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Effects of deficit irrigation on the potato tuber development and quality

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Abstract

This study was conducted to determine the effects of deficit irrigation on tuber growth and quality of potato (*Solanum tuberosum* L.). Certified seeds of potato variety "*Agria"* were used as study material. Irrigation treatments was consisted of one irrigation interval (5 days) and five different levels (I_{100}, I_{85}, I_{70}, I_{55}, I_{40}) of soil water deficit measured before irrigations. First irrigation was applied by drip irrigation up to field capacity the soil water content in 0-60 cm depth in all treatments. Subsequent irrigations were applied according to the treatments.

The irrigation water and evapotranspiration (*ET*) values of treatments ranged from 243.0 to 311.9.4 mm and from 337.1 to 385.9 mm in the first year, respectively, and from 166.7 to 223.2 mm and from 204.0 to 255.7 mm in the second year, respectively. Yields varied from 30.85 to 47.13 t/ha in the first year and from 28.77 to 44.45 t/ha in the second year. The yields were decreased based on water deficit levels. The highest yields were obtained from I_{100}treatment.

The results have indicated that water restriction had a significant effect on yield, single tuber weight, percentage of marketable tuber, plant length, mean tuber length, mean tuber diameter and percentage of tuber peeling. The results were showing that the I_{100} treatment in especially was of the most importance for the highest percentage marketable tuber and tuber yield obtained per unit water applied. Therefore, the I_{100} treatment can be recommended for potato cultivation under similar climatic and soil conditions.

Keywords: Potato, drip irrigation, deficit irrigation

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Introduction

Potato cultivated in many countries of the world ranks as the fourth-most-important food crop, after wheat, corn and rice in terms of the amount produced. It is an essential food in the human diet with regard to carbohydrates, proteins, minerals and vitamins within which it includes. As it is usually consumed as fresh by boiling or frying, it is marketed after processing in various forms like canned food, frozen finger potato, chips, mashed, granules and powder in the industry in developed countries. It is also utilized in the production of livestock feed, starch, flour and alcohol as a byproduct (Onaran et al., 2000). Potato grown for early or off-season production plays a crucial role in the economy of several areas in the Mediterranean countries (Cantore et al., 2014).

The average potato production in the world a yearly 323 million tonnes and its production area is 20 million hectares and average yield per hectare is 17 tonnes. The five largest potato producers are China (33.9%, 87.3 million tons), India (11.4%, 41.5 million tons), the Russian Federation (8.1%, 29.5 million tons), Ukraine (6.4%, 23.3 million tons), and finally the United States (5.7%, 21.0 million tons) (FAOSTAT, 2014). Turkey ranks 13th with 4.8 million tons in potato production (Anon., 2014a).

Potato grows more densely in especially Afyon, Niğde and Nevşehir (Turkey) regions where temperate climate is dominant. These regions where potato production generally makes during the summer could be among the world's most fertile potato areas with their suitability of the soil structure (Vural et al., 2000).

The essential objective of irrigation is not only to enhance productivity in agricultural production, but also to boost the production, thereby maximizing net income by exploiting the water in an efficient manner in the long-term and without having negative effects on the environment and thus water resources. It is essential to convey and distribute the water in a way to minimize loss of water from its source and to control its amount in the soil regularly (Korukcu et al., 2007). Unconscious and inefficient use of water in the agriculture will lead to waste of scarce water resources and polluted the groundwater over time, thereby become drought in agricultural lands.

Potato is a crop highly sensitive to soil water deficits. To optimize yields, the total available soil water should not be depleted by more than 30 to 50%, and the soil should be maintained at a relatively high moisture content. Irrigation at 40% of field capacity (*Fc*) is adequate for seed grade tubers, while "processing/table" crops benefit from irrigation at 65% *Fc* (Doorenbos and Kassam, 1979; Van Loon, 1981).

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Potato plants are more productive and produce higher quality tubers when watered precisely using soil water tension than if they are under- or over irrigated (Ati et al., 2012).

