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Response of Garlic Productivity to Surface and Drip Systems and Irrigation Amounts

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ABSTRACT

A field study was carried out on a clay loam soil at El-Qanater Horticulture Research Station (31^0 11' longitude, 30^0 28' latitude, and 14 m altitude above mean sea level), Qalubia Governorate, Egypt, during the two successive winter seasons of 2014/15 and 2015/16, to investigate the effect of surface and drip irrigation systems and amounts of applied irrigation water (100 and 75% ETp) on garlic growth parameters (plant height and cured bulb diameter), fresh and cured yields and weight loss as well as amounts of applied irrigation water, water consumption, water use efficiency, and water productivity. The main results were as follows:

1- In both seasons, irrigation systems significantly affected vegetative growth parameters, and garlic fresh and cured bulb yields which increased with drip irrigation at 100% of ETp of irrigation water amount compared to (75% of ETp) with surface irrigation method.
2- Seasonal values of applied irrigation water (AIW) for the drip system were 2179 and 2159 m^3 fed^{-1} for the 100% ETp treatment and were 1816 and 1810 m^3 fed^{-1} for the 75% ETp treatment in 2014/15 and 2015/16 seasons, respectively. For the surface irrigation system, the AIW values were 3326 and 3297 m^3 fed^{-1} for the 100% ETp treatment and were 2525 and 2506 m^3 fed^{-1} for the 75% ETp treatment in 2014/15 and 2015/16 seasons, respectively (1 fed = 0.42 ha).
3- The water consumptive use (WCU) values were higher with surface system than the drip system. The obtained values for surface system were 17.42% and 11.48% more than those recorded under drip irrigation system in 2014/15 and 2015/16 seasons, respectively.
4- Average water use efficiency (WUE) and water productivity (WP) values were higher under drip system (2.66 and 2.62 kg/m^{-3}) than the surface system (2.12 and 2.23 kg/m^{-3}) in the two respective seasons.
5- In the two seasons, lower values of bulb weight losses (%) were obtained under the drip system with 75% ETp treatment as compared with surface system with both 75% and 100% ETp treatments.

Key words: Garlic bulb yield, surface and drip irrigation systems, and water relations.

Introduction

Efficient utilization of available water resources is crucial for a country facing severe water scarcity like Egypt, where water consumption in agriculture constitutes more than 85% of the total annual water resources. Sustainability of agricultural production depends on the conservation and appropriate management of scarce water resources especially in arid and semi-arid areas, where irrigation is required for the production of food and cash crops.

Drip and surface systems are two different ways used to irrigate crops. The drip system may have field-level application efficiencies of 70–90% as surface runoff, deep percolation losses and evaporation are minimized (Postel, 2000). The net crop yield increased under drip system as compared with that obtained from surface irrigation system. Results reported by Satyendra *et al.*,

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(2007) indicated that, irrigation near field capacity improved plant height and number of leaves of onion crop.

Worldwide, garlic *(Allium sativum L.)* is a second vital cultivated Allium species after onion Hamma *et al*., (2013). In Egypt, garlic is a high-value cash crop (Abdel-Razzak and El-Sharkawy, 2013). Egypt ranks the fourth leading country in the world for garlic production (244.626 MT) after China, India and Korea (FAO, 2011, and Abou El-Magd *et al.*, 2012). In Egypt, the average annual area cultivated with garlic varieties was estimated at 29,961 fed (12,584 ha) and the total national production of garlic is about 276,556 tons (Economic Affairs Sector, 2015).

El-Dakroury (2008) found that increasing irrigation level from 60 to 100% ETo (reference evapotranspiration) significantly increased plant height, leaves and pods plant in bean varieties. Sankara *et al.* (2008); Hegab *et al.* (2014), and Mandefro and Quraishi (2015) reported that, using drip system and applying 100 % ETc (actual evapotranspiration) regime improved growth parameters, yield and yield contributing parameters of garlic and has more efficiency than surface irrigation.

The effect of drip and surface irrigation on garlic yield and water use efficiency was studied by Ghadami *et al*. (2010). They reported that, the application of drip system produced the highest WUE with the average of 5.2 kg m^{-3}, while the obtained WUE under furrow system averaged 2.7 kg m^{-3} and the saved water by drip relative to furrow system was about 44 to 55%. In this direction, El-Atawy (2007), and Gyanendra *et al.* (2016) reported that, the drip irrigation system has significant influence on garlic productivity. Garlic vegetative growth and water use efficiency values were the highest under 75% of pan evaporation treatment, and declined with increasing irrigation amounts to 100 and 125% of pan evaporation.

Sankara *et al.* (2008) concluded that, drip irrigation decreased water requirement by 30-40 % from total seasonal consumptive use comparing to surface irrigation system. In Egypt, Hussien and Eid (2013) reported that, the amounts of water applied using surface irrigation system were higher than that of drip irrigation system, and the water productivity values of 1.94 and 2.5 kg fruits/m^3 were obtained under surface and drip irrigation systems, respectively. Abd El-Hady and Eldardiry (2016) reported that drip irrigation system has a recognized impact on increasing growth characters, garlic yield, and water productivity.

