Tuber roots quality

Assessing tubers quality, implicated determination of tuber tissue contents, of total N, P, K and starch (as percentages in dried tissues) as well as carotenoids (as mg/g in fresh weight) according to the methods of A.O.A.C. (1990). Also, Total soluble sugar (%) was determined according to the method described by Forsee (1938).

Statistical Analysis: Recorded data were subjected to the statistical analysis of variance according to Snedecor and Cochran (1980), and means separation was done according to Duncan (1958).

RESULTS AND DISCUSSION

Plant Growth

Effect of drip irrigation (DI) systems

It can be seen from data in Table 1 that drip irrigation (DI) systems reflected a significant effect on vine length, leaf area/ plant and shoot dry weight/ plant nevertheless number of branches/ plant was not affected by irrigation

Table 1. Effect of drip irrigation systems and water quantity on growth of sweet potato plants grown in sandy soil during 2009 and 2010 summer seasons

Treatments	Vine length (cm)		Number of branches/ plant		Leaf area/ plant (m^2)		Shoots dry weight/plant (gm)		Relative increase in shoot dry weight (%)	
	Season									
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
	Effect of drip irrigation systems									
SD irrigation*	115.21b	111.41b	13.45a	12.96a	0.716b	0.594b	103.46b	95.01b	00.00	00.00
SSD irrigation**	122.13a	118.34a	14.93a	14.63a	0.907a	0.840a	114.27a	112.98a	10.45	18.91
	Effect of irrigation water quantity (m^3/fed.)									
1000	105.05b	106.97d	11.88d	11.94b	0.640d	0.587d	95.50d	93.43c	00.00	00.00
1500	121.32a	113.02c	13.59c	13.72ab	0.727c	0.666c	105.45c	101.38b	10.42	8.51
2000	123.11a	118.24b	15.17b	14.40a	0.905b	0.784b	115.42b	109.36a	20.86	17.05
2500	125.20a	121.28a	16.12a	15.12a	0.975a	0.831a	119.10a	111.82a	24.71	19.68

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation, SSD irrigation** subsurface drip irrigation

system. Also, subsurface drip SSD irrigation systems gave taller plants, higher leaf area/plant and heavier shoot dry weight than surface drip SD irrigation systems in both seasons. The increases in shoot dry weight were about 10.45 and 18.91% for SSD irrigation system over the SD irrigation system in the 1st and 2nd seasons, respectively.

Effect of irrigation water quantity (IWQ)

The obtained results in Table 1 show that irrigation water quantity (IWQ) had a significant effect on vine length, number of branches/ plant, leaf area/ plant and shoot dry weight/plant. Irrigation of sweet potato plants with 2500 m^3/fed... in the year gave the tallest plants and recorded the maximum values of number of branches/ plant, leaf area/plant and shoot dry weight/ plant, with no significant differences between 2500 and 2000 m^3/fed... in same cases. The increase in shoot dry weight were about 24.71 and 19.68% for IWQ at 2500 m^3/fed... over the IWQ at 1000 m^3/ fed... in 1st and 2nd seasons, respectively.

These results are in accordance with Abdel-Fattah *et al.* (2002) and Al-Easily (2006) who found that drip irrigation rats at level 3000 m^3/ fed... recorded the maximum values of plant growth parameters of sweet potato plants.

Effect of DI systems x IWQ interaction

It is quite clear from data in Table 2 that the interaction between DI systems and IWQ showed a significant effect on vine length, number of branches/ plant, leaf area/ plant and shoot dry weight/ plant in both seasons. The interaction between SSD irrigation system and IWQ at 2000 or 2500 m^3/fed... were the best treatments for stimulating vine length, number of branches/ plant, leaf area /plant and shoot dry weight/ plant. The increases in shoot dry weight were about 34.41 and 46.97 % for IWQ at 2500 m^3/fed.. for the interaction between SSD irrigation system and IWQ at 2000 m^3/fed... and 36.61 and 39.24% for the interaction between SSD irrigation system and IWQ at 2500 m^3/fed... over the interaction between SD irrigation system and IWQ at 1000 m^3/fed... in 1st and 2nd seasons, respectively.

