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IRRIGATION REGIME EFFECTS ON GROWTH AND YIELD OF POTATO UNDER DIFFERENT IRRIGATION SYSTEMS

El-Shikha, D. M.
Agric. Eng. Dept., Fac. of Agric., Mansoura Univ., Egypt.

ABSTRACT

The effect of irrigation water amount is a very important issue for the growth and yield of potato. A field experiment was conducted during the late winter planting seasons of 2004/2005 in a clayey loam soil in Aga, Dakahlia Governorate. This research aimed to study two Irrigation systems (subsurface and surface drip) and four different treatments of irrigation water amount (0.6Ep, 0.8Ep, 1.0Ep, and 1.2Ep). The surface drip irrigation system gave higher values for most of the yield parameters that were measured in this experiment. Even though the application of 120% of the class A pan evaporation resulted in the highest fresh tuber yield, 873.3 g/plant, the highest water use efficiency was associated with the application of 80% of class A pan evaporation. Thus, the optimum Kcp value was the 1.2, which was equivalent to a potato water requirement of 598-mm. It could be concluded that weather service class A pan was a successful tool in determination of the water requirements of potato crop under Egyptian conditions.

INTRODUCTION

Potato (*Solanum tuberosum L.*) is a major food crop in many countries (Shalhevet et al., 1983). It takes the fourth place among the world's various agricultural food products in production volume. It comes after wheat, rice and corn (Fabeiro et al., 2001). It is a moderate crop that grows and gives a good yield under cool and humid climate. Yuan et al. (2003) mentioned that it can be grown in a wide range of climatic regions, tropics to the sub-polar. Potato is widely planted in Egypt under both furrow and drip irrigation systems.

Competition for water supplies is a worldwide phenomenon. As most of agricultural inputs, water should be applied efficiently to produce plentiful and good quality food. Potato is a relatively sensitive plant to water stress, namely, it can respond to water stress with reductions in yield and tuber grade. Many irrigation researches have shown that potato is relatively sensitive to water stress (Shock et al., 1998; Porter et al., 1999 and Fabeiro et al., 2001). Consequently, the availability of soil water is one of most important factors affecting yield and quality of potato.

Drip irrigation presumably improves the soil water regime thus leading to higher crop yields, which is a major demand taking into consideration the vast increase in world population that is expected to reach ten billion by 2050 (Paul and Foyer, 2001). Keshavaiah and Kumaraswamy (1993) showed that drip irrigated potato gave higher yield than furrow irrigated potato. Subsurface drip irrigation can make a real difference in increasing yield and uniformity of a crop, while concurrently reducing water application. El-Ghamry and El-Shikha (2004) studied the effect of different irrigation systems on yield and growth of potato. Authors indicated that subsurface drip irrigation system proved its feasibility and applicability for irrigating potato crop. They found that a maximum fresh yield of 37.93 (Mg/ha) was obtained with the subsurface drip irrigation system. Bogle et al. (1989) compared subsurface trickle and furrow irrigation of fresh-market tomato (*Lycopersicon esculentum Mill.*). They found that marketable tomato yield was greater by 22% for plants irrigated with trickle irrigation system than with furrow irrigation. Also, they mentioned that total water amounts applied to furrow and trickle irrigated plots were approximately 100% and 45%, respectively, of pan evaporation (E_{pan}). Consequently, water-use efficiency was higher for the trickle irrigation.

Many experiments on the irrigation of potatoes have been accomplished based on the US Weather Service Class A pan evaporation, (Ferreira and Carr, 2002; Shalhevet et al., 1983; and Waddell et al., 1999). Under controlled environment, potatoes should be irrigated using pan evaporation factor more than 0.75 (Yuan et al, 2003).

A comparative study was conducted on the use of class A pan evaporation for estimation of potato crop water requirements under surface and subsurface drip irrigation systems. The objectives of this study were:

1. To check the possibility of using US Weather Service Class A pan evaporation for estimation of irrigation water requirement of potato.
2. To evaluate the potential for US Weather Service class A pan to improve water use efficiency.
3. To determine the optimal pan-crop coefficient (K_{cp}) value for surface and subsurface drip irrigated potato.