The study was conducted to determine the effects of water deficits on the tuber growth and quality and the water consumption of potato grown under field conditions in Afyon where it is the largest potato cultivation area of Turkey.

Materials and Methods

Research area and climate

This study was carried out in a farmer's field in 246,5 m^2 situated in the Ihsaniye district of Afyonkarahisar Province in the Aegean region of Turkey. The experimental area is located between +39° 7'14.01" N latitude and +30° 23' 15.54" E longitude. The Ihsaniye has a characteristic of a plateau by all appearances (Anon., 2011).

Afyonkarahisar prevails a steppe climate with cold snowy winters and with hot and dry summers and with rain in the springs and autumns. The hottest and the coldest monthly average temperature was 22.3°C and 0.3°C, respectively. The total average rainfall was 416 mm (Anon., 2011). The average rainfall and water resources are limited in the potato growing season between April and August months.

Soil structure

Soil texture of experiment area is sandy-loamy (SL). The soil bulk density in depth of 0-60 cm varies between 1.08 and 1.28 gr/cm^3, water content at field capacity ranges from 20.49 to 17.68% by weight and wilting point varies between 11.36 and 9.87%. The available water holding capacity of soil is 59.57 mm 60 cm^{-1}.

Sowing and fertilizing

The experiment was carried out as a randomized complete block design with three replications. The experiment consisted of 15 plots. The potatoes were planted at a depth of 15 cm through sowing machine 39 potato seeds (13 seeds per row) in 3 rows with 5 m long, 35 cm intra row and 70 cm between rows in each experimental plot. *Agria* potato variety was used in the treatment. Per hectare were applied 150 kg of DAP (*Diammonium Phosphate)* fertilizer and 200 kg of AS (*Ammonium Sulfate*) fertilizer, considering soil analysis laboratory report. In both years, DAP fertilizer was applied before planting, and one half of AS fertilizer and its other half were implemented during first hoeing and first irrigation, respectively.

Irrigation water

Irrigation water was supplied from the main pipe near to experimental field. The analysis results indicated that water used in the experiment is in C_2S_1 class (sodium risk is low; EC is medium) and it can be used for irrigation (USSL, 1954).

Plots were irrigated by drip irrigation system, that it was composed of main pipeline, side pipelines (manifold) and laterals. Lateral pipes, which had inline drippers at 33 cm intervals, were 16 mm in diameter. Discharge of dripper was 4 L h^{-1} to 2 kPa pressure. The amount of irrigation water was checked by a volumetric meter.

The treatments were formed with five different levels of soil water deficit before irrigation, as explained below.

1- I_{100}: Irrigation up to field capacity of available soil water deficit before irrigation (K_1: 1.00)

2- I_{85}: Irrigation up to 85% of available soil water deficit before irrigation (K_2: 0.85)

3- I_{70}: Irrigation up to 70% of available soil water deficit before irrigation (K_3: 0.70)

4- I_{55}: Irrigation up to 55% of available soil water deficit before irrigation (K_4: 0.55)

5- I_{40}: Irrigation up to 40% of available soil water deficit before irrigation (K_5: 0.40)

Before the regular irrigations, all the treatments were irrigated until field capacity. Then, the subsequent irrigations were applied according to the prescribed program with 5-day intervals. The amount of irrigation water applied in the treatments was determined using Equation 1 and 2 (Ertek and Kara, 2013).

$$Ir = Wsd \times Kn \times A \quad (1)$$

$$Wsd = (Fc - WA) \quad (2)$$

Where, *Ir*– the irrigation water (liter); *Wsd*– soil water deficit before irrigation (mm); *Kn*– the deficit rate of water applied to treatments; *Fc*– field capacity (mm); *WA*– available soil water before irrigation (mm) and *A*– *p*lot area (m^2)

Water consumption by plants in all treatments was calculated using Equation 3 on the basis of the water budget. The soil water content was measured by gravimetric method during sowing, before each irrigation and in the last harvest (Allen et al., 1998).

$$ET = Ir + P + Cr - DP - RO \pm DSW \quad (3)$$

Where *ET*– plant water consumption (mm), *Ir*–irrigation water (mm), *P*– the precipitation (mm), *Cr*– the capillary rise (mm), *Dp*– the deep percolation losses (mm), *RO*– the runoff losses (mm), and *DSW*– the moisture stored in the soil profile (mm).