The main objectives of this research were to study the effect of surface and drip irrigation systems and different amounts of applied irrigation water on garlic growth parameters (plant height and cured bulb diameter), fresh and cured yields and average weight loss as well as amounts of applied irrigation water, water consumption, water use efficiency, and water productivity.

Material and Methods

Site description:

A field experiment was carried out at El-Qanater Horticulture Research Station (31^0 11' longitude, 30^0 28' latitude, and 14m altitude above mean sea level), Qalubia Governorate, Egypt, during the two successive winter seasons of 2014/15 and 2015/16. Monthly average agro-meteorological data at the experimental site and class A pan (Epan) values for the two growing seasons are presented in Table 1.

Soil samples from the experimental site were collected to determine main soil physical and chemical parameters. Soil moisture constants, particle size analysis, and some chemical properties were determined according to Page *et al.* (1982) and Klute (1986) and the values are listed in Tables 2 and 3, respectively.

Experimental design and tested treatments:

A split-plot in randomized complete blocks design with three replicates was used to conduct the field experiment. The main plots were devoted to two irrigation systems and the sub-plots were devoted to two amounts of applied irrigation water as follows:

Irrigation systems (Main plots):
S_1: Surface irrigation
S_2: Drip irrigation

Amounts of applied irrigation water (sub-plots):
I_1: Irrigation with amount of water equals to 100% of potential evapotranspiration (ETp) determined by class A pan.
I_2: Irrigation with amount of water equals to 75% of potential evapotranspiration (ETp) determined by class A pan.

Table1: Mean agro-meteorological and Epan values at the experimental site during the 2014/15 and 2015/16 seasons.

Month	Season	Temperature (ºC)			Relative humidity (%)	Wind speed (m/sec)	Sunshine (hr)	E pan (mm/day)
		Max.	Min.	Mean				
September	2014/2015	37.4	23.7	30.55	52.0	2.2	12.2	5.34
	2015/2016	30.0	24.9	27.45	52.7	2.7	12.2	5.09
October	2014/2015	29.1	19.9	24.50	54.3	2.1	11.3	7.90
	2015/2016	25.6	14.6	20.10	59.7	2.5	11.3	7.22
November	2014/2015	24.0	15.4	19.70	57.7	1.6	10.6	5.72
	2015/2016	20.4	16.2	18.30	65.0	2.1	10.5	5.37
December	2014/2015	22.0	12.9	17.45	50.0	1.8	10.1	2.78
	2015/2016	16.1	11.3	13.70	64.7	2.6	11.6	3.94
January	2014/2015	13.9	10.1	12.00	51.7	2.7	10.3	3.08
	2015/2016	13.8	10.1	11.95	58.0	3.1	11.0	3.18
February	2014/2015	15.0	10.5	12.75	51.0	2.3	11.2	3.06
	2015/2016	18.4	13.4	15.90	53.7	3.1	11.6	3.17
March	2014/2015	17.2	12.3	14.75	54.0	2.2	10.5	5.59
	2015/2016	20.3	15.4	17.85	49.3	3.5	12.8	5.66
April	2014/2015	20.6	14.5	17.55	45.7	1.9	12.8	6.33
	2015/2016	25.7	19.3	22.50	44.0	3.5	12.9	6.41

Table 2: Soil moisture constants and bulk density values of the soil at experimental site.

Depths	Field capacity (%)	Wilting point (%)	Available moisture (%)	Bulk density (g cm^{-3})
00-15	37.9	18.1	19.8	1.27
15-30	36.1	17.6	18.5	1.30
30-45	33.5	16.9	16.6	1.31
45-60	32.5	16.2	16.3	1.34

Table 3: Particle size analysis, textural class, and some chemical properties of the soil at the experimental site in the two seasons.

Characters		2014/2015	2015/2016
Particle size distribution	Coarse sand (%)	1.10	1.40
	Fine sand (%)	34.00	33.5
	Silt (%)	33.50	33.0
	Clay (%)	31.40	32.0
	Textural class	Clay loam	
Chemical properties			
pH, in soil suspension (1:2.5)		7.90	7.90
OM(%)		2.20	2.04
EC_e (dS m^{-1}), in saturated soil paste extract		0.43	0.56
Soluble cations (meq L^{-1})	Ca^{2+}	3.07	3.00
	Mg^{2+}	2.63	2.56
	Na^{+}	4.10	4.00
	K^{+}	0.41	0.44
Soluble anions (meq L^{-1})	HCO_3^-	3.85	3.48
	Cl^-	3.70	3.80
	SO_4^{2-}	2.66	2.77
Macro-elements (ppm)	N	45.00	41.02
	P	12.50	10.00
	K	191.90	194.80

Cultural practices:

The experimental field was plowed and harrowed to pulverize the soil before implementing the experimental trial. Garlic cloves (clone Sids 40 var.) of the same size and weight at the rate of 120 kg/fed were cultivated on ridges in September 15, and were harvested in April 15 of both seasons. A day before planting, bulbs were separated into individual cloves and only the large and healthy ones were selected and soaked in water overnight in order to remove the scale leaves covering the clove to enhance rapid sprouting. The cloves were placed 2-3 cm deep in the soil with the growing point upward and were covered lightly with soil for consolidation. The experimental plots were pre irrigated a day prior to planting. Planting was done manually on the prepared plots with one clove planted per stand. The NPK fertilizers at the rate of 180 kg N/fed as ammonium nitrate (33.5% N), 65 kg P_2O_5/fed as calcium super phosphate (15.5% P_2O_5) and 48 kg K_2O/fed as potassium sulphate (48% K_2O) were applied to all treatments. For surface irrigation, the treatments started 30 days from planting with an irrigation interval of 20 days. For drip irrigation system, treatments started 10 days from planting with a 3-day irrigation interval. All treatments received equal amounts of water at the first irrigation. All other agricultural practices were performed as recommended for garlic production according to the Ministry of Agriculture and Land Reclamation, Egypt.

Irrigation systems:

The description of the two systems was as follows:

1-Surface irrigation:

A furrow surface irrigation method was used to conduct this treatment. An experimental plot of 42 m^2 (6m width x 7m length) with furrows spaced at 0.6m was used. The depth of applied irrigation water (AIW) to the experimental plots was calculated according to the following equation:

$$AIW = ETc / Ea$$

where:
ETc = water consumptive use (CU, mm/d), or actual evapotranspiration (ETc).
Ea = application efficiency (fraction) = 0.6 for surface system at the site.

A submerged flow orifice with fixed dimensions was used to measure the amount of water applied to the experimental plots. The discharge of the orifice was calculated according to the following equation Michael (1978).

$$Q = CA\sqrt{2gh}$$

where:

Q	=	discharge through orifice, (cm^3/sec)
C	=	coefficient of discharge (0.6 up to 0.8).
A	=	cross-sectional area of the orifice (cm^2)
g	=	acceleration of gravity (981 cm/sec^2).
h	=	head of water causing discharge through the orifice (cm).

2-Drip irrigation system:

The drip irrigation system installed in the experimental area included an irrigation pump connected to sand and screen filters and a fertilizer tank, control values, water flow meters, and pressure gauges. The distribution system consisted of PVC pipes forming the mainline (75 mm diameter) and manifolds (63 mm diameter) for supplying and discharging irrigation water to each plot. Irrigation laterals (16mm in diameter and 25 meter long) had in-line emitters spaced 0.3 m apart with 4 L h^{-1} flow rate at pressure of 100 kPa. The actual discharge was 3.8 L h^{-1} due to pressure drop.

The lateral lines were installed such that two drip lines spaced at 0.6 m apart to serve each ridge (110 cm wide). Two rows of plants were cultivated per a drip line.

-Distribution uniformity for drip irrigation system:

The distribution uniformity (DU) was estimated along laterals of the drip irrigation system under working pressure of 1.0 bar using 20 collection cans according to the following equation (Keller and Bliesner, 1990):

$$DU = \frac{Qm}{Qa} * 100$$

where:

DU = distribution uniformity (%).

Qm = average volume of water collected from emitters at the lowest quarter of the line during the test time (0.238 L).

Qa = average volume of water collected from all emitters during the test time (0.246 L).

The collected data for determining the DU values are listed in Table 4.

Table 4: Data collected for estimating distribution uniformity of drip irrigation system.

Can number	1	2	3	4	5	6	7	8	9	10
Collected vol. (L)	0.23	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Can number	11	12	13	14	15	16	17	18	19	20
Collected vol. (L)	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.26	0.26	0.26

The calculated DU was found to be high (96.74%).

The amount of applied irrigation water was measured by a flow meter and was calculated according to FAO (1984) using the following equation:

$$AIW = \frac{Sp * S_l * ETp * Kr * I\text{int}erval}{1000 * Ea}$$

where:

AIW=applied irrigation water (m^3).

Sp= distance between plants in the same drip line (m).

S_l= distance between drip lines (m).

ETp = potential evapotranspiration (mm/d) based on class A pan and calculated according to the following equation (Doorenbos and Priutt, 1984):

$$ETp = \text{Epan X Kpan}$$

Epan = measured class A pan values (mm/d).

Kpan = pan coefficient (= 0.75 under experimental conditions, (FAO, 1979)).

$I_{interval}$ = irrigation interval (= 3 days under experimental conditions).

Kr= reduction factor that depends on ground cover.

Ea= irrigation efficiency = K_1 x K_2 = 0.85

where:

K_1 = emitter uniformity coefficient = 0.95 for the experimental site.

K_2 = drip irrigation system efficiency = 0.90 for the experimental site.

Irrigation under the two systems was stopped two weeks before harvest to allow uniform maturity.