Plant Water Relations

Effect of DI systems

It can be seen from presented data in Table 3 that DI systems had

Table 2. Effect of interaction between drip irrigation systems and water quantity on growth of sweet potato plants grown in sandy soil during 2009 and 2010 summer seasons

Irrigation systems	IWQ (m^3/fed.)	Vine length (cm) 2009	Vine length (cm) 2010	Number of branches/ plant 2009	Number of branches/ plant 2010	Leaf area/ plant (m^2) 2009	Leaf area/ plant (m^2) 2010	Shoots dry weight/plant (gm) 2009	Shoots dry weight/plant (gm) 2010	Relative increase in shoot dry weight (%) 2009	Relative increase in shoot dry weight (%) 2010
SD irrigation*	1000	97.96d	103.4e	11.13d	11.54b	0.539f	0.513e	90.77e	84.10f	00.00	00.00
	1500	117.6bc	109.4d	12.55c	12.46ab	0.609e	0.522e	100.0d	94.30e	10.17	12.13
	2000	120.8ab	114.4c	14.24b	13.37ab	0.766d	0.566e	108.8c	95.07e	19.86	13.04
	2500	124.5a	118.5b	15.89a	14.45ab	0.948b	0.774c	114.2b	106.6cd	25.81	26.75
SSD irrigation**	1000	112.1c	110.6d	12.63c	12.34ab	0.740d	0.661d	100.2d	102.8d	10.39	22.24
	1500	125.0a	116.7bc	14.63b	14.98ab	0.844c	0.809c	110.9c	108.5c	22.18	29.01
	2000	125.4a	122.1a	16.09a	15.43a	1.044a	1.001a	122.0a	123.6a	34.41	46.97
	2500	125.9a	124.1a	16.35a	15.78a	1.001ab	0.887 b	124.0a	117.1b	36.61	39.24

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation, SSD irrigation** subsurface drip irrigation, IWQ: irrigation water quantity

Table 3. Effect of drip irrigation systems and water quantity on plant water relationships of sweet potato leaves grown in sandy soil during 2009 and 2010 summer seasons

Treatments	Total water (%)		Free water (%)		Bound water (%)		Cell sap		Osmotic pressure	
	Season									
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Effect of irrigation systems										
SD irrigation*	80.76b	83.28b	51.27b	52.06b	28.91a	30.59a	6.79a	7.23a	5.38a	5.67a
SSD irrigation**	84.38a	86.54a	64.92a	68.65a	19.08b	17.53b	4.65b	5.28b	3.62b	4.17b
Effect of irrigation water quantity (m^3/fed.)										
1000	81.80b	83.99a	56.07c	59.10b	25.71a	24.39a	6.16a	6.67a	4.77a	5.28a
1500	81.69b	83.86a	55.90c	57.47b	24.79a	25.86a	5.87b	6.26b	4.65b	4.96b
2000	82.98a	85.60a	58.66b	60.30b	23.84a	24.79a	5.46c	6.11b	4.32c	4.84b
2500	83.83a	86.18a	61.74a	64.54a	21.64b	21.22b	5.39c	6.00b	4.27c	4.62c

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation , SSD irrigation** subsurface drip irrigation significant effect on total, free and bound water (%), cell sap and osmotic pressure (OP) in leaf tissues of sweet potato in both seasons. Using SSD irrigation system recorded the maximum values of total and free water (%) than SD irrigation system, whereas using SD irrigation system recorded the maximum values of bound water (%), cell sap and OP in leaves than SSD irrigation system in both seasons.

Effect of IWQ

It is evident from data in Table 3 that IWQ showed a significant effect on plant water relations of sweet potato plants in both seasons. The percentages of total and free water in leaf tissues significantly increased with increasing IWQ up to 2500 m^3/fed. with no significant differences between IWQ at 2000 and 2500m^3/feddan. Whereas bound water (%), cell sap and OP significantly decreased with increasing IWQ up to 2500 m^3/fed. with no significant differences between IWQ at 2000 or 2500 m^3/fed. It means that IWQ at 2000 or 2500 m^3/fed. increased total and free water, whereas IWQ at 1000 or 1500 m3/fed. increased bound water (%), cell sap and OP in leaf tissues of sweet potato plants.

As for plant water relations, from the foregoing results it could be suggested that the increment in water supply would increase the soil moisture content, which in turn would probably led to increase the available water in the soil. That was, in turn, resulted in increase of water absorption and then increased both total and free water in leaf tissues, so that as free water content increase, bound water content should be decreased. Moreover, the increase in the bound water and decrease in free water under water stress was mainly due to the increases in cell sap concentration and its OP resulted from the conversion of starch into soluble carbohydrates (Lancher, 1993).

Effect of DI systems x IWQ interaction

The obtained results in Table 4 show that the interaction between DI systems and IWQ had a significant effect on plant water relations.

