Irrigation Scheduling of Potato Using Class A Pan Under Drip and Surface Irrigation Systems

Abdelshafy, A. A. [1] , Kh. M. Abd El- Latif [2] and A. KH. Abdelhalim[2]
[1]Potatoes and Vegetative Propagated Vegetable Crops Res. Dep. Horticultural Research Inst.
[2]Soils, Water & Env. Res. Inst. – Water Requirements & Field Irrigation Dep.
Agric. Res. Center, Giza, Egypt

DOI: 10.21608/ajsws.2021.227873

Article Information

ReceivedApril 19th 2021

Revised:May 4th 2021

Accepted: june 21st 2021

Published: July 31st 2021

ABSTRACT: A field experiment was conducted at El-Qanater Horticultural Research station, Qalubia Governorate, Egypt during 2018 and 2019 winter seasons to study the effects of two irrigation systems (drip and surface) and three irrigation interval treatments, i.e. 1.4, 1.2, and 1.0 cumulative pan evaporation (CPE) on potato growth and yield parameters (plant height, fresh and dry tuber yields, and total soluble solid contents (TSS), and on the amounts of applied irrigation water (AIW), water consumption, water use efficiency (WUE), and water productivity (WP). The results of both seasons indicated that, irrigation systems and interval treatments significantly affected all the tested traits. Drip irrigation system produced significantly higher fresh and dry tuber yields than surface irrigation system. Results also showed that, the 1.4 CPE irrigation interval treatment recorded significantly highest fresh potato tuber yields (14.41 and 14.49 t/fed) and dry tuber yields (2.55 and 2.47 t/fed) in 2018 and 2019 seasons, respectively. Results indicated that average AIW values under drip irrigation system were 1565 and 1494 m^3/fed, while average applied irrigation water values were 2778 and 2667 m^3/fed for surface irrigation system in 2018 and 2019 seasons, respectively. The average WUE values were higher under drip irrigation system (9.08 and 9.59 kg/m^3) than under surface irrigation system (5.32 and 6.05 kg/m^3) in the 2018 and 2019 seasons, respectively. The WP values were higher under drip irrigation system (8.38 and 8.84 kg/m^3) than under surface irrigation system (3.54 and 4.02 kg/m^3) in the 2018 and 2019 seasons, respectively. It is recommended to use the drip irrigation system with the 1.4 CPE interval to obtain high potato yield and save irrigation water.

Keywords: Drip, surface, irrigation schedule, potato, and some water relations.

INTRODUCTION

Potato is a very important crop in the Mediterranean Basin, occupying an overall area of about one million ha and producing 18 million tons of tubers in several countries, including Egypt, Tunisia, Cyprus, Israel, Lebanon, Italy and Turkey **(Lerna et al. 2011).** Surface irrigation is the conventional method widely used to irrigate most of the vegetable crops grown in Egypt. However, this method uses more water compared to other high-tech water-saving irrigation method such as drip etc. Drip irrigation which is a recent concept where small frequent irrigation applications are applied to saturate the soil and meet the plant water requirements. Many researchers have reported the higher application efficiency of drip irrigation systems over the conventional surface irrigation systems **(Yildirim and Korukcu, 2000)**. Studies the effect of drip irrigation generally achieves better crop yield with minimum water losses. Drip irrigation method enhanced all growth parameters such as plant high, fresh and dry weights of tubers along with tubers yield /fed significantly increased compared with sprinkler one and moisture content in potato tubers grown under drip irrigation method **(Yuan *et al.* 2003 and Nadia *et al.* 2012)**. **Shahevet *et al* (1983)** stated that, under drip irrigation, potato tubers yield increased if the water supply was adequate explained by the higher root density under drip irrigation. This increases application efficiency, making the system more water efficient **(Panigrahi *et al* 2010).** Moreover, they found that increased in water use efficiency about 4.87 was obtained under drip irrigation system; whereas decreased water uses efficiency about 1.66 was obtained in surface irrigation system. The interval between two irrigations should be as wide as possible to save irrigation water without any adverse effect on the growth and yield. Irrigation applied before the time of actual crop need encourages only losses of water through higher evapotranspiration and deep percolation. On the other hand, delayed irrigation causes plant water stress that depresses the growth activities and yield **(Majumdar, 2002).** The total amounts of applied irrigation water for potato crop under drip irrigation system ranged from 297 to 625 mm and from 288 to 598 mm in 2008 and 2009 respectively, **(Yavuz *et al.* 2010).** Irrigated potato by drip irrigation with different levels (40, 60, 80, 100%) of the evaporation gained a significant increase in the growth parameters, total tuber yield of tubers, by increased irrigation level **(Badr et al. 2012 ; Karam et al. 2016). Faberio *et al.* (2001),** in Spain, found that 597 mm irrigation water was required to reach maximum tuber yield 45.18 t ha^{-1}; Other researchers have also reported increased tuber yield with irrigation applications **(Yuan *et al.* 2003; Kang *et al*. 2004). Ali (1993)** shown that the seasonal water consumptive use by potato grown at Qalubia region, Egypt, varies between 300.4 mm and 419.3 mm. The variation is mainly due to climatic conditions and to the irrigation treatments; the highest water use value was obtained under the low water deficient. Increasing soil moisture stress by prolonged irrigation intervals resulted in decreasing water consumptive use. Drip irrigation has been demonstrated to improve crop productivity, improve irrigation efficiency and reduce water loss by deep percolation. **Gameh et al. (2000)** reported that, irrigated potato with drip irrigation gave the highest water use efficiency. **Kumar et al., 2009** conducted an experiment to compare microsprinkler irrigation system with furrow irrigation system under limited water and they found that highest yield of early potato with 1.20 IW/CPE of irrigation under each irrigation system. But microsprinkler recorded higher yield, irrigation production efficiency and fertilizer-use efficiency. On the other hand, the economics revealed that microsprinkler to be a good substitute for existing irrigation system for potato production. Under Egyptian study conditions, the water productivity (kg/m^3) for subsurface drip irrigation treatments gave the highest values using each of soil water balance (SWB) and (the traditional drip irrigation system) comparing with Surface drip irrigation treatment under the same conditions. Which subsurface or surface drip irrigation treatments using (SWB) gave 7.0 and 7.1 kg/m^3 for both Nili and summer season respectively. While the lowest values were for traditional irrigation 4.9 and 5.0 kg/m^3 for both Nili and summer seasons respectively. Therefore, subsurface or surface drip irrigation treatments using (SWB) methods caused reduction in the total applied water compared with the traditional methods. The total water applied crop growth period in the summer season increases by 9.8 and 11% compared to the Nili season under subsurface and surface drip irrigation using (SWB) respectively **(Eid et al., 2017). Singh et al., 2017** found that the higher irrigation production efficiency was recorded at 50% of pan evaporation replenishment and it decreased significantly with an increase in irrigation methods. Irrigation at 125% of Pan Evaporation replenishment resulted in higher gross return, net return and benefit cost ratio. The seasonal water applied, and marketable yield, gross return, net return and benefit cost ratio showed strong quadratic relationship for both drip and surface methods which in turn can be used for optimizing onion production under variable irrigation methods. The results revealed that drip irrigation system is profitable for onion production despite high initial investment**.**