DP and *RO* values were neglected because irrigation was applied to field capacity by drip system. The groundwater problem in the experimental area was not available. Therefore, *Cr* was ignored (Kanber et al., 1993; Ertek et al., 2006). The effective rooting depth of the potato plant is about 60 cm and approximately 85% of the root length is concentrated in the upper 0.3-0.4 m of the soil (Efetha, 2011; Cantore et al., 2004). For this reason, the water consumptions (*ET*) were calculated for the soil layers at the depths of 0-30 cm and 30-60 cm.

Regression analysis was performed to determine the relationship between the yield obtained from treatments and irrigation water and plant water consumption. Furthermore, the water use-yield relationship was determined using the Stewart Model (Doorenbos and Kassam, 1979) (Eq. 4).

$$(1 - \frac{Y_a}{Y_m}) = Ky(1 - \frac{ET_a}{ET_m}) \quad (4)$$

Where Y_a– the real yield (kg ha^{-1}), Y_m– the maximum yield (kg ha^{-1}), ET_m– the maximum plant water consumption (mm), *Ky*– the yield-response factor for ET_a.

Water use efficiency, also expressed as rate of water use and used in comparing the irrigation methods or in evaluating the irrigation programs, was determined using the following Eq. 5 and 6 that were given by Tanner and Sinclair (1983) (Ertek et al. 2006).

$$WUE = \frac{Ey}{ET} \quad (5)$$

$$IWUE = \frac{Ey}{I} \quad (6)$$

Where *IWUE*: the irrigation water use efficiency (t ha^{-1} mm^{-1}), *WUE*: the water use efficiency (t $ha^{-1}mm^{-1}$), and *Ey*: the economical root yield (t ha^{-1}).

Plant observations and measurements

The edge rows of plots were not harvested to avoid the edge effect. The harvest was done in the middle row. Plant observations and measurements were performed on labelled plants in the middle row.

Statistical Analysis

The data obtained from the study were analyzed using Minitab® 16.2.4.packaged software.

Results and Discussion

Irrigation water and plant water consumption

First irrigation was applied up to field capacity the soil water content in 0-60 cm depth in all treatments. Then, the regular irrigation was started to on June 26, 2013 and July 11, 2014. The irrigations were ended on August 11, 2013 and August 25, 2014. All the plots were irrigated for 10 times at intervals of 5 days throughout the irrigation periods in both years.

The lowest and the highest values of irrigation water in 2013 and 2014 years were observed in I_{40} (243.0 mm, 166.7 mm) and I_{100} (311.9 mm, 223.2 mm) treatments, respectively. In both years, the highest water consumption was calculated as 385.9 mm and 255.7 mm in the I_{100} treatment, respectively, and the lowest values were determined as 337.1 mm and 204.0 mm in the I_{40} treatment, respectively. The *ET* values increased with increasing irrigation levels.

When analyzed the figures after and before irrigation, it can be seen that the soil water contents before irrigation didn't drop below the wilting point (WP) in all treatments during both years of the experiment (Figures 1 and 2). Furthermore, the soil water contents after irrigation was field capacity in I_{100} treatment.