MATERIALS AND METHODS

The experiment was conducted from December 21 to May 7 of two consecutive years; 2004 and 2005, in Aga, Dakahlia Governorate that has a latitude of 31°03-N, a longitude of 31°23-E and an altitude of 7-m above sea level. The potato (*S. tuberosum*, cv. Spunta) grown was a variety that requires about 130 days to reach maturity. Potato seed pieces were hand cut to average weight of about 40-g per each seed piece, planted in December 21 for nursing the buds. Then they were transplanted to the field plots in January 1 at an average depth of 0.10 m below the soil surface in rows. The experimental soil was clayey loam with bulk and real densities of 1.20 and 2.65 g/m^3, respectively. Soil mechanical analysis was performed at the laboratory of the Soils Department at the University of Mansoura.

The distance between each two rows had an average value of 0.80-m and plants with 0.25-m spacing between plants in each row. The density of plants was five per each meter squared. The potatoes were planted on beds that were 0.25-m in high. There were eight treatments, which were combinations of two irrigation systems and four crop-pan coefficient (k_{cp}) values. Each treatment was replicated three times. In the experimental design, irrigation systems were the main plots. The four crop-pan coefficient (K_{cp}) values were in the sub-plots. Tap water was used for irrigation. Mineral fertilizer was applied at the recommended rates by the Egyptian Ministry of Agriculture.

All plant seedlings were emerged in soil by the 18th to 25th of January of each year. Mineral N fertilizer was applied uniformly to each of the surface and subsurface drip irrigation treatment using fertigation method.

Surface and subsurface drip systems were installed in the field January 3 to supply water to plants. The field was supplied with water through a 1-inch pipe that delivered the water to the manifold that was 3/4-in.-pipe. Twin-wall drip tapes, 8-m, were placed in the middle of each bed, about 0.25-m below bed surface. The tapes had an outlet spacing of 0.5-m. A flow meter was placed at the beginning of the 1-inch pipe main line to measure the amount of irrigation water.

Two pressure gauges were used to make sure that the operating pressure was within the recommended range. The pressure during irrigation time ranged from 1.0 to 1.5 bars. For the different treatments, irrigation began in January 16, weekly for both the subsurface and surface drip irrigation systems and ended in April 30.

The amount of water used was based on free surface evaporation from a class-A pan of the U.S. Weather Service. Irrigation treatments consisted of four plant-pan coefficients (Kcp1: 0.60; Kcp2: 0.80; Kcp3: 1.0, and Kcp4: 1.2). Therefore water applications were 0.6, 0.8, 1.0 and 1.2 times the cumulative pan evaporation measured within the irrigation interval of 7 days. The US Weather Service Class A pan is a shallow pan, containing water that is exposed to the evaporative influence of the climate. The water depth should be 5 to 7.5 cm below pan rim. It has a diameter of 121 cm, a depth of 25 cm and is placed 15 cm above the ground (Cuenca, 1989). The evaporation pan was easy to build and typically the material could be found locally. The principles of obtaining evaporation rates from the pan were as follows:

1. The pan was installed in the field 15 cm above the ground.
2. The pan was filled with water 5 cm below the rim.
3. The water was allowed to evaporate during a certain period of time, normally 24 hours.
4. The water depth was measured again after 24 hours.
5. The amount of water which was evaporated in a given time was equal to the difference between the two measured water depths.
6. This represented the pan evaporation rate (Epan) in mm/24 hours.

The application efficiency of the subsurface and surface drip irrigation systems was considered as 93%. For better germination percentage, a pre-planting one furrow irrigation at an amount of 100-mm was applied to all the experimental plots. The amounts of irrigation water applied for the surface and subsurface drip systems were listed in table 1.

