Bulgarian Journal of Agricultural Science, 19 (No 1) 2013, 87-95
Agricultural Academy

THE EFFECTS OF DIFFERENT REGIMES ON POTATO (*SOLANUM TUBEROSUM* L. *HERMES*) YIELD AND QUALITY CHARACTERISTICS UNDER UNHEATED GREENHOUSE CONDITIONS

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Abstract

AYAS, S., 2013. The effects of different regimes on potato (*Solanum tuberosum* L. *Hermes*) yield and quality characteristics under unheated greenhouse conditions. *Bulg. J. Agric. Sci.,* 19: 87-95

The aim of this study was to determine the effect of deficit irrigation on yield for potato grown under unheated greenhouse condition. The research was carried out at the Agricultural Research Station of Yenişehir High School of Uludag University in Bursa, Turkey, in 2007. In the study, water was applied to tomato as 1.00, 0.75, 0.50, 0.25 and 0.00 % (as control) of evaporation from a Class A Pan corresponding to 2 day irrigation frequency. Irrigation water applied to crops ranged from 94 to 746 mm and water consumption ranged from 190 to 754 mm. The effect of irrigation water level on the yield, tuber heigth, diameter, weight, dry matter, starch matter, the tuber number per plant and plant height were found to be significant. The highest yield was 36 t ha^{-1}. Crop yield response factor (k_y) was found as 1.13. The highest values for water use efficiency (WUE) and irrigation water use efficiency (IWUE) were found to be 4.84 and 4.29 kg m^{-3} for the $K2_{cp}$ treatment. Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for potato irrigation by drip irrigation under unheated greenhouse condition.

Key words: Evapotranspiration, water use efficiency (WUE), yield and quality parameters, irrigation scheduling

Introduction

Greenhouse technology is a breakthrough in the agricultural production technology that integrates market driven quality parameters with the production system profits (Aldrich and Barto, 1989). In the present scenario of perpetual demand of vegetables and shrinking land holding drastically, protected cultivation or Greenhouse technology is the best alternative for using land and other resources more efficiently. Greenhouses are framed structures covered with transparent or translucent material and large enough to grow crops under partial or fully controlled environmental conditions to get maximum productivity and quality produce. Greenhouse cultivation is a steadily growing agricultural sector all over the world (Enoch and Enoch, 1999; Von Elsner et al., 2000). The type of structure primarily used in Turkey is the so-called Mediterranean greenhouse; low-cost, unheated plastic-covered structures and with soil-grown crops. At present, there are more than 50 countries supporting commercial crop cultivation in green house (Mahajan and Singh, 2006).

Irrigation scheduling involves preventing the soil water deficit from falling below some threshold level for a particular crop and soil condition. This may involve estimating the earliest date to permit efficient irrigation or the latest date to avoid the detrimental effects of water stress on the crop (Ritchie and Johnson, 1990). Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduces production.

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Approaches used to establish schedules for drip irrigation include estimates based on evapotranspiration (Bar-Yosef and Sagiv, 1982; McNeeish et al., 1985; Clough et al., 1990; Hartz, 1993), allowable soil-water depletion (Bogle et al., 1989). A widely adopted method for estimating crop consumptive water use (CWU) is the pan evaporation method, which relates evaporation from a Class A pan to CWU. These two quantities are related by what is called the pan coefficient *K*. Irrigation scheduling based on the pan coefficient *K* is one of the simplest methods where no sophisticated instrument is required. Precise values for *K* are often difficult to establish, given regional and site-specification, soil characteristics, crop physiology and cultural practices. Any recommended value of *K* for regional irrigation scheduling program must be high enough to prevent water stress arising from emergencies and specialized local situations, while remaining low enough for efficient water management (Yuan et al., 2003). Based on the US Weather Bureau Class A pan evaporation, many studies have been completed on the irrigation of potato (Panigrahi et al., 2001; Ferreira and Carr, 2002; Ayas and Korukcu, 2010) cucumber (Ayas and Demirtas, 2009), tomato (Locascio and Smajstrla, 1996), pepper (Demirtas and Ayas, 2009), lettuce (Yazgan et al., 2008), green bean (Buyukcangaz et al., 2008), onion (Ayas and Demirtas, 2009) and broccoli (Ayas et al., 2011).