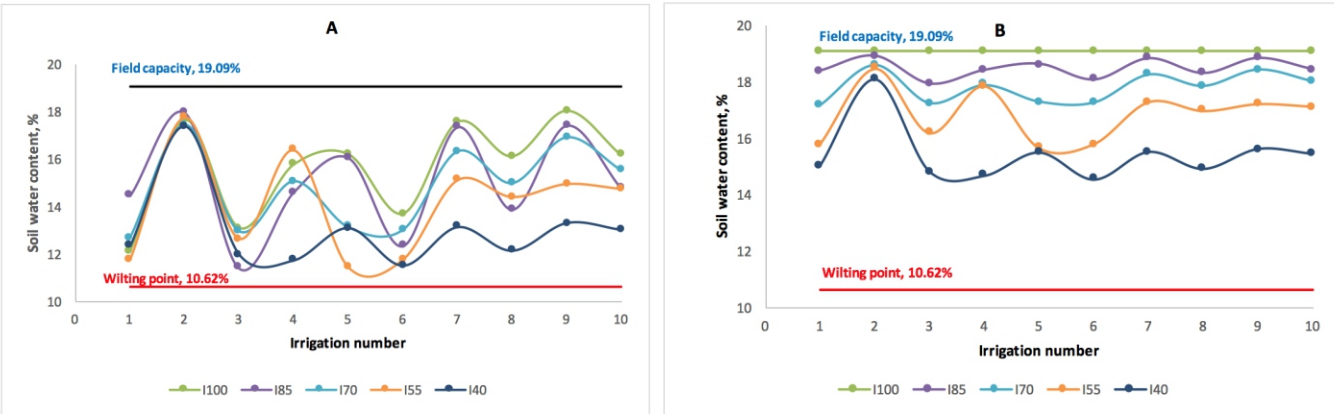

Figure 1. The soil water contents before (**A**) and after (**B**) irrigations during the growth season (2013)

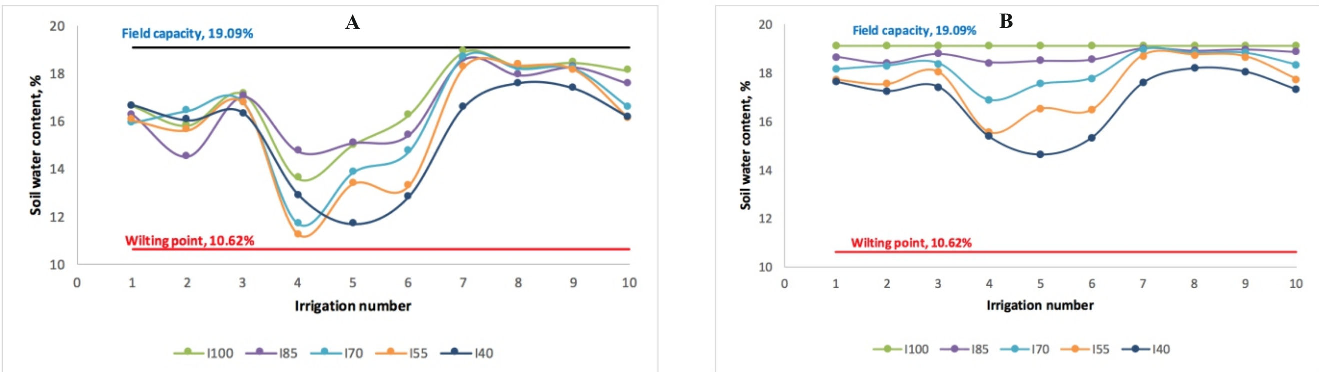

Figure 2. The soil water contents before (**A**) and (**B**) after irrigations during the growth season (2014)

In 2013, the highest and the lowest values of soil water content before irrigation reached at the 9th irrigation of I_{100} treatment by 18.05% and the 5th irrigation of I_{55} treatment by 11.45%, respectively. In 2014, the highest and the lowest values of soil water content before irrigation reached at the 7th irrigation of I_{100} treatment by 18.89% and the 4th irrigation of I_{55} treatment by 11.23%, respectively.

Some differences between years have been observed when analyzed the figures related to soil water contents before irrigations in the years 2013 and 2014. The soil water content in the second year of the study was higher than first year, as a result of local rainfalls, especially during August. Moreover, in both years of the trial, the soil water content before irrigation in the periods between 3rd and 7th irrigations were higher than the other irrigation periods. The reason is that this interval was corresponded to a period at which maximum plant growth and development occurred.