The interaction between SSD irrigation systems and IWQ at 2500 m^3/fed. was significantly increased total and free water percentage. Whereas the interaction between SD irrigation systems and IWQ at 1000 or 1500 m^3/fed. significantly increased bound water (%), cell sap and OP of leaf tissues of sweet potato.

Table 4. Effect of the interaction between drip irrigation systems and water quantity on plant water relationships of sweet potato leaves grown in sandy soil during 2009 and 2010 summer seasons

Treatments		Total water (%)		Free water (%)		Bound water (%)		Cell sap		Osmotic pressure	
Irrigation systems	IWQ (m^3/fed.)	Season									
		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
SD irrigation*	1000	79.58e	82.57b	48.48d	51.16d	31.46a	30.78a	7.34a	7.65a	5.82a	6.09a
	1500	80.96d	82.35b	48.99d	48.41d	30.35ab	33.26a	7.04b	7.31ab	5.58b	5.80ab
	2000	81.01d	83.26b	52.91c	51.37d	27.54bc	31.25a	6.46c	7.21b	5.11c	5.71b
	2500	81.50cd	84.92ab	54.69c	57.29c	26.27c	27.08b	6.32c	6.76c	5.01d	5.09c
SSD irrigation**	1000	84.02b	85.40ab	63.66b	67.04b	19.95de	17.99c	4.97d	5.68d	3.71e	4.47d
	1500	82.42c	85.37ab	62.81b	66.53b	19.22de	18.46c	4.69e	5.20e	3.71e	4.11e
	2000	84.94ab	87.93a	64.4b	69.23ab	20.13d	18.33c	4.46f	5.00e	3.53f	3.96e
	2500	86.15a	87.44a	68.79a	71.78a	17.01e	15.35c	4.46f	5.23e	3.53f	4.14e

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation , SSD irrigation** subsurface drip irrigation, IWQ: irrigation water quantity

Transpiration Rate TR

Effect of DI systems

Data recorded in Table 5 show that DI systems had a significant effect on TR in sweet potato leaves in both seasons. Using SD irrigation system recorded the maximum values of TR through the leaves than SSD irrigation system in both seasons.

Effect of IWQ

It is evident from data in Table 5 that IWQ showed a significant effect on TR of sweet potato plants in both seasons. The percentages of TR significantly increased with increasing IWQ up to 2500 m^3/fed. with no significant differences between IWQ at 2000 and 2500 m^3/feddan.

These results suggested that exposing sweet potato plants to the highest level of water supply increased the TR and vice versa. It is evident that the moisture content in the soil governs opening and closing of stomata. As soil moisture declines, water stress developed, and stomata being closed. Sullivan and Eastin (1974) independently found that stomata closed when plants were exposed to water stress. They added, also, that endogenous ABA content may increase with increased stress and concomitant with increased diffusion resistance and the response of ABA accumulation in water stressed leaves and its affect on stomatal opening is worthy of mention at this time.

These results agree with those obtained by Indira and Kabeerathumma (1990). They found that Transpiration rate in sweet potato leaves decreased with the decrease in soil moisture content.

Effect of DI systems x IWQ interaction

Results in Table 5 show that the interaction between DI systems and IWQ had a significant effect on TR. The interaction between SD irrigation system and IWQ at 2500m^3/fed. significantly increased TR.

N, P, K Contents and Their Uptakes by Shoots

Effect of DI systems

Data in Table 6 show that DI systems had a significant effect on N, P, K (%) and uptake by shoots, except P and K (%) in shoots. Using SSD irrigation system significantly increased N% in shoots, N, P and K uptake by shoots.

Table 5. Effect of the interaction between drip irrigation systems and water quantity on transpiration rate ($mg/cm^2/h$) of sweet potato plants grown in sandy soil during 2009 and 2010 summer seasons

IWQ (m^3/fed.) / Irrigation systems	1000		1500		2000		2500		Average	
	Season									
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
SD irrigation*	1.815b	1.977c	1.682b	1.98c	1.827b	2.187b	2.555a	2.551a	1.970a	2.174a
SSD Irrigation **	0.489d	0.506f	0.548d	0.589ef	0.623d	0.706e	0.886c	1.113d	0.637b	0.729b
Average	1.152b	1.242c	1.115b	1.285c	1.225b	1.447b	1.721a	1.832b	--	--

Means followed by the same letter (s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation, SSD irrigation** subsurface drip irrigation, IWQ: irrigation water quantity