The potato is sensitive to water deficiency in soil. Optimum yield is obtained when the utilizable water in soil is not over 30–50%. If it drops below 50% the available utilizable moisture, yield may decrease. While the potato is considerably affected by water deficiency during germination, tuber formation and tuber bulking periods, it is less sensitive to water during ripening and early vegetative periods. Among potato irrigation methods, furrow, sprinkler and drip irrigation methods are the most common ones. Under some circumstances, below ground drip irrigation systems may be used. However, furrow and sprinkler irrigation methods are the most common methods. Recently, drip irrigation method has become one of the irrigation methods that are used in potato irrigation (Önder and Önder, 2006). With the drip irrigation method, water and plant nutrient elements can be directly given to the plant through its root area, and this may affect the plant positively and increase the irrigation performance by holding water (Phene and Howell, 1984). Potato needs frequent-irrigation for a good growth and yield. Yield is considerably affected by storage quality, disease resistance, and the time, amount and frequency of irrigation (Bartoszuk, 1987).

The objective of this study was to determine the effect of irrigation water level on the yield, tuber heigth, diameter, weight, dry matter, starch matter, the number of tubers per plant and plant height daily and seasonal evapotranspiration, yield response factor (ky), irrigation water use efficiency (IWUE) and water use efficiency (WUE).

Materials and Methods

Field experiment was carried out under unheated greenhouse condition in Yenişehir-Bursa (40^{o}15'09''N latitude, 29^{o}38'43''E longitude and altitude of 225 m above mean sea level). A greenhouse with the size of 8 m x 30 m using plastic coverage placed in north-south direction was used for the experiment. Climate is hot and dry in summer's cold and rainy in winters. Annual mean rainfall and temperature are 482.9 mm and 13.6^{o}C, respectively. Average minimum temperature is 3.6^{o}C in December; maximum temperature is 23.3^{o}C in August (Anonymous, 2003). The soil of the experimental plot can be classified as sandy loam and the soil pH was 7.99-8.04. Some physical and chemical soil properties are given in Table 1.

Table 1
Some of chemical and physical properties of experimental field soil

Soil depth, cm	Γ, g cm^{-3}	Soil type	Field capacity, %	Wilting point, %	pH	Total salt, %	$CaCO_3$, %	Organic matter, %	Available, kg da^{-1}	
									P	K
0-30	1.34	SL	19.66	11.94	7.99	0.058	5.67	2.94	1.53	38.35
30-60	1.37	SL	17.26	9.98	8.04	0.051	8.49	1.39	1.24	19.52

γ :Unit weight of soil, SL:Sandy loam, P: Phosphorus, K: Potassium.

15–15–15 NPK fertilizer was applied to experimental plots while the potatoes were being planted, and 75 kg of fertilizer per one thousand square meters were utilized. Rest of the nitrogen that had to be applied was given to the plots in the form of urea together with the irrigation water. The first half of the urea was applied as 25 kg per one thousand square meters (% 46 N) in the tuber formation period and the second half was applied as 25 kg per 26 a thousand square meters in the tuber-bulking period together with the irrigation water. Additionally, in both of the years, 25 kg of magnesium nitrate fertilizer per one thousand square meters (11 – 0 – 0 + 16 MgO - Nitrogen % 11 and MgO % 16) were utilized in the tuber formation and bulking periods in order to support the generative development. The experimental area was chlorphtifos-ethyl sprayed 10 L ha^{-1} to the experimental area for insects.

Potato tubers were transplanted to the plots (15 March 2007). The plants were grown 0.40 m apart between the rows with 0.70 m spacing in each row. Each plot has contained 36 plants. In order to prevent the water in any one plot from affecting its neighboring plots, only the 10 plants of middle row were harvested. Tuber heigth (cm), diameter (cm) (two repetition in both east-west and north-south directions) and plant hight (cm) were measured by caliper rule and calculated as the average of measured values. Average tuber weight was calculated by weighing 10 tubers in the harvest plot and average tuber diameter and tuber size were found by measuring the weighed potatoes with a diameter scale/ruler and by taking the average of these values. At first, the damp weight of the samples taken from the harvest plot was found, then the dry weight of these samples was found after they were separated and dried at 65ºC in a forced – air oven for 48 hours and in the end, tuber dry matter was calculated. Dry matter of tubers was determined by the Kjeldahl method (AOAC, 2000). Tuber starch was found by having them dissolved in hydraulic acid and by using a poly meter (Özkaya and Kahveci, 1990). The tuber number per plant was calculated with the count of the tubers in the harvest plot.