Similarly, the amount of irrigation water required for potato in the Baghdad–Iraq was determined as 300–338 mm by Ati et al. (2012). When compared with the research results of Ayas and Korukcu (2010), it is clear that there was a similarity with the values obtained in the first year of our study, and the values in the second year were lower. The differences can be attributed to the variations that have occurred in climatic conditions during the irrigation period.

Yield components

In both years of study, the yield, tuber starch ratio, tuber dry-matter content, marketable tuber ratio, tuber length, tuber diameter, tuber weight and number of tubers per crop were found to be the highest at I_{100} treatment.

The yield, marketable tuber ratio, tuber length, tuber diameter, tuber weight and number of tubers per crop were seen to be the lowest at I_{40} treatment (Table 1). The quality and yield parameters in both years were considerable similar to each other.

According to Tukey test results by means of two years, number of tubers per plant were statistically significant at the 1% level and divided into three different groups. Results obtained from this study were significantly similar to previous studies (Yilmaz et al., 1996; Tugay et al., 1997, Yilmaz and Tugay, 1999; Kiziloglu et al., 2006; Aksic, 2014).

It has been found that there was a statistically at 1% significance level between treatments in terms of tuber yield per hectare, tuber weight, tuber length, tuber diameter, marketable tuber ratio, tuber peeling ratio, tuber dry-matter content, tuber starch ratio, while was not statistically significant difference between 2013 and 2014 years. Moreover, the significant effect of irrigation regime on tuber yield was mainly due to the average tuber weight, tuber diameter and tuber length, because the differences in the number of tubers per plant were not significant.

Furthermore, graphical analysis of the relationship between tuber yield and water consumption of treatments has shown to be a statistically significant correlation in both years ($P<0.01$) (R^2: 0.98, 2013 and 0.94, 2014). The tuber yields per hectare from this study were higher than that from Yilmaz et al. (1996) and Tugay et al. (1997). It can be said that this might result from potato variety used and variation in the amount of precipitation between years. In addition, it is seen that tuber weights were higher than those from Yilmaz (1995), Yilmaz et al. (1996) and Yilmaz (1999), and similar to the values from Yilmaz et al. (2003) and Didin (1999).

In a study conducted by Kashyap and Panda (2003) in order to investigate the water-yield relationships in potato, it irrigates when water available in the soil consumes at the rate of 10, 30, 45, 60 and 75%. The study results showed that when falling at 60% and 75% levels of available water in soil, irrigation has caused a significant decline in the tuber yield. Furthermore, in a study conducted by Fakhari et al. (2013) were determined to be the higher potato tuber yields at higher irrigation levels. Mokh et al. (2015) stated that full irrigation regime resulted in the highest tuber yield under all nitrogen levels and there were significant reductions in total yield when applying smaller amounts of irrigation water.

It has been shown that the largest average tuber diameter from this study was greater than those from Ubeyitoğulları (2005) and smaller than those Didin (1999) and Ayas (2007). This can be due to differences between plant varieties used and annual rainfall. The tuber lengths from this study were similar to those from Didin (1999), Ubeyitoğulları (2005) and Ayas (2007).

The percentage of marketable tubers were indicated to be similar to those of a study carried out by Ayas (2007). However, the percentage of marketable tubers were higher when compared with the researches by Yilmaz et al. (1996). This might be attributable to the potato variety used and differences in amount of precipitation.

The tuber peeling ratios in the study were similar to research of Ubeyitoğulları (2005) and Didin (1999), and the average tuber dry-matter content was similar to Ubeyitoğulları (2005), Morales et al. (1992) and Didin (1999) and, however, higher than those worked out by Ertan (1980), Harada et al. (1985), Kara (1995), Yilmaz and Tugay (1999). This can be attributed to the potato varieties and to effective rainfall, especially during tuber development period.

It is clear that the average tuber starch ratio was similar to reported by Didin (1999), but higher than those reported by Ubeyitoğulları (2005), Ertan (1980), Harada et al. (1985) and Kara (1995). In a similar manner, this could also attribute to the potato variety cultivated and to effective rainfall, especially during tuber development period. The previous studies pointed out that the potato varieties and amount of rainfall were effectively on quality and yield of potato. Furthermore, Lynch and Tai (1989) stated that the differential tolerance to moisture stress among potato genotypes may be associated with differences in sensitivity during the ontogeny of yield development.

