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Water-Yield Relationships of Potato in Mediterranean Climatic Conditions

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ABSTRACT

This study was carried out in Isparta University of Applied Sciences, Faculty of Agriculture, Agricultural Research, and Application Farm in 2021 to determine the effect of different irrigation water levels on tuber yield and quality parameters of the Agria potato variety. Drip irrigation method was used in the study and five different irrigation water levels (S_1: 120% of the seven-day ET_o, S_2: 90% of the seven-day ET_o, S_3: 60% of the seven-day ET_o, S_4: 30% of the seven-day ET_o, S_5: No irrigation except germination and emergence) were determined based on the reference evapotranspiration (ET_o). Irrigation water (IW) amounts varied between 85.66-639.26 mm and evapotranspiration varied between 296.54-825.15 mm. Different amounts of IW significantly affected the vegetative growth, yield and quality parameters of potato. As irrigation water decreased, total tuber yield and marketable yield declined. Total tuber yield and marketable yield were 46.11 t/ha and 40.59 t/ha, respectively, in S_1 treatment where the maximum amount of IW was applied, while they were 12.96 t/ha and 6.37 t/ha, respectively, in S_5 treatment where no irrigation was applied. Logarithmic relationships were determined between evapotranspiration and total yield and between the amount of IW and total yield. Water use efficiency was determined between 43.69-55.88 kg/(ha×mm) and irrigation water use efficiency between 32.34-51.86 kg/(ha×mm) and yield response factor (ky) was calculated as 1.19.

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Introduction

Potato (*Solanum tuberosum* L.) plant is a member of the Solanacae and has total of 200 species of which 160-180 species can produce tubers. The origin and first cultivation region of potato, which is an annual crop, is the Alpine mountains. In the late 16th century, the Spaniards brought the potato plant to their own country from the Andes mountains in the South American region. Then it spread to England, Ireland, Scotland, other European countries and other countries of the world. Asian ranks first in potato production worldwide (Berksan, 2002). According to one view, the potato was introduced to Eastern Anatolia and the Black Sea Region via Russia and the Caucasus at the end of the 19th century (Er and Uranbey, 1998; IIisulu, 1957), while according to another view, potato cultivation may have started for the first time in the Sakarya region and then spread all over Türkiye (Berksan, 2002; Er and Uranbey, 1998).

Potatoes are grown in many countries due to its tolerance in terms of climatic requirements, and they have ability to be utilized in different ways, its cheapness, high yield per unit area, high nutritional value, ease of digestion, use in human and animal nutrition, and use in industrial starch production (İncekara, 1973). Thanks to these advantages, potato ranks 7th in the world after sugar cane, maize, rice, wheat and oil palm fruit in terms of the amount of product produced (FAO, 2021). As with other plants, one of the most important cultural practices in potatoes is irrigation. Frequent irrigation application significantly affects tuber yield in potatoes (Kashyap and Panda, 2003) and the highest tuber size is obtained from treatments without deficit irrigation during the ripening period (Fabeiro et al., 2001; Yuan et al., 2003). Similarly, the increase in plant water consumption in parallel with the applied irrigation water significantly incremented tuber yield (Bahramloo and Nasseri, 2010). In addition, when irrigation water is applied together with fertilizer, which is another important cultural practice, its efficiency and water use efficiency increases (Ünlü et al., 2006). Potato is a plant that responds differently in terms of yield according to different irrigation methods, irrigation programs and irrigation method operating methods (Yavuz et al., 2012; Gültekin and Ertek, 2018; Mubarak et al.,2018).

The aim of this study was to determine the effects of water consumption, irrigation water requirement, optimum irrigation program, tuber yield and quality parameters of Agria potato variety adapted to Isparta ecological conditions under sufficient and deficit irrigation.

Material and Method

The study was conducted in Isparta University of Applied Sciences, Faculty of Agriculture, Agricultural Research and Application Farm in 2021. The Isparta province, which has an area of 8933 km^2 in the north of the Mediterranean Region, is located between 30º 20' and 31º 33' longitudes and 37º 18' and 38º 30' north latitudes, and its average height above the sea level is 1050 meters (Anonymous, 2018). The long-term average precipitation of Isparta vary between 14.1 mm and 81 mm on a monthly basis. The highest average temperature was observed in July with 23.4°C, while the lowest temperature was observed in January with 1.8°C.

Agria was used as potato variety in the study. Agria potato variety is a medium late variety with white flower color, yellow skin color and flesh color, oval and elongated tuber shape. Agria is resistant to Y virus and moderately resistant to X virus. It is generally used in the fingerling potato and chips industry (Anonymous, 2022).

Soil and Climate Characteristics of the Research Area

According to the analysis results of the soil samples (0-30 cm, 30-60 cm) of the study area, the soil texture class was determined as clay loam (CL) in both layers. The field capacity was 29.10% (130.08 mm) and 27.73% (113.14 mm), the wilting point 16.85% (75.35 mm) and 17.43% (71.10 mm), available water holding capacity was 12.25% (54.76 mm) and 10.30% (42.03 mm) in 0-30 cm and 30-60 cm soil layers, respectively (Table 1).

The total rainfall measured in 2021 was 362 mm and the rainfall measured during the growing season was 134 mm. The highest average temperature was 24 °C in August and the lowest average temperature was 3.8 °C in February and December. The average relative humidity, on the other hand, was 83.6% and 36%, with the highest and lowest measured in January and August, respectively (Figure 1).