Water use efficiencies of the two irrigation systems based on the fresh tuber yield (FTY) and biomass (B) were calculated using the following equations:

$$Water\ use\ efficiency_{FTY}\ (gram_{tuber} / Liter_{water}) = \frac{Fresh\ tuber\ yield\ (g/m^2)}{Applied\ \ irrigation\ \ water\ (L/m^2)}$$

$$Water\ use\ efficiency_{B}\ (gram_{biomass} / Liter_{water}) = \frac{Biomass\ (g/m^2)}{Applied\ \ irrigation\ \ water\ (L/m^2)}$$

Chlorophyll was estimated using chlorophyll meter (Minolta SPAD 502). The reading of chlorophyll meter was taken on the second leave from the tip of the plant (Yadava, 1986). Its principal is that it measures light transmitted through plant leaf at two bands; one in the red and the other in the near-infrared. The instrument uses the ratio of the light transmitted at these two bands to indicate relative amount of chlorophyll contained in the leaf. On the other hand, potato samples were collected for estimation of starch and protein at the laboratory of the Soils Department, University of Mansoura. The potato tubers were harvested in May 7. Fresh and dry tuber yields and aboveground biomass were estimated too.

The statistical analysis was done using Co-Stat software. The Least Significant Difference (L.S.D.) was used to determine the significance of difference among the values (Co-Stat software, 1991).

Table 1: Applied amounts of irrigation water (mm) under both subsurface and surface drip Irrigation systems.

Date	Irrigation water amounts			
	0.6Ep	0.8Ep	1.0Ep	1.2Ep
Pre-planting	100	100	100	100
16/01/2005	9	12	15	18
23/01/2005	10.14	13.52	16.9	20.28
30/01/2005	13.02	17.36	21.7	26.04
06/02/2005	12	16	20	24
13/02/2005	4.8	6.4	8	9.6
20/02/2005	12.54	16.72	20.9	25.08
27/02/2005	11.28	15.04	18.8	22.56
06/03/2005	13.74	18.32	22.9	27.48
13/03/2005	13.44	17.92	22.4	26.88
20/03/2005	14.34	19.12	23.9	28.68
27/03/2005	14.7	19.6	24.5	29.4
03/04/2005	15.9	21.2	26.5	31.8
10/04/2005	22.5	30	37.5	45
17/04/2005	21.48	28.64	35.8	42.96
24/04/2005	22.74	30.32	37.9	45.48
30/04/2005	24.36	32.48	40.6	48.72
Rainfall events	26	26	26	26
Total	361.98	440.64	519.3	597.96

RESULTS AND DISCUSSION

Crop parameters of potato such as total chlorophyll, starch, protein, fresh and dry tuber yields and aboveground biomass were estimated for both years and values were posted in Table 2. Results were statistically analyzed based on a split pot experimental design, and the results were listed in the same table. The Least significant difference was calculated for all the crop parameters at 0.05 and 0.01 significance levels and values were posted too. Nevertheless, for more clearly visual analysis, figures were developed individually for the yield and all the crop parameters of the experiment. Average values of the first and second years were used to develop these figures.

Table 2: Yield parameters of potato as affected by different irrigation systems and irrigation water amount

Treatments		Total Chlorophyll*	Starch in Tuber %	Protein in Tuber %	Fresh tuber Yield, gram/plant	Dry Tuber Yield gram/plant	Above ground biomass, gram/plant
First year							
Subsurface Drip irrigation	0.6ET	36.70	13.97	10.08	361.30	194.00	19.99
	0.8ET	45.25	13.48	12.81	753.00	397.45	28.97
	1.0ET	44.90	12.47	13.79	806.30	475.80	31.31
	1.2ET	48.10	12.41	15.53	864.00	489.20	38.35
Surface Drip Irrigation	0.6ET	37.50	14.29	9.77	348.15	189.60	19.52
	0.8ET	45.60	14.23	13.02	832.20	449.10	33.17
	1.0ET	46.00	13.91	13.95	842.70	459.58	32.10
	1.2ET	48.38	13 56	16.09	880.10	501.30	43.05
The statistical analysis							
Irrigation regime	Significance	**	**	**	**	**	**
	LSD 0.05	0.854	0.258	0.244	14.38	12.49	0.642
	LSD 0.01	1.244	0.376	0.355	20.92	18.90	0.933
Irrigation system	Significance	**	**	ns	**	*	**
	LSD 0.05	0.282	0.163	--	14.64	08.70	0.5
	LSD 0.01	0.427	0.247	--	22.17	12.65	0.758
Interaction of the two	Significance	Ns	*	*	*	**	**
	LSD 0.05	--	0.307	0.368	27.59	17.39	0.944
	LSD 0.01	--	0.447	0.535	40.14	25.31	1.373
Second year							
Subsurface Drip irrigation	0.6ET	38.1	14.10	10.31	377.60	205.30	20.79
	0.8ET	43.54	13.65	12.50	770.67	420.33	29.90
	1.0ET	45.60	12.69	13.58	797.87	466.47	32.21
	1.2ET	47.95	12.05	15.81	875.80	505.53	38.92
Surface Drip irrigation	0.6ET	36.83	14.62	10.19	359.67	211.60	19.85
	0.8ET	44.70	14.38	12.96	791.20	439 77	33.34
	1.0ET	45.82	13.42	13.84	839.03	450.80	32.60
	1.2ET	48.75	12.89	15.90	866.56	490.35	44.02
The statistical analysis							
Irrigation regime	Significance	**	**	**	**	**	**
	LSD 0.05	1.07	0.65	0.555	34.96	24.15	0.57
	LSD 0.01	1.56	0.95	0.808	50.86	36.53	0.84
Irrigation system	Significance	ns	**	ns	ns	ns	**
	LSD 0.05	--	0.24	--	--	--	0.64
	LSD 0.01	--	0.37	--	--	--	0.98
Interaction of the two	Significance	ns	*	ns	ns	ns	**
	LSD 0.05	--	0.45	--	--	--	0.94
	LSD 0.01	--	0.66	--	--	--	1.37