This research aimed to study effect of two irrigation systems (drip and surface) and three irrigation interval treatments, i.e., 1.4, 1.2, and 1.0 cumulative pan evaporation (CPE) on potato growth and yield parameters (plant height, fresh and dry tuber yields, tuber yield and total soluble solid contents (TSS), and on amounts of applied irrigation water, water consumptive use, water use efficiency, and water productivity.

MATERIALS AND METHODS

Site Description:

A field experiment was conducted during 2018 and 2019 winter seasons at El-Qanater Horticultural Research Station (31^0 11' longitude, 30^0 28' latitude, and 14 m altitude above mean sea level), El-Qalubia Governorate, Egypt. 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.

Table (1): Monthly average meteorological data of El-Qanater weather station during 2018 and 2019 seasons.

Months	Season	Temperature (°C)		Relative humidity (%)	Wind speed (m/sec)	Sunshine (h)	E pan (mm/day)
		Max.	Min.				
February	2018	23.68	9.06	50.86	3.59	11.20	6.02
March		26.44	11.33	43.08	4.13	10.50	7.07
April		32.79	14.24	37.41	4.17	12.80	9.13
May		34.29	17.26	35.22	4.38	12.95	9.36
February	2019	21.4	8.0	60.1	2.1	11.60	4.83
March		25.38	12.04	48.06	2.21	12.80	5.96
April		29.21	15.06	41.20	2.35	12.90	6.87
May		34.65	19.36	34.73	2.61	12.85	8.24

The soil physical, chemical properties and soil-moisture constants at the experimental site, determined according to **Page *et al.* (1982) and Klute (1986)**, are listed in Tables 2 and 3.

Table (2): Some soil physical and chemical properties at the experimental site in 2018 and 2019 seasons.

Season	Particle size distribution*			Textural class	Chemical properties**					
	Clay	Silt	Sand		O.M. (%)	EC dSm-1 (1:5)	Available (ppm)			pH (1:2.5)
	%						N	P	K	
2018	40.8	35.4	23.8	Clay loam	1.84	0.99	45.00	12.5	191.90	7.75
2019	40.7	36.2	23.1		1.82	0.89	41.02	10.00	194.80	7.75

* According to Klute (1986) **according to Page et al.(1982)

Table (3): Some soil water constants and bulk density at the experimental site.

Depths (cm)	Field capacity (%)	Wilting point (%)	Available moisture (%)	Bulk density (g cm -3)	Available moisture (mm/layer)	
0-15	35.8	18.8	17.0	1.21	31.0	59.1
15-30	33.4	17.3	16.1	1.18	28.1	
30-45	31.9	15.1	16.8	1.25	31.5	65.5
45-60	31.7	16.8	14.9	1.52	34.0	

Experimental design and tested treatments:

A split plot experimental design with three replicates was used to implement the field experiment. Irrigation systems represented the main plots and three irrigation intervals treatments based on cumulative pan evaporation (CPE) represented the subplots as follows:

Irrigation systems (IS) (main plots):

Surface irrigation

Drip irrigation

Irrigation interval treatments (sub-plots):

I1: Depth of available water in soil profile / 1.4 * cumulative pan evaporation (CPE)

I2: Depth of available water in soil profile / 1.2 * cumulative pan evaporation (CPE)

I3: Depth of available water in soil profile / 1.0 * cumulative pan evaporation (CPE)

The irrigation interval for each treatment is the number of days in which the cumulative pan evaporation (CPE) times the selected factor is equal to the available water in the soil profile. The irrigation treatments were imposed after the crop foliage nearly covered the ground (Eid et al., 1982). For drip system, irrigation interval is calculated based on the available moisture in the top 30cm layer (59.1mm). For surface system, irrigation interval is calculated based on the available moisture in the top 60cm layer (124.6mm). Irrigation interval is calculated according to:

$$Irrigation\ interval\ (days) = \frac{Available\ Water\ in\ soil\ profile\ (AW, mm)}{Irrigation\ factor\ * CPE\ (\frac{mm}{day})}$$

where:

Irrigation factor: 1.4, 1.2, and 1.0

AW: depth of available water (mm)

CPE: cumulative pan evaporation (mm/days)

Potato cultural practices:

Potato "Solanum tuberosum L." var. Diamant, was planted on the 6th and 8th of February 2018 and 2019, respectively and harvested after 105 days (21st and 23rd of May 2018 and 2019), respectively.