Generally, the *ky* values in the higher water applied treatments are higher than others. This situation shows that the unit water deficit in the higher water applied treatments will be caused higher yield decrease than other treatments. Yield response factors (*ky*) of treatments were 2.49 in the first year, 2.08 in the second year and 2.43 when both years were evaluated together. This indicates that yield might decrease 2.49 per one unit of water deficiency in the first year, 2.08 in the second year and 2.43 when both years were taking into consideration together (Figure 3).

Table 1. Variance analysis results related to some yield and quality components in the years 2013 and 2014

Treatments	Number of tuber per plant	Tuber weight (g)	Tuber diameter (mm)	Tuber length (mm)	Marketable tuber ratio (%)	Tuber peel ratio (%)	Tuber dry-matter ratio (%)	Tuber starch ratio (%)	Yield (t/ha)
2013									
I_{100}	11.9a	102.0a	64.4a	81.9a	95.0a	4.1bc	22.6ab	20.5a	44.45a
I_{85}	11.0a	94.8b	59.4ab	77.2a	86.7ab	3.6c	22.1ab	17.4a	43.89a
I_{70}	11.2a	87.3c	53.1bc	66.5b	80.0abc	3.6c	22.5ab	16.9a	36.70ab
I_{55}	11.8a	77.9d	53.9bc	63.0b	69.5bc	5.4ab	24.1a	18.2a	32.73b
I_{40}	10.8a	72.1d	45.8c	59.3b	61.7c	6.0a	20.7b	17.8a	28.77b
2014									
I_{100}	12.0a	104.2a	59.7a	72.7a	91.7a	3.6c	25.2b	14.7a	47.13a
I_{85}	11.8a	102.3a	57.2ab	73.8a	88.3ab	4.0bc	27.1a	16.8a	42.71ab
I_{70}	10.8a	95.4ab	56.0ab	71.1ab	83.3ab	4.6bc	28.2a	16.3a	40.02ab
I_{55}	11.0a	76.8ab	52.2bc	67.7ab	74.5bc	5.2ab	26.4ab	15.4a	32.23ab
I_{40}	10.7a	66.9b	49.1c	64.7b	63.3c	6.5a	27.8a	15.0a	30.85b

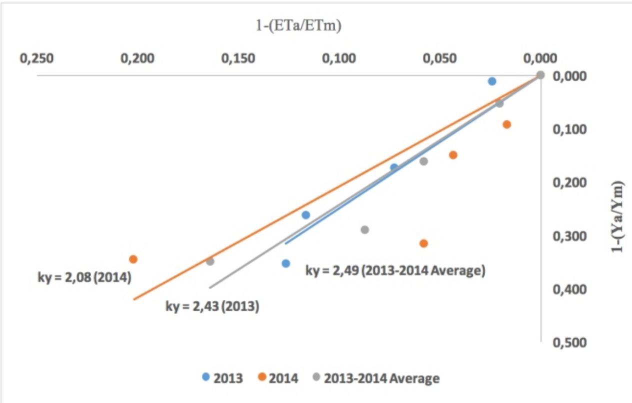

Figure 3. Relationship between deficit in seasonal water consumption and proportional reduction in yield.

Doorenbos and Kassam (1979) reported that effects on different plant species of the equal *ET* deficit during the entire growing season were different, and the seasonal *ET* deficit (*ky*<1) for crops such as peanut, grape, cotton and soybean caused less yield loss than the same *ET* restriction (*ky*>1) in crops like potato and pepper.

In both years, the highest values were obtained for the highest water consumption treatment. This is showing that potato is sensitive to water stress. The fact that yield-response factor (*ky*) values by years are very larger than 1 (one) also corroborates these results.

In both years, the highest and the lowest *IWUE* values were determined in I_{100} and I_{40} treatments, as 0.183 and 0.092 t ha^{-1}mm in first year and 0.283 and 0.138 t ha^{-1}mm in the second year, respectively. In the second years *IWUE* values were the higher than one in the first year (Table 2).