Table 6. Effect of drip irrigation systems and water quantity on the N,P and K contents and their uptakes by sweet potato shoots during 2009 and 2010 summer seasons

Treatments	Mineral contents (%)						Mineral uptake (mg/ plant)					
	N		P		K		N		P		K	
	Season											
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
	Effect of irrigation systems											
SD irrigation*	3.39b	3.57b	0.454a	0.384a	2.30a	2.42a	3543b	3428b	475.2b	367.7b	2401b	2338b
SSD irrigation**	3.84a	4.06a	0.462a	0.398a	2.35a	2.51a	4418a	4612a	533.5a	450.5a	2707a	2862a
	Effect of irrigation water quantity (m^3/fed.)											
1000	3.15d	3.25d	0.375d	0.352b	1.99d	1.85d	3020d	3055d	357.8d	330.1d	1903d	1736d
1500	3.40c	3.66c	0.434c	0.385ab	2.18c	2.22c	3594c	3733c	457.8c	391.0c	2300c	2257c
2000	3.79b	4.05b	0.489b	0.404a	2.47b	2.73b	4391b	4461b	564.0b	441.5b	2853b	2991b
2500	4.13a	4.32a	0.536a	0.424a	2.66a	3.06a	4918a	4832a	638.0a	474.0a	3162a	3418a

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation, SSD irrigation** subsurface drip irrigation

Effect of IWQ

The obtained results in Table 6 reflected a significant effect on N, P and K (%) in shoots and their uptakes. Content of N, P , K and its uptake by shoots significantly increased with increasing IWQ up to 2500 m^3/fed. in both seasons. This means that IWQ at 2500 m^3/fed. recorded the maximum values of N,P and K contents and their uptake by shoots.

Effect of DI systems x IWQ interaction

The obtained results in Table 7 show that the interaction between DI systems and IWQ showed a significant effect on N,P and K contents and its uptake by shoots. The interaction between SSD irrigation system and IWQ at 2500 m^3/fed. significantly increased N, P and K contents and their uptake by shoots of sweet potato.

Proline Amino acid Content

Effect of DI systems

Data in Table 8 show that DI systems showed a significant effect on proline amino acid content in leaves. Using SD irrigation system significantly increased proline content in leaves of sweet potato as compared to SSD irrigation system. That is due to that in SD evaporation from soil surface increased and /also the plants faces state stress between irrigation intervals 9 2day) in hot summer.

Effect of IWQ

The obtained results in Table 8 IWQ show a significant effect on proline amino acid content in leaves. IWQ at 1000 m^3/fed. recorded the maximum values of proline amino acid content in leaves.

Effect of DI systems x IWQ interaction

Recorded data in Table 8 indicate that the interaction between DI systems and IWQ showed a significant effect on proline amino acid content in leaves. The interaction between SD irrigation system and IWQ at 1000 m^3/fed. significantly increased proline amino acid content in leaves of sweet potato.

Yield and Its Components

Effect of DI systems

Presented data in Table 9 show that irrigation systems reflected a significant effect on average tuber root weight, yield/ plant and marketable, unmarketable and total yield in both seasons.

Using SSD irrigation system gave higher average tuber root weight,

Table 7. Effect of the interaction between drip irrigation systems and water quantity on the N, P and K contents and their uptakes by sweet potato shoots during 2009 and 2010 summer seasons

Treatments		Mineral contents (%)						Mineral uptake (mg/plant)					
		N		P		K		N		P		K	
Irrigation systems	IWQ (m^3/fed.)	Season											
		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
SD irrigation*	1000	2.89g	2.99f	0.370d	0.333b	1.94e	1.77h	2623h	2515e	335.8f	280.1f	1761g	1489e
	1500	3.13f	3.34e	0.421cd	0.375ab	2.16c	2.13f	3131g	3150d	421.1d	353.6e	2160e	2009d
	2000	3.53d	3.78cd	0.485ab	0.402a	2.43b	2.65d	3842e	3594c	527.9c	382.2d	2645c	2519c
	2500	4.01b	4.18ab	0.539a	0.427a	2.66a	3.13a	4579c	4455b	616.3b	455.1b	3038b	3336b
SSD irrigation**	1000	3.41e	3.50de	0.379d	0.370ab	2.04d	1.93g	3418f	3596c	379.8e	380.2d	2045f	1983d
	1500	3.66c	3.98bc	0.446bc	0.395a	2.20c	2.31e	4058d	4317b	494.5c	428.4c	2439d	2505c
	2000	4.05b	4.31ab	0.492ab	0.405a	2.51b	2.80c	4940b	5329a	600.1b	500.7a	3062b	3462ab
	2500	4.24a	4.45a	0.532a	0.421a	2.65a	2.99b	5257a	5209a	659.6a	492.8a	3286a	3500a