Soil-water relations:

Water consumptive use (CU):

Water consumptive use (CU), or actual evapotranspiration (ETc), values were determined by Time Domain Reflectometry (TDR) sensor which measured the volumetric soil moisture contents in the surface 0.6 m depth 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 values were 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, ETa (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).

Water use efficiency (WUE):

Water use efficiency (WUE, kg m–3) reported in this paper as the ratio of potato yield (Y) to actual evapotranspiration (ETc) according to Stanhill (1986):

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

where:

Y = potato yield (kg fed–1).

ETc =Actual evapotranspiration for growing season (m3 fed–1).

Crop water productivity (WP):

The WP is defined as crop yield per a unit of applied irrigation water (Zhang, 2003) and is given as follow:

$$\mathrm{WP} = \frac{\text{Potato yield (kg/fed)}}{\text{Applied irrigation water } (\mathrm{m}^3/\text{fed})}$$

Measured plant measurements:

Plant height (cm) and fresh weight (g plant-1) were measured in five plants after 90 days from planting. Dry weight of tuber/plant (g/plant) was measured at harvesting in five plants taken randomly from each treatment. Tuber yield (t/fed) was also measured and recorded. Plant samples after harvesting, were dried at 70ºC; grounded, digested and assigned for analyzing. A total soluble solid (TSS) in the fresh potato tubers was done using a hand refractometer (Cox and Pearson, 1962).

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

Tuber yield and yield components:

The effect of tested variables on plant height, fresh and dry tuber weights, and total soluble solids during the two growing seasons for each treatment are listed in Table 4.

Plant height and fresh weight:

Results indicated that plant height and fresh weight were significantly affected by irrigation systems. The two parameters were significantly higher for drip irrigation system as compared with the surface system. The highest average values of plant height and fresh weight were 84.00 and 83.90cm and 484.44 and 485.78 g/plant obtained under drip irrigation system in 2018 and 2019 seasons, respectively. The relative increases under drip system as compared with surface system were 38.00 and 38.35% for plant height; and 69.37 and 69.66% for fresh weight during 2018 and 2019 seasons, respectively. Under the present experimental conditions, the increased vegetative growth characters under drip irrigation might be due to better availability of moisture during the entire crop growth period which favored the growth environment and the growth attributes. These results are in harmony with those obtained by Yuan et al. (2003) and Nadia et al. (2012).

Concerning the effect of irrigation interval treatments, results in Table 4 indicated that the adapted CPE factors significantly affected plant height and fresh weight in 2018 and 2019 seasons. The highest figures of the plant height and fresh weight were recorded with 1.4 CPE treatment (shortest interval), whereas the lowest values were detected from irrigation at 1.0 CPE (longest interval). The highest average values of plant height and fresh weight were 84.06 and 84.01cm and 549.8 and 550.4 g/plant for 1.4 CPE irrigation interval treatment in 2018 and 2019 seasons, respectively. Such findings may be due to the more available moisture in the root zone, which improve the plant height and fresh weight. The results are in harmony with those obtained by Badr et al. (2012) and Karam et al. (2016).

Concerning the interaction effect between the two studied factors on the plant height and fresh weight parameters, results in Table 4 illustrated that the highest significant values of 99.67 and 99.93cm and 723.3 and 724.3 g/plant in 2018 and 2019 seasons, respectively were obtained by drip irrigation system and the 1.4 CPE irrigation interval treatment. Meanwhile, the lowest values of 53.33 and 53.34cm and 126.7 and 127.2 g/plant in 2018 and 2019 seasons, respectively were obtained from the 1.0 CPE and surface irrigation treatment. These results agreed with those obtained by Sankar et al. (2008) and Hegab et al. (2014).

Fresh and dry potato tuber yields:

Results in Table 4 showed significant effect of irrigation systems and intervals on both fresh and dry tuber yields. Drip irrigation system produced significantly higher fresh and dry tuber yields than surface irrigation system. The increases in fresh and dry tuber potato yields for drip over surface system were 35.64% and 63.00%, and 93.95 and 78.80% in 2018 and 2019 seasons, respectively. The low yields from surface irrigation system could be attributed to inefficient use of irrigation water, deep percolation and uneven distribution of irrigation water. The higher yield in drip irrigation system might be due to the fact that frequent watering resulted into higher water potential, thus minimizing fluctuation in soil moisture in effective root zone, which holds promise for increase in crop yield (Hanson et al., 1997). The better crop performance under drip irrigation could be attributed to the better microenvironment which facilitate better photosynthesis, root aeration, and plant growth resulted in higher yield (Shahevet et al., 1983). These findings agreed with those obtained by Ghosh et al. (2000) who found that the tuber yield decreased with decreasing soil moisture with the greatest reduction at 45% AW.

Results revealed that, potato tuber yield increased with the decrease in irrigation interval from 1.0 to 1.4 CPE (Table 4). Results showed that, the 1.4 CPE irrigation interval treatment recorded significantly highest fresh potato tuber yields (14.41 and 14.49 t/fed) and dry tuber yields (2.55 and 2.47 t/fed) in 2018 and 2019 seasons, respectively as compared with the 1.2 and 1.0 CPE treatments. The better performance of yield with 1.4 CPE treatments may be attributed to significant increase in growth parameters. The obtained results agreed with those reported by Kashyap and Panda (2002), who indicated that the difference in potato tuber yield with irrigation levels was mainly due to the variation in available soil moisture. They also reported that water stress decrease plant growth and yield. Also, Yaun et al. (2003) reported decrease in tuber weight due to with decreasing irrigation water.