The following parameters were measured:

I. Soil-water relations:

1. Water consumptive use (CU):

Water consumptive use (CU) value was determined by using Time Domain Reflectometry (TDR) sensor which measured the volumetric soil moisture for depth 0.6 m of soil before and after each irrigation. The TDR is widely used to measure soil water content according to Cataldo *et al.* (2011). The CU value was calculated according to Israelsen and Hansen (1962) using the following equation:

$$CU = \sum_{i=1}^{i-4} \frac{\theta 2 - \theta 1}{100} \times d$$

where:
CU = water consumptive use or actual evapotranspiration, ETc (mm).
i = number of soil layer.
θ2 = soil moisture content after irrigation, (%, by volume).
θ1 = soil moisture content just before irrigation, (%, by volume).
d = depth of soil layer, (mm).

2. Water use efficiency (WUE):

Water use efficiency (WUE, kg mm^{-1}) reported here as the ratio of garlic yield (Y) to actual evapotranspiration (ETc) according to Stanhill (1986):

$$\text{WUE} = \frac{\textit{Garlic yield, Y (kg/fed.)}}{\textit{Consumed irrigation water, ETc } (m^3/\textit{fed.})}$$

where:
Y =Garlic yield (kg fed^{-1}).
ETc =Actual evapotranspiration for growing season (mm fed^{-1}).

3. Crop water productivity (WP)

WP is defined as crop yield per unit applied irrigation water that is looking into the efficient use of applied irrigation water (Zhang, 2003) and is given as follow:

$$WP = \frac{\textit{Garlic yield (kg/fed.)}}{\textit{Applied irrigation water (m3/fed.)}}$$

II. Plant measurements:

1. Vegetative growth.

Ten plants were randomly selected from each treatment after 145 days from planting for measuring plant height and cured bulb diameter.

2. Yield and its components:

At harvesting time (190 days from planting), all plants of each treatment were harvested and the total yield per fed was calculated after curing for 7 days. In addition, 10 bulbs were randomly collected from each treatment to determine plant fresh weight, bulb fresh weight, cured bulb weight and fresh bulb yield.

3. Average weight loss:

After curing process, random samples (5 kg of marketable yield) from all treatments were collected and stored at the typical room conditions. The losses of total weight (%) were monthly recorded through six months of storage.

Statistical Analysis:

Data collected from the studied variables were subjected to statistical analysis using MStat computer package to calculate F ratio according to Snedecor and Cochran (1980).The means were compared using Least Significant Difference (LSD) at 5% level according to Waller and Duncan (1969).

Results and discussion

I. Soil-water relations:

Applied irrigation water (AIW):

Seasonal values of applied irrigation water used for the two irrigation systems and amounts of applied irrigation water (AIW) treatments are presented in Table 5. Results showed that the amounts of applied irrigation water varied from 1816 to 3326 m^3/fed in 2014/15 and from 1810 to 3297 m^3/fed in 2015/16. Results showed also that, the AIW to garlic were less under drip system as compared with surface system in both seasons. Average AIW values under drip irrigation system were 1997.5 and 1984.5 m^3/fed, while average applied irrigation water values were 2920.5 and 2901.5 m^3/fed for surface irrigation system in the 2014/15 and 2015/16, respectively.

Table 5: Seasonal applied irrigation water (m^3 fed^{-1}) used under the adopted irrigation systems in 2014/15 and 2015 /16 seasons.

Irrigation systems	Irrigation treatments	Applied irrigation water (m^3 fed^{-1})		Mean
		2014/15	2015/16	
Drip	100% ETp	2179	2159	2169
	75% ETp	1816	1810	1813
Mean		1997.5	1984.5	
Surface	100% ETp	3326	3297	3312
	75% ETp	2515	2506	2511
Mean		2920.5	2901.5	

For the tested amounts of applied irrigation water (AIW), 100 and 75% ETp, results indicated that surface irrigation system recorded the highest figures of seasonal applied water, which amounted at 3326 and 3297 m^3 fed^{-1} for 100% ETp treatment, and 2525 and 2506 m^3 fed^{-1} for 75% ETp treatment in 2014/15 and 2015/16 seasons, respectively. While the seasonal applied water obtained under drip irrigation recorded the lowest figures which amounted to 2179 and 2159 m^3 fed^{-1} for the 100% ETp treatment and 1816 and 1810 m^3 fed^{-1} for the 75% ETp treatment in 2014/15 and 2015/16 seasons, respectively. Such result might be reasonable, since the exposed surface area under surface irrigation system provides high evapotranspiration opportunity from the relatively wet rather than dry soil surface as in drip irrigation. Also, the high amount of applied irrigation water under surface system reflects the low system efficiency as compared with the drip system. The obtained results were in harmony with those reported by Sankar *et al.* (2008) and Hussien and Eid (2013).

I.1- Water consumptive use (CU):

Average CU values as affected by irrigation systems and amounts of applied irrigation water in both seasons are presented in Table 6. Results indicated that the amount of water consumptive use increased in case of surface irrigation system compared to the drip irrigation system. In 2014/15 season, the increase in water consumptive use for garlic crop due to increasing water applied reached 17.42% more than those recorded under drip irrigation system. Similar trends were observed in 2015/16 season, where average CU value for the surface system was 11.48% higher as compared with drip system.

Table 6: Water consumptive use (CU, m^3 fed^{-1}) as affected by the tested treatments in 2014/15 and 2015/16 seasons.