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation, SSD irrigation** subsurface drip irrigation, IWQ: irrigation water quantity

Table 8. Effect of drip irrigation systems and water quantity and their interaction between them on proline amino acid (mg/100 gm DW) of sweet potato leaves grown in sandy soil during 2009 and 2010 summer seasons

IWQ (m^3/fed.) / Irrigation systems	1000		1500		2000		2500		Average	
	Season									
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
SD irrigation*	190.59a	143.40a	142.17c	122.46c	111.63e	119.91c	106.35e	125.11c	137.69a	127.72a
SSD Irrigation **	157.59b	132.17b	118.96d	110.48d	93.98f	103.88e	79.58g	87.96f	112.53b	108.62b
Average	174.09a	137.79a	130.57b	116.47b	102.81c	111.90c	92.97d	106.54d	--	---

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation, SSD irrigation** subsurface drip irrigation, IWQ: irrigation water quantity

yield/ plant and marketable yield as well as total yield/ fed. of sweet potato than SD irrigation system. The increases in total yield was about 36.32 and 11.72% for SSD irrigation system over the SD irrigation system in the 1st and 2nd seasons, respectively.

The ability of subsurface drip irrigation to improve tuber roots yield could be attributed to the less water loss from soil surface through evaporation, which resulted in optimum crop yield. Moreover, subsurface drip irrigation allows maintenance of optimum soil moisture content in the root zone, which improved the efficiency of water and fertilizers use (Thompson and Doerge, 1996).

These results agree with those obtained by Sakellariou *et al.* (2002) on sugar beet and Selim *et al.* (2009) who found that, subsurface drip irrigation was more efficient than surface drip irrigation on enhancing tubers yield quantity of potato plants.

Effect of IWQ

Presented data in Table 9 indicate that IWQ showed a significant effect on average tuber root weight, yield/ plant and marketable, unmarketable and total yield in both seasons.

Average tuber root weight, yield/plant, marketable and total yield/fed. significantly increased with increasing IWQ up to 2500 m^3/fed. This means that IWQ at 2500 m^3/fed. was the superior treatment for increasing yield and its components of sweet potato in both seasons. The increases in total yield were about 41.22 and 32.79% for IWQ at 2500 m^3/fed. over the IWQ at 1000 m^3/fed. in 1st and 2nd seasons, respectively.

Higher IWQ (2500 m^3/fed.), to sweet potato plants, led to keep higher water content in the plant tissues and this in turn produced heavier tuber roots than those under water stress. Water stress causes an increase in ABA/CYT ratio, which in turn decreased plant growth (Marschner, 1995). Also, he added that under sufficient water conditions there was a decrease in ABA and increase in CYT, GA and IAA reflecting good growth, dry matter content and yield. Moreover, under water stress the synthesis of ABA from carotenoids in roots occurs and then transport to different parts of plant especially leaves and this in turn affect the dry matter accumulation in leaves and different organs (Lancher, 1993).

Results of such research were in accordance with those obtained by

Table 9. Effect of drip irrigation systems and water quantity on yield and its components of sweet potato grown in sandy soil during 2009 and 2010 summer seasons

Treatments	Average of tuber root weight (g)		Yield/ plant (kg)		Yield (ton/fed.) Marketable		Yield (ton/fed.) Non - marketable		Yield (ton/fed.) Total		Relative increase in total yield (%)	
	Season											
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Effect of irrigation systems												
SD irrigation*	148.1b	123.7b	0.679b	0.445b	8.550 b	10.525 b	0.314 a	0.428 a	8.864 b	10.953 b	00.00	00.00
SSD irrigation**	157.0a	149.2a	0.725a	0.571a	11.775 a	11.844 a	0.309 a	0.392 b	12.084a	12.237 a	36.32	11.72
Effect of irrigation water quantity (m^3/fed.)												
1000	135.1c	101.4d	0.573d	0.315d	8.500 d	9.280 d	0.325 a	0.437 a	8.825 d	9.716 c	00.00	00.00
1500	156.0b	124.8c	0.710c	0.427c	9.305 c	10.693 c	0.314 a	0.414 ab	9.619 c	11.108 b	09.00	14.33
2000	158.5a	152.6b	0.745b	0.597b	10.695 b	12.250 b	0.295 a	0.402 ab	10.990 b	12.652 a	24.53	30.22
2500	160.7a	166.9a	0.779a	0.693a	12.150a	12.515a	0.313 a	0.387 b	12.463 a	12.902 a	41.22	32.79

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.
SD irrigation*: surface drip irrigation, SSD irrigation** subsurface drip irrigation

Abdel-Fattah *et al*. (2002) and Al-Easily (2006) who found that drip irrigation rats at level 3000 m^3/fed. being superior for enhancing yield and its components.