The layout of the experiment was a completely randomized block design with three replications for each of the five irrigation treatments tested. However, replications have been distributed to the random blocks in such a way that following same range in three blocks not to disturb the existing irrigation system. Irrigation treatments consist of five different crop pan coefficients ($K1_{cp}$:1.00, $K2_{cp}$:0.75, $K3_{cp}$:0.50, $K4_{cp}$:0.25, $K5_{cp}$:0.00-control). The amount of irrigation water was calculated by using the equation given below:

$$IW = E_{pan} \times K_{cp} \times P,$$

where E_p is the cumulative evaporation for the 2-day irrigation interval (mm) and K_{cp} is the coefficient of pan evaporation and P is the percentage of wetted area. Evaporation between the irrigation intervals was measured with US Weather Bureau Class A pan located in the center of greenhouse. Irrigation water was applied in the 2-day frequency and drip irrigation method was used. Required irrigation water was measured by flow meter device at the head of each plot.

Irrigation water was supplied from a deep well (3 L s^{-1}) drilled in the area. Quality properties of irrigation water are given in Table 2. The water is placed in C_2S_1 class with low sodium risk, medium EC value. Since there is no recorded problem with water quality, it is well suited for irrigation.

Crop evapotranspiration (ET_c) was estimated using the following form of the water balance equation:

$$ET_c=(SWC_{t0} – SWC_{t1}) + IW – D,$$

where (SWC_{t0} – SWC_{t1}) is the change in volumetric soil water content between two measurement dates; IW and *D* are respectively the total volumes of applied irrigation water and collected drainage for the period under

Table 2
Chemical composition of irrigation water used in the experiment

Water source	$EC_{25}x(10^6)$	Na^+	K^+	Ca^{++}	Mg^{++}	pH	Class	SAR
		me L^{-1}						
Deep well	715	2.3	2.56	9.25	5.7	7.12	C_2S_1	0.85

consideration. The water content of plant root depth (0.60 m) was determined by gravimetric method before irrigation aater application Lorenz and Maynard (1980) and monitored in 30 cm depth increments to 0.90 m after irrigation for each irrigation treatments. Monitoring the soil water content in the plots revealed that deep percolation below 0.60 m depth was negligible.

In this study, the Stewart model has contributed to define the relationships between yield and ET (Doorenbos and Kassam, 1979).

$$(1-Y_a / Y_m)= k_y (1-ET_a / ET_m)$$

where Y_a is the actual yield (t ha^{-1}), Y_m is the maximum yield (t ha^{-1}), ET_a is the actual evapotranspiration (mm) and ET_m is the maximum evapotranspiration (mm). Values of k_y indicate the response factor of potato to deficit irrigation. The water use efficiency (WUE) was determined to evaluate the productivity of irrigation in the treatments. WUE and irrigation water use efficiency (IWUE) are two terms used to promote the efficient use of irrigation water at the crop production level. WUE was calculated as the ratio of yield (YLD) to ET_a, given as WUE = YLD/ET_a (kg m^{-3}). IWUE was estimated by following equation.

$$IWUE(kg\ m^{-3}) = \frac{YLD - YLD_{rainfed}}{IRGA},$$

where $YLD_{rainfed}$ is the yield obtained from the rainfed treatment or dryland yield and IRGA is the seasonal irrigation amount used in millimeter.

In the harvest time, 130 days after the potato tubers were (day of year (DOY) 130) transplanted; the plants were fully developed and had the diameter, height, weight, colour and the flavour characteristics of the species. Harvested tubers from each plot were evaluated immediately according to yield, tuber heigth, diameter, weight, dry matter, starch matter, the tuber number per plant and plant hight.

Analysis of variance was performed on yield and yield component data using the MSTAT-C (version 2.1-Michigan State University 1991) and MINITAB (University of Texas at Austin) software. The significance of irrigation treatments were determined at the 0.05 and 0.01 probability levels, by the F-test (Stell and Torrie, 1980).