Table 1. Some characteristics of the soils in the study area

Characteristics	Unit	Soil depth, cm		
		0-30	30-60	0-60
Field capacity	%	29.10	27.73	
	mm	130.08	113.14	243.23
Wilting point	%	16.85	17.43	
	mm	75.35	71.1	146.44
Available water holding capacity	%	12.25	10.30	
	mm	54.76	42.03	96.79
Soil bulk density*	g/cm^3	1.49	1.36	
Clay	%	37.46	37.59	
Silt	%	37.08	37.21	
Sand	%	25.5	25.2	
Soil texture class		CL	CL	

* Ucar et al. (2020).

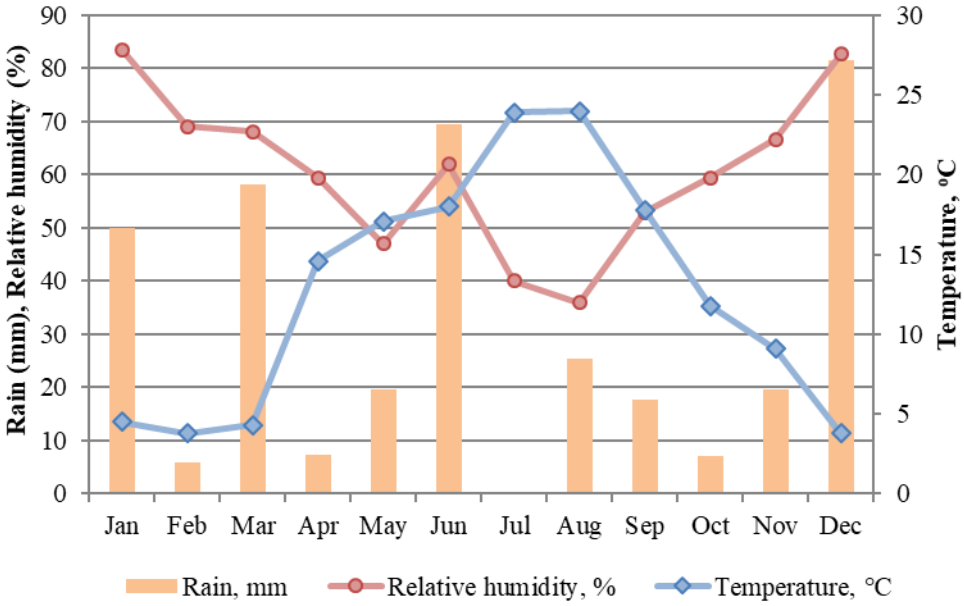

Figure 1. Some climate parameters of the trial area in 2021

Agricultural Practices

Before planting, pure 10 kg MAP (12-61-0) and 20 kg 15-15-15 compound fertilizer were applied per decare, then 30 kg Nitro Power (26% nitrogen) and 15 kg potassium nitrate (13-0-51) and potassium sulfate (0-0-51) fertilizers were applied at different stages of the development period. Insecticides were applied when potato pests were observed.

Tubers were planted on April 29 with a planting machine with 70 cm between rows and 30 cm above rows and harvested by hand on October 13. In the harvest, one row was left from each side of the plots and the remaining part was harvested.

Experimental Design

The study was carried out in three replications according to the randomized blocks design. A total of 15 parcels, each with an area of 21 m^2, were included in the experiment. The parcel length is 6 m and the parcel width is 3.5 m. Thus, the trial was carried out on a total area of 481 m^2. The irrigation interval was taken as seven days and five different irrigation water levels were created based on the reference evapotranspiration (ET_o) according to the Penman-Monteith method calculated by the meteorological station (Pessl Instruments. Metos 3.3) located 200 m away from the experiment area. Irrigation levels followed S_1: Application of 120% of the seven-day ET_o total as irrigation water, S_2: Application of 90% of the seven-day ET_o total as irrigation water, S_3: Application of 60% of the seven-day ET_o total as irrigation water, S_4: Application of 30% of the seven-day ET_o total as irrigation water, S_5: Rainfed conditions.

Irrigation Water (IW) Amount

Drip irrigation method was used in the study. The IW was applied by cumulative ET_o values calculated on daily basis, at 7-day intervals, according to the ratios specified in the trials by using equation 1. In the determination of the plant cover percentage, the plant crown with was measured before each irrigation and calculated according to equation 2 (Ertek and Kanber, 2001).

$$I=A \times Eto \times P \times R \quad (1)$$

$$P=(z/y) \times 100 \quad (2)$$

Where;

I: Irrigation water (liter), A: Plot area (m^2), ET_o: Total reference evapotranspiration (mm), P: Crop cover percentage (%), R: ET_o ratio, z: Plant crown (cm), y: Row spacing (cm)

Evapotranspiration (ET)

Effective root depth was taken as 60 cm in evapotranspiration calculations (Salimi et al., 2017). Before each irrigation, soil samples were taken from 0-30 cm, 30-60 cm soil layers. Evapotranspiration was calculated for 7-day periods using soil moisture values using equation 3 on the basis of water budget (James, 1988).

$$ET=I + P + Cp + -Dp \pm Rf \pm \Delta S \quad (3)$$

Where;

ET: Evapotranspiration (mm), I: Irrigation water amount (mm), P: Precipitation measured over a seven day period (mm), Dp: Deep percolation (mm), Cp: Capillary rise (mm), Rf: Surface runoff (mm) and ΔS: Change of water content in soil profile (mm).