Effect of DI systems x IWQ interaction

Results in Table 10 indicate that the interaction between DI systems and IWQ showed a significant effect on average tuber root weight, yield/plant, marketable and total yield of sweet potato plants in both seasons.

The interaction between SSD irrigation system and IWQ at 2500 m^3/fed. recorded the maximum values of average tuber root weight, yield/ plant, marketable and total yield with no significant differences with the interaction between SSD irrigation system and IWQ at 2000 m^3/fed. with respect to yield/ plant in both seasons, marketable and total yield in the 2nd season. The increases in total yield/fed. were about 75.54 and 49.89% for the interaction between SSD irrigation system and IWQ at 2500 m^3/fed. and 67.32 and 48.46% for the interaction between SSD irrigation system and IWQ at 2000 m^3/fed. over the interaction between SD irrigation system and IWQ at 1000 m^3/fed. in 1st and 2nd seasons, respectively.

Water Use Efficiency

Effect of DI systems

Data in Table 11 show that DI systems reflected a significant effect on WUE in both seasons. The SSD irrigation system had higher WUE (7.362 and 7.613 kg tuber root/m^3 water) than SD irrigation system (5.497 and 6.691 kg tuber root/m^3 water) in the 1st and 2nd seasons, respectively. Subsurface drip irrigation considered to be the most modern irrigation system with efficient water delivery, that can be contribute immensely on improving crop water use efficiency and conserving water (Hanson and May, 2004).

Effect of IWQ

Presented data in Table 11 indicate that IWQ showed a significant effect on WUE in both seasons. IWQ at 1000 m^3/fed. recorded the maximum values of WUE; i.e., 8.825 and 9.716 kg tuber root/m^3 water in the 1st and 2nd seasons, respectively. In addition such treatment recorded the lowest total yield/fed.; i.e., 8.825 and 9.716 ton/fed. in the 1st and 2nd seasons, respectively. Whereas, IWQ at 2500 m^3/fed. recorded the minimum values of WUE; i.e., 4.985 and 5.160 kg tuber roots/m^3 water in the 1st and 2nd seasons, respectively. In addition,

Table 10. Effect of the interaction between drip irrigation systems and water quantity yield and its components of sweet potato during 2009 and 2010 summer seasons grown in sandy soil

Treatments		Average of tuber root weight (gm)		Yield / plant (kg)		Yield (ton/fed.)						Relative increase in total yield (%)	
						Marketable		Non - marketable		Total			
Irrigation systems	IWQ (m^3/fed.)	Season											
		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
SD irrigation*	1000	125.9e	97.3h	0.554f	0.291d	7.690 e	8.370 f	0.326 a	0.457 a	8.016 e	8.827 f	00.00	00.00
	1500	151.2c	112.1f	0.695d	0.358d	7.700 e	9.780 e	0.318 a	0.431 ab	8.018 e	10.211 e	00.02	15.68
	2000	155.2b	132.9e	0.713d	0.504c	8.270 e	11.780 c	0.298 a	0.420 ac	8.568 e	12.200 bc	06.89	38.21
	2500	160.1a	152.6c	0.752bc	0.625bc	10.540 c	12.170 b	0.315 a	0.403 ac	10.855 c	12.573 b	35.42	42.44
SSD irrigation**	1000	144.3d	105.5g	0.591e	0.337d	9.310 d	10.190 d	0.323 a	0.416 ac	9.633 d	10.606 d	20.17	20.15
	1500	160.8a	137.5d	0.723cd	0.494c	10.910 c	11.607 c	0.311 a	0.398 bc	11.221 c	12.005 c	39.98	36.00
	2000	161.8a	172.4b	0.776ab	0.689ab	13.120 b	12.720 a	0.292 a	0.385 bc	13.412 b	13.105 a	67.32	48.46
	2500	161.3a	181.2a	0.806a	0.761a	13.760 a	12.860 a	0.311 a	0.371 c	14.071 a	13.231 a	75.54	49.89