Results

Water applied and water used: After planting, 90 mm irrigation water was applied to some treatments to bring the soil water content in 0–60 cm soil depth up to level of field capacity. Irrigation treatments were started measuring of evaporation from Class A pan after the first irrigation application. The maximum amount of water applied to the crop was 746 mm in the $K1_{cp}$ treatment while the minimum amount was 94 mm in the $K5_{cp}$ treatment during the experimental year. The amount of water applied to other treatments ranged between 560–187 mm values. Seasonal evapotranspiration (ET_a) was increased with the applied irrigation water. The actual evapotranspiration ranged between 190 mm to 754 mm for $K5_{cp}$ and $K1_{cp}$ treatments, respectively (Table 3).

Linear relationships were observed between the crop evapotranspiration (ET_c) with yield (Y_a) and irrigation water (IW) with yield (Y_a). The equation for the relationship was $Y_a = 0.0553ET_c - 5.316$ with R^2=0.99 and $Y_a = 0.0476IW - 1.738$ with R^2 =99 (Figure 1).

In our study, treatment $K1_{cp}$ had the highest yield 36 t ha^{-1} followed by $K2_{cp}$, $K3_{cp}$, and $K4_{cp}$ irrigation treatments with 30 t ha^{-1}, 20 t ha^{-1} and 10 t ha^{-1}, respectively.

Table 3
Relationship between the decrease in relative water use and decrease in relative yield and yield response factor for potato irrigated by a drip system

Irrigation treatment	Yield, t ha^{-1}	Applied water, mm	ETa, mm	ET_a/ET_m	Y_a/Y_m	$1-(ET_a/ET_m)$	$1-(Y_a/Y_m)$	k_y
$K1_{cp}$	36	746	754	1.000	1.000	0.000	0.000	0.000
$K2_{cp}$	30	560	620	0.822	0.833	0.178	0.167	0.938
$K3_{cp}$	20	373	464	0.615	0.556	0.385	0.444	1.156
$K4_{cp}$	10	187	296	0.393	0.278	0.607	0.722	1.189
$K5_{cp}$	6	94	190	0.252	0.167	0.748	0.833	1.114

As expected, non-irrigated control $K5_{cp}$ had the lowest yield (6 t ha^{-1}).

Water deficits, particulary in the three or four week prior to harvest, lower crop yields and quality. Deficit irrigation had a significant effect on tuber weigth, while the values of $K1_{cp}$ and $K2_{cp}$ were in the same group, $K3_{cp}$, $K4_{cp}$ and $K5_{cp}$ treatments were placed in different groups. It can be concluded that the deficit of applied irrigation water (25%) is not compatible with the reduction in fruit diameter (Table 4). Positive linear relation was found among tuber heigth, diameter, weight, the tuber number per plant and plant height negative linear relation was found between dry matter and starch matter and amount of water applied (IW). The equation for the relationship was *tuber heigth* = $0.0056IW + 3.545$ with $R^2 = 0.97$ (Figure 2a), *tuber diameter* = $0.0061IW + 2.790$ with $R^2 = 0.95$ (Figure 2b), *tuber weight* = $0.1695IW - 67.375$ with $R^2 = 0.97$ (Figure 2c), *dry matter* = $-0.0143IW + 20.188$ with $R^2 = 0.98$ (Figure 2d), *starch matter* = $-0.0147IW + 19.257$ with $R^2 = 0.96$ (Figure 2e), *the tuber number per plant* = $0.0067IW + 2.759$ with $R^2 = 0.94$ (Figure 2f) and *plant height* = $0.0524IW + 30.380$ with $R^2 = 0.98$ (Figure 2g) treatments.