Water-Yield Relationships

In determining the yield-response factor of potato, the following equation was used based on the Stewart model (Stewart et al., 1976; Doorenbos and Kassam, 1979).

$$ky= [1-(Y/Ym)]/[1-(ETa/ETm)] \quad (4)$$

Where;

ky: Yield response factor, Ya: Actual yield, (kg/da), Ym: Highest yield, (kg/da), ETa: Actual evapotranspiration, (mm), ETm: Maximum evapotranspiration, (mm).

Equation 5 and 6 as suggested by Howell et al., (1990) were used to calculate irrigation water use efficiency and water use efficiency.

$$IWUE=(Ey-Eyni)/I \quad (5)$$

$$WUE= Ey/ET \quad (6)$$

Where;

IWUE: Irrigation water use efficiency [kg/(ha×mm)], WUE: Water use efficiency [kg/(ha×mm)], E_y: Yield (kg/ha), E_{yni} : Yield obtained in rainfed conditions (kg/ha), I: Irrigation water (mm), ET: Evapotranspiration (mm).

Yield and Quality Parameters

Plant height (cm): In each replicate, in selected 10 plants, and their heights were measured and averaged to determine the plant height.

Number of main stem: When vegetative growth stopped, the main stems of 10 random plants were counted and averaged.

Leaf area index (LAI): Three plant samples were taken from each plot and measured with a leaf area meter and then the leaf area index was determined by proportioning the measured area to the plant crown area.

Number of tubers per plant: The number of tubers obtained from each plot after harvest was divided by the number of plants in that plot.

Tuber yield per plant (g/plant): Determined in g by dividing the total yield obtained from the harvested area by the number of plants in that area.

Average tuber weight (g): After harvesting, the average weights of the tubers in each plot were determined and the values obtained were divided by the number of tubers taken from each plant and determined as g.

Total tuber yield (t/ha): The tubers obtained from the plots were weighed and the unit area tuber yield was found by proportioning the obtained values to 1 ha surface area.

Marketable tuber yield (t/ha): The diameters of the harvested tubers were measured with the help of calipers and tubers with diameters larger than 3.5 cm were accepted as marketable tubers. The obtained tubers were weighed, and marketable tuber yield was calculated (Karadoğan, 1990).

Amorphous tuber ratio (%): It was calculated by weighing of the tubers showing amorphous development in each plot and proportioning them to the total tuber weight.

Cracked tuber ratio (%): It was calculated by weighing of the tubers showing tuber cracks in each plot and proportioning them to the total tuber weight.

Specific gravity (g/cm^3): Specific bulk density of tubers was determined by applying the air-water weighing method.

Starch content (%): Calculated using the following formula (Hassanpanah et al., 2011).

Starch (%) $= 17{,}546 + 119{,}07 \times (Specific\ gravity - 1{,}0988)$

Dry matter ratio (%): Tuber samples were cut into thin slices and dried in an oven at 78 °C until constant weight and the dry matter weights of the tubers were determined. Dry matter ratios of the tubers were calculated by proportioning dry weights to wet weight (Şenol, 1973).

%Brix: Determined using a refractometer.

Statistical Analysis

Variance analyzes of the data obtained from the study, which was carried out in triplicate according to the randomized plot design, "IBM SPSS Statistics 23.0" made with software. If the differences between the applications were significant, Duncan's multiple comparison tests was applied.

Results and Discussion

Irrigation Water (IW) Amount and Evapotranspiration (ET)

A total of 85.66 mm of IW was applied during the 45 days after planting (DAP). After DAP 45 (when the plants reached 5-7 cm height), the irrigation programs were started. During the growing season, a total of 639.3 mm, 503.3 mm, 364.1 mm, 224.9 mm and 85.7 mm IW was applied to S_1, S_2, S_3, S_4 and S_5 treatments, respectively (Figure 2). In Bursa, Ayas and Korukçu (2010) applied 316-535 mm IW to the Hermes potato cultivar at different growth stages, while Önder et al. (2015) applied 274 mm, 182 mm, 91.5 mm, and 0 mm with surface drip irrigation method and 285 mm, 189 mm, 95 mm and 0 mm with subsurface drip irrigation method in Hatay. On the other hand, Camargo et al. (2015) stated that 796.30 mm, 694.65 mm, 581.15 mm, and 473.35 mm of IW was applied according to different irrigation subjects (60%, 80%, 100%, and 120% of plant water requirement) in the Agria potato variety. As can be understood from the previous studies, the amount of IW applied varies depending on regions where the potatoes are grown, the potato variety used, the irrigation method used in irrigation, and the irrigation program changes.