Total soluble solids in potato tuber

Results reported in Table (4) revealed that, the total soluble solids content in tuber was affected significantly by irrigation systems and intervals. The drip system recorded significant TSS values of 55.4 and 55.58 g/L in the 2018 and 2019 seasons, respectively as compared with surface system. Results also indicated that, increasing irrigation interval from 1.4 CPE to 1.0 CPE significantly increased the TSS contents in potato tuber. These findings agreed with those obtained by El-Metwally (2003) who reported that increased irrigation caused very slight decrease in TSS.

Table 4. Plant height (cm), plant fresh weight (g/plant), fresh tuber yield (t/fed), dry tuber yield (t/fed), and total soluble solids (g/L) as affected by irrigation systems and irrigation interval treatments in the two seasons.

Treatments	Plant height (cm)		Plant fresh weight (g/plant)		Fresh tuber yield (t/fed)		Dry tuber yield (t/fed)		TSS (g/L)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
A) Irrigation systems										
Drip	84.00	83.90	484.44	485.78	13.33	13.44	2.89	2.70	55.40	55.58
Surface	60.88	60.64	286.02	286.32	9.84	9.88	1.49	1.51	44.69	44.67
L.S.D.	**	**	**	**	**	**	**	**	**	**
B) Evaporation pan factors										
1.4	84.06	84.01	549.8	550.4	14.41	14.49	2.55	2.47	47.13	47.17
1.2	72.61	72.29	450.7	450.8	11.81	11.91	2.25	2.18	50.36	50.36
1.0	60.67	60.51	155.2	157.0	8.54	8.57	1.76	1.67	52.64	52.85
L.S.D.	7.59	5.252	24.11	25.42	1.50	1.50	0.16	0.18	3.735	5.296
Interactions										
Drip * 1.4	99.67	99.93	723.3	724.3	17.62	17.75	3.54	3.343	51.13	51.20
Drip * 1.2	84.33	84.10	546.3	546.3	13.27	13.42	2.99	2.837	57.03	57.03
Drip * 1.0	68.00	67.67	183.6	186.8	9.09	9.147	2.13	1.920	58.02	58.52
Surface * 1.4	68.44	68.09	376.3	376.4	11.19	11.23	1.56	1.607	43.12	43.14
Surface * 1.2	60.89	60.47	355.1	355.4	10.40	10.40	1.510	1.523	43.69	43.69
Surface * 1.0	53.33	53.34	126.7	127.2	8.00	10.40	1.39	1.417	47.26	47.19
L.S.D. A*B	24.11	7.24	34.10	35.95	2.12	2.127	0.23	0.266	NS	NS

Tuber dry matter, protein and starch in potato tuber

Data reported in Table (5) revealed that, tuber dry matter, protein and starch in potato tuber were significantly affected with irrigation systems and applied irrigation water rate.

Tuber dry matter content (gkg-1):

Results indicated that tuber dry matter was significantly increasing affected by drip irrigation and the lowest was by the surface irrigation in first season and non-significantly in second season.

The highest effect was given by 1.0 CPE and the lowest was by the 1.4 CPE. Mean values in seasons 2018 and 2019 were as follows: 1.0 CPE gave the highest height of (176.8 and 194.0) followed by 1.2 CPE which gave (175.7 and 190.2) and the lowest value was obtained from 1.4 CPE (153.6 and 165.9) g /kg in the first and second seasons, respectively. As for the effect of interaction, there was significant interaction effect caused by irrigation system with irrigation treatments. The superiority of 1.0 CPE and 1.2 CPE under conditions of drip irrigation in both seasons. The current results disagree with those obtained by **Eskandari et al. (2013)** who mentioned that application of full irrigation requirement provided the highest value of tuber dry weight. These results are similar to those obtained by **Carli et al. (2014)** who recorded that the reduction of water supply after tuberization increased dry matter content (ranged from 204 to 231 gkg-1). The current results agree with those obtained by **Darwish et al. (2006)** the tuber dry matter was decreased with the increasing water levels and the values of dry matter were 209.1, 205.2 and 203.9 gkg^{-1} under the applied 80, 100 and 120 % of ET, respectively.

Table 5. Dray matter, protein and starch as affected by irrigation systems and irrigation interval treatments in the two seasons.

Treatments	Tuber DM g/kg		Tuber Protein (g/kg DW)		Tuber starch (g/kg)	
	2018	**2019**	**2018**	**2019**	**2018**	**2019**
A) Irrigation systems						
Drip	188.1	205.6	60.50	66.15	130.4	142.6
Surface	149.3	161.1	69.21	70.14	150.1	132.4
L.S.D.	**	**	**	**N.S**	**N.S**	**N.S**
B) Evaporation pan factors						
1.4	153.6	165.9	58.44	65.07	129.5	131.1
1.2	175.7	190.2	66.98	69.58	143.1	134.4
1.0	176.8	194.0	69.15	69.79	148.2	140.9
L.S.D.	4.608	5.123	4.789	N.S	10.86	9.505
Interactions						
Drip * 1.4	173.9	190.1	51.20	55.98	117.7	128.7
Drip * 1.2	192.9	210.9	63.85	69.81	134.7	147.2
Drip * 1.0	197.5	215.9	66.46	72.66	138.8	151.8
Surface * 1.4	133.4	141.8	65.68	66.92	141.2	153.0
Surface * 1.2	153.9	164.5	70.11	69.34	147.5	123.1
Surface * 1.0	160.7	177.1	71.84	74.17	161.7	121.0
L.S.D. A*B	6.517	7.246	6.772	6.900	15.36	13.44

Tuber protein content (gkg^{-1})

The effect of tested variables on protein content during the two growing seasons for each treatment are listed in Table 5. Results indicated that protein content was significantly affected by irrigation systems in 2018 season and non-significantly in the second season. The protein content was significantly higher for surface system as compared with the drip irrigation system. The highest average values of protein content were 69.21 and 70.14 g/kg obtained under surface irrigation system in 2018 and 2019 seasons, respectively. The relative increases under surface system as compared with drip system were 14.6 and 6.0% in protein content during 2018 and 2019 seasons, respectively.