Crop yield response factor (k_y): Crop yield response factor (k_y) indicates a linear relationship between the decrease in relative water consumption and the decrease in relative yield. It shows the response of yield with respect to the decrease in water consumption. In other words, it explains the decrease in yield caused by the per unit decrease in water consumption (Stewart et al., 1975; Doorenbos and Kassam, 1979). Seasonal yield response factor was determined as 1.13 for irriga-

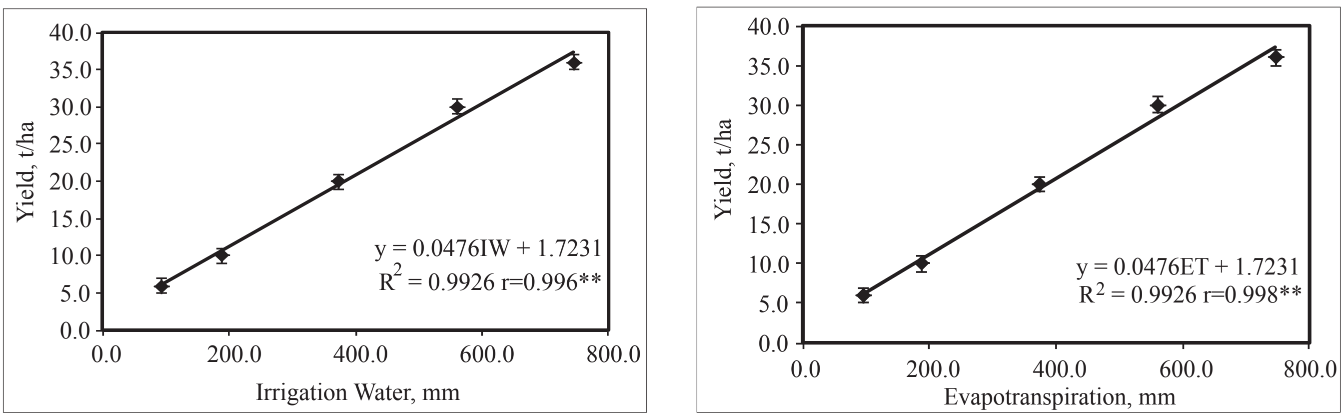

Fig. 1. The relationship between crop evapotranspiration with yield and water irrigation with yield. (The errors bars are SE of 10 plants)

Table 4
Effects of irrigation treatments on potato marketable parameters

Irrigation treatment	Tuber height, cm	Tuber diameter, cm	Tuber weight, g	Dry matter, %	Starch matter, %	The number of tubers per plant	Plant height, cm	Yield, t ha^{-1}
$K1_{CP}$	7.5a	7.0a	185a	9.0d	7.7d	7.5a	69.5a	36.0a
$K2_{CP}$	7.0ab	6.5a	172a	13.0c	12.2c	6.5ab	58.0b	30.0a
$K3_{CP}$	6.0abc	5.5ab	134b	15.0bc	13.3c	6.0ab	52.0b	20.0b
$K4_{CP}$	4.5bc	4.0bc	102c	17.0ab	15.8b	4.0bc	42.0c	10.0c
$K5_{CP}$	4.0c	3.0c	76d	19.0a	18.4a	3.0c	33.0c	6.0c
Treatments	**	**	**	**	**	**	**	**
Blocks	**	ns	ns	ns	ns	ns	ns	ns