The difference in the amount of IW applied caused a difference in ET. The highest ET was measured in S_1 (825.2 mm), where 12 times the ET_o was applied, while the lowest ET was measured in S_5 (296.5 mm), where no IW was applied after the plants reached 5-7 cm. ET in S_2, S_3 and S_4 were 699.3 mm, 567.4 mm and 443.1 mm, respectively (Figure 2). According to the treatments, 74.07 mm of the measured ET was measured before the irrigation programs. Fabeiro et al. (2001) measured the maximum ET of Agria as 659 mm in Spain, while Gültekin and Ertek (2018) reported that it varied between 337.12-385.91 mm in Afyonkarahisar. Yavuz et al. (2012) determined the average ET as 670.2 mm, 618.3 mm and 572.2 mm in sprinkler, furrow, and drip irrigation methods, respectively. In another method comparison was conducted by Akram et al. (2020), ET was measured as 562 mm in furrow irrigation method and 374 mm in drip irrigation method. In Bursa, Ayaş and Korukçu (2010) reported that ET was measured between 385-651 mm under deficit water conditions applied at different growing periods. Önder et al. (2015) stated that ET between 453-714 mm in sweet potato cultivar according to the treatments, while Karataş (2018) reported it as 826.45 mm in Beniazuma sweet potato cultivar and 808 mm in Koganesengan sweet potato cultivar. As it can be seen from previous studies, ET varies according to the variety, growing region and irrigation method. It is seen that the ET of our study are slightly higher than the ET values of Agria potato in previous studies. While the long-term temperature in May, July and August in the study area were 15.5°C, 23.4°C and 23.3°C, the average temperature values in these months in the trial year were 17.1°C, 23.9°C and 24.0°C. It is thought that this increase in the average temperature values in the experimental year has an increasing effect on ET.

Tuber Yield and Quality Parameters

Statistical results showed that the IW had a similar effect on both the vegetative and generative aspects of potato. Vegetative parameters including plant height, number of main stems, and LAI statistically affected (P<0.01) by IW amount and varied between 48.43-70.76 cm, 2.83-4.47, and 1.00-3.03, respectively (Table 2).

Table 2. Tuber yield and quality parameters (P<0.05)

Parameters	F	Treatments				
		S_1	S_2	S_3	S_4	S_5
Plant height (cm)	86.626**	70.67^a	66.87^b	63.53^c	57.03^d	48.43^e
Number of main stems	156.679**	4.47^a	4.20^b	3.77^c	3.10^d	2.83^e
Leaf area index	181.526**	3.03^a	2.65^b	2.32^c	1.31^d	1.00^e
Number of tubers per plant	3.679*	8.04^a	6.72^{ab}	6.60^{ab}	6.08^b	5.39^b
Tuber yield per plant (g/plant)	87.785**	1089.3^a	854.28^b	660.82^c	475.50^d	304.27^e
Average tuber weight (g)	44.823**	135.71^a	12810^a	93.18^b	78.28^b	58.01^c
Total tuber yield (t/ha)	84.604**	46.11^a	36.16^b	26.47^c	20.23^d	12.96^e
Marketable tuber yield (t/da)	209.070**	40.59^a	30.75^b	21.81^c	14.69^d	6.37^e
Amorphous tuber ratio (%)	34.841**	2.04^b	2.01^b	1.53^b	2.85^b	18.18^a
Cracked tuber rate (%)	0.407^{ns}	3.7	6.07	7.59	7.12	8.66
Specific gravity (g/cm^3)	23.500**	1.06^c	1.07^b	1.07^b	1.08^a	1.08^a
Starch rate (%)	19.712**	13.29^d	14.13^c	14.39^{bc}	14.87^{ab}	15.39^a
Dry matter content (%)	33.362**	17.74^b	19.94^a	20.41^a	20.82^a	21.06^a
Brix (%)	153.866**	4.98^e	5.12^d	5.29^c	5.62^b	5.79^a

*: Statistically significant at the 0.05 probability level. **: Statistically significant at the 0.01 probability level. F: F-values.

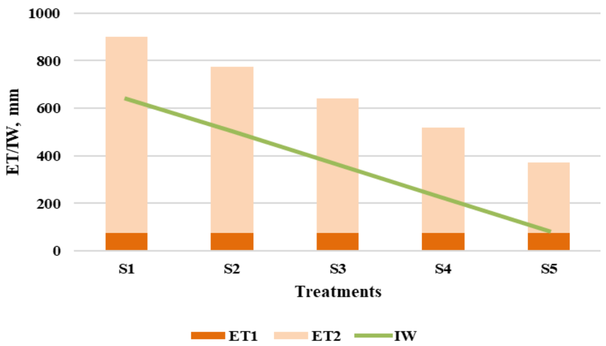

Figure 2. Irrigation water amount and evapotranspiration (ET1: Evapotranspiration measured before irrigation programs, mm; ET2: Evapotranspiration measured after irrigation programs, mm; IW: Irrigation water, mm)

In general, it was observed that all the vegetative parameter values decreased as the reduced irrigation water and each of them was in different statistical groups. In previous studies with different IW, Meligy et al. (2020) found plant height between 39.92 cm – 47.26 cm, Gültekin and Ertek (2018), 63.27–73.23 cm, Ayas and Korukçu (2010) 33.10-69.50 cm and Erdem et al. (2006) 86.8-98.8 cm. While Ayas and Korukçu (2010) found the number of main stems between 2.85-5.70, Gültekin and Ertek (2018) found 3.97-6.03, LAI was determined between 3.08-3.38 by Zin El- Abedin et al. (2017) and 1.4-3.92 by Salimi et al. (2017) under deficit irrigation practices.

All previous studies reported that plant height, number of main stems, and LAI were statistically affected by deficit water application (Erdem et al., 2006; Ayas and Korukçu, 2010; Zin El- Abedin et al., 2017; Salimi et al., 2017; Gültekin, and Ertek, 2018; Meligy et al., 2020). The results of plant height, number of main stems and LAI obtained from our study are consistent with some of the previous studies, while they are different from others. The differences are thought to be due to the differences in potato cultivars, growing environments, agricultural techniques, and irrigation programs.

