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Response of Potato *(Solanum tuberosum L.)* under Different Levels of Irrigation and Fertigation through Drip System

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ABSTRACT

There are very few studies on cabbage at different fertigation levels in the Marmara Region, where this study was conducted. In this respect, our study has a unique quality. This study was carried out in Bursa Uludag University Yenisehir İbrahim Orhan Vocational School application greenhouses in 2014-2015 years. Five different irrigation treatments (T_1: 100% (full irrigation), T_2: 75%, T_3: 50%, T_4: 25%, T_5: 0% (non-irrigated)) and two different fertigation treatments; $F_{1.0}$: 100% (100:100:100 NPK) fertigation and $F_{0.5}$: 50% (50:50:50 NPK) fertigation were combined together to determine the effects on yield and quality parameters of potatoes. The amount of irrigation water in 2014 and 2015 years varied between 0.0-630.0 mm and 0.0-660 mm, respectively, while evapotranspiration values varied between 180.0-670 mm and 190.0-675 mm, respectively. It was determined that irrigation water and fertigation levels, yield and quality parameters of potatoes were affected significantly. In both application years, the highest yield was obtained from $T_1F_{1.0}$ treatment as 45.0 and 47.0 tons' ha^{-1} respectively, while the lowest yield was obtained from $T_5F_{1.0}$ treatment as 4.0 and 5.0 tons ha^{-1}, respectively. In 2014 and 2015 years the crop response factor (k_y) values of potato were calculated as 1.11-1.11 and 1.21-1.14, respectively. When the full fertigation ($F_{1.0}$: 100% -100:100:100 NPK) and the insufficient $F_{0.5}$: 50% - (50:50:50 NPK) fertigation treatments are compared, significant differences have arisen in terms of yield and quality parameters. $T_2F_{1.0}$ and $T_2F_{0.5}$ treatments can be recommended as the most effective irrigation and fertilization levels of potato.

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Introduction

Potato production has an important place in world agriculture. Four countries realize half of the world potato production. These countries produce China (25%), India (13%), Russia (6%) and Ukraine (6%) of world potato production in 2019 year, respectively. In 2019 year, potato productions in the world and in Turkey are about 368,000,000 tons and 4,980,000 tons. Turkey is in the 19th place in potato production in the world (FAO, 2019). Potato is one of the remarkable vegetables produced in Marmara region, Turkey. Potatoes are produced and consumed by almost all countries of the world in terms of growing in all kinds of climate, wide usage area, high yield and nutritional value. It is an important product with different usage and utilization features in providing food security of the increasing world population. It is the most consumed nutrient after cereals. It is an important product that will also contribute to the solution of hunger and malnutrition problems. In the world and Turkey, close to half of the potato production in various forms (baking, boiling, and frying) is consumed as edible. The rest is used as processed food product (frozen, finger potato and chips), animal feed, industrial starch and seeds. However, it is used for the production of ethanol by liquefying the starch rich jackets of potatoes and other worthless waste left after processing. Therefore, yield response of potato to different irrigation water levels in Bursa province has not been searched widely (Anonymous, 2019).

Proper irrigation management for potatoes requires knowledge of both soil water interaction and irrigation systems features. Potatoes can be grown by many irrigation methods. But some irrigation methods are better than others to get high quality tubers. Potato is a water sensitive plant and systems that can apply frequent, small amount of water and homogeneous irrigation should be preferred. If these criteria are taken into account, when the choice is made from highest to lowest, ranking; drip, solid-set portable sprinkler, linear-move, center-pivot, side roll sprinkler, hand-move sprinkler, and furrow (King et al., 2020). Studies in many countries have shown that drip irrigation can save water use by 30% to 70% and raises crop yields by 20% to 90% depending on soil, climatic and crop characteristics, and farmer's practices if it is properly desiged, installed and operated (Postel et al., 2001; Çetin and Bilgel, 2002; Çetin and Tolay, 2009).

In fertigation, the efficiency of fertilizer use increases due to the direct and frequent application of fertilizers to the plant root area. Therefore, it is possible to reduce the amount of fertilizer applied without compromising the yield of vegetables. With fertigation, fertilizer is applied efficiently by drip irrigation. Plant nutrients are first transported to the plant roots and then to other parts of the plant with fertigation. Fertilizer use is minimized in fertigation applications and potatoes are very sensitive to fertilizer applications. With the application of fertigation with drip irrigation systems, the costs of irrigation and fertilization are reduced, while the nutrient intake in plants is maximized. Optimum fertigation management is possible by knowing the nutrient taken by the fertilization rate to ensure the highest plant productivity (Agrawal et al., 2018; Nikzad et al., 2020). In a study conducted on cotton in Turkey, statistically significant differences were observed between the effect of different irrigation practices on the intake of macro and micro nutrients of cotton plant (Ektiren and Değirmenci, 2018). Many studies have been carried out in the world and in Turkey on the irrigation of potatoes (Ünlü et al., 2006; Kızıloğlu et al., 2006; Önder and Önder, 2006; Erdem et al., 2006; Ayas and Korukçu, 2010; Ayas, 2013; Gültekin and Ertek, 2018; Çetin and Akalp, 2019). One aim of the study was to determine the effect of production inputs applied under controlled weather and production conditions on potatoes. The obtained yield and quality parameters in greenhouse were affected by the controlled weather and production conditions, and increases in yield and quality parameters compared to open field conditions.

Previous studies have clearly shown that potato yield, tuber diameter, tuber weight, tuber size, number of tubers per plant, plant height, dry matter ratio and starch matter ratio are highly correlated with the amount of irrigation water and fertigation. In this study, the effects of different irrigation and fertigation levels on potato yield and quality parameters were researched. The differences of this study from previous studies is that it provides the opportunity to determine the effect of different fertilization levels on potatoes. Considering different irrigation and fertigation levels, as the irrigation water and fertigation amount decreased, yield and the quality parameters of potatoes decreased significantly.

Material and Methods

The research was carried out in plastic covered greenhouse conditions in 2014 and 2015 years. Bursa-Yenişehir region was chosen as the study area and 8×40 m^2 dimensional greenhouse was placed in the North-South direction. While the summer months are hot and dry, the winter months are cold and rainy in Yenişehir province. The average annual rainfall and temperature values for the region where the greenhouse experiments were made in 2014 and 2015 were 620.8 – 784.4 mm and 14.0 – 13.3°C respectively (Anonymous 2016a). The maximum and minimum temperature values of greenhouse inner air in June-July-August months, which are considered as the plant growing period (92 days) were measured. Maximum and minimum temperature values were 38-38°C and 0.9-3.3°C, respectively in 2014-2015 years (Figure 1 and 2).