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level, ns non-significant

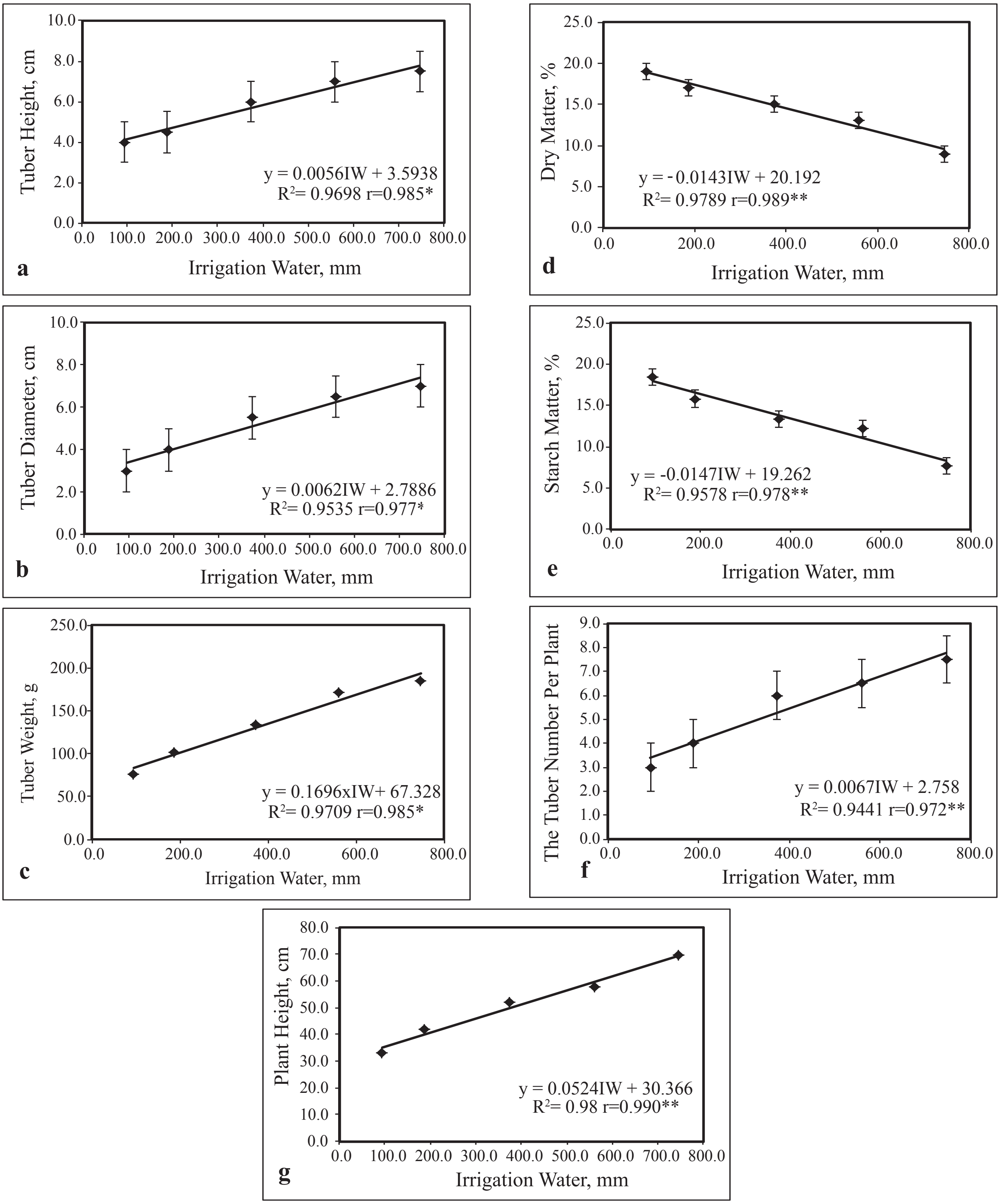

Fig. 2. Relationship between applied of irrigation water and tuber height (a), diameter (b), weight (c), dry matter (d), starch matter (e), the tuber number per plant (f) and plant height (g) (The errors bars are SE of 10 plants)

tion treatments (Figure 3). Values of k_y increased with increasing water deficit except in $K5_{cp}$.

Water use efficiencies: WUE and IWUE values decreased when irrigation water amount decreased. The highest WUE and IWUE were obtained from treatment $K2_{cp}$, 4.84 and 4.29 kg m^{-3} respectively. When considering IWUE values of $K1_{cp}$, $K3_{cp}$ and $K4_{cp}$ treatments, IWUE values of $K2_{cp}$ treatment was found higher than that of $K1_{cp}$ treatment and followed by $K3_{cp}$ (Table 5).

Discussion

In this study, irrigation treatments significantly affected yield, tuber height, diameter, weight, dry matter, starch matter, the tuber number per plant and plant

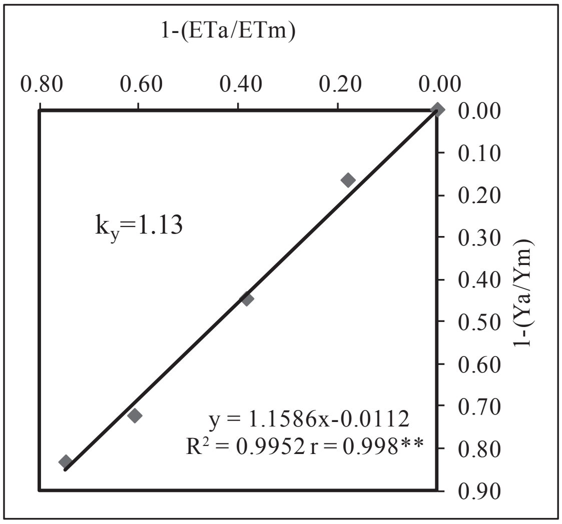

Fig. 3. Relationship between relaative yield decrease and relative crop evapotranspiration for potato throughout the total growing season