On the other hand, the highest content was obtained by 1.0 CPE followed by 1.2 CPE both of which were not significantly different and were significantly superior to 1.4 CPE. Mean values of protein content in the irrigation treatment were as follows: 69.15 and 69.79, (66.98 and 69.58) and (58.44 and 65.07) g/kg DW. at 1.0, 1.2 and1.4 CPE in 2018 and 2019 seasons, respectively.

Therefore 1.0 CPE and 1.2 CPE showed increases of 10.6 and 12.5 % respectively. However, there was significant interaction caused by irrigation systems and affected applied irrigation water rate. This was manifested when 1.4 CPE gave protein content height under conditions of surface irrigation system in the second season. The current results are similar to those obtained by **Gunel and Karadogan (1998)** who reported that at the harvested stage a significant decrease in tuber protein content was observed under increasing of the frequent irrigation at growth stages, however, the highest protein value was observed from the potatoes irrigated until maturity. Greater irrigation must have increased plant growth with increased uptake of N, hence increased protein contents particularly. **Ramink et al. (1998)** found that protein content increased with increasing irrigation. **Uppal et al. (1997)** showed that terminating irrigation two weeks before harvest increased the protein content of potato tubers compared with terminating irrigation 4 weeks before harvest. Regarding to the effect of interaction, there was significant interaction effect caused by irrigation system with irrigation treatments. The superiority of 1.0 CPE and 1.2 CPE under conditions of surface irrigation in both seasons. this obtained results in agreement with those obtained by **Eskandari et al. (2013)** who mentioned that application of full irrigation requirement provided the highest value of tuber dry weight.

Starch content in potato tubers starch A high content of tubers starch in potato tubers starch indicates a high value for nutrition potato tuber as a source of energy. The effect of tested variables on tubers starch during the two growing seasons for each treatment is listed in Table 5. Results indicated that tubers starch was non-significantly affected by irrigation systems in two seasons. The relative increases under surface system as compared with drip system were 15.1 and 9.2% in tubers starch during 2018 and 2019 seasons, respectively. The highest content was obtained by 1.0 CPE followed by 1.2 CPE both of which were not significantly different and were significantly superior to 1.4 CPE. Mean values of tubers starch in the irrigation treatment were as follows: (143.1 and 140.9), (134.1and 134.4) and (129.5 and 131.1) g/kg DW. at 1.0, 1.2 and1.4 CPE in 2018 and 2019 seasons, respectively. These findings agreed with those obtained by **Eid et al. (2013)** who recorded that the content of tuber starch was increased with the increasing soil moisture depletion levels. **Carli et al. (2014)** who recorded that the reduction of water supply after tuberization increased starch tuber content.Regarding to the effect of interaction, there was significant interaction effect caused by irrigation system with irrigation treatments. The superiority of 1.0 CPE and 1.2 CPE under conditions of surface irrigation in the first season.

Soil water relations:Applied irrigation water (AIW): The effect of irrigation systems and intervals on the amounts of applied irrigation water is presented in Table 6. Results indicated that average AIW values under drip irrigation system were 1565 and 1494 m^3/fed, while average applied irrigation water values were 2778 and 2667 m^3/fed for surface irrigation system in 2018 and 2019 seasons, respectively. The values of average irrigation water saved between drip and surface systems were 39.3, 45.2, and 47.9% for the 1.4, 1.2, and 1.0 CPE irrigation interval treatments, respectively. Results also revealed that, irrigating at 1.4 CPE shortest interval) resulted in highest amounts of irrigation water applied to potato crop (1831 m^3/fed) under drip irrigation and 3016 under surface irrigation, due to more frequent irrigation, followed by watering at 1.2 CPE (1527.5 and 1234.0 m^3/fed) and 1.0 CPE (2789 and 2363 m^3/fed) in the respective growing seasons. The results were in agreement with those of **Majumdar (2002)** and **Yavuz *et al*. (2010)**, who indicated that, the frequency of irrigation and interval of irrigation are closely related and are often interchangeable.

Table 6. Seasonal applied irrigation water (m^3 fed^{-1}) under the adopted irrigation systems and intervals in 2018 and 2019 seasons.

Irrigation system	Irrigation Interval	Applied irrigation water (m^3 fed^{-1})		Mean
		2018	2019	
Drip	1.4 CPE	1877	1786	1831.5
	1.2 CPE	1584	1471	1527.5
	1.0 CPE	1236	1226	1231.0
Mean		1565	1494	
Surface	1.4 CPE	3127	2906	3016.5
	1.2 CPE	2823	2756	2789.5
	1.0 CPE	2386	2341	2363.5
Mean		2778	2667	

Water consumptive use (WCU):

Seasonal amounts of water consumed by potato crop under various treatments are presented in Table 7. Results indicated that the water consumptive use increased in case of surface irrigation system compared to the drip irrigation system. In 2018 season, the increase in water consumptive use for potato crop due to increasing water applied reached 28% more than those recorded under drip irrigation system. Similar trends were observed in 2019 season. Average CU value for the surface system was 28.8% higher as compared with drip irrigation. Under drip irrigation system, average water use values were 1689, 1408 and 1135 m^3/fed for irrigated plants at 1.4, 1.2 and 1.0 CPE, respectively. Similar trends were observed under surface irrigation system, the average water use values were 2008, 1857 and 1573 m^3/fed for the respective irrigation interval treatments. These results demonstrate that water consumption increased as soil moisture was maintained high by frequent irrigations which provide chance for more consumption of water which result in increasing transpiration and evaporation from the soil surface. The obtained results are in harmony with those reported by **Ali (1993)**. The observed water use by potato crop under this investigation was close to that reported by **Tolga *et al.* (2006)**, who stated that the seasonal evapotranspiration values were 683mm (2003) and 647mm (2005) under furrow irrigation method, with irrigation when 30% of the available water was consumed.