Generative parameters including total tuber yield, marketable tuber yield, average tuber weight, tuber yield per plant and number of tubers per plant were affected ($P<0.01$) by IW and varied between 12.96–46.11 t/ha, 6.37–40.59 t/ha, 58.01–137.71 g, 304.27–1089.3 g/plant, and 5.39–8.04, respectively (Table 2).

Table 2 demonstrated that as the irrigation water increased, both total yield and marketable yield incremented, and the highest total and marketable yield were obtained from S_1 where the highest IW was applied, and all irrigation treatments were statistically different from each other in terms of total yield and marketable yield. Of the total yield, 88%, 85%, 82%, 73%, and 49% were determined as marketable yield in S_1, S_2, S_3, S_4, and S_5, respectively. Several research has been conducted to assess the effects of IW amount potato tuber yield. For example, Hassanpanah (2010) reported that the tuber yield of Agria was affected by different amounts of IW, the yield was 40.7 t/ha under full irrigation conditions, while it was 35.3 t/ha under moderate deficit water conditions and 34.6 t/ha under high deficit water conditions. In another study conducted for Agria, Eskandari et al. (2013) stated that the yield was 32.83 t/ha, 25.81 t/ha, and 19.56 t/ha under full irrigation, 30%, and 70% deficit water application compared to full irrigation, respectively, while yield was found between 45.79 kg/ha and 29.81 kg/ha by Gültekin and Ertek (2018) under Afyonkarahisar conditions. Similar results on marketable yield were found by Hassanpanah (2010), Nouri et al. (2016) and Gültekin and Ertek (2018).

The decrease in the amount of IW in potato caused a decline in the number of tubers per plant, tuber yield per plant and average tuber weight. The number of tuber per plant varied between 5.39-8.04, tuber yield per plant between 304.27–1080.30 g and average tuber weight between 58.01–135.71 g. Many researchers found similar results and stated that decreased irrigation water caused the lessened number of tubers per plant, tuber yield per plant, and average tuber weight in potato growing (Ayas and Korukçu, 2010; Badr et al., 2010; Önder et al., 2015; Nouri et al., 2016; Salimi et al., 2017; Gültekin and Ertek, 2018; Akram et al., 2020).

The effect of different irrigation water amounts on the amorphous tuber ratio was statistically significant ($P<0.01$), while the effect on the cracked tuber ratio was insignificant. Amorphous tuber ratios were found as 2.04%, 2.01%, 1.53%, 2.85%, and 18.18%, respectively, according to the treatments S_1, S_2, S_3, S_4, and S_5 (Table 2). The results correspond with Essah et al. (2020) using 'Mercury Russet' and 'Rio Grande Russet' cultivars. Although the rate of cracked tuber increases with decreasing irrigation water, the relationship between the amount of irrigation water and the rate of the cracked tuber is not clear.

Dry matter ratio and specific gravity, two important quality parameters related to tuber processing (Yuan et al., 2003), are closely related to starch content (Cantore et al., 2014). All these three quality parameters of potato were significantly affected ($P<0.01$) by the amount of IW. According to the S_1, S_2, S_3, S_4, and S_5 treatments, dry matter content was 17.74%, 19.94%, 20.41%, 20.82% and 21.06%, specific gravity was 1.06 g/cm^3, 1.07 g/cm^3, 1.07 g/cm^3, 1.08 g/cm^3, 1.08 g/cm^3 and starch content was 13.29%, 14.13%, 14.39%, 14.87% and 15.39%, respectively (Table 2). Dry matter content, specific gravity, and starch content results obtained from relatively less IW amounts applied illustrated that significantly higher than full irrigation conditions. Dry matter content, specific gravity, and starch content are affected by amounts of IW were also emphasized by many researchers such as Eskandari et al. (2013), Byrd et al. (2014). Cantore et al. (2014), Meligy et al. (2020).

The effect of the IW amount on brix was statistically significant. Brix was found as 4.98%, 5.12%, 5.29%, 5.62% and 5.79% for S_1, S_2, S_3, S_4 and S_5 subjects, respectively. As presented in Table 2, the highest brix value was determined in S_5 treatment at 5.79%, and the lowest brix value was obtained from S_1 treatment at 4.98%. Brix values decreased as the amount of irrigation water increased. All irrigation treatments were in different groups in terms of brix.

Water yield relationships

The crop yield response factor (ky) states a linear relationship between relative crop evapotranspiration and relative yield decline. It shows the yield response to relative plant evapotranspiration.