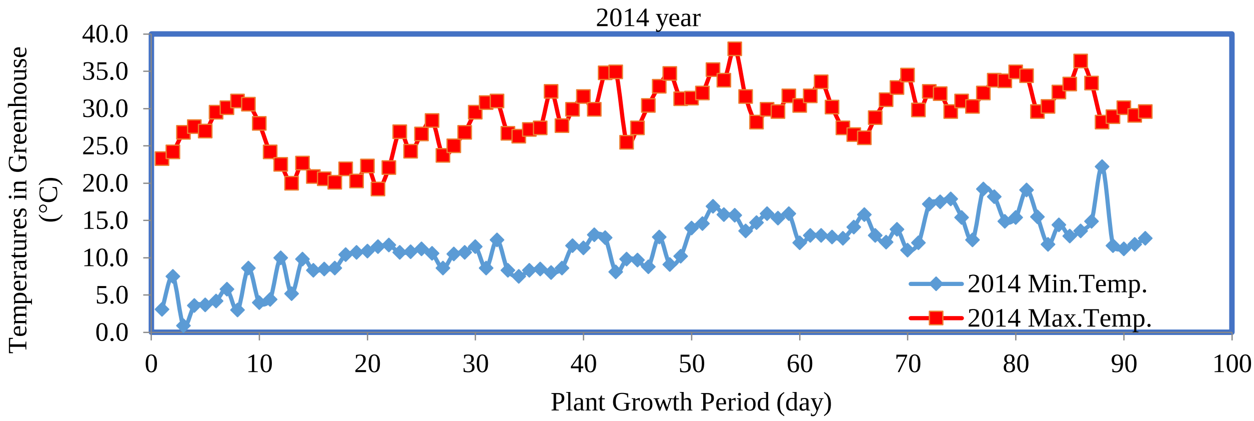


Figure 1. Temperatures in greenhouse during the plant growth period in 2014

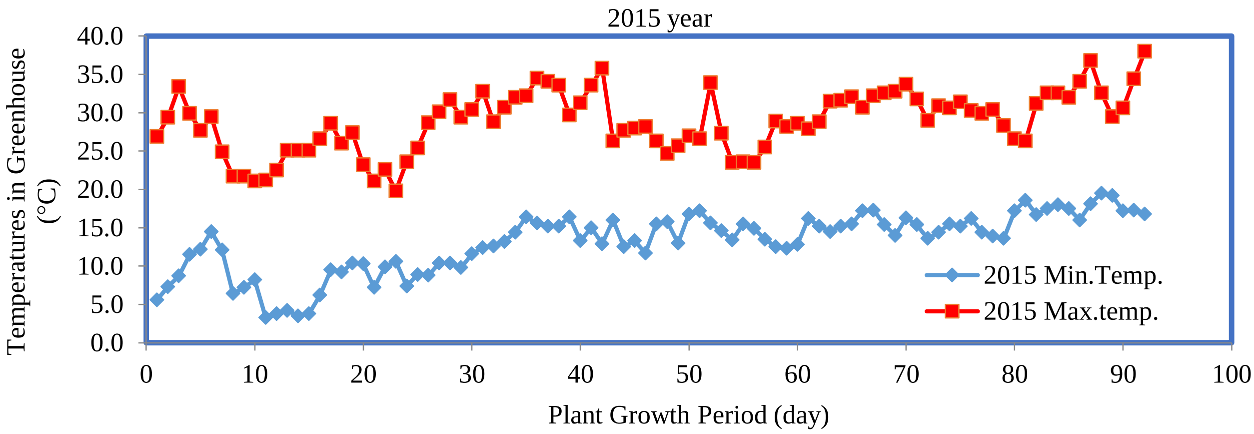


Figure 2. Temperatures in greenhouse during the plant growth period in 2015

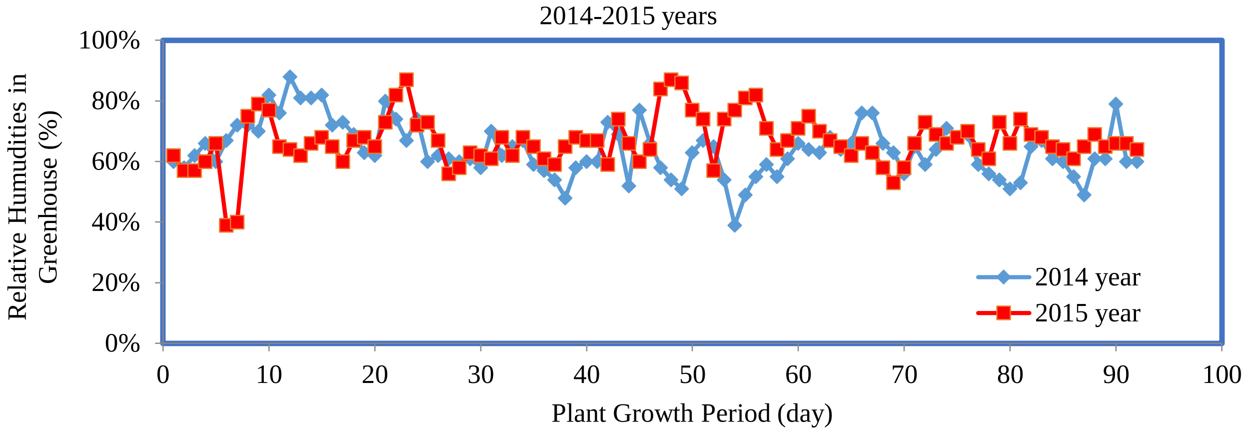


Figure 3. Relative humidities in greenhouse during the plant growth period in 2014-2015 years

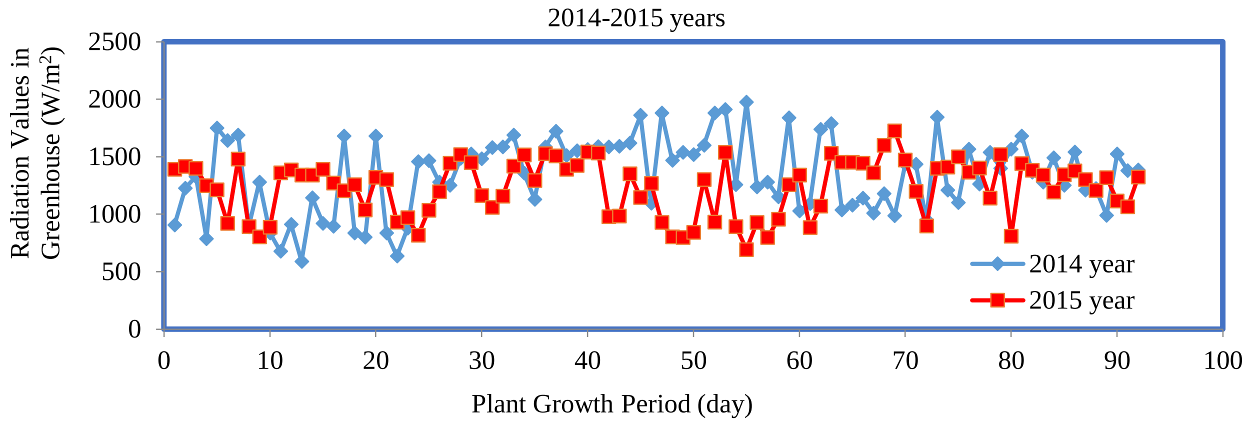


Figure 4. Radiation values in greenhouse during the plant growth period in 2014- 2015 years

Table 1. Some specific properties of the experimental soil

Soil depth (cm)	Soil Texture	Unit weight (g/cm^3)	Field capacity (%)	Wilting point (%)	pH	Total salt (%)	$CaCO_3$ (%)	Organic matter (%)
0-30	SL	1.35	31.37	23.47	8.01	0.043	17.8	3.10
30-60	SL	1.38	28.86	20.88	8.24	0.037	31.5	1.54
60-90	SL	1.60	35.29	25.76	7.90	0.038	32.8	1.17
90-120	SL	1.54	37.65	28.86	8.08	0.035	35.6	0.98

SL: sandy loam

The average relative humidity values for 2014 and 2015 were 75.8 -76.8%. The highest and lowest relative humidity values in greenhouse in 2014 and 2015 years were found as 88-87% and 39-40%, respectively (Figure 3). In addition, the highest and lowest radiation values in greenhouse in 2014-2015 years were measured as 1974-1725 W/m^2 and 589-797 W m^{-2}, respectively (Figure 4) (Anonymous, 2016b).

The soil of the trial site was sandy-loam and the soil reaction (pH) value vary between 7.90 to 8,08. Some of the physical and chemical properties of the soil of the experiment site are presented in Table 1.

Hermes is a medium late potato variety and is used in the production of chips. Its flower color is light pink and tuber color is yellow. Storage period is long and resistant to external impacts. The chips quality of Hermes variety is high and its dry matter content is high. The starch content of this variety is medium high. The shape of the tubers is oval and round. This variety has a medium high level of resistance to fungal deseases. Hermes has a low resistance to nematode pests and frost. However, drought resistance is high. Hermes variety was registered in Germany in 1972 and improved by tuber hybridization method. Hermes' parents are DDR x 163/55 (Anonymous 2020).

Mankozeb (80% WP-350 g/da) and Endosulfan (32.9% EC/WP-360g/l) were used as chemical drugs against potato diseases and insects. In addition, 10 l ha^{-1} chlorophyll-ethyl was sprayed against the insects. Two weeks before planting potato tubers in the greenhouse, 100 kg ha^{-1} of potassium nitrate (13% N and % 46 K_2O) and 20 l ha^{-1} of phosphoric acid (61% P_2O_5) were applied as base fertilizer for 100% (100:100:100 NPK) fertigation treatment, while 50 kg ha^{-1} of potassium nitrate (13% N and 46% K_2O) and 10 l ha^{-1} of phosphoric acid (61% P_2O_5) were applied at 50% (50:50:50 NPK) fertigation treatment. Six weeks after planting potato tubers in the greenhouse to promote vegetative growth, 40 kg ha^{-1} of potassium nitrate (13% N and % 46 K_2O) and 10 l ha^{-1} of phosphoric acid (61% P_2O_5) were applied for 100% (100:100:100 NPK) fertigation treatment, while 20 kg ha^{-1} of potassium nitrate (13% N and 46% K_2O) and 5 l ha^{-1} of phosphoric acid (61% P_2O_5) were applied for 50% (50:50:50 NPK) fertigation treatment. Twelve weeks after planting potato tubers in the greenhouse to promote generative growth, 50 kg ha^{-1} of potassium nitrate (13% N and 46% K_2O) and 10 l ha^{-1} of phosphoric acid (61% P_2O_5) were applied for 100% (100:100:100 NPK) fertigation treatment, while 25 kg ha^{-1} of potassium nitrate (13% N and 46% K_2O) and 5 l ha^{-1} of phosphoric acid (61% P_2O_5) were applied for 50% (50:50:50 NPK) fertigation treatment. In addition, 30 kg ha^{-1} urea (45-46% N) fertilizer was applied for 100% (100:100:100 NPK) of fertigation in order to encourage tuber development during the generative development period, while 15 kg ha^{-1} urea (45-46% N) fertilizer was applied for 50% (50:50:50 NPK) fertigation treatment.