*Minolta SPAD Chlorophyll meter reading

Total chlorophyll content

Total chlorophyll content, meter reading, was illustrated in Figure 1. There was a clear increase of the total chlorophyll content with increasing the irrigation water application. The magnitude of the increase in chlorophyll content as irrigation water increased from 60% to 80% of pan evaporation was almost three times that obtained as irrigation water amount increased from 80% to 120% of evaporated from the pan. The highest chlorophyll contents of the subsurface and surface irrigation systems were achieved with the 1.2Ep irrigation treatment. The surface drip system recorded higher chlorophyll content than the subsurface drip system; however, the difference was not significant at the 1.2Ep. No significant difference was seen between the 1.0Ep and the 0.8Ep irrigation water treatments. The best combination, based on highest chlorophyll content, was attained from using surface drip irrigation and the application of 120% of the evaporated from the class A pan.

Tuber starch content

Tuber starch content in percentage was demonstrated in Figure 2. There was a decreasing trend of the starch content in potato tubers with increasing the water application. The surface drip had higher starch content than the subsurface drip. The highest starch contents of the subsurface and surface irrigation systems were accomplished with the application of 60% of the evaporated water of the class A pan. In general, the starch content had a decreasing trend with the irrigation water amount. The difference was not significant between the starch contents of the 0.6Ep and 0.8Ep for both the surface and subsurface drip irrigated potato. Hence, the difference in starch content between the 0.6Ep and 0.8Ep of both drip system was not significant; the greatest combination was attained from using surface drip irrigation system and the application of 60-80% of the evaporated from the class A pan. The rationale behind decreasing the starch content with increasing the water application might be the potato specific gravity, the weight of potato divided by its volume, which tends to decrease with increasing the irrigation water application as mentioned by Yuan et al. (2003). The decrease in specific weight and the relative increase in water content of potatoes as the irrigation water increased might have diluted their starch contents.

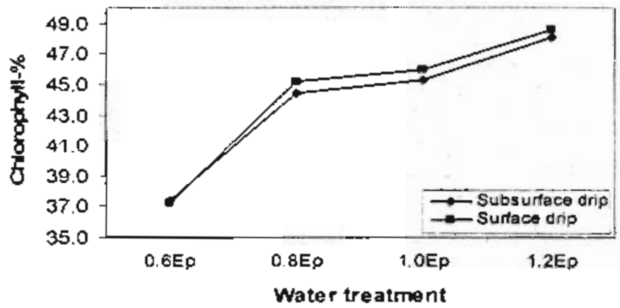

Figure 1: Percentage of chlorophyll in potato leaf as affected by irrigation systems and irrigation water amount.