Table 3. Water use and irrigation water use efficiency

Irrigation treatment	WUE [kg/(ha×mm)]	IWUE [kg/(ha×mm)]
S_1	55.88[a]	51.86[a]
S_2	51.71[ab]	46.10[ab]
S_3	46.73[bc]	37.12[bc]
S_4	45.75[bc]	32.34[c]
S_5	43.69[c]	

(P<0.05)

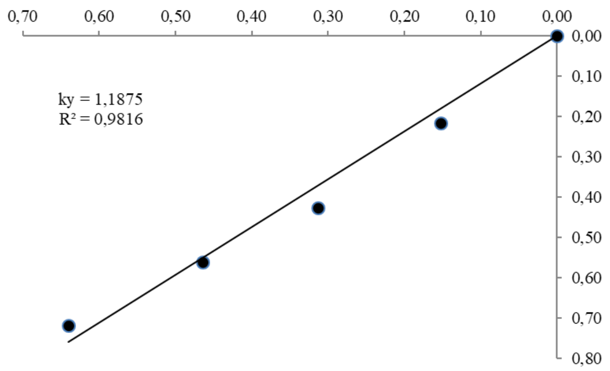

Figure 3. Yield response factor (ky)

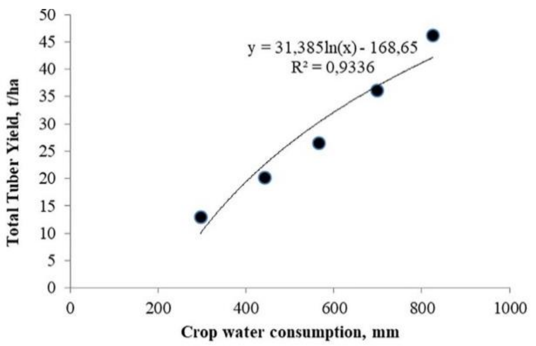

Figure 4. The relationship between evapotranspiration and total tuber yield

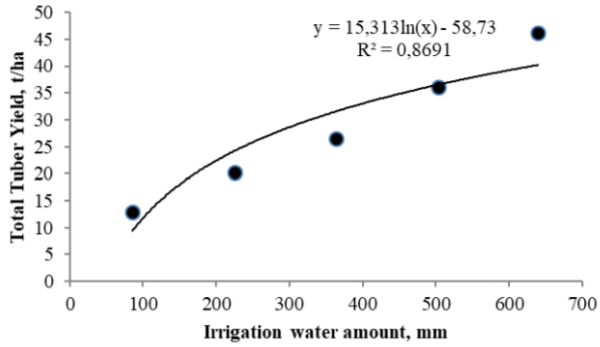

Figure 5. The relationship between irrigation water amount and total tuber yield

The yield response factor varies mainly depending on the growth stage, growth season, and severity of the water deficit (Badr et al., 2022). In other words, it accounts for yield losses due to insufficient water use (Ayas and Korukcu, 2010). The yield response factor (ky) is unique to each plant and varies according to the growing periods. A yield response factor greater than 1 indicates that the plant is sensitive to water stress and that there will be a greater decrease in yield per unit decrease in water use, while a yield response factor less than 1 indicates that the plant is more resistant to water stress and that the decrease in yield per unit decrease in water use will be lower (FAO, 2012). In this study, ky was calculated as 1.19 (Figure 3). This value shows that potato is sensitive to water stress. In the studies conducted in Türkiye on ky, Kızıloğlu et al. (2006) found ky as 1.12 under Erzurum conditions, Ayas and Korukçu (2010) found it as 0.851 under Bursa conditions, and Önder et al. (2015) found it as 1.59. On the other hand, in a study conducted for Agria under Afyonkarahisar conditions, ky was found as 2.24 (Gültekin and Ertek, 2018). The studies conducted in Türkiye differ considerably in terms of ky value. While the ky calculated in our study is similar to Kızıloğlu et al. (2006), it is remarkably different from Gültekin and Ertek (2018). This difference is thought to be due to the differences in growing conditions and agricultural techniques.

There was a logarithmic relationship between evapotranspiration and the total tuber yield with a R^2 of 0.93 [$y=31.385\ln(x)-168.65$] and between IW and the total tuber yield with a R^2 of 0.87 [$y=15.313\ln(x)-58.73$] (Figure 4 and Figure 5). While Kızıloğlu et al. (2006), Ayas and Korukçu (2010) and Cantore et al. (2014) reported a linear relationship between evapotranspiration and tuber yield, Aksic et al. (2014), stated that a quadratic relation between potato yield and crop evapotranspiration. Ross (2006) found a cubic polynomial relationship between potato yield and the seasonal IW amount and Karam et al. (2014) determined a strong quadratic relationship between fresh potato tuber yield and seasonal IW in Agria cultivar.

The effect of different IW amounts on WUE and IWUE is significant ($P<0.05$). While the lowest water use efficiency was determined for S_5 [43.69 kg/(ha×mm)] and the highest was obtained for S_1 [55.88 kg/(ha×mm)]. It was found to be 51.71 kg/(ha×mm) in the S_2 treatment, 46.73 kg/(ha×mm) in the S_3 treatment, and 45.75 kg/(ha×mm) in the S_4 treatment. The lowest irrigation water use efficiency was determined for S_5 [32.34 kg/(ha×mm)]and the highest was found for S_1 [51.86 kg/(ha×mm)]. It was determined to be 46.10 kg/(ha×mm) in the S_2 subject and 37.12 kg/(ha×mm) in the S_3 treatment (Table 3). Ayas and Korukçu (2010) reported that WUE varied between 2.99-5.23 kg/mm and IWUE varied between 1.69-4.35 kg/mm in Hermes potato variety. Akram et al. (2020) found that WUE was 5.95 kg/m^3 in furrow irrigation method and 14.1 kg/m^3 in drip irrigation method, while IWUE was 6.68 kg/m^3 in furrow irrigation and 16.3 kg/m^3 in drip irrigation. Ahuja et al. (2019) reported that WUE varied between 36.1-92.2 kg/(ha×mm) and Salih et al. (2018) reported that it varied between 59.98-99.62 kg/(ha×mm). Djaman et al. (2021) stated that potato has a high water use efficiency among the main foods (FAO, 2008), and potato WUE strongly depends upon the genetic material, management practices, irrigation regime, fertilizer rate, and other environmental conditions.