Potato tubers were planted on June 01 in 2014 and in 2015. The plant and row spacing applied in the experiment was 0.35 m and 0.60 m, respectively. Each parcel involved 36 tubers of potato. 10 plants in the middle of each parcel were harvested as sample plants, considering that water would leak from adjacent parcels. The tuber size of the potatoes taken as an example were measured with a caliper tool and the average of the measured values was calculated. The dry matter content of the fruit was determined by drying the sample potatoes (at 65°C in a drying oven). The amount of dry matter of the tubers was determined by using (AOAC, 2000). The details of the experimental plot and place are shown in Figure 5 and 6.

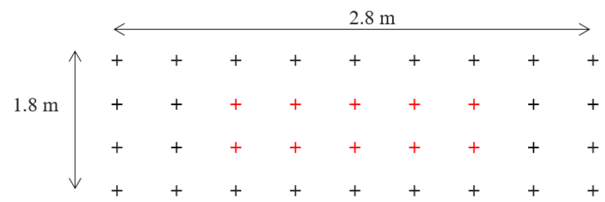


Figure 5. the detail of a plot

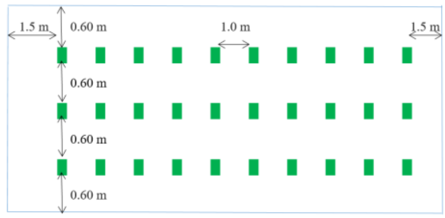


Figure 6. the detail of the experimental place

Figure 7 (a) Drip irrigation system, (b) Main and lateral pipes

Table 2. Specific properties of irrigation water

Water source	EC_{25}×(10^6)	Na^+	K^+	Ca^{2+}	Mg^{2+}	pH	Class	SAR
		(me L $^{-1}$)						
Deep well	723	2.5	2.67	9.55	5.8	7.17	C_2S_1	0.85

The drip irrigation equipment in greenhouse used in the study was given in Figure 7.

The experimental design was determined as a 3-replicate and two-factor random block design. 5 different irrigation levels (T_1: 100% (full irrigation), T_2: 75%, T_3: 50%, T_4: 25%, T_5: 0% (non-irrigated)) and two different fertilizer treatments ($F_{1.0}$: 100% (100:100:100 NPK) fertigation and $F_{0.5}$: 50% (50:50:50) NPK) fertigation were distributed randomly to each block. All treatments are formed as follows: $T_1F_{1.00}$: 100% irrigation and 100% (100:100:100 NPK) fertigation, $T_2F_{1.00}$: 75% irrigation and 100% (100:100:100 NPK) fertigation, $T_3F_{1.00}$: 50% irrigation and 100% (100:100:100 NPK) fertigation, $T_4F_{1.00}$: 25% irrigation and 100% (100:100:100 NPK) fertigation, $T_5F_{1.00}$: 0% irrigation and 100% (100:100:100 NPK) fertigation, $T_1F_{0.50}$: (100% irrigation and 50% (50:50:50 NPK) fertigation, $T_2F_{0.50}$: 75% irrigation and 50% (50:50:50 NPK) fertigation, $T_3F_{0.50}$: 50% irrigation and 50% (50:50:50 NPK) fertigation, $T_4F_{0.50}$: 25% irrigation and 50% (50:50:50 NPK) fertigation application, $T_5F_{0.50}$: 0% irrigation (non-irrigated) and 50% (50:50:50 NPK) fertigation. Since irrigation wasn't applied in $T_5F_{1.00}$ ve $T_5F_{0.50}$ treatments, fertigation wasn't applied. The evaluations of decreases in efficiency and quality parameters in all treatments were applied according to $T_1F_{1.00}$: 100% irrigation and 100% (100:100:100 NPK) treatment. Because full irrigation and fertilization application has been applied in $T_1F_{1.00}$: 100% irrigation and 100% (100:100:100 NPK) treatment. The reason for irrigation with 7 day intervals is the evaluation of the amount of evaporation from the soil and the plant, as well as the phenological observations of the plant.

Drip irrigation method was used in the trial. Irrigation water amount was calculated by placing flow measurement devices per parcel. The need for watering of the potato is provided by a deep well (3 l s^{-1}) located in the greenhouse area. The depth of the well is 18 meters. Chemical composition of irrigation water was presented in Table 2. Groundwater composition of Yenişehir province is generally alkaline. The irrigation water applied in the experimental research was analysed and was determined to be in the C_2S_1 class with low sodium risk and medium EC value. The water of the C_2S_1 quality class has low sodium risk and medium electrical conductivity (EC). The irrigation of water of this quality class is used for plants with medium and highly salinity resistant. In addition, C_1S_1 quality class water can be used in all plants and soils without creating a risk of alkalinity. C_2S_1 quality class water was applied in a study on potato plants (Ashraf and Ewees, 2008).

Soil moisture between 30-120 cm before and after irrigation was monitored by gravimetric method. Evapotranspiration (ET) was calculated by means of the water balance equation (Eq.1).

$$ET = I + P - Rf - Dp \pm \Delta S \quad \text{(Eq.1)}$$

In the water balance equation, ET, I, P, Rf, Df and ΔS symbols symbolize plant water consumption (ET), effective irrigation water (I), total precipitation (P), surface flow (Rf) (mm), the infiltrating water under the root zone (mm), the amount of change in storage (mm/120 cm), respectively. Irrigation water was applied to the crop by the drip irrigation method before planting seedlings. Total precipitation (P) and surface flow (Rf) were neglected in water requirements and consumption calculations in greenhouse. Soil water values in soil profiles deeper than 120 cm were accepted as deep drainage (Dp) and these values were neglected.

The amount of fertilizer to be applied to each unit area was determined and calculated in kg ha^{-1} by the equation as follows (İşcan et al., 2002) (Eq. 2):

$$Fw = \frac{Fr \cdot 100}{Cn} \quad \text{(Eq.2)}$$

In equality; Fw, Fr and Cn symbolize fertilizer weight (kg ha^{-1}), nutrient amount (kg ha^{-1}) and nutrient density contained in the fertilizer, (respectively Eq. 2). Similarly, the fertilizer valume to be applied to each unit area was given in the third equation (İşcan et al., 2002) (Eq. 3):

$$Fv = \frac{F_w}{S_w} \quad \text{(Eq.3)}$$

In equality; Fv, Fw and Sw symbolize the volume of fertilizer (l ha^{-1}), fertilizer weight (kg ha^{-1}) and unit weight of the fertilizer, (respectively Eq. 3). The application time chemical fertilizer to be given with water per unit area (kg ha^{-1} or l ha^{-1}) was calculated with the fourth equation (Eq. 4) given below **(**İşcan et al., 2002**)**:

$$T = \frac{V_w}{Q_t} \quad \text{(Eq.4)}$$

In equality; T, Vw and Qt symbolize the application time of chemical fertilizer (h), the amount of water (l ha^{-1}) and the flow rate of the fertilization tank, (respectively Eq. 4). Steward Model (Eq.5) helps to describe the relationship between yield and ET in this experimental research **(**Stewart et al., 1975; Doorenbos and Kassam, 1979**)**. The equation can be given as:

$$\left(1-\frac{Ya}{Ym}\right) = ky \left(1-\frac{ETa}{ETm}\right) \quad \text{(Eq.5)}$$

In the Steward Equation, Ym (t ha^{-1}) and Ya (t ha^{-1}) symbols symbolize the highest and actual yields, respectively, while ETm (mm) and ETa (mm) symbols symbolize the highest and actual evapotranspiration, respectively. Irrigation efficiency was determined by the WUE value, while the symbol ky was defined as the yield response factor. WUE and IWUE are expressed as two terms that show how efficiently irrigation water is used during the production periods of the plant (Bos, 1980). WUE value was calculated by dividing the economic yield by the seasonal evapotranspiration (Eq. 6):

$$WUE = \frac{E_y}{ET} \quad \text{(Eq. 6)}$$

In the equation, Ey and ET values show the economic yield (t ha^{-1}) and seasonal evapotranspiration (mm), respectively. IWUE value was calculated by dividing the economic efficiency by the amount of irrigation water (Zhang et al., 1999) (Eq. 7):

$$IWUE = \left(\frac{E_y}{I}\right) \quad \text{(Eq.7)}$$

In the equation, Ey and I values show the economic yield (t ha^{-1}) and the amount of the irrigation water (mm), respectively. Before the seedlings were plant into the greenhouse soil, the water content of the soil up 120 cm depth was calculated. Moisture level of the soil was completed to the level of field capacity in all treatments before starting irrigation. The amount of decrease in soil moisture was determined by gravimetric method. This process was carried out by taking soil samples from the 90 cm profile depth of the soil with soil sampling cases every 2 days. Full irrigation was carried out until the available moisture in the soil reached the field capacity point. Irrigations applied in other treatments were applied by decreasing certain rates (25-50-75-100%) compared to full irrigation. Irrigation was begun on June 08 in 2014 and in 2015 and it was repeated every 7 days.