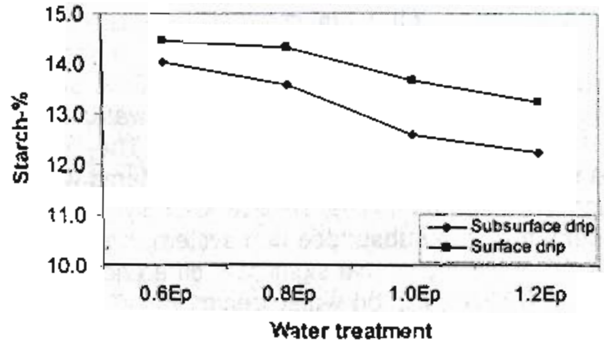

Figure 2: Percentage of starch in potato tuber as affected by irrigation systems and irrigation water amount.

Protein content in potato tuber

Tuber protein content was presented in Figure 3. The protein content in potato tuber, increased with increasing the amount of water application, which might be justified by its effect on increasing the availability of nitrogen and other nutrients. The highest protein content of the subsurface and surface drip irrigation systems were attained with the highest water application amount (1.2Ep). The surface drip irrigation system recorded higher protein content than the subsurface drip system; however, the differences between the two systems were not significant. The matchless combination, based on highest protein content, was attained from using surface drip irrigation and the application of 120% of the evaporated from the class A pan.

Fresh and dry tuber yield

Fresh and dry tuber yields, average of the two years, were represented in Figure 4. Increasing the irrigation water increased both the fresh and dry tuber yields. The surface drip system had higher fresh and dry yield values over the subsurface drip for all the irrigation amount treatments except for the 1.0Ep. At which, the surface drip system indicated lower dry tuber yield. The differences in fresh and dry tuber yield, among the different water regimes, were significant except for the differences between the 0.8Ep and 1.0Ep for the surface system, which were not significant. The highest fresh tuber yield was 873.30 g/plant, which was associated with the use of surface drip system and the 1.2Ep treatment. On the other hand, the maximum dry tuber yield was 497.40 g/plant, which was attained with the application of 120% of the evaporated water of the class A pan using the subsurface drip irrigation system. The surface drip irrigation system recorded the second highest dry tuber yield, no significant difference, at the same water application. The most excellent combination, based on highest fresh and dry tuber yields, was achieved from using surface drip irrigation and the application of 120% of the evaporated from the class A pan.

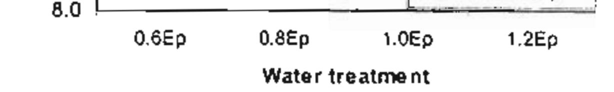

Figure 3: Percentage of protein content in potato tubers as affected by irrigation systems and irrigation water amount.

Above ground biomass

The above ground biomass was plotted in figure 5. Similar to the tuber yield, the surface drip system recorded higher above ground biomass; nevertheless, the differences between the two systems were not significant only at water application of 0.6 of the evaporated water of class A pan. Also, the above ground biomass increased, significantly, as the irrigation water amount increased. The incomparable combination, based on highest above ground biomass, was accomplished from using surface drip irrigation and the application of 120% of the evaporated from the class A pan. It resulted in an average above ground biomass value of 43.50 g/plant.

Pan evaporation

The measured pan evaporation values, average of the two years, were plotted versus the ones, average of the posted data of the two years, obtained from the Egyptian magazine of agricultural meteorology (Ministry of Agriculture; 2004, 2005) in Figure 6. The measured pan evaporation had fairly good agreement with the evaporation obtained from the weather station. The calculated correlation coefficient was 0.93. Since the measured data by the weather station was not available at the time of irrigation and as the construction and use of a class A pan was easy and not expensive, class A pan evaporation was preferable over any other water requirement estimation method. The average cumulative water applications of the two years for different treatments were plotted in Figure 7. It showed a typical increasing trend of the irrigation water amount with the day of year. Also, it indicated increasing the difference in irrigation water amount among the four treatments with the day of year, which was coherent since temperature had an increasing trend with the day of year.