Results

In order to determine the water-yield relationships of potato, a deficit irrigation water was imposed throughout the growing season. According to the results of the study, restricted application decreased average tuber weight, tuber yield per hearth, number of tubers per hearth, total tuber yield and marketable tuber yield. The decrease in irrigation water also negatively affected the quality parameters, and an increase in amorphous tuber and cracked tuber rates was observed with decreasing irrigation water amounts. Marketable tuber yield is the most important factor in potato cultivation in addition to other parameters. Considering the marketable tuber yield, it is predicted that S_1 can be used as an irrigation program in the study area if there is sufficient water supply, and if there are not enough water resources, S_2 can be used as an irrigation program by accepting some decreased in tuber yield.

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References

Ahuja S, Khurana DS, Singh K. 2019. Soil matric potential-based irrigation scheduling to potato in the Northwestern Indian plains. Agricultural Research, 8(3): 320-330.

Akram MM, Asif M, Rasheed S, Rafique MA. 2020. Effect of drip and furrow irrigation on yield, water productivity and ecomomics of potato (Solanum tuberosum L.) grown under semiarid conditions. Science Letters, 8(2):48–54. https://doi.org/https://doi.org/10.47262/SL/8.2.132020004

Aksic M, Gudzic S, Deleti´c N, Gudzic N, Stojkovic S, Knezevic J. 2014. Tuber yield and evapotranspiration of potato depending on soil matric potential. Bulgarian Journal of Agricultural Science, 20: 122–126.

Anonymous, 2018. Isparta İli Çevre Durum Raporu. Isparta Çevre ve Şehircilik İl Müdürlüğü. https://webdosya.csb.gov.tr/db/ced/icerikler/isparta_-cdr2018-20190704114736.pdf [Accessed 10 january 2022]

Anonymous, 2022 Agria Tohum Özellikleri. https://artarim.com/tr/urun/agria [Accessed 23 December 2022]

Ayas S, Korukçu A. 2010. Water-yield relationships in deficit irrigated potato. Journal of Agricultural Faculty of Uludag University, 24(2): 23-36.

Badr MA, Abou Hussein SD, El-Tohamy WA, Gruda N. 2010. Efficiency of subsurface drip irrigation for potato production under different dry stress conditions. Gesunde Pflan, 62(2): 63-70.

Bahramloo R, Nasseri A. 2010. Effect of deficit irrigation on yield and water use efficiency of potato cultivar santeh. Iranian Journal of Irrigation and Drainage, 4: 90–98.

Berksan Öf, 2002. Patates Tarımı. Kar Tarım. Ankara

Byrd SA, Rowland D., Bennett J, Zotarelli L, Wright D, Alva A, Nordgaard J. 2014. Reductions in a commercial potato irrigation schedule during tuber bulking in Florida: Physiological, yield, and quality effects. Journal of Crop Improvement, 28(5): 660-679. https://doi.org/10.1080/15427528.2014.929059

Camargo DC, Montoya F, Córcoles JI, Ortega JF. 2015. Modeling the impacts of irrigation treatments on potato growth and development. Agricultural Water Management, 150: 119-128. https://doi.org/10.1016/j.agwat.2014.11.017

Cantore V, Wassar F, Yamaç SS, Sellami MH, Albrizio R, Stellacci AM, Todorovic M. 2014. Yield and water use efficiency of early potato grown under different irrigation regimes. International Journal of Plant Production, 8(3): 409–428.

Doorenbos J, Kassam AH. 1979. Yield Response to Water. FAO Irrigation and Drainage. Paper 33, 257.

El-Abedin TKZ, Mattar MA, Alazba AA. Al-Ghobari HM. 2017. Comparative effects of two water-saving irrigation techniques on soil water status, yield, and water use efficiency in potato. Scientia Horticulturae, 225: 525-532.

Er C, Uranbey S. 1998. Nişasta ve Şeker Bitkileri. Ankara Üniversitesi Ziraat Fakültesi Yayınları. Vol.1504.

Erdem T, Erdem Y, Orta H, Okursoy H. 2006. Water- yield relationships of potato under different irrigation methods and regimens. Scientia Agricola, 63, 226-231.

Ertek A, Kanber R. 2001. Pamukta uygun sulama dozu ve aralığının pan evaporasyon yöntemiyle belirlenmesi. Turkish Journal of Agriculture, 24(2000): 293–300.

Eskandari A, Khazaie HR, Nezami A, Kafi M, Majdabadi A, Soufizadeh S. 2013. Effects of drip irrigation regimes on potato tuber yield and quality. Archives of Agronomy and Soil Science, 59(6): 889-897.

Essah SY, Andales AA, Bauder TA, Holm DG. 2020. Response of Two Colorado Russet Potato Cultivars to Reduced Irrigation Water Use. American Journal of Potato Research, 97(3): 221-233.

Fabeiro CMDSOF, de Santa Olalla FM, de Juan A. 2001. Yield and size of deficit irrigated potatoes. Agricultural Water Management, 48(3): 255–266.