Potatoes were harvested 105 days after planting in the greenhouse. Yield and quality parameters of potatoes were analyzed. By means of the LSD multiple comparison test ($P<0.05$), the variance analysis of the yield and quality parameters was evaluated. The values of yield productivity and quality parameters by using MSTAT-C and MINITAB software were analysed (Steel and Torrie, 1980).

Results

Before planting, each plot were irrigated to bring the soil moisture level up to field capacity (that is, 0-60 cm soil depth moisture level). After a week from planting potato tubers, the first irrigation water was applied. The maximum and minimum irrigation water amounts for 2014 and 2015 years were obtained from $T_1F_{1.0}$-$T_1F_{0.5}$ and $T_5F_{1.0}$-$T_5F_{0.5}$ treatments were 630.0-0.0 mm and 660.0-0.0 mm, respectively. The amounts of other irrigation water applied during the experiment years ranged between 473.0-150.0 mm and 495.0-150.0 mm, respectively. Seasonal evaporation (ET_a) increased in parallel with the increase in the amount of applied irrigation water. The actual evapotranspiration values for $T_1F_{1.0}$–$T_1F_{0.5}$ and $T_5F_{1.0}$-T_5F_{05} treatments in the first year varied between 670.0-675.0 mm and 180.0-190.0 mm, respectively. These values in the second year varied between 680.0-710.0 mm and 225.0-200.0 mm, respectively (Table 3, 4, 5). The relationship between irrigation water (IW) with yield (Ya) and the relationship between ET_c with yield (Ya) for 2014 and 2015 years were given in figure 8 and 9.

Table 3. Applied water and ET values according to irrigation and fertigation treatments in 2014 and 2015 years

Fertilization	IT	AW 2014	AW 2015	CE 2014	CE 2015
100% Fertilization ($F_{1.0}$: 100% 100:100:100 NPK)	$T_1F_{1.0}$	630.0	660.0	670.0	680.0
	$T_2F_{1.0}$	473.0	495.0	500.0	505.0
	$T_3F_{1.0}$	315.0	330.0	343.0	380.0
	$T_4F_{1.0}$	158.0	165.0	227.0	300.0
	$T_5F_{1.0}$	0.0	0.0	180.0	225.0
50% Fertilization (F0.5: 50% 50:50:50 NPK)	$T_1F_{0.5}$	600.0	600.0	675.0	710.0
	$T_2F_{0.5}$	450.0	450.0	485.0	530.0
	$T_3F_{0.5}$	300.0	300.0	324.0	400.0
	$T_4F_{0.5}$	150.0	150.0	210.0	260.0
	$T_5F_{0.5}$	0.0	0.0	190.0	200.0

Table 4. Relationship between yield and yield response factor (ky) with the decrease in water use, for potato in 2014 year

	Yield (t ha^{-1})	Applied Water (mm)	ETa (mm)	ETa/ETm	Ya/Ym	1-(ETa/ETm)	1-(Ya/Ym)	ky
$T_1F_{1.0}$	45.0	630.0						
$T_2F_{1.0}$	33.5	473.0						
$T_3F_{1.0}$	22.0	315.0	343.0	0.512	0.489	0.488	0.511	1.047
$T_4F_{1.0}$	11.0	158.0	227.0	0.339	0.244	0.661	0.756	1.143
$T_5F_{1.0}$	4.0	0.0	180.0	0.269	0.089	0.731	0.911	1.246
$T_1F_{0.5}$	42.0	600.0	675.0	1.000	1.000	0.000	0.000	0.000
$T_2F_{0.5}$	30.0	450.0	485.0	0.719	0.714	0.281	0.286	1.015
$T_3F_{0.5}$	19.0	300.0	324.0	0.480	0.452	0.520	0.548	1.053
$T_4F_{0.5}$	9.0	150.0	210.0	0.311	0.214	0.689	0.786	1.141
$T_5F_{0.5}$	5.0	0.0	190.0	0.281	0.119	0.719	0.881	1.226

Table 5. Relationship between yield and yield response factor (ky) with the decrease in water use, for potato in 2015 year.

	Yield (t ha^{-1})	Applied Water (mm)	ETa (mm)	ETa/ETm	Ya/Ym	1-(ETa/ETm)	1-(Ya/Ym)	ky
$T_1F_{1.0}$	47.0	660.0	680.0	1.000	1.000	0.000	0.000	0.000
$T_2F_{1.0}$	35.0	495.0	505.0	0.743	0.745	0.257	0.255	0.992
$T_3F_{1.0}$	23.0	330.0	380.0	0.559	0.489	0.441	0.511	1.157
$T_4F_{1.0}$	11.5	165.0	300.0	0.441	0.245	0.559	0.755	1.352
$T_5F_{1.0}$	5.0	0.0	225.0	0.331	0.106	0.669	0.894	1.336
$T_1F_{0.5}$	46.5	600.0	710.0	1.000	1.000	0.000	0.000	0.000
$T_2F_{0.5}$	34.5	450.0	530.0	0.746	0.742	0.254	0.258	1.018
$T_3F_{0.5}$	23.0	300.0	400.0	0.563	0.495	0.437	0.505	1.157
$T_4F_{0.5}$	11.5	150.0	260.0	0.366	0.247	0.634	0.753	1.188
$T_5F_{0.5}$	6.0	0.0	200.0	0.282	0.129	0.718	0.871	1.213

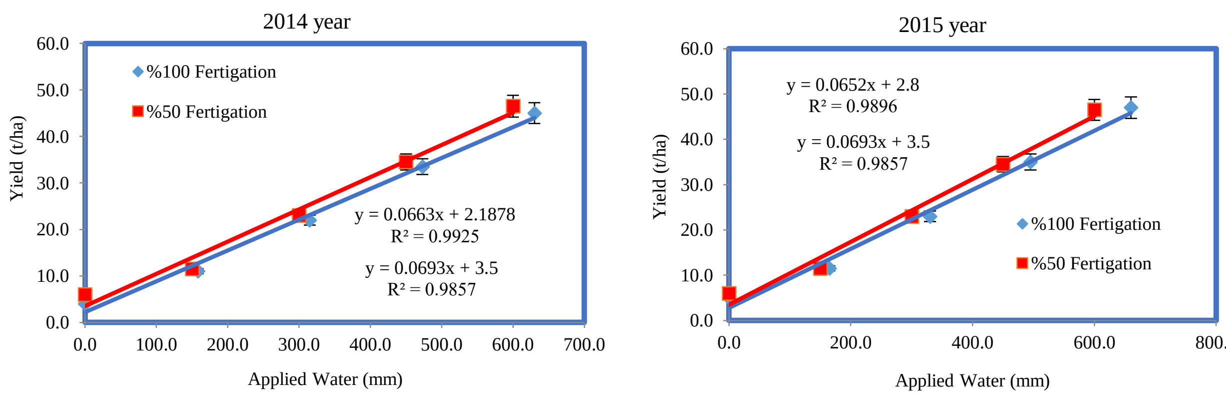


Figure 8. The relationship between irrigation water (IW) with yield (Ya) for 2014 and 2015 years. (The errors bars are SE of 14 plants)

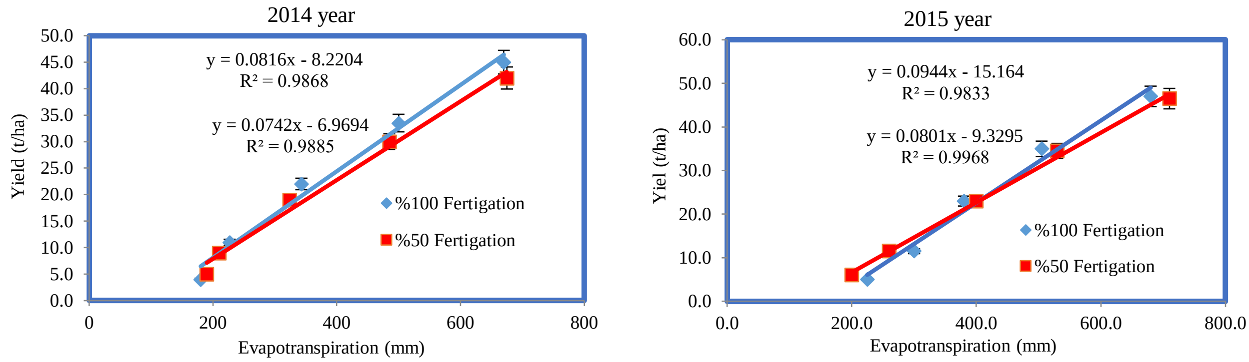


Figure 9. The relationship between ET_c with yield (Ya) for 2014 and 2015 years. (The errors bars are SE of 14 plants)

Table 6. Effects of irrigation treatments on yield and quality parameters of potato in 2014 year.