Table 7. Water consumptive use (WCU, m^3 fed^{-1}) under the adopted irrigation systems and intervals in 2018 and 2019 seasons.

Irrigation system	Irrigation interval	WCU (m^3 fed^{-1}) 2018	2019	Mean
Drip	1.4 CPE	1731	1647	1689
	1.2 CPE	1461	1356	1408
	1.0 CPE	1140	1131	1135
Mean		1444	1378	
Surface	1.4 CPE	2081	1934	2008
	1.2 CPE	1879	1834	1857
	1.0 CPE	1588	1558	1573
Mean		1849	1775	

Water use efficiency (WUE):

Water use efficiency expressed in kg of tuber yield/m^3 of water consumed as affected by irrigation systems and intervals is preened in Table 8. Results indicated that the obtained WUE values were higher under drip irrigation system (9.08 and 9.59 kg/m^3) than under surface irrigation system (5.32 and 6.05 kg/m^3) in the 2018 and 2019 seasons, respectively. It was also noticed that WUE values for drip irrigation system and the 1.4 CPE recorded the highest water use efficiency (10.18 and 10.78 kg/m^3) in 2018 and 2019, respectively. While the surface irrigation system and the 1.0 CPE treatment recorded the lowest WUE values (5.04 and 5.67 kg/m^3) in 2018 and 2019, respectively. These findings agreed with those obtained by **Panigrahi *et al*. (2010)** and **Gameh *et al*. (2000)**. The results showed that, when irrigation water is limited, 1.0 CPE irrigation interval and drip system could be applied for increasing the water use efficiency. Difference in WUE is due to different amounts of water consumed and the corresponding yields.

Crop water productivity (WP):

Water productivity values for potato crop (kg/m^3 applied water) as affected by the two irrigation systems and CPE irrigation interval treatments are presented in Table 8. The obtained values were higher under drip irrigation system (8.38 and 8.84 kg/m^3) than under surface irrigation system (3.54 and 4.02 kg/m^3) in the 2018 and 2019 seasons, respectively. It was also noticed that WP values for drip irrigation system and the 1.4 CPE irrigation interval treatment recorded the highest WP values (9.39 and 9.94 kg/m^3) in 2018 and 2019, respectively. While the surface irrigation system and the 1.0 CPE treatment recorded the lowest WP values (3.35 and 4.44 kg/m^3) in 2018 and 2019, respectively. The results showed that, when irrigation water is limited, 1.0 CPE and drip system could be applied for increasing the water productivity.

Table 8. Applied water, water use efficiency and water productivity under the adopted irrigation systems in 2018 and 2019 seasons.

Irrigation system	Irrigation Interval	2018 Yield (t/fed)	2018 AIW (m^3/fed)	2018 WUE (kg/m^3)	2018 WP (kg/m^3)	2019 Yield (t/fed)	2019 AIW (m^3/fed)	2019 WUE (kg/m^3)	2019 WP (kg/m^3)
	1.4 CPE	17.20	1877	10.18	9.39	17.75	1786	10.78	9.94
Drip	1.2 CPE	13.27	1584	9.08	8.38	13.42	1471	9.90	9.12
	1.0 CPE	9.09	1236	7.98	7.36	9.14	1226	8.09	7.46
Mean		13.19	1565	9.08	8.38	13.44	1494	9.59	8.84
	1.4 CPE	11.19	3127	5.38	3.58	11.23	2906	5.81	3.86
Surface	1.2 CPE	10.40	2823	5.53	3.68	10.40	2756	5.67	3.77
	1.0 CPE	8.00	2386	5.04	3.35	10.40	2341	6.67	4.44
Mean		9.86	2778	5.32	3.54	10.68	2667	6.05	4.02

CONCLUSIONS:

Drip irrigation system produced significantly higher fresh and dry tuber yields than surface irrigation system. Results also showed that, the 1.4 CPE irrigation interval treatment recorded significantly highest fresh potato tuber yields (14.41 and 14.49 t/fed) and dry tuber yields (2.55 and 2.47 t/fed) in 2018 and 2019 seasons, respectively. Results indicated that average AIW values under drip irrigation system were 1565 and

1494 m^3/fed, while average applied irrigation water values were 2778 and 2667 m^3/fed for surface irrigation system in 2018 and 2019 seasons, respectively. The average WUE values were higher under drip irrigation system (9.08 and 9.59 kg/m^3) than under surface irrigation system (5.32 and 6.05 kg/m^3) in the 2018 and 2019 seasons, respectively. The WP values were higher under drip irrigation system (8.38 and 8.84 kg/m^3) than under surface irrigation system (3.54 and 4.02 kg/m^3) in the 2018 and 2019 seasons, respectively. It is recommended to use the drip irrigation system with the 1.4 CPE interval to obtain high potato yield and save irrigation water.

REFERENCES

Ali . M . A, 1993. Physiological studies on water requirements of potato plant. Ph . D. thesis. Fac . Agric . Moshtohor , Zagazig Univ.

Badr, M.A., W.A. El-Tohamy and A.M. Zaghloul, 2012. Yield and Water Use Efficiency of Potato Grown under Different Irrigation and Nitrogen Levels in an Arid Region. Agricultural Water Management, 110: 9-15.