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In the first year, the highest and the lowest *WUE* values were determined in I_{85} and I_{40} treatments as 0.117 t ha^{-1}mm and 0.085 t ha^{-1}mm, respectively. During the second year, the highest and the lowest *WUE* were determined as 0.184 t ha^{-1} mm in I_{100} and 0.151 t ha^{-1}mm in I_{55} treatment, respectively. Due to the reduction in the yield per unit of water, the first year *WUE* and *IWUE* were lower than the value of the second year. The different effect of drought on *WUE* observed in different studies can be attributed to the level of water stress encountered by the crop (Cantore et al., 2014). Similarly, *WUE* values were determined as 0.081-0.098 t ha^{-1}mm for the highest and the lowest evapotranspiration treatments by Aksic et al. (2014). Furthermore, Wang et al. (2006) found that *WUE* was 0.103-0.132 t ha^{-1}mm in the conditions of North China Plain. It was closer to the values in our study.

The water use efficiencies and *ky* values in this study are indicated that the yield and quality of potato will be significantly affected by deficit irrigations. Early studies have shown that water is the most important limiting factor in potato production and it is possible to increase production levels by well-scheduled irrigation programs throughout the growing season (Shock et al., 1998; Shock et al., 2003; Yuan et al., 2003; Onder et al., 2005; Erdem, et al., 2006).

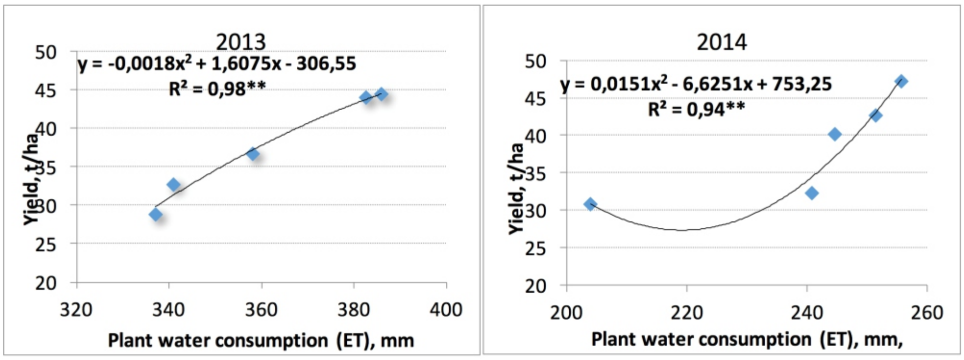

Figure 4. Relationship between water consumption and yield in 2013 and 2014

Table 2. Water use efficiencies

	2013		2014	
Treatments	***IWUE* (t /ha/ mm)**	***WUE* (t/ha/mm)**	***IWUE* (t /ha/ mm)**	***WUE* (t/ha/mm)**
I_{100}	0.183	0.115*	0.283	0.184*
I_{85}	0.167	0.117*	0.220	0.170
I_{70}	0.132	0.103	0.190	0.164
I_{55}	0.107	0.096	0.149	0.134
I_{40}	0.092	0.085	0.138	0.151

Conclusion

Results have indicated that the water stress were statistically significant effected on quality and yield components of potato such as yield per hectare, single tuber weight, percentage of marketable tuber, tuber length, tuber diameter, percentage of tuber peeling.

It can be said that potato yield and quality will occur considerable losses for soil water deficit in 70, 55 and 40%. The I_{85} and I_{100} treatment is more appropriate to prevent the loss of potato yield and quality. The results were showing that the I_{100} treatment in especially was of the most importance for the highest percentage marketable tuber and tuber yield obtained per unit water applied. Therefore, the I_{100} treatment can be recommended for potato cultivation under similar climatic and soil conditions.

As a conclusion, considering to the results of our and previous studies, it is clear that deficit irrigation is not suitable in the potato cultivation, because the profits from the reduced water applications cannot compensate for the income loss from the yield reduced.

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