Irrigation system	Irrigation treatments	CU		Mean
		2014/15	2015/16	
Drip	100% ETp	1817	1952	1885
	75% ETp	1379	1460	1420
	Mean	1598	1706	
Surface	100% ETp	2134	2155	2145
	75% ETp	1619	1649	1634
	Mean	1876.5	1902	

Regarding the two AIW treatments, 100 and 75% ETp, results indicated that average CU values increased under 100% ETp treatment as compared with the 75% ETp treatment for the two irrigation systems. Results in Table 8 revealed that the adopted 75% ETp treatment recorded lower figures of seasonal water consumptive use (1420 and 1634 m^3 fed^{-1}) than with the 100% ETp treatment (1885 and 2145 m^3 fed^{-1}). This trend show that water consumptive use depends on the availability of soil moisture in root zone. These results may be due to more available soil moisture under surface system. In connection, Hafiz and Ewis (2015) stated that increasing applied irrigation water significantly increased evaporation and/or transpiration for onion crop. Furthermore, El-Akram (2012) found that onion actual evapotranspiration (ETc) was higher with more frequent irrigation, i.e. irrigating as 40% of available soil moisture was depleted, in comparison with irrigation at 60 and 80% depletion treatments. The obtained results were in harmony with those obtained by Sankara *et al.* (2008).

Relationship between AIW and CU:

A linear regression analysis was developed between the applied irrigation water (AIW) and water consumed water (CU) under the tested treatments (Fig. 1). The obtained results indicated a positive relation between CU and seasonal AIW.

For the drip irrigation system, the developed relation was:

CU (m^3 fed^{-1}) = 1.279 AIW (m^3 fed^{-1}) - 931.84, $R^2 = 0.925$

For the surface irrigation system, the obtained relation was:

CU (m^3 fed^{-1}) = 0.657 AIW (m^3 fed^{-1}) - 33.822, $R^2 = 0.989$

In a similar study, Payero *et al.* (2008) reported a strong quadratic relationship between seasonal CU and seasonal AIW for maize under sprinkler irrigation. On the other hand, Mengu and Ozgürel (2008) developed a linear relationship for these two variants.

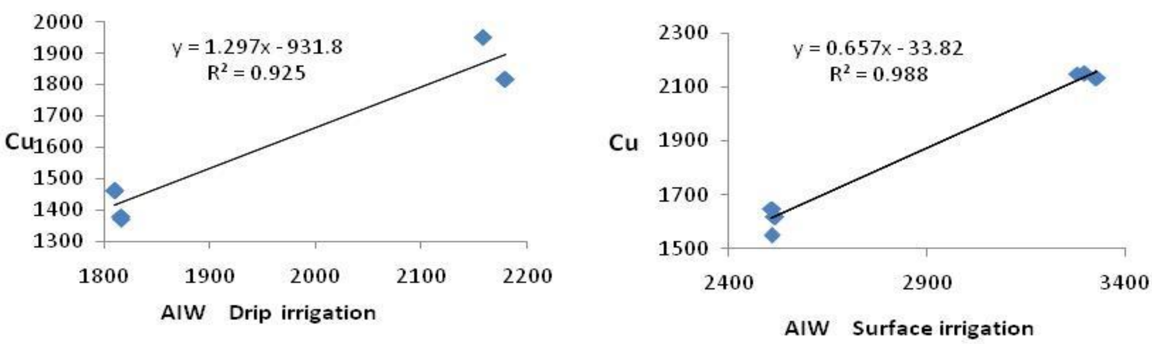

Fig. 1: Relationships between applied irrigation water (AIW) and seasonal water consumptive use (CU) by garlic crop for the two irrigation systems.

Garlic yield and water–yield relationships

A linear relation between applied irrigation water for the two irrigation systems and garlic yields was developed (Fig. 2). For the drip irrigation system, the obtained relation was:

Yield (kg fed^{-1}) = 2.517 AIW (m^3 fed^{-1}) – 624.93, R^2 =0.913
For the surface system, the obtained relation was:
Yield (kg fed^{-1}) = 1.24 AIW (m^3 fed^{-1}) – 850.15, R^2 =0.889

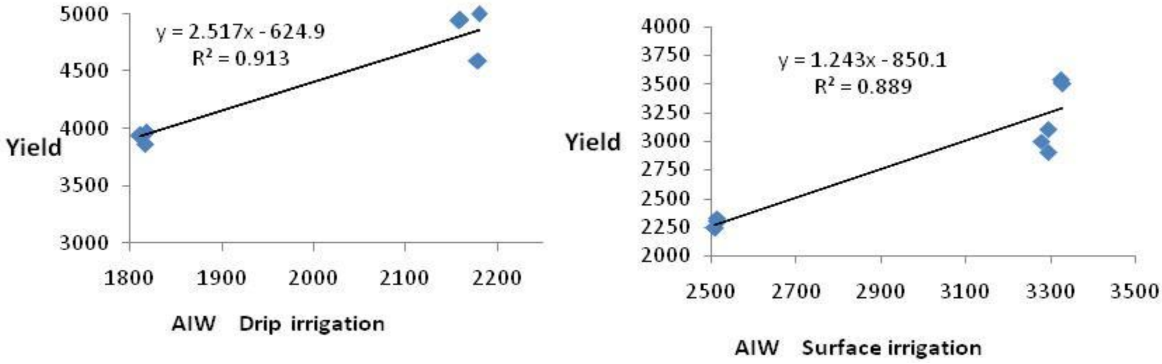

Fig. 2: Relationships between applied irrigation water and garlic yield under the two irrigation systems.