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.
SD irrigation*: surface drip irrigation , SSD irrigation** subsurface drip irrigation, IWQ: irrigation water quantity

Table 11. Effect of drip irrigation systems and water quantity and their interaction between them on water use efficiency (kg tuber roots/ m^3 water) of sweet potato plants grown in sandy soil during 2009 and 2010 summer seasons

IWQ (m^3/fed.) / Irrigation systems	1000		1500		2000		2500		Average	
	Season									
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
SD irrigation*	8.016 b	8.827 b	5.345 e	6.807 d	4.284 f	6.100 f	4.342 f	5.029 h	5.497b	6.691b
SSD Irrigation **	9.633 a	10.606 a	7.481 c	8.003 c	6.706 d	6.553 e	5.628 e	5.292 g	7.362 a	7.613a
Average	8.825 a	9.716 a	6.413b	7.405b	5.495 c	6.326 c	4.985d	5.160d	---	--

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation, SSD irrigation** subsurface drip irrigation, IWQ: irrigation water quantity

such treatment recorded the highest total yield; i.e., 12.463 and 12.902 ton/fed. respectively with seasons tested.

Effect of DI systems x IWQ interaction

The obtained results in Table 11 indicate that the interaction between DI systems and IWQ showed a significant effect on WUE by sweet potato plants in both seasons. The interaction between SSD irrigation system and IWQ at 1000 m^3/fed. gave the highest WUE in both seasons; i.e., 9.633 and 10.606 kg tuber roots/m^3 water in the 1st and 2nd seasons, respectively.

Tuber Roots Quality

Effect of DI systems

It can be seen from data in Table 12 that DI system had a significant effect on carotenoids content in tuber roots in both seasons, N, K in the 2nd season and starch (%) in the 1st season. While DI systems did not reflect a significant effect on P and total sugars contents in tuber roots in both seasons. SSD irrigation system recorded higher N, K, starch and carotenoids contents in tuber roots as compared to SD irrigation system.

Effect of IWQ

The obtained results in Table 12 show that IWQ had a significant effect on N, P, K, starch, total sugar and carotenoids contents in tuber roots in both seasons. N, P, K, starch, total sugar and carotenoids contents in tuber roots were significantly increased with increasing IWQ up to 2500 m^3/fed. with no significant differences between 2000 and 2500 m^3/fed. in the most cases, except K (%) in the 2nd season and total sugar (%) in both seasons.

Effect of DI systems and IWQ

It is quite clear from data in Table 13 that the interaction between DI system and IWQ reflected a significant effect on N, P, K, starch, total sugar and carotenoids contents in tuber roots in both seasons.

The interaction between SSD irrigation and IWQ at 2500 m^3/fed. was the best treatment for stimulating K content in tuber roots in the 2nd season, total sugar in both seasons and carotenoids contents in tuber roots in the 1st season. While N, P and starch contents had the highest values with addition of 2000 or 2500 m^3 water/fed. to sweet potato plants through the two irrigation systems in both growing seasons.

Table 12. Effect of drip irrigation systems and water quantity on tuber root quality of sweet potato at harvest during 2009 and 2010 summer seasons

Treatments	Mineral contents (%)						Starch (%)		Total sugar (%)		Carotenoids (mg/gm FW)	
	N		P		K							
	Season											
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
	Effect of irrigation systems											
SD irrigation*	1.05a	1.11b	0.176a	0.162a	1.52a	1.72b	50.90b	54.90a	9.63a	8.67a	11.98b	12.50b
SSD irrigation**	1.11a	1.17a	0.187a	0.169a	1.66a	1.91a	55.01a	58.22a	9.98a	9.15a	13.20a	13.70a
	Effect of irrigation water quantity (m^3/fed.)											
1000	0.89b	0.92d	0.146b	0.128b	1.23b	1.32d	47.71c	50.35c	8.33d	7.69d	10.50d	10.70c
1500	0.97b	1.03c	0.175ab	0.163ab	1.40b	1.71c	50.15b	54.16b	9.54c	8.56c	12.00c	12.40b
2000	1.19a	1.36a	0.197a	0.178a	1.77a	2.00b	57.00a	59.35a	10.36b	9.39b	14.30a	14.50a
2500	1.28a	1.26b	0.207a	0.194a	1.95a	2.24a	56.97a	62.38a	10.99a	10.00a	13.55b	14.80a

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.