Carli, C., Yuldashev, F., Khalikov, D., Condori, B., Mares, V. and Monneveux, P. 2014. Effect of different irrigation regimes on yield, water use efficiency and quality of potato (Solanum tuberosum L.) in the lowlands of Tashkent, Uzbekistan: A field and modeling perspective. Field Crops Research, 163: 90–99.

Cataldo, A., De. B. Egidio and C. Giuseppe. 2011. Broadband Reflectometry for Enhanced Diagnostics and Monitoring Applications. Berlin, Heidelberg: Springer Press. ISBN 978-3-642-20233-9.

Cox, H. E. and Pearson, D. 1962. The Chemical Analysis of Foods, Chemical Publishing Co. Inc., New York.

Darwish, T. M., Atallah, T. W., Hajhasan, S. and Haidar, A. 2006. Nitrogen and water use efficiency of fertigated processing potato. Agricultural Water Management. 85(1–2): 95–104. https://doi.org/10.1016/j.agwat.2006.03.012

Eid, H.M. and Metwally, M.A. and Mahrous, F.N. (1982). Evaporation pan as an index to consumptive use of water and scheduling irrigation in some field crops. Agric. Res. Review (5), 257-279.

Eid, S. F. M. ; Tarek S. M. and E. A. El Samra, 2017. Irrigation Scheduling of Potato to Increase the Water Productivity under Drip Irrigation System on Sandy Soil. J. Soil Sci. and Agric. Eng., Mansoura Univ., Vol. 8 (12): 779 -785.

El-Metwally, M. E. 2003. Fertigation of drip irrigated potatoes (solanum tubersum, L.) Ph. D. Thesis, Fac. Of Agric. Mansoura University ,Egypt.

Eskandari, A., Khazaieb, H. R., Nezamib, A., Kafib, M., Majdabadia, A. and Saeid, S. 2013. Effects of drip irrigation regimes on potato tuber yield and quality. Archives of Agronomy and Soil Science. 59(6): 889–897.

Faberio, C.; Olalla, F.M S.; Juan, J.A. (2001). Yield size of deficit irrigated potatoes. Agriculture and Water Management, v.48, p.255-266.

Gameh, M. A; M. M. A. Abd Alla and M.H. Aboul-Nasr (2000) Improving water use efficiency in the new valley. J. Agric. Sci., Mansoura Univ., 25 (1) : 541-554.

Ghosh, S.C., Asanuma, K, K. A., Toyota, M. (2000). Effects of moisture stress at different growth stages on the amount of total nonstructural carbohydrate, nitrate reductase activity and yield of potato. Japanese – Journal of Tropical Agric. 44: 158 – 166.

Gunel, E. and Karadoĝan, T. 1998. Effect of irrigation applied at different growth stages and length of irrigation period on quality characters of potato tubers. Potato Research. 41 : 9–19.

Hanson B R, Schwanki L J, Schulbach K F and Pettygove G S. 1997. A Comparison of furrow, surface drip and subsurface drip irrigation on lettuce yield and applied water. Agricultural Water Management 33: 139–57.

Hegab, A. S. A., M. Fayed, M. A. Hamada and M. A. A. Abdrabbo. 2014. Productivity and irrigation requirements of faba bean in North Delta of Egypt in relation to planting dates. Annals of Agricultural Science., 2: 185–193.

Israelsen, O.W. and Hansen, V.E. 1962. Irrigation Principles and Practices 3rd Ed., John Willy and Son Inc., New York, U.S.A.

Kang, Y.; Wang, F.X.; Liu, H.J.; Yuan, B.Z. (2004). Potato evapotranspiration and yield under different drip irrigation regimes. Irrigation Science, v.23, p.133-143.

Karam, F., Mohamed, A. A. A., and Hegab S.A.M., 2016. Growth and productivity of potato under different irrigation levels and mulch types in the North West of the Nile delta, Egypt. Middle East Journal of Applied Sciences. ,6 (4): 774-786.

Kashyap P S and Panda R K. (2002). Effect of irrigation scheduling on potato crop parameters under water stressed conditions. Agricultural Water Management 71: 1-1 8.

Klute, A., 1986. Methods of Soil Analysis. Part 1. 2nd ed. ASA and SSSA. Madison, Wisconsin, USA.

Kumar, S, R. Asrey, G. Manda and R. Singh, 2009. Microsprinkler, drip and furrow irrigation for potato (Solanum tuberosum) cultivation in a semi-arid environment. Indian J. of Agric. Sci. 79 (3): 165–169.

Lerna, A., Pandino, G., Lombardo, S. and Mauromicale, G. 2011. Tuber Yield, Water and Fertilizer Productivity in Early Potato as Affected by a Combination of Irrigation and Fertilization. Agric. Water Manage., 101: 35-41

Majumdar, D.K. (2002). Irrigation water management, principles and practice. Prentice-Hall of India Privet Limited, New Delhi, India, pp. 261-283.

Nadia, G., Rahim, I.S. and M. Abd El-Hady, 2012. potato yield quantity and quality under different irrigation regimes in the newly reclaimed soil. Middle East Journal of Agriculture Research, 1(1): 26-32.

Page, A. L., Miller, R. H. and Keeny, D. R. 1982. Methods of Soil Analysis. Part II. Chemical and Microbiological Properties 2nd ed. Amer. Soc. Agron. Inc. Soil Sci. Sco. Amer. Inc. Madison, Wisconsin, USA.

Panigrahi, B., Roy, D.P., Panda, S. N. 2010. Water use and yield response of tomato as influenced by drip and furrow irrigation. International Agricultural Engineering Journal, Vol. 19, No. 1, 19:30.