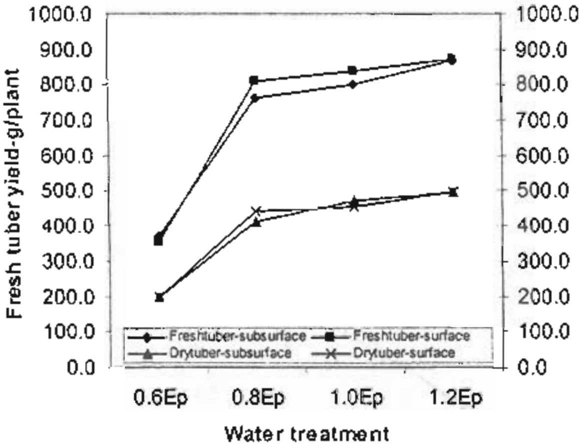

Figure 4: Fresh and dry tuber yield as affected by irrigation systems and irrigation water amount.

Water use efficiency

Water use efficiencies of both the fresh tuber yield and above ground biomass were illustrated in Figure 8. In general, the surface drip irrigation system had higher water use efficiencies than the subsurface drip system.

The lowest water application treatment resulted in the lowest water use efficiency values (tuber and biomass based) at no significant differences between the two systems due to the considerable decrease in yield that was associated with that specific water treatment. The maximum water use efficiencies, tuber and biomass based, were obtained with the application of 80% of the evaporated water of class A pan. After which, the water use efficiency decreased with increasing the water application for both the surface and subsurface irrigation systems. The unmatched combination, based on highest water use efficiency, was attained from using surface drip irrigation and the application of 80% of the evaporated from the class A pan.

Since the application of 120% of the evaporated water of US weather service class A pan resulted in the best yield and crop parameters, the average potato water requirement of the two years under the conditions of this experiment was 598-mm. That result agreed with the water requirement estimation by Shock and Feibert (2002) who estimated the water requirement of potato grown in eastern Oregon, United States of America, on a silt loam soil as 593-mm.

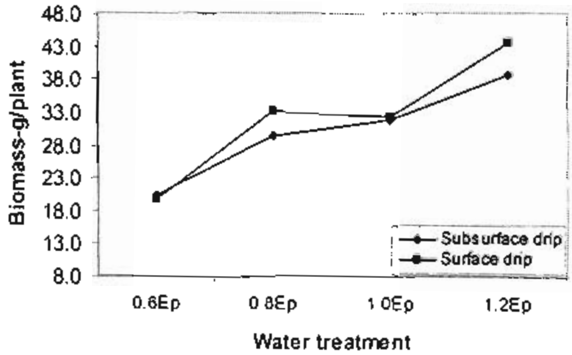

Figure 5: Above ground biomass as affected by irrigation systems and irrigation water amount.

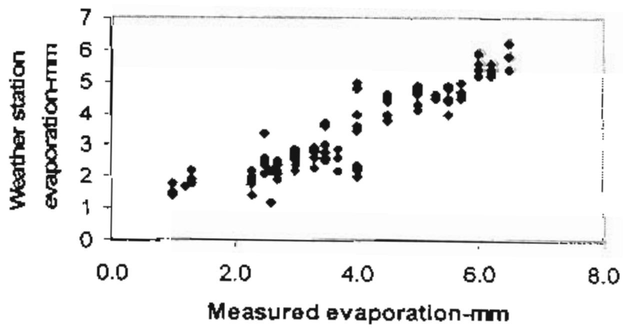

Figure 6: Measured pan evaporation values versus the ones obtained from the weather station of Dakahlia.

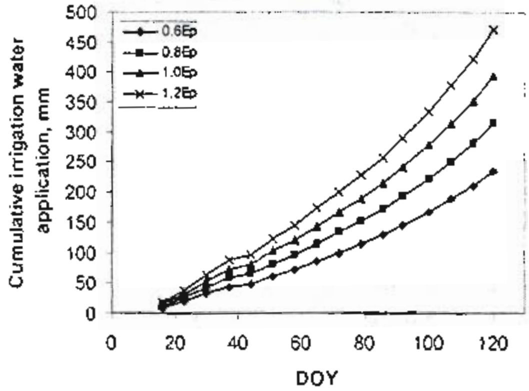

Figure 7: Cumulative irrigation water application for different treatments.