I.2- Water use efficiency (WUE):

Results in Table 7 shows the water use efficiency values as affected by the tested treatments. Results indicated that, there was an effect of the irrigation systems on WUE values. The obtained values were higher under drip irrigation system (2.66 and 2.62 kg/m^3) than under surface irrigation system (1.55 and 1.40 kg/m^3) in the 2014/15 and 2015/16 seasons, respectively. It was also noticed that WUE values for drip irrigation system and the 75% ETp treatment recorded the highest water use efficiency (2.80 and 2.70 kg/m^3) in 2014/15 and 2015/16, respectively. While, the surface irrigation system and the 75% ETp treatment recorded the lowest WUE (1.44 and 1.36 kg/m^3) in 2014/15 and 2015/16, respectively. The results showed that, when irrigation water is limited, e.g. 75% ETp, drip system could be used for increasing the water use efficiency. Difference in WUE is due to different water amount applied and similar yields. Applied water in drip irrigation system were 1997.5 and 1984.5 m^3/fed and in surface irrigation system 2920.5 and 2901.5 m^3/fed in two consecutive years. The obtained results were in accordance with findings of Saman (2002) who obtained high water use efficiency under raised beds with drip irrigation system. The results agreed also with those obtained by El-Atawy (2007) and Gyanendra *et al.* (2016).

Regarding to water saved (m^3/fed.) and garlic bulb yield reduction (%), results indicated that, the 75% ETp treatment under drip irrigation system saved 363 and 349 m^3/fed and reduced the yield by 16 and 20.4% in the 2014/15 and 2015/16 seasons, respectively (Table 9). While, under the surface irrigation system and the 75% ETp treatment, the saved amounts of water were 811 and 791 m^3/fed and yield reduction reached 34 and 27.4% in the two seasons, respectively.

I.3- Crop water productivity (WP):

Water productivity (WP) values for cured garlic bulb yield (kg/m^3) as affected by the two irrigation systems and amounts of applied irrigation water are presented in Table 7. In general, the average irrigation water productivity differed considerably among tested treatments. The WP values increased with a decline in irrigation water in two seasons. Average values of the WP were higher under the drip irrigation system than those at surface irrigation system, which ranged from 2.12 to 2.23 kg/m^3 and 1.0 to 0.92 kg/m^3 in 2014/15 and 2015/16 seasons, respectively. These results were in harmony with those obtained by Hussien and Eid (2013) and Abd El-Hady and Eldardiry (2016). Results were also in line with Shdeed (2001), who stated that water productivity probably will become more important as access to water become more limited.

Table 7: Applied water, water use efficiency, water saved, percent yield reduction and water productivity under the adopted treatments in 2014/15 and 2015/16 seasons

Irrigation system	Irrigation treat.	2014/15						201516					
		yield kg/fed	AIW	WUE kg/m^3	Water saved (m^3/fed)	Yield Reduction (%)	WP kg/m^3	yield kg/fed	AIW	WUE kg/m^3	Water saved (m^3/fed)	Yield Reduction (%)	WP kg/m^3
Drip	100% ETp	4590	2179	2.53	-	-	2.11	4950	2159	2.54	-	-	2.29
	75%ETp	3860	1816	2.80	363	16	2.13	3940	1810	2.70	349	20.4	2.18
Mean				2.66			2.12			2.62			2.23
Surface	100%ETp	3540	3326	1.66	-	-	1.06	3100	3297	1.44	-	-	0.94
	75%ETp	2330	2515	1.44	811	34	0.93	2250	2506	1.36	791	27.42	0.90
Mean				1.55			1.00			1.40			0.92

II. Vegetative Growth:

II.1- Plant height and Cured bulb diameter.

Results indicated that, plant height and cured bulb diameter were significantly influenced by the two irrigation systems and the amounts of irrigation water in both seasons (Table 8). The highest average values of plant height, and cured bulb diameter were 70.90 and 75.53 cm; 5.50 and 5.63 cm, respectively in 2014/2015 and 2015/2016 seasons, obtained under drip irrigation system. The relative increases in the same respective parameters under drip system as compared with surface system were 53.20 and 71.93%; and 26.14 and 25.11% during 2014/2015 and 2015/2016 seasons.

Table 8: Plant height and cured bulb diameter as affected by irrigation systems and amounts of irrigation water treatments in the two seasons.