Table 5
Total water use efficiency (WUE) and irrigation water use efficiency (IWUE) values for potato irrigated by a drip system at different irrigation treatments

Irrigation treatment	Yield, t ha^{-1}	WUE, kg m^{-3}	IWUE, kg m^{-3}
$K1_{cp}$	36	4.77	4.02
$K2_{cp}$	30	4.84	4.29
$K3_{cp}$	20	4.31	3.75
$K4_{cp}$	10	3.38	2.14
$K5_{cp}$	6	3.16	0.00

height. The amount of water applied ranged between 560–187 mm values while the actual evapotranspiration ranged between 190 mm to 754 mm. Irrigation requirements of potato ranged between 500 and 700 mm (Önder and Önder, 2006). Fabeiro et al. (2001) reported that the total water received ranged from 319 to 659 mm. Water use of the potato crop ranged from 490 to 760 mm for sprinkler-irrigated plots and 565–830 mm for trickle-irrigated treatments (Ünlü et al., 2006). Erdem et al. (2006) reported that the water requirements of potato ranged between 464 mm and 683 mm and the highest seasonal evapotranspiration was measured for the 30% irrigation regimen treatment (D-IR2): 583 mm in 2003 and 488 mm in 2005 for drip irrigation. Ferreira and Carr (2002) investigated the potato's response to water and nitrogen rates and concluded that actual evapotranspiration (ET) of potato crops varied from 150 to 320 mm based on treatments in the first year, and from 190 to 550 mm in the second year. Early research reports that seasonal potato ET ranged from 350 to 800 mm for different climatic and environmental conditions (Doorenbos and Kassam, 1979; Panigrahi et al., 2001; Shock et al., 2003; Ünlü et al., 2006).

According to results, there was effect of deficit irrigation on tuber yield. Yield was significantly reduced as the amount of irrigation water decreased. The yield ranged from 6 t ha^{-1} to 36 t ha^{-1}. Faberio et al. (2001), in Spain, found that 597 mm irrigation water was required to reach maximum tuber yield 45.18 t ha^{-1}. Önder et al. (2005) determined that surface drip irrigation and subsurface drip irrigation methods did not significantly affect tuber yield under Turkey soil/climate conditions. Other researchers have also reported increased tuber yield with irrigation applications (Wolfe et al., 1983; Shock et al., 1998; Kashyap and Panda, 2003; Star et al., 2008; Kang et al., 2004).

The non-irrigated treatment ($K5_{cp}$) produced 500% lower yield than the $K1_{cp}$ treatment. However $K2_{cp}$, $K3_{cp}$, and $K4_{cp}$ had 20, 80, 260 % less yield compared with treatment $K1_{cp}$ (Table 4). In a similar study, it was found out that yield drops/losses are caused by deficit irrigation in different growth periods of the potato (Hassan et al., 2002). In the study, it was found out that that deficit irrigation has a significant effect on yield and quality parameters at P<0.01 level. These results are consistent with the information in the literature data (Haverkort et al., 1990; Karafyllidis et al., 1996; MacKerron and Jefferies, 1986; MacKerron and Jefferies, 1988; Ojala, 1990; Yuan et al., 2003).

The significant increases in dry matter were found as parallel to irrigation water deficit and the highest and lowest dry and starch matter were found at $K5_{cp}$ and $K1_{cp}$, respectively. This may be attributed to higher fruit weight observed from $K1_{cp}$ treatment than those of deficit irrigation treatments (Wadas et al., 2004). The tuber number per plant increased from 3.0 to 7.5. Similarity, Önder et al. (2005) reported that the number of tuber per plant was not significantly affected by irrigation methods. These results are similar to those of Patel and Rajput (2007), Lynch et al. (1995) and Erdem et al. (2006).

Conclusions

Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for potato irrigation by drip irrigation under the unheated greenhouse condition.

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Received February, 23, 2012; accepted for printing December, 2, 2012.