Ramink, S.; Dubey, Y.P. and Sharma, R. (1998). Effect of irrigation and nitrogen on yield attributes, size and protein content of tubers of potato (Solanum tuberosum L.) in Lahaul valley of Himalayas. Annals of Agric. Bio Research. 3 (1): 61-66.

Sankara, V., K.E. Lawande, and P.C. Tripathi. 2008. Effect of micro irrigation practices on growth and yield of garlic (Allium sativum). J. Spices Arom. Crops. 3: 230-234.

Shalhevet, J., D. Shimshi and T. Meir, 1983. Potato irrigation requirements in a hot climate using sprinkler and drip methods. Aj-Abstract, American Society of Agronomy, 75(1): 13-16.

Singh A., S. K. Srivastava, K. J.L.G. Kumar, D.M. Denis and A. Thomas, 2017. YIELD, irrigation production efficiency and Economic return of onion under variable Irrigation methods. The Allahabad Farmer, Vol. LXXIII, No. 1:1-7.

Snedecor, G.W. and Cochran, W.G. 1980. Statistical Methods 7th Ed. Iowa State Univ. Press, Iowa, U.S.A.

Stanhill, G., 1986. Water use efficiency. Adv. Agron., 39: 53-85.

Tolga E., Yesim E., Halim O. and Hakan O. (2006). Water-yield relationships of potato under different irrigation methods and regimens. Sci. Agric. (Piracicaba, Braz.), v.63, n.3, p.226-231.

Uppal, H.S; Surat, P. Mahal; S.S Bhupinder; K. Prakash S. and Kaur B. (1997). Effect of time of K application and withdrawal of irrigation on yield and chip quality of potato. Journal of Potassium Research 13 (3-4): 277-282.

Waller, R.A. and Duncan, C.B. 1969. Abays rule for symmetric multiple comparison problem Amer. State Assoc. Jour., December: 1485-1503.

Yavuz, D., Yavuz, N., and Suheri, S. 2010. Design and Management of a Drip Irrigation System for an Optimum Potato Yield. J. Agri. Sci. Tech. Vol. 18: 817-830.

Yildirim, O. and A. Korukcu, (2000). "Comparison of Drip, Sprinkler and Surface Irrigation Systems in Orchards". Faculty of Agriculture, University of Ankara, Ankara Turkey. 47p.

Yuan, B., S. Nishiyama and Y. Kang, 2003. Effect of drip irrigation regimes on the growth and yield of drip irrigated potato. Agricultural Water Management. 63 (31): 153:167.

Zhang H.,2003. Improving water productivity through deficit irrigation: Examples from Syria, the north China Plain and Oregon, USA. In: Water Productivity in Agriculture: Limits and Opportunities for Improvement. CABI publishing, 332 p.

الملخص العربي

جدولة ري البطاطس باستخدام وعاء البخر القياسي تحت نظامي الرى بالتنقيط والسطحى

أشرف ايوب عبدالشافى[1] وخالد محمود عبداللطيف[2] وعبدالهادى خميس عبدالحليم[2]

[1] معهد بحوث البساتين معهد بحوث البساتين – قسم بحوث البطاطس والخضر خضرية التكاثر – مركز البحوث الزراعية – مصر

[2]معهد بحوث الأراضي والمياه والبيئة – قسم بحوث المقننات المائية والرى الحقلى – مركز البحوث الزراعية – مصر

أجريت دراسة حقلية بالارض الطينية الطمية بمحطة البساتين بالقناطرالخيرية بمحافظة القليوبية – مصر– خلال موسمي شتوي 2018 و2019 لدراسة تأثير أنظمة الري السطحي والتنقيط تحت ثلاث فترات رى المقدرة بناء على معاملات البخر التراكمي 1.4، 1.2، 1.0 على ارتفاع النبات، والمحصول النباتي الطازج، درنة الجافة، ومحصول الدرنات والمواد الصلبة الذائبة (TSS) وكميات مياه الرى المضافة والماء المستهلك وكفاءة استخدام وإنتاجية وحده المياه. وكانت اهم النتائج على النحو التالي: في كلا الموسمين، أثرت نظم الري بشكل كبير على محصول الدرنات ومكوناته ومحصول البطاطس الطازجة التي زادت مع الري بالتنقيط عند 1,2 من كمية مياه الري مقارنة بـ (1,0 و0,8) مع طريقة الري السطحي في كلا الموسمين. كما بلغ إجمالي كمية مياه الرى المضافة أعلى قيم لنظام الري بالتنقيط 1236 و1226 م 3 للفدان لمعاملة البخر التراكمي 0,8 وكانت 1584 و1471 م 3 للفدان لمعاملة البخر التراكمى 1,0 وكانت 1877 إلى 1786 م3 للفدان لمعاملة البخر التراكمي 1,2 في موسمي 2018 و2019، على التوالي. بالنسبة لنظام الري السطحي فقد بلغ إجمالي كمية مياه الرى المضافة 2386 م و2341 م 3 للفدان لمعاملة البخر التراكمي 0.8 وكانت 2823 و2756 م 3 للفدان لمعاملة البخر التراكمى 1,0 وكانت 3127 إلى 2906 للفدان لمعاملة البخر التراكمي 1,2 في فترتي 2018 و2019 على التوالي. وبالنسبة لمتوسطات كفاءة استخدام المياه (WUE) ومعدل إنتاجية المياه (WP) أعلى تحت نظام الري بالتنقيط (10,48، و9,66 كجم / م 3) من الري السطحي في كلا الموسمين، على التوالي. تم الحصول على أعلى إنتاجية للبطاطس (17,62 و17,75 طن / فدان) بنظام الري بالتنقيط تحت 1,2 البخر التراكمي وتحت نظام الري السطحي كانت اعلى انتاجية (11,19 و11,23 طن / فدان) لموسمي 2018 و2019 على التوالي.