FT	T	Y	TD	TW	TS	NTP	PH	DM	SM
100% Fertilization (F1.0: 100%)	$T_1F_{1.0}$								
	$T_2F_{1.0}$								
	$T_3F_{1.0}$	22.0^{c}	6.1^{bc}	162.0^{e}	6.5^{c}	6.3^{c}	64.0^{e}	15.0^{f}	13.6^{f}
	$T_4F_{1.0}$	11.0^{d}	4.8^{d}	104.0^{g}	5.0^{d}	5.5^{d}	50.0^{g}	17.5^{c}	16.5^{c}
	$T_5F_{1.0}$	4.0^{f}	3.8^{e}	82.0^{i}	4.0^{e}	3.8^{f}	37.0^{i}	20.0^{a}	18.6^{a}
Treatments		**	**	**	**	**	**	**	**
Blocks		ns	ns	ns	ns	ns	ns	ns	ns
50% Fertilization (F0.5: 50%)	$T_1F_{0.5}$	42.0^{a}	6.8^{ab}	182.0^{b}	7.6^{ab}	7.5^{a}	70.0^{b}	11.0^{i}	9.5^{i}
	$T_2F_{0.5}$	30.0^{b}	6.4^{abc}	170.0^{d}	7.3^{b}	7.0^{b}	69.0^{c}	13.5^{g}	13.0^{g}
	$T_3F_{0.5}$	19.0^{c}	5.7^{c}	150.0^{f}	6.4^{c}	6.2^{c}	65.0^{d}	16.0^{e}	14.1^{e}
	$T_4F_{0.5}$	9.0de	4.5^{de}	96.0^{h}	5.1^{d}	5.2^{e}	53.0^{f}	17.0^{d}	15.8^{d}
	$T_5F_{0.5}$	5.0^{ef}	4.0de	80.0^{j}	4.2^{e}	3.5^{g}	42.0^{h}	19.5^{b}	18.2^{b}
Treatments		**	**	**	**	**	**	**	**
Blocks		ns	ns	ns	ns	ns	ns	ns	ns

FT: Fertilization Treatments, T: Treatments, Y: Yield (t ha^{-1}), TD: Tuber Diameter (cm), TW: Tuber Weight (g), TS: Tuber Size (cm), NTP: Number of Tubers Per Plant, PH: Plant Height (cm), DM: Dry Matter (%), SM: Starch Matter (%)

Table 7. Effects of irrigation treatments on yield and quality parameters of potato in 2015 year.

FT	T	Y	TD	TW	TS	NTP	PH	DM	SM
100% Fertilization (F1.0: 100%)	$T_1F_{1.0}$	47.0^{a}	6.9^{a}	185.0^{a}	7.8^{a}	7.5^{ab}	73.0^{a}	9.2^{j}	8.4^{i}
	$T_2F_{1.0}$	35.0^{b}	6.8^{a}	177.0^{c}	7.6^{a}	7.1^{b}	69.0^{c}	10.4^{h}	9.7^{h}
	$T_3F_{1.0}$	23.0^{c}	6.0^{b}	168.0^{e}	6.7^{b}	6.4^{c}	65.0^{e}	12.8^{f}	11.9^{f}
	$T_4F_{1.0}$	11.5^{d}	4.5^{c}	114.0^{h}	5.2^{d}	5.3^{d}	54.0^{g}	15.0^{d}	14.0^{d}
	$T_5F_{1.0}$	5.0^{e}	3.7^{d}	92.0^{j}	4.4^{f}	3.4^{e}	40.0^{i}	17.8^{b}	16.9^{b}
Treatments		**	**	**	**	**	**	**	**
Blocks		ns	ns	ns	ns	ns	ns	ns	ns
50% Fertilization (F0.5: 50%)	$T_1F_{0.5}$	46.5^{a}	6.9^{a}	182.0^{b}	7.7^{a}	7.6^{a}	70.0^{b}	9.6^{i}	8.5^{i}
	$T_2F_{0.5}$	34.5^{b}	6.7^{a}	175.0^{d}	7.5^{a}	7.3^{ab}	68.0^{d}	11.2^{g}	10.9^{g}
	$T_3F_{0.5}$	23.0^{c}	6.2^{b}	160.0^{f}	6.3^{c}	6.4^{c}	64.0^{f}	13.4^{e}	13.0^{e}
	$T_4F_{0.5}$	11.5^{d}	4.7^{c}	118.0^{g}	4.8^{e}	5.1^{d}	52.0^{h}	16.5^{c}	16.1^{c}
	$T_5F_{0.5}$	6.0^{e}	3.6^{d}	96.0^{i}	3.9^{g}	3.4^{e}	40.0^{i}	18.4^{a}	17.7^{a}
Treatments		**	**	**	**	**	**	**	**
Blocks		ns	ns	ns	ns	ns	ns	ns	ns

FT: Fertilization Treatments, T: Treatments, Y: Yield (t ha^{-1}), TD: Tuber Diameter (cm), TW: Tuber Weight (g), TS: Tuber Size (cm), NTP: Number of Tubers Per Plant, PH: Plant Height (cm), DM: Dry Matter (%), SM: Starch Matter (%)

The highest yield values in treatments which is applied as 100% and 50% of fertigation for the 2014-2015 years were obtained from $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments and found as 45.0-42.0 t ha^{-1} and 47.0-46.5 t ha^{-1}, respectively. $T_1F_{1.0}$ treatments in both trial years were followed by $T_2F_{1.0}$, $T_3F_{1.0}$, $T_4F_{1.0}$ and $T_2F_{0.5}$, $T_3F_{0.5}$, $T_4F_{0.5}$ treatments and yield values for 2014 and 2015 years were 33.5, 22.0, 11.0 – 30.0, 19.0, 9.0 t ha^{-1} and 35.0, 23.0, 11.5 – 34.5, 23.0, 11.5 t ha^{-1}, respectively. As expected, minimum yield values for 2014 and 2015 years were found from control $T_5F_{1.0}$ and $T_5F_{0.5}$ treatments (4.0 – 5.0 and 5.0 – 6.0 t ha^{-1}), in which irrigation was not applied. During the 2014 and 2015 testing years, the product yield of the untreated $T_5F_{1.0}$ and $T_5F_{0.5}$ treatments were lower by 1025.0-740.0 % and 840.0-675.0 % compared to the $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments. In 2014 and 2015 years, the yield losses in $T_5F_{1.0}$ and $T_5F_{0.5}$ treatments were 185% and 65%, respectively. In addition, compared to the first year $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments, $T_2F_{1.0}$, $T_3F_{1.0}$, $T_4F_{1.0}$ and $T_2F_{0.5}$, $T_3F_{0.5}$, $T_4F_{0.5}$ treatments achieved 34.3%, 104.6%, 309.1% - 40.0%, 121.1%, 366.7% and 34.3%, 104.4%, 308.7% - 34.8%, 102.2%, 304.4%, lower product yields in the second year, respectively (Table 6 and 7). Yield and quality have been reduced due to water shortages.

In the first year of the study, yield, size, diameter and weight of tubers for two different fertigation levels were affected by deficit irrigation. The mean values obtained from $T_1F_{1.0}$, $T_2F_{1.0}$, $T_3F_{1.0}$, $T_4F_{1.0}$, $T_5F_{1.0}$ and $T_1F_{0.5}$, $T_2F_{0.5}$, $T_3F_{0.5}$, $T_4F_{0.5}$, $T_5F_{0.5}$ treatments were almost all in a different statistical group. The number of tubers per plant values were affected by too much deficit irrigation. All values every two years were situated in a different statistical group. Therefore, plant height values in 2014 and 2015 years also differed statistically. In the second year, almost all the yield values obtained from the treatments were found in a different statistical group while tuber diameter and tuber size values in $T_1F_{1.0}$ – $T_2F_{1.0}$ and $T_1F_{0.5}$ – $T_2F_{0.5}$ treatments were in the same statistical group. Number of tubers per plant and plant height values were affected by deficit irrigation and each of the treatments were situated in a different statistical group. While there was a high linear relationship between the amount of applied water (IW) and tuber diameter, tuber size, tuber weight, number of tubers per plant and plant height, there was a negative linear relationship between dry matter – starch matter and IW. The amount of dry matter and starch decreases as the water content in the tuber increases. Relationship between applied of irrigation water and tuber diameter, weight, size, number of tubers per plant, plant height, dry matter ratio and starch matter ratio were given in figure 10.