SD irrigation*: surface drip irrigation , SSD irrigation** subsurface drip irrigation

Table 13. Effect of the interaction between drip irrigation systems and water quantity on tuber root quality of sweet potato at harvest during 2009 and 2010 summer seasons

Treatments		Mineral contents (%)						Starch (%)		Total sugar (%)		Carotenoids (mg/gm FW)	
		N		P		K							
Irrigation systems	IWQ (m^3/fed.)	Season											
		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
SD irrigation*	1000	0.86c	0.86f	0.135b	0.119b	1.15d	1.25f	44.92d	47.48d	8.14h	7.52g	10.6f	10.8cd
	1500	0.93c	0.97e	0.166ab	0.161ab	1.29cd	1.61d	46.23d	52.95c	9.3f	8.24e	11.6e	11.8bcd
	2000	1.15ab	1.41a	0.194ab	0.174ab	1.72ab	1.87c	55.06b	57.69bc	10.2d6	9.07c	13.2c	13.6ab
	2500	1.25a	1.19c	0.207a	0.194a	1.91a	2.16b	57.40ab	61.48ab	10.82b	9.83b	12.5d	13.8ab
SSD irrigation**	1000	0.91c	0.97e	0.157ab	0.136ab	1.31cd	1.39e	50.49c	53.21c	8.52g	7.85f	10.4f	10.6d
	1500	1.01bc	1.09d	0.183ab	0.164ab	1.51bc	1.80c	54.07b	55.37c	9.78e	8.87d	12.4d	13bc
	2000	1.22a	1.30b	0.200a	0.181ab	1.82ab	2.13b	58.94a	61.01ab	10.45c	9.7b	15.4a	15.4a
	2500	1.31a	1.32b	0.206a	0.193a	1.99a	2.31a	56.54ab	63.27a	11.16a	10.17a	14.6b	15.8a

Means followed by the same letter(s) are not significantly different at 0.05 level of probability.
SD irrigation*: surface drip irrigation, SSD irrigation** subsurface drip irrigation, IWQ: irrigation water quantity

It could be concluded that, under the same conditions, using SSD irrigation systems and the highest rate of water quantity ($2500m^3$/fed.) was the best interaction treatment for increasing plant growth, yield and its components as well as root tuber quality of sweet potato plants.

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تأثير نظم الرى بالتنقيط وكمية ماء الرى على النمو والمحصول وكفاءة استخدام الماء لنبات البطاطا النامى تحت ظروف الأرض الرملية

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أجرى هذا البحث لدراسة تأثير نظامين للري بالتنقيط (السطحي وتحت السطحي) وكميات ماء الري (١٠٠٠ و ١٥٠٠ و٢٠٠٠ و٢٥٠٠ م^3/ فدان) وكذلك التفاعل بينهما على النمو ، والعلاقات المائية في النبات ، وكفاءة استخدام الماء ، ومحصول الجذور المتدرنة لنبات البطاطا وجودتها تحت ظروف الأراضي الرملية .

أدى استخدام نظام الري تحت السطحي إلى زيادة معنوية في كل قياسات النمو المدروسة، والماء الحر والكلى فى الأوراق، والنسبة المئوية للنيتروجين فى العرش وكذلك الممتص من النيتروجين والفوسفور والبوتاسيوم، كما أحدث هذا النظام للرى زيادة معنوية فى محصول الجذور المتدرنة/للفدان وجودتها، بينما سجل نظام الرى بالتنقيط السطحى زيادة معنوية فى محتوى أنسجة الأوراق من الماء المرتبط (%)، والعصير الخلوى، والضغط الأسموزى، ومعدل النتح، والحمض الأمينى البرولين، وسجل رى النباتات بمعدل ٢٥٠٠ م^3/فدان أعلى القيم لكل قياسات النمو، والنسبة المئوية لمحتوى أنسجة الأوراق من الماء الحر والكلى، والنسبة المئوية لمحتوى العرش من كل من النيتروجين والفوسفور والبوتاسيوم وكذلك الممتص منها، ومحصول الجذور المتدرنة للنبات وللفدان وجودتها وكل المكونات الكيميائية بها.

وإضافة إلى ما تقدم فقد سجل رى النباتات بالتنقيط تحت السطحى بمعدل ٢٥٠٠م^3/فدان أعلى القيم لكل قياسات النمو المدروسة وأعلى محصول للجذور المتدرنة كماً ونوعاً.