FAO, 2008. Potato and Water Resources; Hidden Treasure: International Year of the Potato. http://www.potato2008.org/en/potato/water.html [Accessed 22 December 2020]

FAO, 2012. Crop yield response to water. https://www.fao.org/3/i2800e00.htm [Accessed 24 January 2023)

FAO, 2021. Production quantities of crops in the world. https://www.fao.org/faostat/en/#data/QCL [Accessed 11 January 2023]

Gültekin R, Ertek A 2018. Effects of deficit irrigation on the potato tuber development and quality. International Journal of Agriculture Environment and Food Sciences, 2(3): 93-98.

Hassanpanah D. 2010. Evaluation of potato cultivars for resistance against water deficit stress under in vivo conditions. Potato Research, 53(4): 383–392.

Hassanpanah D, Hassanabadi H, Azizi Chakherchaman SH. 2011. Evaluation of cooking quality characteristics of advanced clones and potato cultivars. American Journal of Food Technology, 6(1): 72-79.

Howell TA, Cuenca RH, Solomon KH. 1990. Crop yield response management of farm irrigation systems. In American Society of Agricultural Engineers. pp. 93-312.

IIisulu K. 1957. Potato Industry in Turkey. American Potato J., 34 97–105.

İncekara F. 1973. Endüstri Bitkileri ve Islahı. Ege Üniversitesi Ziraat Fakültesi Yayınları, Ege Üniversitesi Basımevi.

James LG. 1988. Principles of farm irrigation systems design. John Wiley and Sons Limited.

Karam F, Amacha N, Fahed S, El Asmar T, Domínguez A. 2014. Response of potato to full and deficit irrigation under semiarid climate: Agronomic and economic implications. Agricultural Water Management, 142: 144–151.

Karadoğan T. 1990. Farklı Gelişme Dönemlerinde Değişik Seviyelerde Sulama ve Su Kesme Zamanlarının Patatesin Verim ve Unsurlarına Etkileri Üzerine Bir Araştırma. PhD Dissertation. Institute of Natural and Applied Sciences, Atatürk University, Erzurum, Turkey.

Karataş MC. 2018. Sulama Rejiminin Tatlı Patates (Ipomoea batatas L.) Çeşitlerinde Büyüme, Verim ve Kalite Parametrelerine Etkisinin Belirlenmesi ve Su Stresi Koşullarında Bitki Enerji Kullanımının Hiperspektral Ölçümlerle İlişkilendirilmesi MSc Thesis. Institute of Natural and Applied Sciences, Akdeniz University, Antalya, Turkey.

Kashyap PS, Panda RK. 2003. Effect of irrigation scheduling on potato crop parameters under water stressed conditions. Agricultural Water Management, 59(1): 49–66.

Kızıloğlu FM, Sahin U, Tun T, Diler S. 2006. The Effect of Deficit Irrigation on Potato Evapotranspiration and. Journal of Agronomy, 5(2): 284-288.

Meligy MM, Abou-Hadid A, El-Shinawy MZ, El-Behairy U. 2020. Impact of climate change on water requirements and the productivity on potato crop. Egyptian Journal of Horticulture, 47(1): 57-68.

Mubarak, Janat M, Makhlou M. 2018. Response of two potato varieties to irrigation methods in the dry Mediterranean area. Agriculture/Pol'nohospodárstvo, 57–64(2).

Nouri A, Nezami A, Kafi M, Hassanpanah D. 2016. Growth and yield response of potato genotypes to deficit irrigation. International Journal of Plant Production, 10(2): 139-157.

Önder D, Önder S, Çalişkan ME, Çalişkan S. 2015. Influence of different irrigation methods and irrigation levels on water use efficiency, yield, and yield attributes of sweet potatoes. Fresenius Environmental Bulletinl, 24: 3398-3403.

Ross CW. 2006. The effect of subsoiling and irrigation on potato production. Soil Tillage Research, 7: 315–325.

Salimi K, Hosseini NM, Hosseini MB, Siosemardeh A. 2017. The efficacy of regulated deficit and partial root zone rrying irrigation strategies on yield and water use efficiency of potato. Agricultural Communications, 5(3).

Salih SA, Abdulrahman FA, Mahmood YA. 2018. The effect irrigation interval on tuber yield and quality of potato (Solanum tuberosum L.). Kurdistan Journal of Applied Research, 3(2): 27-31.

Stewart JI, Hagan M, Pruitt WO. 1976. Production functions and predicted irrigation programs for principal crops as required for water resources planning and increased water use efficiency. Tech. Bureau Recl. , 14-06-D-7329: 79–80.

Şenol S. 1973. Patates muhafazasında, sıcaklık, müddet, yumru özgül ağırlığı ve çeşit özelliğinin yumruda şeker, kuru madde ve cips kalitesine etkisi. Atatürk Üniversitesi, Ziraat Fakültesi Yayını, 159: 49–76.

Ünlü M, Kanber R, Şenyiğit U, Onaran H, Diker K. 2006. Trickle and sprinkler irrigation of potato (Solanum tuberosum L.) in the Middle Anatolian Region in Turkey. Agricultural Water Management, 79(1): 43–71.

Yavuz D, Kara M, Suheri S. 2012. Comparison of different irrigation methods in terms of water use and yield in potato farming. J. Selcuk Univ. Nat. Appl. Sci, 2: 1-12.

Yuan BZ, Nishiyama S, Kang Y. 2003. Effects of different irrigation regimes on the growth and yield of drip-irrigated potato. Agricultural Water Management, 63(3) 153–167.