Treatments	Plant height (cm)		Cured bulb diameter (cm)	
	2014/15	2015/16	2014/15	2015/16
A) Irrigation systems:				
Drip	70.90	75.53	5.50	5.63
Surface	46.28	43.93	4.36	4.50
L.S.D.	**	**	**	**
B) Amounts of applied irrigation water:				
100% of ETp	66.35	58.93	5.30	5.33
75% of ETp	50.83	60.53	4.72	4.53
L.S.D.	**	**	**	NS
Interactions:				
Drip X 100% ETp	80.90	75.46	5.67	5.73
Drip X 75% ETp	60.90	75.60	5.63	5.26
Surface X 100% ETp	51.80	45.46	4.93	4.93
Surface X 75% ETp	40.77	42.40	3.80	3.80
L.S.D. A*B	3.21	1.65	0.65	0.54

Under the present experimental conditions, the increased vegetative growth characters under drip irrigation might be due to better availability of moisture during entire crop growth period which favored the growth environment and the growth attributes. These findings agreed with those obtained by Gyanendra *et al.* (2016) and Abd El-Hady and Eldardiry (2016) who reported that, highly significant vegetative growth parameters were achieved under drip irrigation treatment, and garlic used most stored water in root zone more than that under surface irrigation treatment.

As for the effect of the amounts of applied irrigation water, results in Table 8 revealed that the tested vegetative growth parameters were significantly responded to increasing amount of applied irrigation water (AIW) to 100% of ETp in both seasons, except for the cured bulb diameter in the 2015/16 season. The better performance of growth parameters under 100% of ETp was due to maintenance of soil moisture content in the root zone closer to field capacity. These results are in agreement with those obtained by El-Dakrory (2008), El-Atawy (2007) and Mandefro and Quraishi (2015).

Concerning the interaction effect between the two studied factors on the abovementioned parameters, results in Table 8 illustrated that the highest significant values of the studied parameters were obtained by drip irrigation system and the 100% of ETp treatment in both seasons. Meanwhile, the lowest ones were recorded by the 75% of ETp and surface irrigation system in both seasons. The maximum values of the tested parameters were 80.90 and 75.46 cm; 5.67 and 5.73 cm in 2014/2015 and 2015/2016 seasons, respectively. While, the lowest ones were 40.77 and 42.40 cm; 3.80 and 3.80 cm obtained from the 75% of ETp and surface irrigation treatment in 2014/2015 and 2015/2016 seasons, respectively. These results are in agreement with those obtained by Sankar *et al.* (2008) and Hegab *et al*. (2014).

II.2 Yield and its components:

Plant fresh weight (g), bulb fresh weight (g), and cured bulb weight (g):

Results in Table 9 showed that, there were significant effects of the irrigation systems on the studied parameters. Results revealed that, the values of fresh weight, bulb fresh weight, and cured bulb weight under the drip irrigation system were significantly higher than those under surface irrigation system in the two successive seasons of study. Results showed that the increase in the abovementioned parameters under drip irrigation was 76.43%, 46.32%, and 53.15% and 86.60%, 54.17, and 66.16% in 2014/15 and 2015/16 seasons, respectively more than those under surface irrigation system. The obtained results could be due to using the drip system maximizes all estimated garlic growth characters and allows garlic plants to use most stored water in root zone than that happened in case of surface irrigation. Similar results were obtained by Abd El-Hady and Eldardiry (2016), who reported that the drip irrigation system caused better water distribution and better water management.

Table 9: Fresh weight, bulb fresh weight, cured bulb weight (g), fresh and cured yields as affected by irrigation systems, applied irrigation amounts and their interactions in the two seasons.

Treatments	Fresh weight (g/plant)		Bulb fresh weight (g)		Cured bulb weight (g)		Fresh bulb yield (ton/fed)		Cured bulb yield (ton/fed)	
	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16
A) Irrigation systems:										
Drip	68.05	62.13	97.50	91.08	60.48	59.36	7.13	6.57	4.23	4.44
Surface	38.57	42.46	63.66	48.81	39.23	35.73	4.77	3.65	2.93	2.67
L.S.D.	**	**	**	**	**	**	**	**	**	**
B) Applied irrigation water amounts:										
100% ETp	63.40	56.86	89.96	78.01	56.50	53.76	6.74	5.59	4.07	4.02
75% of ETp	43.21	47.73	71.20	61.88	43.21	41.33	5.34	4.63	3.09	3.09
L.S.D.	**	**	**	**	**	**	**	**	**	**
Interactions:										
DripX100%	75.07	66.30	104.26	100.1	65.70	66.17	7.82	7.00	4.59	4.95
Drip X75%	61.03	57.97	90.73	82.03	55.26	52.57	6.80	6.15	3.86	3.94
SurfaceX100%	51.73	47.43	75.66	55.90	47.30	41.37	5.67	4.19	3.54	3.10
Surface X 75%	25.40	37.50	51.66	41.73	31.16	30.10	3.87	3.12	2.33	2.25
L.S.D. A*B	8.48	5.54	2.40	1.27	2.07	1.26	0.19	0.10	0.16	0.10

For the amounts of applied irrigation water (AIW), results showed that water given at 100% of ETp recorded significantly higher fresh weight (63.40 and 56.86 g/plant), bulb fresh weight (89.96 and 78.01 g) and cured bulb weight (56.50 and 53.76 g) as compared to the 75% of ETp treatment. These results were in agreement with those obtained by Hegab *et al.* (2014) and Mandefro and Quraishi (2015).