Crop Yield Response Factor (ky)

The linear relationship between the proportional reduction in water consumption and the proportional reduction in yield productivity is indicated by ky and reflects the response of product efficiency to the reduction of water consumption. That is, they explain the decline in product productivity related to the decrease in water consumption per unit (Stewart, 1975, Doorenbos and Kassam, 1979**).** ky in different fertigation levels (100% 100:100:100 NPK and 50% 50:50:50 NPK) fertigation levels) for the 2014 and 2015 experimental years was calculated as 1.11-1.11 and 1.21-1.14, respectively (Figure 11). Except $T_5F_{1.0}$ *and* $T_5F_{0.5}$ treatments, ky values increased parallel to the increase of water amount.

Water-use Efficiency

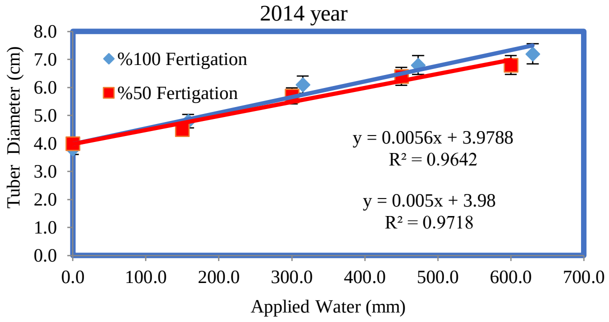
During the trial years, when the irrigation water amount decreased, the WUE and IWUE values also decreased. The highest WUE values of both years were obtained from $T_1F_{1.0}$, $T_2F_{1.0}$ and $T_1F_{0.5}$, $T_2F_{0.5}$ treatments and were calculated as 0.067, 0.067 – 0.062, 0.062 kg m^{-3} and 0.069, 0.069 – 0.065, 0.065 kg m^{-3}, respectively. The highest IWUE values of both years were similarly obtained from $T_1F_{1.0}$, $T_2F_{1.0}$ and $T_1F_{0.5}$, $T_2F_{0.5}$ treatments and were calculated as 0.071, 0.071 – 0.070, 0.067 kg m^{-3} and 0.071, 0,071 - 0,078, 0.077 kg m^{-3}, respectively. The WUE and IWUE values of $T_1F_{1.0}$ and $T_2F_{1.0}$ treatments in 2014 were found to be higher than the other treatments such as $T_3F_{1.0}$, $T_4F_{1.0}$, $T_5F_{1.0}$ and $T_3F_{0.50}$, $T_4F_{0.5}$, $T_5F_{0.5}$ respectively. The WUE and IWUE values of $T_1F_{1.0}$, $T_2F_{1.0}$, $T_1F_{0.50}$, $T_2F_{0.5}$,treatments in 2014 and 2015 years were found to be higher than the other treatments such as $T_3F_{1.0}$, $T_4F_{1.0}$, $T_5F_{1.0}$ and $T_3F_{0.5}$, $T_4F_{0.5}$, $T_5F_{0.5}$ respectively (Table 8 Table 9).

Table 8. WUE and IWUE values for drip-irrigated potato at different irrigation treatments for 2014 year.

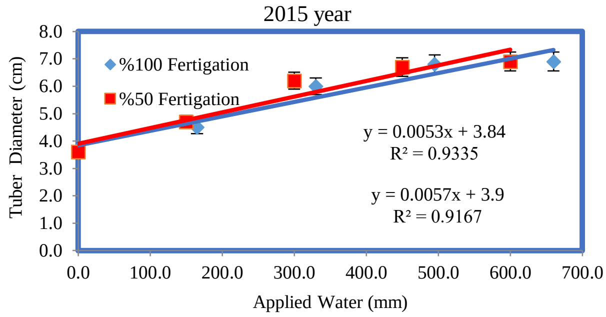
Fertigation Treatments	Yield (t ha^{-1})	Applied Water (mm)	ETa (mm)	WUE (kg m^{-3})	IWUE (kg m^{-3})
T1F1.0	45.0	630.0	670.0	0.067	0.071
T2F1.0	33.5	473.0	500.0	0.067	0.071
T3F1.0	22.0	315.0	343.0	0.064	0.070
T4F1.0	11.0	158.0	227.0	0.048	0.070
T5F1.0	4.0	0,0	180.0	0.022	0.000
T1F0.5	42.0	600.0	675.0	0.062	0.070
T2F0.5	30.0	450.0	485.0	0.062	0.067
T3F0.5	19.0	300.0	324.0	0.059	0.063
T4F0.5	9.0	150.0	210.0	0.043	0.060
T5F0.5	5.0	0.0	190.0	0.026	0.000

Table 9. WUE and IWUE values for drip-irrigated potato at different irrigation treatments for 2015 year.

Fertigation Treatments	Yield (t ha^{-1})	Applied Water (mm)	ETa (mm)	WUE (kg m^{-3})	IWUE (kg m^{-3})
T1F1.0	47.0	660.0	680.0	0.069	0.071
T2F1.0	35.0	495.0	505.0	0.069	0.071
T3F1.0	23.0	330.0	380.0	0.061	0.070
T4F1.0	11.5	165.0	300.0	0.038	0.070
T5F1.0	5.0	0.0	225.0	0.022	0.000
T1F0.5	46.5	600.0	710.0	0.065	0.078
T2F0.5	34.5	450.0	530.0	0.065	0.077
T3F0.5	23.0	300.0	400.0	0.058	0.077
T4F0.5	11.5	150.0	260.0	0.044	0.077
T5F0.5	6.0	0.0	200.0	0.033	0.000



10.a.I



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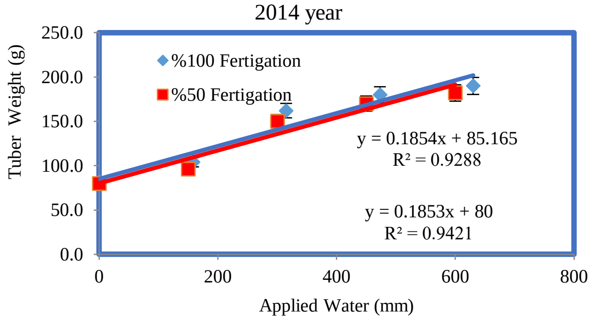

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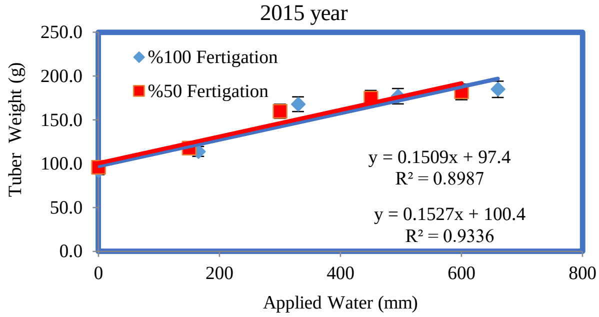

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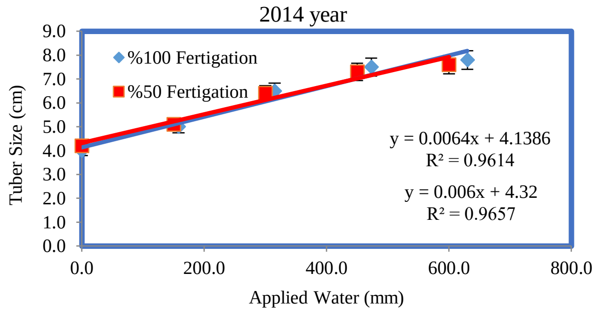

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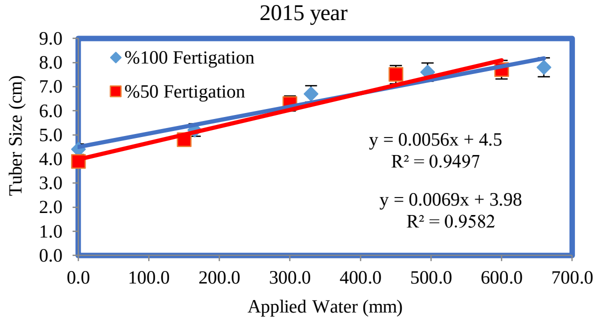

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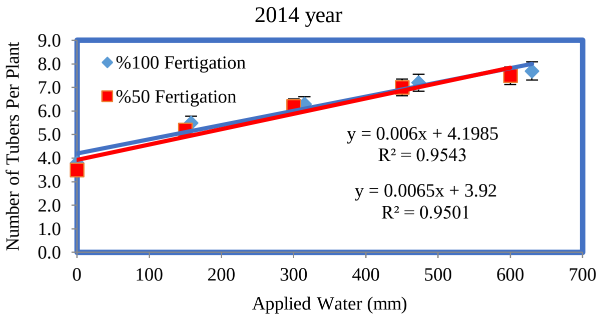