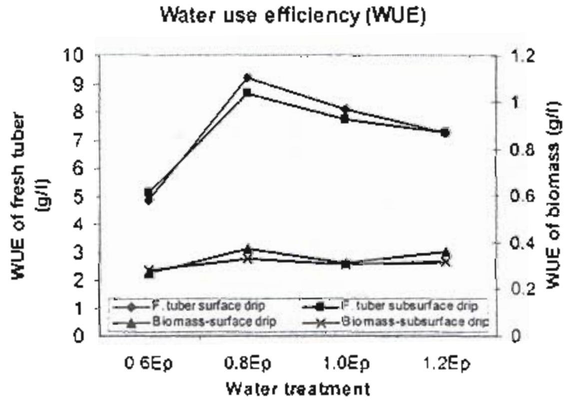

Figure 8: Water use efficiency (fresh tuber and biomass) as affected by different irrigation systems and irrigation water amount.

CONCLUSIONS

The use of surface drip irrigation and the application of 120% of the evaporated from the class A pan resulted in the highest chlorophyll content. In regards to the starch content in tubers, it had a decreasing trend with increasing the irrigation water application. The use of surface drip irrigation and the application of 120% of the evaporated from the class A pan resulted in the highest protein content.

The highest fresh tuber yield was related to the use of surface drip irrigation system and the application of 120% of class A pan evaporation. Also, the maximum dry tuber yield was obtained from using the subsurface drip irrigation system and applying 120% of the evaporated water of class A pan. The measured evaporation using class A pan agreed with pan evaporation data reported by the weather station of Dakahlia. Water use efficiency was maximized with the surface drip irrigation system and the application of 80% of the evaporated water of the class A pan.

Similar to the fresh tuber yield, the peak above ground biomass was attained from the use of surface drip irrigation systems and an application of 120% of the evaporated water of the class A pan.

In summary, the surface drip irrigation system gave higher values of yield and most of the crop parameters that were measured in this experiment. However, the subsurface system resulted in the highest dry tuber yield and the second highest fresh tuber yield, at no significant difference, at the same water application. Although, the application of 120% of the class A pan evaporation resulted in the highest yield, the highest water use efficiency was associated with the application of 80% of class A pan evaporation. After which, the water use efficiency had a decreasing trend with increasing the water application.

Therefore, weather service class A pan proved its success in determination of water requirements of potato crop under Egyptian conditions. Based on the measured yield parameters, the optimum Kcp value was the 1.2. Consequently, the equivalent potato water requirement under the experimental conditions was 598-mm.

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تأثير كمية الميـــاه و نظم الري المختلفة على نمو ومحصول البطاطس

ضياء الدين محمد الشيخة

قسم الهندسة الزراعية – كليـــة الزراعة– جامعة المنصورة– مصر

يعد تأثير كمية المياه و نظم الري المختلفة من أهم العوامل المؤثرة على نمو ومحـــصول البطاطس. لذلك فقد أجريت تجربة حقلية في تربة طينية بمزرعة بمركز أجاء محافظة الدقهليـــة، خلال السنتين ٢٠٠٤ و ٢٠٠٥.و تهدف هذه التجربة إلى دراسة نظامين للري (التنقـيط التحــت سطحي و التنقيط السطحي) وأربعة كميات من مياه الري و هي ٠,٦ و ٠,٨ و ١,٠ و ١,٢ مـــن قيمة البخر المقدر باستخدام حوض البخر الأمريكي (أ). وقد أوضحت النتائج أن اســتخدام نظـــام الري بالتنقيط السطحي مع إضافة كمية مياه ري مقدارها ١٢٠% من المقدرة بإســتخدام حــوض البخر قد أعطت أعلي متوسط لمحصول السنتين (٨٧٣,٣ جرام للنبات) و أحسن نمـــو خـــضري للبطاطس. بينما كانت أعلي كفاءة لإستخدام المياه مرتبطة بإضافة ٨٠% فقط من المقدرة بإستخدام حوض البخر. كما أشارت النتائج إلي إمكانية إستخداماحواض البخر لتقدير الإحتياجات المائيـــة لمحصول البطاطس. مما سبق يتضح أن أنسب قيمة لحاصل ضرب معامل المحصول و معامـــل حوض البخر هي ١,٢.