Concerning the interaction between irrigation systems and amounts of applied irrigation water (AIW), results indicated there were significant effects on fresh weight, bulb fresh weight, and cured bulb weight in both seasons (Table 9). The highest significant values of such parameters were noticed by drip irrigation system with 100% of ETp treatment in both seasons. Meanwhile, the lowest ones were recorded by the 75% of ETp with surface irrigation system in both seasons. The obtained results were similar to those reported by Hegab *et al.* (2014).

Fresh and cured bulb yields (ton/fed):

The effects of irrigation systems and amounts of applied water on fresh and cured yields (ton/fed) in both seasons are shown in Table 9. Drip irrigation system produced significantly higher yields than surface irrigation system. The increased fresh and cured yields under drip system were 49.47% and 80.0%, and 44.36 and 66.29% higher than the yields under surface system in 2014/15 and 2015/16 seasons, respectively. Such increase could be occurred as a result of adequate moisture distribution and availability within the soil profile, which contributes to making the nutrients easily available for plant uptake. Also, the lower yield in surface irrigation system could be attributed to inefficient use application of irrigation water, deep percolation and uneven distribution of irrigation water. These findings agreed with those obtained by Sankara *et al.* (2008), who reported highly significant garlic bulb yield under drip irrigation system. The obtained results agreed also with the findings of Abby and Joyce (2004) and Satyendra *et al*. (2007).

Results in Table 9 revealed also that irrigation amount given at 100% of ETp recorded significantly higher fresh yields 6.74 and 5.59 ton/fed and cured yields 4.07 and 4.02 ton/fed compared to the 75% of ETp in 2014/15 and 2015/16 seasons, respectively. The obtained results could be due to quick moisture replenishment through drip irrigation directly at the root system of the crop and to the maintenance of soil moisture regime closer to field capacity. The better performance of yield with 100% of ETp treatment may be attributed to significant increase in growth parameters. Similar results for higher bulb yield were reported by Anonymous (2002) and Hanson and May (2004).

Fresh and cured bulb yields of garlic were influenced significantly by the interaction between irrigation systems and amounts of applied irrigation water (AIW) (Table 6). Applying amounts of irrigation water at 100% of ETp under drip irrigation system recorded the highest fresh 7.82 and 7.00 ton/fed. and cured bulb yields 4.59 and 4.95 ton/fed. followed by drip irrigation at 75% with fresh 6.80 and 6.15 ton/fed. and cured yields 3.86 and 3.94 ton/fed. in 2014/15 and 2015/16 seasons, respectively. These results were in agreement with those obtained by Mandefro and Quraishi (2015) and confirm the earlier findings of Patel *et al.* (1996), who found a linear relationship between the amount of water applied and garlic yield under drip irrigation system.

II.3- Average weight loss after storage:

Average garlic bulb weight loss (%) values after six months of storage as affected by the two irrigation systems and amounts of applied irrigation water (AIW) treatments are shown in Table 10. Results showed that the average weight loss percentage was higher under surface system than under drip system. Average weight loss values under drip irrigation system were 64.33 and 65.48%, while the same values were 73.29 and 72.13% for surface irrigation system in the 2014/15 and 2015/16, respectively.

As for the effect of different amounts of applied irrigation water (AIW), results showed that the average weight loss values for the 100% ETp were more than those of the 75% ETp treatment. The recorded values were 70.91 and 58.90% and were 77.01 and 68.% under drip and surface systems, respectively. These variations may be attributed to the difference in the amounts of applied irrigation where more weight loss was noticed with more water added. The obtained results agreed with those reported by Satyendra *et al.* (2007), who stated that irrigation at 0.80 Ep (pan evaporation) resulted into minimum physiological loss in weight (%) during onion storage. The results agreed also with those of Rabbani *et al.* (1986), who reported that storage losses could be as high as 66% and many factors such as, bulb maturity, moisture content of the bulb, temperature, and relative humidity, are considered as main factors affecting storability.

Table 10: Average garlic weight loss (%) after six months of storage as affected by the tested variables in 2014/15 and 2015/16 seasons.

Irrigation system	Irrigation treatments	Weight loss (%)		Mean
		2014/15	2015/16	
Drip	100% ETp	70.32	71.51	70.91
	75% ETp	58.34	59.46	58.90
Mean		64.33	65.48	
Surface	100% ETp	77.15	76.88	77.01
	75% ETp	69.42	67.39	68.40
Mean		73.29	72.13	

Conclusion

From the obtained results it could be concluded that, drip irrigation system significantly improved growth parameters, fresh and cured yields, water use efficiency, and water productivity values of garlic crop grown under the experimental conditions in Egypt as compared with surface irrigation system.

The lowest weight loss was obtained under the drip irrigation system and 75% ETp irrigation treatment.

The combined effect of drip irrigation system and applying 100% ETp was superior in terms of improving growth characters, producing high marketable garlic yield, water use efficiency, water productivity than surface irrigation system.

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