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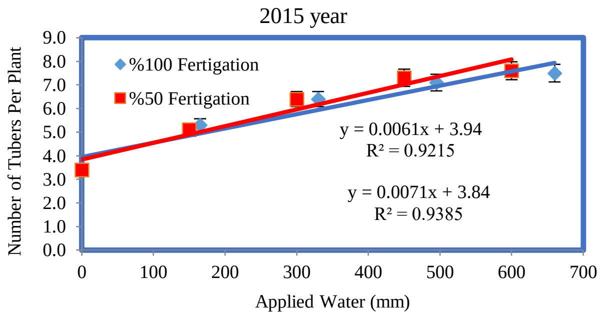

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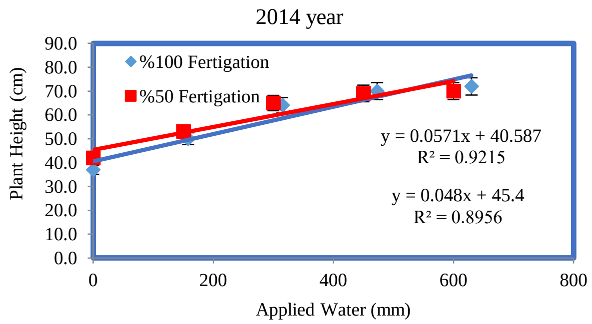

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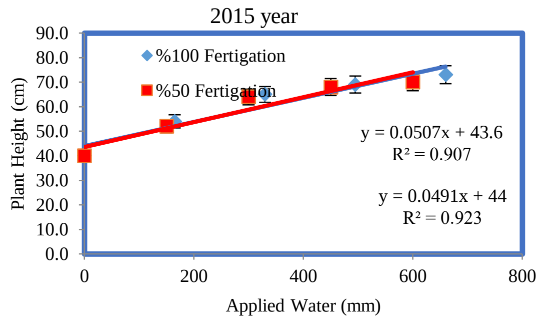

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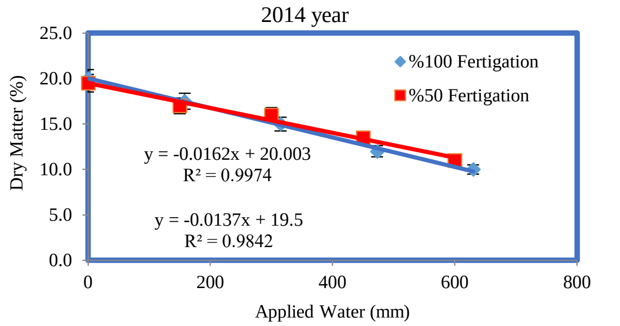

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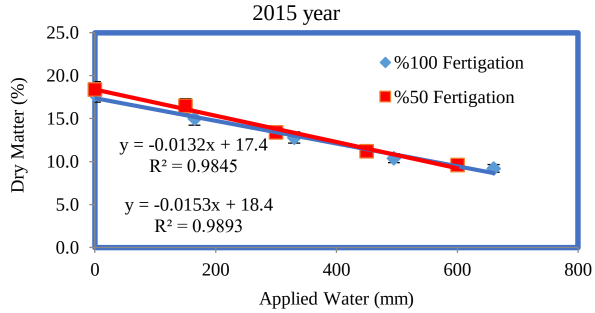

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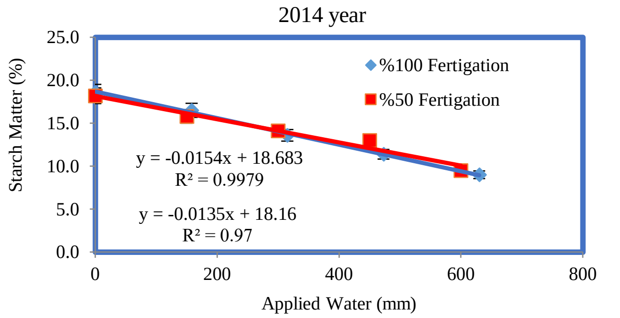
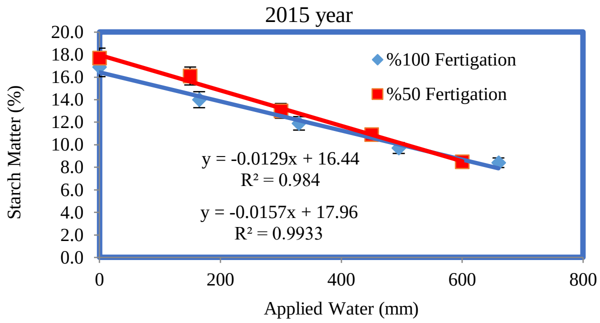


10.g.I



10.g.II

Figure 10. Relationship between applied of irrigation water and tuber diameter (a.I-a.II),weight (b.I-b.II),size (c.I-c.II), number of tubers per plant (d.I-d.II), plant height (e. I-e. II), dry matter ratio (f.I-f.II) and starch matter ratio (g I-g II).

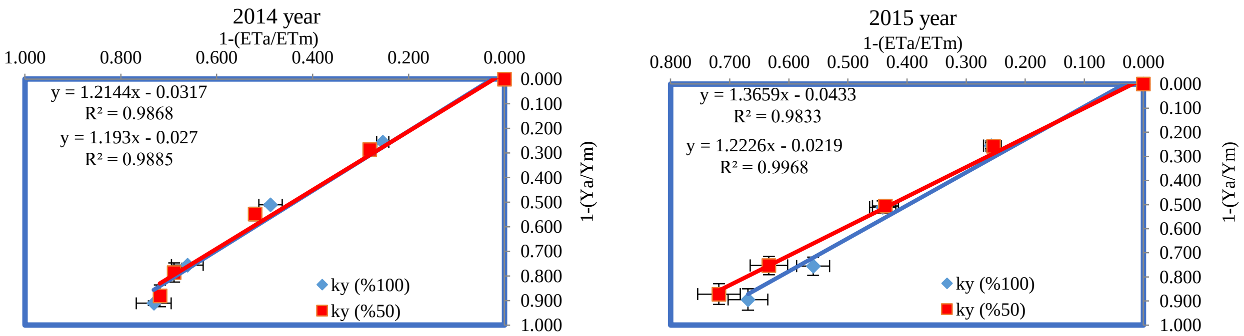


Figure 11. The relationship between relative yield decrease and relative evapotranspiration deficit for the experimental years (2014 and 2015)

Discussion

In our study years, the amount of water applied ranged between 0.0 – 630.0 mm and 0.0 – 660.0 mm while the actual evapotranspiration ranged between 180.0 – 675.0 mm and 200.0 – 710.0 mm. Ayas (2010) reported that the amount of irrigation water applied to the plants ranged between 345.0 and 585.0 mm in the first year, and between 286.0 and 485.0 mm in the second year and plant water consumption varied between 399.0 and 655.0 mm in the first year and between 370.0 and 646.0 mm in the second year. Ayas (2013) have pointed to potato is sensitive to drought stress and Irrigation water applied to crops ranged from 94.0 to 746.0 mm and water consumption ranged from 190.0 to 754.0 mm. Fakhari et al. (2013) reported that applied irrigation water content during irrigation period for 100, 80 and 60 percent of crop requirements were 558.7, 446.96 and 335.22 mm respectively. Eid et al. (2017) stated that the total water applied crop growth period were 1810, 1971, 1713 and 1892 m^3 fed^{-1} in the Nili season while in the Summer season were 2050, 2243, 1900 and 2155 m^3 fed^{-1}, respectively. Gültekin and Ertek (2018) have determined 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. Essah et al. (2020) have determined the irrigation water amounts between 330.0 mm and 559.0 mm were applied to Mercury Russet and Rio Grande Russet varieties. These results were consistent with irrigation water and water consumption values obtained from previous studies **(**Ayas, 2010; Ayas, 2013; Fakhari et al., 2013; Abubaker et al., 2014; Eid et al., 2017; Kassu et al., 2017; Gültekin and Ertek, 2018; Essah et al., 2020).

The maximum WUE values of both years were obtained from $T_1F_{1.0}$, $T_2F_{1.0}$ and $T_1F_{0.5}$, $T_2F_{0.5}$ treatments and were calculated as 0.067, 0.067 – 0.062, 0.062 kg m^{-3} and 0.069, 0.069 – 0.065, 0.065 kg m^{-3}, respectively. The highest IWUE values of both years were similarly obtained from $T_1F_{1.0}$, $T_2F_{1.0}$ and $T_1F_{0.5}$, $T_2F_{0.5}$ treatments and were calculated as 0.071, 0.071 – 0.070, 0.067 kg m^{-3} and 0.071, 0,071 - 0,078, 0.077 kg m^{-3}, respectively. The results of water use efficiency were found to be similar when compared with the findings of different researchers (Ayas, 2010; Ayas, 2013; Mokh et al., 2014; Nagaz et al., 2016; Gültekin and Ertek, 2018; Essah et al., 2020).

The yield response factors (k_y) in treatments which is applied as 100% (100:100:199 NPK) and 50% (50:50:50 NPK) fertigation for 2014 and 2015 years were calculated as 1.11-1.11 and 1.21-1.14 for potato, respectively. The factors of k_y (1.11-1.11 and 1.21-1.14) values close to 1.00 and bigger than 1.00 showed that the potato was susceptible to water. The factor of ky also shows similarities with values found by other researchers working on the same topic (Ayas, 2010; Ayas, 2013; Cabrera et al., 2014; Gültekin and Ertek, 2018; Essah et al., 2020).

Fertigation together with drip irrigation provided high water use efficiency and fertilizer and chemicals could be applied in safe and desired concentrations in our study. Fertigation together with drip irrigation provided less water and fertilizer usage. However, a significant increase of crop production and quality was observed. The highest yield values in treatments which is applied as 100% (100:100:100 NPK) and 50% (50:50:50 NPK) fertigation for the 2014-2015 trial years were obtained from $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments and found as 45.0-42.0 t ha^{-1} and 47.0-46.5 t ha^{-1}, respectively. As expected, minimum yield values for 2014 and 2015 years were found from control $T_5F_{1.0}$ and $T_5F_{0.5}$ treatments (4.0 – 5.0 and 5.0 – 6.0 t ha^{-1}), in which irrigation was not applied. The results of the study show that the influence of deficit irrigation on yield was quite important. According to the yield results, all treatments for 2014-2015 years were ranked as the different statistical groups. All treatments in 2014 and 2015 years were almost ranked as the different statistical groups from the stand point of tuber weight. In the first year of the experiment, size, diameter and weight of tubers for two different fertigation levels were almost affected by deficit irrigation. In the second year of the experiment, size, diameter and weight of tubers for two different fertigation levels were affected by deficit irrigation. In 2014 and 2015 years, number of tubers per plant and plant height were affected by deficit irrigation. This result agrees with (Ayas, 2010; Alva et al., 2012; Ayas, 2013; Gültekin and Ertek, 2018; Abdulrahman et al., 2018; Essah et al., 2020). Similar results were obtained in previous fertigation studies on potato (Ayas, 2013; Bero et al., 2014; Adhikari and Rana, 2017; Gültekin and Ertek, 2018; Essah et al., 2020). As the irrigation water amounts decreased, the yield decreased significantly as well. Tuber diameter, size and weight of potato showed a similar response to deficit irrigation as observed in the yield. All irrigation and fertigation treatments have higher values than the $T_5F_{1.0}$ and $T_{5F0.5}$ treatments in which water is not used. These values show similarities with (Ayas, 2010; Alva et al., 2012; Badr et al., 2012; Ayas, 2013; Feng et al., 2018; Gültekin and Ertek, 2018; Essah et al., 2020). Tuber weight values of $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments were higher than the other treatments. In terms of tuber weight, the values closest to these treatments were obtained from $T_2F_{1.0}$ and $T_2F_{0.5}$ treatments. When evaluated according to the number of tubers per plant, the mean values of these were almost ranked as the different statistical groups in both trial years. In both years of the study, the highest dry and starch matter rate values were observed in $T_5F_{1.0}$ and $T_5F_{0.5}$ treatments, while the lowest dry matter rate values were found from $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments. In light of this information, it can be decided that with the increase in irrigation water deficit, there will be significant increase in the amount of dry and starch matter. These results are consistent with those of (Ayas, 2010; Alva et al., 2012; Ayas, 2013; Zhiwei et al., 2013; Mokh et al., 2015: Gültekin and Ertek, 2018; Eid et al., 2020; Essah et al., 2020).

In our study, 100% and 50% fertigation levels had an important effects on the yield and quality of the potato. The highest yield and quality values were obtained from the $T_1F_{1.0}$ treatment applied of 100% irrigation and 50% fertigation, while the amount of the irrigation water and fertigation level fell as yield and quality values also decreased. The findings are in accordance with (Ayas, 2010; Alva et al., 2012; Ayas, 2013; Gültekin and Ertek, 2018; Essah et al., 2020).

Type of the potato, climate, and soil structure and water use efficiency affects the yield and quality values. As stated by Davis et al. (2008), it can be stated that this is due to the variety and cultural practices under different climatic and geographical conditions.

Conclusions

According to the results of the study, irrigation water were applied 630 and 660 mm in $T_1F_{1.0}$ treatment applied to full irrigation and fertigation in 2014 and 2015 years. The plant water consumption of potato was determined as 670-675 mm and 680-710 mm in for $T_1F_{0.5}$ and $T_1F_{1.0}$ treatment 2014 and 2015 years.

Crop yield response factors (k_y) for the different irrigation and fertigation levels ($T_1F_{1.0}$, $T_2F_{1.0}$, $T_3F_{1.0}$, $T_4F_{1.0}$, $T_5F_{1.0}$ and $T_1F_{0.5}$, $T_2F_{0.5}$, $T_3F_{0.5}$, $T_4F_{0.5}$, $T_5F_{0.5}$ treatments) in 2014 and 2015 years were calculated as 1.11-1.11 and 1.21-1.14 for potato, respectively. The factors of k_y (1.11-1.11 and 1.21-1.14) values bigger than 1,00 showed that the potato was susceptible to water. The crop yield response factors (k_y) in two different fertigation (100% and 50% fertigation) were close to each other in both years of the study. The highest yield decreases in all treatments were in $T_5F_{1.0}$ and $T_5F_{0.5}$ treatments, while the lowest yield decreases were in $T_1F_{1.0}$ and $T_1F_{0.5}$ periods. In our study, it was studied out those irrigation treatments considerable influences yield, tuber size, tuber diameter, tuber weight, number of tubers per plant, plant height, dry matter ratio and starch matter ratio.

In 2014 and 2015 years, the highest yield in different fertigation levels (100% and 50% fertigation) were 45.0-42.0 t h$^{-1\ and}$ 47.0-46.5 t h$^{-1\ and}$ it was found in $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments. The yield values closest to the highest yield values were obtained from $T_2F_{1.0}$ and $T_2F_{0.5}$ treatments. The lowest yields were also found as 4.0-5.0 t ha^{-1} and 5.0-6.0 t ha^{-1} in $T_5F_{1.0}$ and $T_5F_{0.5}$ treatments, respectively. The yield decreased significantly due to the irrigation water deficiency.

The relative decreases in yield in 2014 and 2015 years, the product yield of the untreated $T_5F_{1.0}$ and $T_5F_{0.5}$ treatments were lower by 1025.0-740.0 % and 840.0-675.0 % compared to the $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments. In addition, compared to the first year $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments, $T_2F_{1.0}$, $T_3F_{1.0}$, $T_4F_{1.0}$ and $T_2F_{0.5}$, $T_3F_{0.5}$, $T_4F_{0.5}$ treatments achieved 34.3%, 104.6%, 309.1% - 40.0%, 121.1%, 366.7% and 34.3%, 104.4%, 308.7% - 34.8%, 102.2%, 304.4%, lower product yields in the second year, respectively. WUE and IWUE values of $T_1F_{1.0}$ - $T_2F_{1.0}$ and $T_1F_{0.5}$ - $T_2F_{0.5}$ treatments were the highest values. In water deficiency conditions, $T_2F_{1.0}$ and $T_2F_{0.5}$ treatments of potato are the most suitable periods for deficit irrigation and the yield and quality value decreases was the lowest in these treatments.

As a result, of possible deficit irrigation in a semi-humid climate condition, it is necessary to plan carefully and it is possible to say that the levels and times of the deficit irrigation and fertigation were significantly effective on potato yield. In potato irrigation, if the deficit irrigation treatment is obligatory, water deficiency should be planned only for $T_2F_{1.0}$ and $T_2F_{0.5}$ treatments. The water and fertigation deficiency shouldn't be applied in $T_1F_{1.0}$ and $T_1F_{0.5}$ treatments and irrigation and fertigation in these treatments should be exactly applied. In addition, in the irrigation planning to be done in similar climatic conditions may be benefited from crop yield response factor (ky) values. The results used to determine the amount of reduction in yield in response to the water and fertigation deficiency to be applied to the plant may be used in studies related to potato. $T_2F_{1.0}$ (75% irrigation and 100% (100:100:100 NPK) fertigation level) and $T_2F_{0.5}$ treatment (75% irrigation and 50% (50:50:50 NPK) fertigation level) can suggested as the most effective irrigation and fertigation level for potatoes that are inadequate in water and are drip irrigation in unheated greenhouse conditions.

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